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EFFECTS OF MARCELLUS SHALE DEVELOPMENT ON SONGBIRD ABUNDANCE AND HABITAT USE IN NORTHCENTRAL PENNSYLVANIA FORESTS

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Ethan P. Barton

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The thesis of Ethan P. Barton was reviewed and approved* by the following:

Margaret C. Brittingham
Professor of Wildlife Resources
Thesis Co-Adviser

Walter M. Tzilkowski
Associate Professor Emeritus of Wildlife Science
Thesis Co-Adviser

Duane R. Diefenbach
Adjunct Professor of Wildlife Ecology
Leader, PA Cooperative Fish & Wildlife Research Unit

Michael G. Messina
Head and Professor
Department of Ecosystem Science and Management

*Signatures are on file in the Graduate School.

ABSTRACT

Due to recent instability in the international petroleum products market, American industries are seeking to develop domestic sources of energy, and foremost among these domestic sources is natural gas. The Marcellus Shale formation in the northeastern portion of the United States contains a vast portion of the natural gas reserve of North America; the northeastern US also contains many large core forest reserves important for breeding songbirds. Within the last decade, development of wells within the Marcellus has rapidly expanded, and the number of wells permitted for drilling has increased steadily. In forested areas, Marcellus development creates large disturbances and causes substantial fragmentation, but the landscape matrix remains dominated by stands of mature forest. I examined the effects of Marcellus Shale gas development on songbird abundance and habitat use surrounding 30 well pads, mean size 2 hectares, placed within an extensive forest landscape in northcentral Pennsylvania. I used fixed-radius point counts to assess songbird abundance relative to well pads at four distances from the pad edge: two points in new edge habitat (0m and 50m) created by pad development and two points in remnant post-development interior habitat (150m and 250m), which served as a reference. I conducted bird and vegetation surveys in both northern hardwood and mixed oak habitat. To determine whether bird abundance and species composition differed between edge and reference points, I analyzed the aggregate avian community at edge and interior points and also built linear mixed models for three guilds of species based upon habitat preference: forest interior, early-successional, and synanthropic species. I also constructed linear mixed models for individual bird species within the guilds observed at ≥50% of field sites. Avian communities differed between forest interior and pad edge, and they also differed by forest habitat type (northern hardwood or oak) overall and at interior reference points. However, communities did

not differ by forest habitat type at edge points, indicating biotic homogenization may be occurring near well pads. Forest interior species were significantly less abundant near the pad edge relative to interior reference points. Interior habitat associates such as black-throated green warblers (*Setophaga virens*), black-throated blue warblers (*Setophaga caerulescens*), ovenbirds (*Seiurus aurocapilla*), red-eyed vireos (*Vireo olivaceus*), hermit thrushes (*Catharus guttatus*), and scarlet tanagers (*Piranga olivacea*) were less abundant at edge points than within the forest interior. In contrast, synanthropic species were more abundant near pad edges than at interior points. American robins (*Turdus migratorius*) were more abundant within 100m of well pad edges than at reference points within the forest interior surrounding well pads. Distance from edge was not a significant predictor of abundance for the early successional species guild or individual species associated with the guild. Common yellowthroats (*Geothlypus trichas*) and eastern towhees (*Pipilo erythrophthalmus*), two species associated with early successional habitat, did not exhibit a detectable response to development. I took nested-plot vegetation samples at points surrounding well sites to assess vegetative changes near well pads as a possible explanation for bird distribution. Average canopy cover, mean litter depth, the number of tree stems >8cm diameter at breast height, and the number of small sapling stems <2.5cm were significantly lower at the immediate pad edge (0m) than at sample points of greater distances, but no other differences were detected. My results suggest development has not largely altered vegetation beyond the immediate edge, but the length of post-disturbance time elapsed may be insufficient for vegetative edge effects to be detectable. Absence of increased sapling density near well pads and lack of a detectable positive response to development by early-successional guild members present evidence Marcellus development is not currently creating early successional habitat. Instead, unconventional gas development appears to be creating a degree of

radiative habitat loss beyond what forest is removed for pad construction: forest interior birds are significantly less abundant in forest within 100m of well pad edges. Edge and generalist species, which were previously rare or absent within the forest landscape, are moving into new edge habitat near Marcellus well pads, suggesting an ongoing shift in the bird community near well pad development and possible biotic homogenization as common generalist species replace less common forest specialists.

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I would like to dedicate this thesis to the memory of Alan M. Barton (1934-1973), my grandfather, who instilled in his son a passion for conservation and the wonders of the natural world. In his final years, he proudly served as a Deputy Game Protector for the Commonwealth

of Pennsylvania, giving back to the fields & forests he saw recover from years of overuse and abuse. He dreamed of seeing his son going on to be a biologist, to see through the implementation of conservation policies in Penn's Woods; however, that dream prematurely came to end when he passed away at age 39, subsequently making it financially impossible for my father to attend college. I am so very grateful that my father gave to me what his father showed him, and taught me all he knew about the woods and waters. The journey has been lengthy and fraught with challenges, but I am proud that my grandfather's dream of inspiring a biologist has been realized four decades after he left this Earth. The memory of the man I knew only in spirit has kept me firmly on the path that led me to this point, and kept me motivated to finish my research even when the straits grew most dire; may it guide me forever on to follow the faint light that leads to truth and discovery throughout my career as a biologist.

INTRODUCTION

The northeastern region of pre-Columbian North America looked far different from the landscape of the present day. Vast forests covered approximately 72% of New England, Pennsylvania, New Jersey, and Delaware; these forests were home to mountain lions (*Puma concolor*), white-tailed deer (*Odocoileus virginianus*), bobcats (*Lynx rufus*), black bears (*Ursus americanus*), elk (*Cervus canadensis canadensis*), wolves (*Canis* spp.), and many species of neotropical migrant songbirds (Clawson 1979, Smith et al. 2009). By 1907, land clearing and expansive timber harvesting had reduced the amount of forest cover to only 32%, but conservation practices, sustainable timber management, and farm abandonment brought about a trend of forest regrowth that continued until approximately 2007. Today, nearly 42% of northeastern North America is forested in aggregate, but modern forest cover is fundamentally different from pre-Columbian cover: forest species composition has changed, natural disturbance events have decreased in frequency, and the level of fragmentation of forests is far greater (Smith et al. 2009). Infrastructures such as roads, electrical lines, and homes create much of the fragmentation in present-day forests. Energy development, such as coal mining and petroleum extraction, has also contributed to forest fragmentation in Pennsylvania to a noteworthy degree.

Conventional oil and gas development began in the northeast, particularly within Pennsylvania, in the latter portion of the 19th Century; low-pressure pipelines and well sites associated with petroleum transport and extraction further fragmented forests. Some species of forest songbirds, used frequently as indicators of forest health due to sensitivity and rapid response to change, declined in abundance near conventional oil and gas edge and within the extensively-fragmented forest habitat matrix (Thomas 2011, Thomas et al. 2014). While

conventional oil and gas development has slowed substantially in recent years, a new cause of forest fragmentation has come into being: unconventional oil and gas development.

Unconventional oil and gas drilling began in earnest within the first decade of the 21st Century. As opposed to conventional or "shallow" oil and gas resources, unconventional petroleum resources are locked within ancient shale layers that are often miles below the Earth's surface. While conventional oil and gas reserves do not require mechanical stimulation to produce petroleum, effective extraction of unconventional resources requires a deep-layer geological disturbance action to increase rock fracture permeability and subsequently release the desired gas or oil (Schmoker 1999). Development infrastructure must perforce be larger to support heavier drilling rigs, larger-diameter pipes, and higher gas pressures. The occurrence of unconventional oil and gas development within core forest habitat, or forest fragmentation associated therewith, has the potential to impact breeding birds. To understand why that potential exists, one must first understand the forests of the northeast, the development process, and northeastern wildlife and songbirds.

Forests in the Mid-Atlantic Province of North America

Before the arrival of European settlers, most of the area spanning the Mid-Atlantic province of what was to become the United States was covered by contiguous forest (Keddy and Drummond 1996). Land was cleared for habitation and agricultural purposes following settlement, but large-scale land clearing was conducted only limitedly through most of the Mid-Atlantic province until the mid-19th Century (Smith et al. 2009). As human populations grew and expanded, the need for more agricultural land and wood products consequently led to the expansion of land-clearing and timber harvesting; between the years 1850 and 1910, farmers and loggers cleared more forested land than had been cleared in 250 years prior to that period (Fedkiw 1989). Heavy industrial timber harvest occurred throughout most of the Northeast

through the early 1900s, and logging proceeded until entire tracts of timber had been felled; these sites were frequently burned over by incidental fires throughout the early 20th Century (Abrams and Nowacki 1992). Economic hardship throughout the early 1900s led to the abandonment of many corporate timber tracts and small family farm-holdings.

Following the abandonment of old farmsteads and timber stands in the early 1900s, forests began to regenerate across the Northeastern United States, but recent changes in land use and resource development have reversed the trend of forest gain and most of the forest area in the Mid-Atlantic province is declining (Drummond and Loveland 2010). Furthermore, most forests in the United States are contained within already fragmented landscapes, and only approximately 9.9% of forests nationwide exist in contiguous forest habitats (Riiters et al. 2002). Despite the trend of forest gain between 1950 and 2007, more than 40% of the pre-Columbian native forest area in the Mid-Atlantic province has been lost to urban, agricultural, and energy development (Williams 1989, Smith et al. 2004). Large amounts of forest do persist in a number of northeastern states such as Maine, New York, West Virginia, and Pennsylvania. By land area, Pennsylvania's forest reserve is the second largest in the region at approximately 68,412 square kilometers (Smith et al. 2004).

Forest Condition in Pennsylvania

Nearly 60% of the Pennsylvania Commonwealth has been forested since the 1970s, but urban development is increasing across nearly all of the Mid-Atlantic province states. Between 1989 and 2004, more than 2,600 square kilometers of forest were lost to development, with approximately 1,700 square kilometers of that being lost to residential and industrial development; this loss has been tempered with the reversion of old agricultural land to forest (McWilliams et al. 2007). Nowak and Walton (2005) predict that Pennsylvania will lose

approximately 7,500+ square kilometers of forest to urbanization by 2050, constituting a decline of 5-10% in forest cover. Pennsylvania forest is currently distributed between core forest, which is more than 100 meters from an edge or road, and edge forest, which is marked by various degrees of fragmentation (Goodrich et al. 2002). Approximately 29,931 square kilometers of forest, or 42% of the total forested area in the state, are classified as core forest habitat by Goodrich et al. (2002). Of the core forest remaining in Pennsylvania, only 30% occurs in contiguous patches larger than 20 square kilometers, suggesting that large forests are becoming rare.

The majority of remaining core forest habitat in Pennsylvania occurs in the northcentral region across the following counties: Cameron, Centre, Clearfield, Clinton, Elk, Huntingdon, Lycoming, McKean, Potter, Sullivan, and Tioga (Fig. 1). Many of these counties were subjected to heavy forest harvesting in the late 1800s and early 1900s, with strip mining, oil drilling, and shallow natural gas drilling also occurring. While shallow natural gas drilling did not occur as heavily in the northcentral part of the state as in the western counties, some wells are nonetheless present in core forest habitat where they create small perforations of the canopy. The newest form of human-associated forest disturbance in Pennsylvania is unconventional oil and gas development, which creates larger forest canopy openings and more edge per site than shallow gas development. Swathes opened in the forest canopy by land-clearing associated with unconventional development run the gamut from slightly greater than one hectare to greater than five hectares. The core forest-rich northcentral region of Pennsylvania happens to be underlain by one of the richest unconventional gas reserves in all of North America: the Marcellus Shale.

The Marcellus Shale Region and Development

The Marcellus Shale formed during the Devonian period (416-359.2 million years ago) when terrigenous sediments and organic material accumulated at the bottom of the Appalachian basin, a vast inland sea that formed at the foot of the now-defunct Acadian Mountains during the Acadian orogeny. As mountains rose following a southeasterly strike-slip tectonic fault, the basin fell away in increasing depths as subsidence occurred (Ettensohn 1987). In some places, the waters of the basin were 150m deep, and sediments that collected at extreme depth below the thermocline did not decay due to anoxic conditions (Sageman et al. 2003). These organic-rich sediments eventually hardened into the layer known as the Marcellus Shale; due to the entrapment of organic material within the shale, the Marcellus contains pockets of natural gas and oil formed by the effects of millions of years of heat and pressure. The Marcellus formation begins at the foot of the Catskill Mountains in New York, stretches southward to the western corner of Virginia, spans west to Ohio, and spans east to the northeastern corner of Pennsylvania (Fig. 2). The most recent estimate of the natural gas reserve locked in the Marcellus Shale is approximately 15 trillion barrels (≈2.38 trillion cubic meters), and 3.4 billion barrels of that reserve are estimated to be technically recoverable (USGS 2011). While the Marcellus formation has been known to science for some time, it has not been developed until recently due to lack of sufficient drilling technology, inadequate extraction efficiency, and low wellhead gas prices (Soeder and Kappel 2009, MSETC 2010, Jiang et al. 2011). Drilling of the first Marcellus well in Pennsylvania occurred in 2004 (Jiang et al. 2011).

The Marcellus Shale formation is broadly categorized as an unconventional resource reserve; tar sands and oil or gas-producing shale formations fall into the same category. Development of unconventional reserves has become increasingly attractive due to rising oil

prices, concerns with greenhouse gas emissions, the passing of the estimated peak of conventional oil production, and projections of rapid increase in global energy demands (Northrup and Wittemyer 2013). Additionally, technological innovations such as hydraulic fracturing and socioeconomic factors such as job creation and the desire for domestic energy security have driven a dramatic increase in the rate of unconventional reserve development within the last decade (US EIA 2010). Natural gas is extracted by means of vertical and horizontal drilling, coupled with hydraulic fracturing to maximize production output. Roads must be created or expanded to allow for transportation of drilling rigs, water tanks, and other necessary equipment. Drilling rigs must be very large to support the mechanical infrastructure necessary to propel a drill bit more than one mile vertically below the ground surface and up to an additional mile horizontally. Land must be cleared, leveled, and re-surfaced to support heavy drilling rigs and associated truck traffic. Most well pads are from one to two hectares in size, and most surfacing material is crushed limestone that is imported and compacted to make the well pad stable (Fig. 3). Well pads have been constructed in both field and forest, and developers seem to attempt to construct pads in proximity to preexisting roads, particularly on tracts of Pennsylvania state property. Many well pad access roads on state land were formerly small two-track forest roads that were expanded by developers.

Following well completion, development companies are scheduled to remove most of the limestone surface material from the well pad and re-grade the land to approximately match pre-development conditions (Marcellus Shale Coalition 2011); however, site restoration does not yet appear to be occurring on most of the well sites in Pennsylvania, particularly on state property. In theory, well sites will be reduced from approximately 2 hectares of disturbance to about 0.4 hectares of disturbance following completion of well drilling and hydraulic fracturing. While

true restoration has not yet occurred on many producing well pads, development companies often lay erosion-preventative netting and plant cover crops such as ryegrass (*Lolia* spp.) and clover (*Trifolium* spp.) on limits of disturbance not occupied by the stone well pad as a temporary "restoration." There is no current information regarding how long a developed pad will remain in the landscape without full site restoration. Even following theoretical resurfacing and grading of sites, a sizeable canopy gap remains and edge effects may take hold, increasing the level of fragmentation of core forest and increasing amount of edge habitat. Little is known thus far regarding the long-term effects of Marcellus Shale drilling on Pennsylvania forest wildlife species and core forest habitat.

Natural Gas Development and Pennsylvania Core Forest

A large amount of Pennsylvania's core forest habitat reserve lies within the Susquehanna River Basin, which spans the majority of the state's central counties. Most of the Susquehanna River Basin is also underlain by the Marcellus Shale formation, and consequently more developed wells exist in this basin than any of the other drainage basins within the state (Drohan et al. 2012). Current permit data from the Pennsylvania Department of Conservation and Natural Resources (PA-DCNR) suggest that development will continue at a heavy rate into the near foreseeable future. As of early 2012, 885 well pads existed in the Susquehanna River Basin, and 26% of those occurred within core forest habitat primarily on private property. Approximately 342 well pads existed within core forest habitat across the Commonwealth in 2012; of those, 230 pads occurred within the Susquehanna River Basin- 67% of the total Marcellus Shale within-core-forest development (Drohan et al. 2012). Of Pennsylvania's ≈60% forest cover, about 40% qualifies as being core forest- forest interior habitat more than 100m from any edge (McWilliams et al. 2007, Goodrich et al. 2002).

Because Marcellus Shale drilling is so new to Pennsylvania, little research has been conducted to determine the effects of Marcellus Shale natural gas drilling on forests. The nature of fragmentation due to shale drilling is very different from most other forms of fragmentation of the Pennsylvania forest. Shallow natural gas drilling is perhaps the most comparable form of edge genesis, but the edge created by shallow drilling occurs on a much smaller scale and in a very different disturbance matrix. Unlike more common forms of forest fragmentation such as agricultural land-clearing, strip mining, and urban development, shallow gas development retains a landscape matrix dominated by mature forest after development is complete (when drilling occurs in previously forested areas). Although the landscape matrix remains relatively intact and forested, it is perforated by many small openings and gravel roads associated with gas extraction and access (Thomas 2011) (Fig. 4). Marcellus development occurs in less-clustered fashion than conventional development, but it creates a few large disturbances in a given area as opposed to smaller, more numerous ones. The mean pad size for a conventional gas well is approximately 0.4 hectares while the average Marcellus pad can exceed 2 hectares in size, so the nature of forest disturbance differs greatly between the two development types (Drohan et al. 2012, Thomas et al. 2014).

Soeder (2010) identified some environmental concerns associated with Marcellus Shale development in Pennsylvania: (1) drilling could contribute to forest fragmentation as forests were covered with a network of access roads and well pads, and (2) that invasive vegetation species introduction by equipment operation and water hauling was a distinct possibility. There are currently no completed studies regarding the fragmentation of Pennsylvania forests because Marcellus Shale development is so new to the landscape. The only information currently available to Pennsylvania wildlife managers regarding energy development effects on wildlife

pertains to conventional/shallow oil and gas. However, since unconventional petroleum development is not unique to the northeastern United States, biologists and wildlife managers do have access to impact studies conducted elsewhere in North America from which to glean information and generate hypotheses.

Unconventional Oil and Gas Development and Effects on Wildlife

Due to the relative recentness of Marcellus gas extraction, almost nothing is known regarding effects of development on core forest habitat or the wildlife residing therein; the best current information comes from studies of similar unconventional resource development elsewhere in North America. While development of unconventional reserves may result in economic benefits, it can also result in large-scale disturbance of ecosystems, namely in the form of habitat fragmentation or complete loss (Leu et al. 2008). While the fact that energy development can cause habitat alterations is known to science (Walker et al. 2007, Thomas et al. 2014), the effects of unconventional reserve development on wildlife are relatively poorly understood primarily due to the newness of the activity.

A number of recent biological studies have given evidence to a number of development impacts: habitat fragmentation by access road and pipeline networks; habitat change by well pads and other portions of the development footprint; behavioral changes in wildlife, such as edge avoidance, brought about by noise, activity, and human exposure; and increased likelihood of further fragmentation, natural resource extraction, or wildlife mortality due to increased ease of access to what were once wild and unfragmented lands (Northrup and Wittemyer 2013). Most wildlife impact studies of unconventional reserve development in the United States and Canada have focused on large ungulates, numerous songbird species, or the near-threatened greater sage grouse (*Centrocercus urophasianus*). Development effects on mammals included displacement

of mule deer (*Odocoileus hemionus*) in developed areas and around development infrastructure in the American West (Sawyer et al. 2006) and altered movement and home range patterns in woodland caribou (*Rangifer tarandus caribou*) in Alberta, Canada (Dyer et al. 2002). Few studies were able to attribute landscape-scale population impacts directly to oil and gas development, but a number of them have established development influence on decreases in survival rates of elk (*Cervus elaphus*) and grizzly bears (*Ursus arctos*) (Dzialak et al. 2011, Nielsen et al. 2006) and localized declines in caribou (*Rangifer* spp.) in developed areas (Sorensen et al. 2008). Effects on mammalian and avian migration corridors have not been well-studied, and the majority of forest wildlife research has focused primarily upon general fragmentation effects and not those specifically applicable to resource development.

Effects of Forest Fragmentation on Songbirds

Avian biologists have used songbirds, especially neotropical migrants, as indicators of forest health for some time due to their relatively rapid response to changes in forest habitat quality (Simons et al. 1999). Forest fragmentation and anthropogenic edge habitat genesis have been concerns for avian biologists since the later part of the 20th Century (Donovan and Flather 2002). Large patches of core forest habitat are particularly important to many species of neotropical migrant songbirds, and fragmentation of forest patches can negatively affect abundance of those species (Lynch and Whigham 1984). Results of studies in eastern North American forests have demonstrated that more than 25 species of songbird occur in significantly greater numbers in contiguous forest blocks than in extensively-fragmented forest patches (Askins et al. 1987). Fragmentation may reduce the abundance and diversity of neotropical migrant forest songbirds even when they occur in a mostly forested landscape (Askins 1994). Birds that nest in smaller forest patches, as would be found in a fragmented landscape, are

significantly more likely to have their nests predated than birds that nest in forest interior (Wilcove 1985). Avian nest predators such as blue jay (*Cyanocitta cristata*), American crow (*Corvus brachyrynchos*), and common grackle (*Quiscalus quiscula*) are more common along forest edges than within forest interior (Robbins 1980). Edges and open habitat are also known to attract brown-headed cowbirds (*Molothrus ater*); brood parasitism of forest-nesting songbirds occurs most frequently near open habitat, and birds that nest in small patches of forest are significantly more likely to have their nests parasitized (Brittingham and Temple 1983). Robinson et al. (1995) found reproductive success rates of forest-nesting songbirds in heavily-fragmented habitats to be so low that these locations were considered to be population sinks; local extinction risks and turnover rates of bird populations in fragmented forest patches were much higher than in larger, unfragmented forest tracts. Some songbird species exhibit edge avoidance, a negative reaction to forest fragmentation, as a possible function of increased nest predation, parasitism, decreased suitable habitat, or decreased number of conspecifics near edge (Bollinger and Switzer 2002). Development in the Marcellus Shale is creating edge habitat and sizeable canopy openings in contiguous forest habitat that was, on the whole, previously unfragmented.

While fragmentation can have negative effects on some songbird species, the newly-created edges can be beneficial for other species. The creation of forest openings allows more light to reach the forest floor, and this facilitates new plant growth and fruiting (Murcia 1995). Adventitious branch growth and heightened light exposure increases fruit production at forest edges and provides more abundant food for frugivorous birds. Bird distribution responds to edge creation and changes seed dispersal rates over time, suggesting that edges undergo succession and various degrees of edge effects (Restrepo et al. 1999). Because edges encourage generalist

and early-successional species colonization, local-scale fragmentation can increase overall species richness at the edge (Nitshchke 2008). Additionally, because two different plant communities intersect at an edge (e.g. forest and openings such as fields), the density and variety of organisms at the border between the communities tend to be higher (Harris 1988).

Effects of Oil and Gas Development on Songbirds in North America

Hartzler (1999) conducted research on the effect of shallow well drilling in Clear Creek State Forest in western Pennsylvania and discovered species-dependent positive and negative correlations between bird abundance and level of habitat disturbance. The estimated species richness and Shannon's diversity index were higher for well site habitats than control sites composed primarily of core forest. However, species richness in a habitat with increased amounts of edge land is expected to be higher due to influx of generalist bird species and growth of early-successional plant species. While the α-diversity increases, this increase could be negative, as invasive species and previously non-present species move into the area and core forest habitat is reduced. Displacement of forest interior birds by habitat fragmentation and new species invasion would subsequently reduce β-diversity in the landscape immediately surrounding the pad despite the rise in alpha diversity at the pad edge.

The majority of studies regarding the impacts of unconventional oil and gas development on songbirds come from the western United States and western and central Canada. Some bird species, such as the ovenbird (*Seiurus aurocapilla*), responded negatively to anthropogenic noise related to gas drilling and edge effects associated with pad installation (Bayne et al. 2008). Additionally, ovenbirds responded negatively to the presence of seismic lines in the boreal forest of Northwest Territory, Canada; ovenbirds moved away from seismic lines, decreased in abundance in areas with high-density seismic lines, and seemed to use seismic lines as territorial

boundaries (Machtans 2006). Grassland bird species that tended to avoid non-native grass species avoided use of well pads and declined in areas where well pad density was high (Dale et al. 2008). Gilbert and Chalfoun (2011) cited habitat use as a driver of bird population response in Wyoming sagebrush habitat impacted by natural gas drilling.

However, the bird species (and aggregate floral and faunal communities) of the American West and Canada are not comparable to those of deciduous northeastern North America, and because of the differences in habitats and species, their reactions to development may not be indicative of eastern bird species' reactions. Additionally, because habitat types differ so widely between the American east and west, fragmentation effects in western boreal forests cannot be expected to be the same as fragmentation effects in eastern mixed hardwood deciduous forests (Sisk and Battin 2002). Because the base of biological and ecological knowledge regarding the effects of Marcellus Shale drilling on forested habitats in Pennsylvania is currently lacking, it is vital to delineate these effects and determine their magnitude. Knowledge of these effects will allow the professional scientific conservation community to provide regional landowners, energy developers, and forest managers with critical information regarding ecological impacts of shale drilling; this information may aid the involved parties in making responsible decisions when it comes to energy development in the Marcellus Shale.

Why Study Songbirds?

Managers frequently cannot measure every natural variable in an ecosystem, so they often use indicator species to make informed decisions regarding management actions. Valuable indicator species may serve one or more of the following functions: 1) provide early warning of natural responses to environmental impacts through numerical or behavioral reaction; 2) indicate directly the causes of population trend change; 3) act as a continuous assessment of an ecological

impact, i.e. the species will not vanish from an area or fail to respond beyond a certain threshold; and 4) are relatively simple to measure, cost-effective, and easily identifiable by all people involved (Carignan and Villard 2002). Birds, especially neotropical migrants, are oft-used indicator species because they exhibit interspecific dynamic interactions, such as allospecific territorial competition, and hence populations of one species will often respond to changes in those of another species; furthermore, species with similar habitat requirements often occur in the same habitat and are absent from the same habitat if it is unsuitable (Cody 1969, Cody 1981).

Boulinier et al. (2001) demonstrated local bird communities function as mesopopulations, and landscape changes and responses to habitat fragmentation by these regional populations are important to local community dynamics. Dynamic colonization and extinction processes, as well as temporal variation in species richness and composition, are likely functions of both the regional species abundance and local landscape attributes such as degree of fragmentation (Boulinier et al. 2001). However, numerical response in bird population size is not the only relevant point of study when it comes to the use of songbirds as indicators. Canterbury et al. (2000) demonstrated that composition of avian communities in forested habitat can act as an index of forest condition: as forests become more fragmented by development or disturbance events, disturbance-tolerant generalist species occupy habitat that was once unsuitable for them. Community composition can therefore be used to assess changes in "healthy" levels of forest continuity if comparisons are made between interior forest and adjacent edge forest habitats. A result giving evidence to increases in edge/generalist species and decreases in interior species suggests forests are becoming less continuous and more fragmented.

Pennsylvania is rich in plant and animal species that are forest-dependent or heavily associated with forest habitats; approximately 600 species of plant and animal that occur in

Pennsylvania are forest-dependent (USDA 2003). Because of the plenitude of forest-obligate species, many of which are threatened or endangered, present in the state, it becomes critically important to understand how habitat loss and fragmentation due to energy development impacts flora, fauna, and larger ecological systems. Songbirds respond dynamically to habitat changes as more information becomes available to them, and they use social information (e.g., location of conspecific territories) and observational information (e.g., abundance of diurnal nest predators) to make habitat selection decisions (Betts et al. 2008). The rapidity with which songbirds respond to perceived changes in habitat quality makes them an excellent candidate group to serve as biological indicators.

Research Objectives

The purpose of this study is to determine the local-scale (well pad level) effects of Marcellus Shale gas development on songbird occurrence and relative abundance; to assess the potential for avian community shifts due to development; to examine vegetation and habitat factors surrounding well pads; and, based on results, to determine implications of further shale gas resource development for core forest habitat areas of Pennsylvania and in similar areas with extensive core forest habitat also experiencing shale gas development. I hypothesize that bird relative abundance is affected by distance from Marcellus pads (and other edges), and that species occurrence is related to distance from well pads. I hypothesize that synanthropic bird species, or those species associated with humans and edge-creating habitat disturbance events, will be more abundant near pad edges, while forest interior bird species will be less abundant near pad edges. I also intend to assess potential creation of early successional habitat by development by using early successional bird species as an indicator. If development is

generating early successional habitat at the pad edge, I would expect early successional birds to be more abundant at the edge.

Based on my hypotheses regarding habitat preference-dependent bird responses to Marcellus development, it logically follows to hypothesize some avian community shifts surrounding well pads. I would expect local bird communities near well pads to be composed of more synanthropic species, and in greater abundance, than communities within the forest interior due to creation of new edge habitat favorable to those species. I predict canopy cover will be reduced at the pad edge due to land clearing, but I am uncertain whether enough time has passed to observe other vegetative edge effects that could either drive or predict bird community composition.

METHODS

Study Area

Climate.- The seven-county region of northcentral Pennsylvania in which the study occurred falls broadly within the Eastern Temperate Forest and Northern Forest ecoregions, both in the humid temperate domain of North America; the northernmost portions of the study area lie near the dividing line between the two broad-category ecoregions (US EPA 2007). The study region is further divided between the warm continental division and the warm continental regime mountains of the Eastern Temperate Forest ecoregion. These two divisions contain numerous physiographic provinces (USFS 1994): four of the seven counties fall within the northern Appalachian plateau and uplands of the Eastern Temperate Forest, while the three northernmost counties fall within the North Central Appalachians of the Northern Forest.

The North Central Appalachians are part of a large elevated plateau that was largely unaffected by continental glaciation during the Laurentian Ice Age (Wiken et al. 2011). It

consists mainly of plateau surfaces, high hills, and low mountains that are markedly different from the larger ridges and deeper valleys of lands to the North and West. The mean annual temperature is between 3°C and 8°C, and the mean annual precipitation is 1,082mm. The nature of the climate and topography translates to the presence of many perennial moderate to high-gradient streams and a number of lakes, bogs, and marshes.

The Northern Appalachian Plateau and Uplands ecoregion is a transitional region between the less topographically irregular, more agricultural Erie Drift Plains and the more mountainous, more sparsely-populated North Central Appalachians. Unlike the North Central Appalachian region, this region was affected by the Laurentian glaciation, making the terrain more irregular with numerous mountains, rolling hills, and broad valleys. The mean annual temperature is approximately 7°C, and the mean annual precipitation is 969mm. Small glacial lakes and low to moderate-gradient streams are present throughout the region (Wiken et al. 2011).

Vegetation.- Forests in the seven-county study region are broadly divided into two categories: Northern hardwood and mixed oak forests. I attempted to divide site selection between the two forest types equally. Classification of forest types depended primarily upon canopy dominant tree species and understory shrub characteristics; mixed oak habitat was characterized by dominance of oak species in the overstory and presence of ericaceous shrubs in the understory. While numerous forest subtypes can be further divided from the broad category of Northern hardwood forests, I opted for the broad classification because understory characteristics did not differ extensively across the study sites.

Forests in the North Central Appalachian ecoregion, which is primarily Northern hardwood habitat, are largely composed of red maple (*Acer rubrum*), sugar maple (*A.*

saccharum), American beech (*Fagus grandifolia*), yellow birch (*Betula alleghaniensis*), black birch (*B. lenta*), black cherry (*Prunus serotina*), tulip-poplar (*Liriodendron tulipifera*), white ash (*Fraxinus americana*), white pine (*Pinus strobus*), and Eastern hemlock (*Tsuga canadensis*). Species including oaks (*Quercus* spp.), hickories (*Carya* spp.), and pitch pine (*Pinus rigida*) are also present in relatively low densities (Wiken et al. 2011). The forest understory is composed of similar woody species as the overstory, with thickets of American beech and striped maple (*Acer pensylvanicum*) being common in many areas. Other common understory plant species include Allegheny blackberry (*Rubus alleghaniensis*), maple-leafed viburnum (*Viburnum acerifolium*), hay-scented fern (*Dennstaedtia punctilobula*), and maidenhair fern (*Adiantum pedatum*).

The forest of the Northern Appalachian Plateau and Uplands ecoregion is markedly different from the North Central Appalachian forest, where Northern hardwood is the more common forest type. Portions of Lycoming, Clinton, Centre, and Clearfield counties are almost exclusively composed of mixed oak forest. Species such as northern red oak (*Quercus rubra*), eastern black oak (*Q. velutina*), white oak (*Q. alba*), chestnut oak (*Q. prinus*), black gum (*Nyssa sylvatica*), red maple, and eastern white pine compose the majority of the high canopy (Wiken et al. 2011). The more acidic soil of this region enables ericaceous shrubs such as mountain laurel (*Kalmia latifolia*), rhododendron (*Rhododendron maximum*), and northern highbush blueberry (*Vaccinium corymbosum*) to dominate the forest understory. Witch hazel (*Hamamelis virginiana*) is also common as an understory species.

Wildlife.- Songbird community composition is frequently related to differential use of plant species and foraging substrates by birds that occupy different ecological niches and use different foraging strategies and maneuvers (Holmes et al. 1979). Species such as Canada warbler (*Cardellina canadensis*) and ovenbird are more common in Northern hardwoods, while

species such as black-throated blue warbler (*Setophaga caerulescens*) and chestnut-sided warbler (*Setophaga pensylvanica*) are more common in mixed oak habitat. Mammals such as eastern gray squirrel (*Sciurus carolinensis*), white-tailed deer, raccoon (*Procyon lotor*), bobcat, eastern coyote (*Canis latrans* var.), and black bear are relatively common across the seven-county region, as are game birds such as wild turkey (*Meleagris gallopavo*) and ruffed grouse (*Bonasa umbellus*) (Wiken et al. 2011).

Site Identification and Selection

I identified Marcellus study sites using ArcMap Version 10 (Arc10) GIS software, landowner contact, ground-truthing, and cooperation with Pennsylvania state land managers including the Pennsylvania Game Commission (PGC) and the Pennsylvania Department of Conservation and Natural Resources (DCNR). I avoided sites that were in the process of development in the interest of safety, compliance, and maximizing bird detection. I used a hand-held global positioning system (GPS) unit to mark the perimeter of each well pad. I then imported the marked perimeter points into Arc10 and used landscape measurement tools to set point count locations at true distances. All point count locations were exported to a portable GPS unit; I ground-truthed all points to assess accuracy of the GIS placement and marked all points with a single ribbon of surveyor flagging to maximize visibility. All field sites were restricted to a seven-county area in forest habitat with >75% forest cover within a 5km from the pad location (Table 1, Appendix D, Table D-2). I selected sites on both public and private property. The seven counties were located in northcentral Pennsylvania and encompassed various levels of Marcellus development: Lycoming, Clinton, Tioga, Potter, Clearfield, Bradford, and Centre (Appendix D, Table D-1).

I identified sites of interest using Arc10 aerial photography of the landscape, completed between 2005 and 2012, and PA Department of Environmental Protection (DEP) permitting information. I mapped pads of interest that were not visible on aerial photographs by driving through the area and identifying developed pads. In May 2011, I made contact with DCNR and the PGC to discuss lease access legality before I mapped sites or performed any surveys. Both agencies informed me that accessing public land well sites was legal as long as I did not walk on the well pad; development companies post signs and enforce strict "no trespassing" policies in the interest of public safety. Therefore, on public land, I was able to immediately map the perimeter of sites with a GPS unit. However, sites of interest I identified on private land necessitated a different approach. I identified private land leases using the DEP permitting information and lease permits posted at the site by the development companies (PADEP 2011). I made personal contact, generally via telephone and meeting, with landowners and received their permission to access the land surrounding the well pad before mapping the sites if the sites were not visible on aerial photographs. Private sites that appeared on the PAMap images could be mapped with Arc10 without accessing the property prior to receiving permission from the landowner.

As of February 2012, approximately 230 Marcellus pads existed in core forest areas of the Susquehanna River basin, which contains all seven counties of interest but also contains many other counties. My study included 30 well sites; therefore, sampling intensity was ≥13% of the pads within forest that existed at the time. Most northern hardwood sites were located on private property while most mixed oak sites were located on public land; because most large blocks of state forest land are composed of mixed oak forests, the odds ratio of habitat type and ownership class is very disparate (OR= 13.2, Table 1). Because I had to access well sites within

the forest, the sites needed to be inactive for the sake of safety and accurate bird detection. However, development had only begun to conclude on many potential field sites and they could not be included in the study. Additionally, while access to developed sites on state property was possible, many pads were not suitable for use in our study because they were being utilized as staging areas despite the completion of drilling on site. Security checkpoints and heavy traffic on small dirt roads made access impractical and detection difficult near these sites; despite cooperation from developers and state management agencies, staging sites were avoided in the interest of producing accurate results. On private property sites, pads were less frequently used as staging areas following completion of drilling. Approximately 90% of Marcellus development has occurred on private property (Drohan et al. 2012), so finding property owners and receiving permission for access was often an issue. Numerous large tracts of property with well pads are owned by hunting and fishing clubs within the Susquehanna drainage basin; receiving permission for access from many of these organizations was more difficult than working with a single landowner. Absentee landowners were nearly impossible to contact, so many potential sites on private property had to be abandoned.

Point Count Procedure and Location

Point counts are a method of determining relative bird abundance by listening for singing birds and recording all observations within a fixed distance over a fixed time period. Male songbirds sing to defend their territories during the breeding season, particularly during the early morning; while they continue to sing intermittently throughout the day, song frequency declines greatly around mid-day as bird activity shifts to foraging and care of nestlings (Bart and Schoultz 1984). Because many forest bird species are somewhat difficult to observe visually, aural counts within a confined area can often provide a better approximation of bird density than visual

counting; this concept encapsulates the fundamental principle of the point count. Count duration and fixed radial distance is usually somewhat dependent upon habitat type or cover density (Hutto et al. 1986). Ralph et al. (1995) evaluated various-length point count data from wooded habitat for efficiency and determined that point counts should ideally be five or six minutes in length. While longer counts may increase likelihood of detecting cryptic and sensitive species, they do not offer any real benefit when the goals of surveying are community structure delineation or abundance approximation (Fuller and Langslow 1984). The most common fixed radial size for a point count in forested habitat is 50m, although lesser or greater distances are sometimes used when cover density necessitates the change for the sake of accurate detection (Hutto et al. 1986). A count radius of ≤50m provides some protection against saturation bias, a phenomenon in which observers are not able to distinguish between multiple singing individuals of an abundant species and therefore underestimate abundance (Bart and Schoultz 1984). Similarly, sampling bias against canopy-singing species, whose sound may be attenuated by obstructing layers of vegetation, and species that sing at barely-audible frequencies is reduced when count radius is kept appropriately short (Waide and Narins 1988). An additional benefit of fixed-radius point counts of ≤50m sampling radius is that vegetation characteristics can be measured in physical proximity to locations where birds where actually observed, thereby presumably increasing accuracy and the clarity of interpretation of subsequently-derived bird/habitat relationships (Petit et al. 1995).

My point counts had a sampling radius of 50m and sampling occurred for six minutes at each point, following procedures derived from Petit et al. (1995). I recorded all singing male songbirds by species and by distance from point center. Birds within 50m of the point center were considered “in,” and birds singing more than 50m away were considered “out.” Only birds

that were “in” were used for data analysis. I used singing males as a metric of bird relative abundance because males actively defend occupied territories during the breeding season by singing (Johnston and Odum 1956). Sampling generally began 30 minutes before sunrise and did not proceed after 11:00AM, as birds were not singing at full capacity by late morning and detection was therefore likely to suffer. Additionally, I did not perform point counts during moderate to heavy rain events, windy conditions, or heavy fog events because avian activity decreases significantly during such adverse conditions.

I established point count locations at four distances from edge and, where feasible, within forest: 0m (at the pad edge), 50m from any non-forest edge, 150m from any edge, and 250m from any edge (Fig. 5). The points at distance 0m and 50m were classified as edge points, the 150m point was a transitional interior point, and the 250m point was classified as an interior point. The 150m transitional interior point was the first point that fell outside the 100m distance-to-edge limit of the core forest operating definition (UConn CLEAR 2013). I marked points using Arc10, beginning at a random compass bearing identified by a random number generator; where I could not set a complete point transect of 0-250m, I continued to go through compass bearings clockwise from the random bearing until I was able to do so. At some sites where the forest was more fragmented, I used transects of 0-150m and randomly placed 250m points where the habitat allowed. Point transects were kept 150m apart at minimum to avoid double-counting of birds. Bird count points of the same distance class located closer together than 150m were eliminated from the study due to concerns with artificially inflated relative abundance. Where habitat surrounding a pad was fragmented to such a degree that made placement of an entire point transect impossible, remaining point counts were randomly placed at appropriate distances. The number of point transects surrounding each pad, and the number of points at each site, were

perforce dependent upon the size of the pad and the amount of forested, unfragmented habitat remaining around the pad. I avoided, wherever possible, placing point transects where habitat islands or large amounts of change in elevation occurred to reduce the probability of inflating the detected relative abundance of certain bird species.

I visited 13 field sites during the 2011 bird breeding season and 17 Marcellus sites during the 2012 bird breeding season to reach the target number of 30 sites. Active development restricted the availability of sites during both years since only inactive well pads could be included in the survey. I collected bird data over a total of 249 point count locations during the 2011 and 2012 breeding seasons. I conducted 39 counts at 0m or the pad edge, 76 counts at 50m from edge, 77 counts at 150m from edge, and 57 counts 250m from edge; the numbers were not balanced due to unequal availability of suitable locations at all sites. Points at 0m were difficult to place because of point proximity to one another. It was often impossible to place two 0m points at the edge of an individual pad without invoking the potential for double-counting due to inadequate point separation. Counts at 250m were difficult to place because of ongoing forest fragmentation and difficulty in ground-truthing distance to edge.

While initially I had aimed to conduct point counts at each site two times to increase detection probability, time constraints brought about by the process of locating and mapping sites made this an unrealistic objective. However, Petit et al. (1995) determined that one encounter occasion per point per sample site in forested habitat produced results strong enough to be used as an index to abundance, particularly with neotropical migrant species. Furthermore, a literature review of ornithological studies demonstrated that 50-90% of bird species occupying a forested sample site are detected during the first encounter occasion, adequate to provide a representative picture of local-scale avian communities (Petit et al. 1995).

Vegetation Sampling

I collected vegetation data using a modified sampling regime adapted from the University of Montana's BBIRD protocols (Martin et al. 1997). A 5m radius low cover sampling plot was nested within a larger 11.2m radius tree sampling plot. I gathered data via visual estimate for percent ground cover, ground cover composition, dominant woody shrub species, and dominant sapling species within the 5m radius sample plot; visual cover estimates, canopy cover estimates, and canopy height approximations were made from point center (Table 2). Ground cover categories included the following: % green, % grass, % shrub, % forb, % fern, % moss, % leaf litter, % rock, % natural woody debris and % gas-associated woody debris, % wetland, % water, and % bare ground. I estimated canopy height with a laser rangefinder; where I was unable to use the rangefinder to estimate canopy height because of mid-story canopy cover, I mathematically estimated upper canopy height based on relative scaling and triangulation. I estimated percent canopy cover with a spherical densiometer using the four cardinal directions as points of reference.

Within the 5m sample plot, I also counted shrub and sapling stems that were ≥50cm in height and put them into categories based on stem diameter at 10cm above the ground level. I collected data via visual percent cover estimate for dominant tree species and counted the number of tree stems within the 11.2m radius sample plot; I sorted trees into size categories based on diameter at breast height (dbh). I identified all trees and woody shrubs by species and recorded the number in each plot. Additionally, each central vegetation plot (point center) had three outrigger plots located 30m from point count center, and these locations were selected by taking one random compass bearing. I placed the first outrigger plot at that bearing, and additional outrigger plots at the random bearing plus and minus 120 degrees, resulting in

randomized 360 degree vegetation sampling around point count center; thus, four vegetation sampling plots occurred within and were all encapsulated by the boundary of the 50m radius bird sampling point (Figure 6). I recorded vegetation data at two point count locations of each distance category per site where feasible. I selected two transects at random in which to sample vegetation, but where points were disjointed from the main transect line there was no randomization in selection unless there were more than two disjointed points of the same distance category. Disjointed points generally became an issue only at long distances (150 and/or 250m) from pad edge in landscapes that were already somewhat fragmented.

Data Analysis

Landscape Characteristics.– I used Arc10 landscape analysis and PA land use maps to determine landscape characteristics surrounding all 30 Marcellus sample sites. I identified three buffer areas to investigate: 500m radius from pad center, 1km radius from pad center, and 5km radius from pad center. I used the 500m buffer to obtain a "snapshot" of the land cover immediately surrounding well pads. The 1km and 5km buffers were intended to obtain information about the landscape on a larger scale than the area immediately near the well pad. I collected land cover data around all sites for five cover categories: percent road surface area, percent forest cover, percent core forest, percent edge forest, and percent agriculture. Core forest was classified as forest >100m from edge, and edge forest was forest within 100m of edge (UConn CLEAR 2013). Percent forest cover was a summative term such that [% core forest + % edge forest] encompassed all wooded land cover. I used Minitab 16 statistical software (Minitab 2010) to determine both mean and median values, due to the potentially inflating or deflating influence of one site with large amounts of an otherwise uncommon land cover type. I conducted 2-sample t-tests in Minitab on percent cover means to assess differences in land cover

characteristics by habitat type. I expected significant differences in percent road cover, percent edge forest, and percent agriculture to translate to differences in synanthropic bird species abundance due to presence of larger source populations.

Avian Community.– I examined habitat and distance effects on avian community structure with a non-parametric multivariate analysis of variance (NPMANOVA) in PAST Version 2.17c statistics software (Hammer et al. 2001). NPMANOVA tests for significant differences in response between two or more groups based on any distance measure. The benefit of a non-parametric approach to MANOVA over a parametric approach lies in the absence of assumption that the data conform to a multivariate normal distribution, which is often unrealistic for most ecological data sets (Anderson 2001). NPMANOVA allows the same additive partitioning of variation as MANOVA, allowing it to be useful with any distance measure or ANOVA design, but it retains the flexibility of non-parametric methods (Anderson 2001). An assumption of non-parametric multivariate analysis of variance is similar distribution between groups, i.e. the groups have similar variances. The statistical tests of the analysis cannot distinguish between significance due to differences in mean, differences in dispersion, or a combination of both. I performed Levene's test for equal variance between groupings to ascertain dispersion; if the variance was equal between groups, then the significance of the community analysis was largely attributable to differences in the mean values.

Like a parametric multivariate analysis of variance, the non-parametric equivalent returns Fisher's F statistic and the associated p-value (Hammer et al. 2012). Analyses are pairwise between groups and PAST reports results for all comparisons. The p-value is determined by permutation in group membership with procedural replicates; I ran analyses with the default 9,999 replicates in PAST. I used Bonferroni's p-value correction for multiple comparisons to err

on the side of conservatism. I selected the Morisita (1959) overlap index, which assesses similarity in abundance of species present in two biological communities that differ based on a measured variable, as the operating index for NPMANOVA analysis. In the analysis, the program collapses observations by group into an index value and then compares the distance between groups. The Morisita overlap index is given by:

$$\boldsymbol{C_D = \frac{2\sum_{i=1}^{S} X_i Y_i}{(D_x + D_Y)XY}};$$

Where: X_i = the number of times species "i" is represented in the total X of one group,

Y_i = the number of times species "i" is represented in the total Y of another group,

and D_x and D_Y are Simpson's Index values for the samples.

X and Y are the totals of groups X and Y (e.g., total encounters in the group).

Simpson's Index is a proportional abundance of the species of interest.

$\mathbf{C_D}$ is constrained between 0 (if the samples do not overlap) and 1 (if species occur in the same proportions in both groups)

Wolda (1981) found that, when compared to other indices of overlap or similarity (e.g. Bray-Curtis or Sørensen), the Morisita index was far less sensitive to differences in sample size or species diversity because it operated under the premise that increases in sample size would subsequently increase diversity by way of encompassing more habitat types. In summary, the avian communities being compared are dissimilar in terms of species present, relative abundance, greater variation in observation frequency, or a combination of the aforementioned factors if the NPMANOVA returns a significant result. I chose a p-value of less than 0.05 as the threshold for significance.

I opted to compare communities using distance, habitat type, and distance by habitat type as differentiating criteria. Significant differences in bird communities, represented here in proxy by the raw bird encounter data identified by distance, between the forest at the well pad edge and

the surrounding interior forest would suggest that Marcellus edge genesis is leading to shifts in species composition. Significant differences in northern hardwood and mixed oak bird communities would establish precedent for further comparison: if the aggregate communities differ by habitat type, how do they compare when habitat type is partitioned into distance groupings? I constructed three hypothetical models to answer the three different questions about avian communities surrounding Marcellus well pads:

1) $Y_1 = \alpha + \beta_{dist}$: to investigate effect of distance from pad on avian community.
2) $Y_2 = \alpha + \beta_{hab}$: to assess community differences based upon habitat type.
3) $Y_3 = \alpha + \beta_{dist} + \beta_{hab} + \beta_{dist*hab}$: to determine distance effects grouped by habitat type.

I performed Levene's test for equal variance on group mean residuals for each of the three hypothetical models given above to verify that significance of the community analysis was primarily attributable to differences in mean values. Levene's test is, in essence, a one-way ANOVA on the absolute values of the differences between individual observations and the mean values for each group. The null hypothesis of the test is that the variances are equal between groups; a p-value less than 0.05 is sufficient to reject the null hypothesis and conclude variances are unequal. By Levene's test, variance between groups was equal for each of the three hypothetical models: distance (F=2.713, p=0.487), habitat (F=3.951, p=0.300), and distance*habitat (F=2.126, p=0.282). Therefore, the data met the assumptions of NPMANOVA and the majority of community analysis significance was due to differences in group means.

Habitat Association Guilds.– While community analysis can indicate differences in bird communities by group, it cannot answer questions about the direction of the difference, i.e. it cannot expressly determine how the community differs. Guild analysis, however, can reveal information about the nature of community shifts, thereby addressing the "how" aspect of the

community analysis results. I placed species with clear habitat preferences, supported by evidence from the 2nd Pennsylvania Breeding Bird Atlas (Wilson et al. 2012) and a similar development impact study (Thomas et al. 2014), into guilds for statistical analysis. I established three bird guilds based on habitat association and hypothesized response to Marcellus development: synanthropic species, early successional species, and forest interior species (Appendix A). These guilds reflected bird habitat choices in relation to preference for anthropogenic edges and degree of use of human-related habitat disturbances, similar to analytical procedure used by Marzluff (2005), Leu et al. (2008), and Thomas et al. (2014). Synanthropic birds are disturbance-tolerant species that occupy forest edge habitat, such as American robin (*Turdus migratorius*), or species that are heavily associated with anthropogenic disturbance, such as brown-headed cowbird. Early successional species, such as eastern towhee (*Pipilo erythropthalmus*) and chestnut-sided warbler, require young or emergent forest habitat characterized by dense understory and smaller-diameter trees. The forest interior guild includes area-sensitive, closed canopy mature forest specialists such as black-throated green warbler (*Dendroica virens*) and edge-avoiding understory birds such as hermit thrush (*Catharus guttatus*).

I calculated guild relative abundance by summing selected guild member mean encounters per point per site by distance category (0m, 50m, 150m, and 250m). Because the 0m and 50m point counts overlapped, double counting could occur at sites where point counts of both distance categories were used. To avoid double counting, I randomly selected sites for which to use 0m or 50m as the edge metric by numbering sites 1-30; I then selected the 0m relative abundance for odd-numbered sites and the 50m relative abundance for even-numbered sites. Sites for which there were no 0m points were automatically assigned to the 50m category.

I analyzed the data in Minitab 16 using general linear modeling for relative abundance with four general predictors: distance from edge, forest habitat type (Northern hardwood or mixed oak), a random site factor, and a distance*habitat interaction term. I constructed models including different combinations of predictors until I found the most parsimonious model; that is to say, only terms that were significant were left in the model, except in the case where a dependent or interactive relationship existed and insignificant base predictors had to be left in the model. I considered α=0.05 to be significant for guild models. I used Tukey's honestly significant difference (HSD) (Tukey 1949), a pairwise comparison for multiple means, at the 95% confidence level to assess differences between distance and habitat-based abundance means.

Individual species.– I observed 62 passerine or near-passerine bird species during the 2011 and 2012 breeding seasons while conducting point counts near Marcellus sites. Of the 62 species observed, only 11of them were encountered at ≥50% of field sites. I constructed models for individual bird species observed at ≥ 50% of field sites using the same four predictors of relative abundance as for the guild models. I calculated mean encounters per point by summing species-by-species encounters on a per-site basis by distance from edge, then dividing the aggregate encounter sum by the number of points of the given distance category (0, 50, 150, or 250m from edge); the resulting number was a relative abundance metric. To account for point overlap, I randomly selected sites for 0m or 50m relative abundance presence in general linear models using the same criteria as I did for guild analysis. After selection, the 50m relative abundance represented the edge metric for 16 sites and the 0m relative abundance represented the remaining 14 sites. All 30 sites had 150m point counts and bird observations, and 28 of the 30 sites had 250m counts and observations. I considered results to be significant at α=0.05 for

individual species model predictors. I used Tukey's HSD at the 95% confidence level to assess differences between means.

For individual species not encountered at 50+% of sites, I examined observations by distance to provide a general picture of where those species were being detected. I determined the number of observations by species that occurred within given distance bands and divided by the total number of observations to calculate the fraction of distance-specific observations. I reported this value as a percent of the total; while this value may carry little weight where species were observed only once or twice, it remains noteworthy where these infrequently-observed and relatively uncommon species occurred relative to Marcellus pads.

Temporal Differences in Bird Abundance. – Because no site was surveyed during both 2011 and 2012, I was unable to incorporate an explanatory "year" factor into analysis of bird data. I conducted G-tests on annual means for species for which there appeared to be a large amount of disparity between observations in each year. The G-test is a likelihood ratio test and serves purposes similar to Pearson's chi-squared test, but better approximates the χ^2 distribution than does the chi-squared test which is based on an approximation of G (Woolf 1957). I selected a p-value of less than 0.05 as the threshold for determining statistical significance and difference between annual means. While I could not incorporate temporal differences into any abundance model, I wanted to determine whether there was statistical noise in the form of unexpected or inexplicable fluctuation in annual abundance present in the forest bird community.

Vegetation Factors.– Each vegetation sample plot was identifiable by site name and distance class (0, 50, 150, or 250m from edge). While each bird point count location was associated with four vegetation sample plots (point center and three "outrigger" plots), none of the vegetation plots overlapped and they fell within the same distance band. I used Minitab 16

general linear modeling to assess numerous vegetation factors with respect to distance from pad edge. I built models to investigate distance effects on mean litter depth, mean canopy cover, tree diameter at breast height, the number of small and large sapling stems, and the various percent ground cover categories within the plot. I considered α=0.05 to be significant and used Tukey's HSD at the 95% confidence level to assess means. I did not assess differences in vegetation by habitat type due to small sample size in mixed oak forest- ongoing development such as pipeline installation prevented sampling on a number of sites and also deforested some point count locations. Between 2011 and 2012, I collected vegetation data at 94 bird survey points across 14 field sites and completed a total of 349 vegetation sample plots.

RESULTS

Marcellus Pads and Landscape Characteristics

The mean size of well pads in the study (not including limit of disturbance) was approximately 2.1 (±0.3) hectares. I did not find any differences in land cover percentage by habitat type in any buffer size category (Table 3). The amount of road surface did not differ by habitat type at any of the three spatial scales. Percent forest cover and percent core forest were both marginally higher in mixed oak habitat, and edge forest was perforce slightly more common in northern hardwood habitat. The amount of agricultural land surrounding sites in northern hardwood forest was generally slightly larger, although the 95% confidence intervals ($t_{0.025, 28}$=2.048) overlapped at each of the three spatial scales. The mean values for percent agriculture were always marginally higher in northern hardwood habitat. Standard error values decreased as spatial scale increased, i.e. more land cover types were captured within the sample. In other words, the likelihood of the sample being largely composed of only uncommon land cover types was substantially reduced as larger areas of habitat were sampled.

Distance-Specific Bird Observations

Some individual bird species not observed frequently enough to permit model building were disproportionately observed at points near edge (0m, 50m) or within the forest interior (150m, 250m) surrounding Marcellus well pads. While the small sample size for these species limits methods and implications of quantitative description, the patterns of observation frequency for species observed in unidirectional disproportion closely followed individual species habitat association (Table 4). For example, species such as mourning dove (*Zenaida macroura*) and brown-headed cowbird- both heavily associated with agricultural habitat- were observed primarily near pad edges, while forest-obligate species such as blue-headed vireo (*Vireo solitarius)* and veery (*Catharus fuscescens*) were observed overwhelmingly within the forest interior. A total of 54 species were observed in edge forest, and 11 of these were never observed within the forest interior. In contrast, 8 of the 51 species observed in the forest interior were never once observed within edge forest.

Temporal Variation in Observations

Some species exhibited large variation in frequency of observation between the two breeding seasons, despite similarity in site characteristics and habitat type. Two species- the American redstart (*Setophaga ruticilla*) and great crested flycatcher (*Myiarchus crinitus*)- observed with some frequency during the 2011 breeding season (16 observations and 10 observations, respectively) were not observed once during the 2012 season. Common forest bird species such as ovenbird, red-eyed vireo, and Eastern towhee were all observed with significantly less frequency during point count surveys in 2012 than in 2011 (Table 5). While the number of sites and the total number of point counts were unequal during the two field seasons,

frequency of observation for many species differed significantly from expected values weighted for sampling intensity.

Avian Community Analysis

Results for northern hardwood habitat closely followed aggregate results for distance comparisons; only the 0m-50m and 150m-250m comparisons were not significant ($p>0.05$) (Table 6, Fig. 7). However, results for mixed oak habitat did not exactly mirror results for the aggregate: though the 0m-50m and 150m-250m communities were not significantly different from one another, the 50m-150m communities also did not differ in a statistically significant manner. Comparisons between habitat types revealed that the northern hardwood and mixed oak interior communities all differed significantly from one another ($p<0.05$), but communities at edges did not differ within distance classes (e.g. 0m vs 0m) or between distance classes (e.g. 0m vs. 50m). Communities at the immediate pad edge and within adjacent edge forest were characterized by the same species regardless of habitat type (Table 7, Fig. 7).

Habitat Guilds and Individual Species

Synanthropic species.

Distance from edge ($F=11.17$, $P<0.001$) was the only significant predictor of relative abundance for synanthropic (human-associated) bird species. Mean abundance was highest at the pad edge, but while abundance at the 0m point differed from the 150m and 250m interior points, it did not differ from that of the 50m point (Fig. 8, Fig. 9, Table 8). Mean abundance at 50m from edge also differed from the interior points. The 150m and 250m interior abundance means did not differ from one another.

Distance from edge was the only significant predictor in the general linear model for American robins ($F=8.12$, $P<0.001$), the only synanthropic species observed with frequency

enough to warrant individual analysis. Robins were present at 18 of 30 Marcellus sites and were more abundant at edge points than interior points. Relative abundance was highest at 50m from the pad edge but did not differ from mean abundance at the 0m point (Fig. 10, Table 9). Abundance means differed between the 50m and the interior points, but did not differ between the 0m point and the 150m point. Mean relative abundance at the 150m point did not differ from that of the 250m point. Among less frequently observed species, 10 of 11 brown-headed cowbirds were observed within 100m of pad edge, and all 15 observations of song sparrows occurred within 100m of the edge (Table 4).

Early successional species.

Two predictors, the random site covariate (F=7.39, P=0.008) and habitat type (F=4.31, P=0.041), were significant in the linear mixed model for early successional species abundance. Members of this guild were more abundant in ericaceous-rich mixed oak habitat than in the more open understory of northern hardwood habitat (Table 8). Early successional bird species were slightly more abundant in the interior of mixed oak habitat and near the edge (50m) of northern hardwood habitat, although none of the means differed (Fig. 9, Table 8). The interaction term distance*habitat was not significant, and distance in and of itself was not a significant predictor of early successional species abundance (Fig. 8).

None of the predictors were significantly correlated with common yellowthroat abundance. The species was marginally more abundant in ericaceous-rich mixed oak forest than in the more open northern hardwood forest, but the 95% confidence mean abundance between the two forest types did not differ (Fig. 11, Table 9).

Neither distance from edge (F=2.25, P=0.089) nor habitat type (F=3.03, P=0.085) were significant predictors of chestnut-sided warbler abundance. This species was marginally more

abundant at interior points although none of the means differed from one another (Fig. 12, Table 9). Similar to common yellowthroat, another early-successional songbird species, chestnut-sided warblers were marginally more abundant in mixed oak habitat than in northern hardwoods but the means did not differ. Despite the lack of significant predictors in the model, a positive trend in observations yields some evidence of a positive correlation between abundance and distance from edge in mixed oak habitat. A large disparity in observations for this species between the 2011 breeding season and the 2012 breeding season may obscure stronger trends (Table 5).

Habitat type ($F=8.41$, $P=0.005$) and the random site covariate ($F=9.89$, $P=0.002$) were both significant predictors of eastern towhee abundance. Towhees were more abundant in mixed oak habitat than in northern hardwoods (Fig. 13, Table 9) and were frequently observed in areas with dense mountain laurel growth. Relative abundance differed among sites, and part of this difference may be attributable to large annual differences in observation of this species between 2011-2012. Among less frequently observed species, 10 of 11 gray catbirds were observed within 100m of the pad edge, and all observations of both brown thrashers and field sparrows were within 100m of the edge (Table 4).

Forest interior species.

Distance from pad edge ($F=53.90$, $P<0.001$), habitat type ($F=10.98$, $P=0.001$), and the random site covariate ($F=48.65$, $P<0.001$) were all significant predictors of relative abundance for forest interior guild members. Birds in this group were most abundant at the 250m point, and relative abundance at 250m differed from the other three distance categories (Fig. 8, Table 8). The second highest abundance occurred at the 150m point; abundance did not differ between the 50m and 0m edge points. Forest interior birds were more abundant in northern hardwood habitat

than in mixed oak habitat (Fig. 9), possibly attributable to the large number of observations of ovenbird in northern hardwood habitat and as a component of the guild mean.

Abundance of black-throated green warblers differed with distance from pad edge ($F=16.89$, $P<0.001$). Abundance was highest at the 250m interior point and lowest at the two edge points (Fig. 14, Table 9). Similarly, abundance of hermit thrushes also differed with distance from edge ($F=5.35$, $P=0.002$). Hermit thrushes were more abundant at forest interior points than at edge points (Fig. 15, Table 9). They were most abundant at 250m from edge and encounter frequency decreased with increasing proximity to Marcellus pad edge.

Black-throated blue warbler abundance differed by distance from pad edge ($F=11.94$, $P<0.001$), habitat type ($F=11.95$, $p<0.001$), the interaction term distance*habitat ($F=5.57$, $P=0.002$), and the random site covariate ($F=9.51$, $p=0.003$). This species was more abundant at interior points than at edge points, but there was no difference in means within the edge and interior distance categories (Fig. 16, Table 9). Black-throated blue warblers were more abundant in mixed oak habitat than in northern hardwood habitat. They were most abundant at mixed oak interior points, and relative abundance means at those points differed from every other distance*habitat interaction term mean.

Significant predictors of ovenbird abundance included distance from pad edge ($F=7.97$, $P<0.001$), habitat type ($F=29.57$, $P<0.001$), and the random site covariate ($F=17.72$, $P<0.001$). Ovenbirds were most abundant at the 250m interior point, although abundance at this point did not differ from relative abundance at the 150m interior point (Fig. 17, Table 9). The lowest mean abundance occurred at the 0m distance class, directly on the pad edge, while the mean abundance at 50m from edge did not differ from either the 0m or the 150m abundance. Ovenbirds were encountered significantly more frequently in northern hardwood habitat than in mixed oak

habitat. Red-eyed vireos exhibited a similar pattern of abundance distribution: significant and near-significant predictors of red-eyed vireo relative abundance were distance from edge ($F=9.61$, $P<0.001$), habitat type ($F=3.52$, $P=0.064$), and the random site covariate ($F=3.56$, $P=0.063$). The species was more abundant at interior points than at edge points, although abundance means did not differ between the 250m and 150m points (Fig. 18, Table 9). While red-eyed vireos were marginally more common in northern hardwood habitat, abundance did not differ between the two habitat types.

Distance from pad edge ($F=4.10$, $P=0.009$) and the random site covariate ($F=4.80$, $P=0.031$) were both significant predictors of scarlet tanager abundance. The species was more abundant in interior forest than at the immediate pad edge, but the mean abundance at the 50m point did not differ from abundance at 0m, 150m, or 250m from edge (Fig. 19, Table 9). Black-and-white warbler abundance was also marginally correlated with distance from edge ($F=2.68$, $P=0.052$) and the random site covariate ($F=3.73$, $P=0.057$), although neither of these predictors was significant. Mean abundance was highest 250m from edge, though means did not differ between 250, 150, and 50m points (Fig. 20, Table 9). Large disparities in frequency of observation for this species occurred between the 2011 and 2012 breeding seasons (Table 5). Among less frequently observed species, 12 of 14 observations of Blackburnian warblers occurred at interior reference points, and 27 of 29 blue-headed vireo observations occurred at reference points (Table 4).

Vegetation

Canopy cover ($F=59.6$, $P<0.001$) and leaf litter depth ($F=26.66$, $P<0.001$) differed by distance from edge. Both percent canopy cover (Fig. 21) and mean litter depth (Fig. 22) were lesser at the 0m distance when compared to the interior distance categories. Neither percent

canopy cover nor mean litter depth differed away from the immediate pad edge. Percent leaf litter cover- a visual estimate of the amount of ground surface covered by floral detritus- was higher in the forest interior than at the pad edge ($F=10.38$, $P<0.001$). Percent litter cover was higher at the interior points than at the edge points (Fig. 23). Conversely, percent grass cover decreased with increasing distance from pad edge ($F=5.93$, $p=0.001$). The amount of grassy cover was far greater at the pad edge (0m) than at any other distance, with the 250m distance having the lowest percent grass coverage (Fig. 24).

Three of the four tree stem size categories, all above 8cm in diameter at breast height, exhibited differences in frequency of observation by distance from pad edge (Fig. 25, Table 10). Small to medium tree stems, those 8-23cm diameter at breast height, were most abundant away from the immediate pad edge ($F=3.24$, $P=0.024$). Medium to large trees (23-38cm dbh) were less abundant at 0m than at all other distances ($F=9.32$, $P<0.001$). Similarly, large trees- those >38cm in diameter at breast height- were less abundant at the pad edge ($F=2.71$, $p=0.05$) and were most commonly observed at interior points.

Percent fern cover, percent shrub cover, the number of small woody shrub stems per plot, and the number of snags per plot were not strongly correlated with distance from edge. While other vegetation measurements were taken and analyzed, many of them were not expressly relevant as possible explanatory factors for shifts in bird abundance. They were therefore not included as results for this study, but statistics for all vegetation measurements can be found in the appendices (Appendix C).

DISCUSSION

Development of the Marcellus shale resource in Pennsylvania forests is in the early stages, yet I was able to detect local changes in the bird community within northern hardwood

and mixed oak forests and changes in abundance of two of the three habitat guilds presumably in response to the increase in edge habitat created by well pads and associated infrastructure.

Avian Community Analysis

In my study design, I considered the points at 150m and 250m from the pad edge to be reference points used to describe the expected bird community without shale-gas development, as these points represented the habitat and bird species that were present before pads were installed. The NPMANOVA local community comparisons enabled me to statistically test whether the community was different in relation to distance from pad edge and whether this difference occurred only at the pad edge (where there was visible disturbance) or extended farther into the forest. Because my survey radius was 50m, my edge point describes the community within 50m of the pad edge, and my 50m point describes the bird community out to 100m from the pad edge.

For my combined northern hardwood and oak study sites, the avian community differed between the two edge points and the two interior points, demonstrating that the bird community within 100m of the pad edge was different from the reference community. Neither bird abundance nor species composition differed significantly between the physical edge of the well pad and a point 100m into the surrounding forest. Community change is therefore not occurring solely in birds at the immediate edge around the pad but is in fact stretching into the forest beyond the pad edge, indicating that edge effects are radiative and are not confined only to the immediate and visibly-altered portions of habitat. Similarly, there was no significant difference between bird communities at forest interior points 150m and 250m from edge, suggesting that interior bird communities remain relatively intact within core forest >100m from edges. Temple (1986) used an edge effect penetration distance of 100m to measure core areas of 49 forest

fragments for 16 species of forest interior bird species, and for all 16 species, fragment core areas were a better predictor of abundance than total forest fragment area.

I also examined community differences by habitat type. As expected, the aggregate communities differed between northern hardwood and mixed oak forest types, concurring with Thomas et al. (2014). When I split habitat types into distance classes and compared within type, effects of development on avian community structure were clearer in northern hardwood than in mixed oak forest, as was also the case in Thomas (2011). The difference in edge effects between the two forest types may be due to more apparent changes in habitat conditions immediately near edge in northern hardwood forest as mesic conditions become more xeric with increased ambient temperatures due to decreased canopy cover, increased forest floor exposure to sunlight, and increased exposure to wind. Oak forests tend to be more xeric overall and have more developed understories than northern hardwood forests (Johnson et al. 2009). Community changes in mixed oak habitat may therefore be buoyed by extensive thickets of ericaceous shrubs that dominate the forest understory; shrub-nesting and ground-nesting birds such as eastern towhee and common yellowthroat were abundant almost anywhere mountain laurel was present in quantity. Relative sparseness of woody shrubs, such as Allegheny blackberry (*Rubus allegheniensis*) and black raspberry (*Rubus occidentalis*), in the understory of northern hardwood forests probably explains the paucity of shrub-nesting species within the habitat type and a portion of the subsequent avian community difference.

Similar to the community changes reported by Thomas et al. (2014) due to effects of shallow gas development, I found the bird communities in northern hardwood and oak forests differed from one another at reference points where disturbance from gas development was absent, but they lost this difference and their unique characteristics in areas within 100m of

development, suggesting that suitable habitat for endemic, rare, and specialized species is declining around well pads, and that habitat modification is expanding the habitable area for cosmopolitan species presumably by disturbing and fragmenting contiguous forest.

Habitat Association Guilds and Individual Species

Because dispersion was the same between groups, the noted changes in community composition primarily resulted from changes in the abundance of individual species and guilds of birds. In the strictest definition, a guild is a group of organisms that use resources similarly; they are frequently useful in comparing communities based upon resource use- regardless of taxonomic relationships- because it is difficult to study all species in one particular niche or habitat at a given time (Simberloff and Dayan 1991). A benefit of guild response over individual species response analysis is that guilding allows similar but infrequently-observed species to be lumped into a class of observations; this class of observations can then be statistically analyzed for aggregate response and used as an index to individual species response. If a habitat-related community of birds responds to change in a particular way, it logically follows that most other bird species which share characteristics, but are cryptic or infrequently detected, will respond similarly.

Synanthropic Species

Synanthropic bird species are most frequently generalists associated with human-related edge and adapt well to anthropogenic changes to habitat (Marzluff 2005, Smart et al. 2006, Hepinstall et al. 2008). Site invasion rate will most likely depend upon distance between source populations in pre-existing agricultural or urban habitat and the newly-created Marcellus edge. Eventual colonization of forest habitat near well pads by synanthropic species may drive the

further loss of community uniqueness if the same species colonize both northern hardwood and mixed oak forest edge.

A number of bird species were observed only at or within 100m of well pad edges, suggesting that Marcellus-generated forest openings are drawing new bird species which were presumably not found at the site before forest clearing occurred. Many of the newly-present species are edge-generalist and cosmopolitan- those species included in the synanthropic guild- and are therefore already doing numerically well at the level of the metapopulation. As new species successfully invade, avian communities at anthropogenic edges tend to become more and more alike in a process known as taxonomic homogenization; as abiotic features become more simplified, as in large-scale fragmentation of landscapes, biotic features also tend to become more uniform (Olden et al. 2004). While it may yet be too early to see full homogenization of the edge communities, new species such as chipping sparrow, song sparrow, indigo bunting, and brown-headed cowbird have moved into the forest surrounding well pad edges. None of those species were present at >50% of my sites, so I did not test for abundance-by-distance differences. Time until establishment and occupation of edges likely depends upon distance to proximate edge habitat that existed before Marcellus development; areas that are vastly forested, as were most of my study sites, will probably take longer to see new species than forest patches surrounded by agricultural areas, suburbs, or old fields.

Successful establishment of synanthropic species does not sound the death knell for interior species in forest surrounding well pads. In an extensive review of species introduction studies, Simberloff (1981) found that 79% of species introductions resulted in no extinction of native species. However, the addition of edge invaders to once-forested habitat should not be considered to contribute meaningfully to α-level species diversity because the generation of new

edge displaces interior species. While α-level, or within community, diversity may technically increase with the addition of synanthropic species, the β-level, or between community, diversity will decrease as biotic communities become more uniform across forest habitat types (Thomas et al. 2014). Another potential negative impact on forest interior bird communities living on the periphery of Marcellus development by newly-established edge bird communities is brood parasitism by brown-headed cowbirds; this phenomenon could decrease fecundity and nest success of breeding pairs near well pads and subsequently lead to further declines in abundance of interior bird species (Gates and Gysel 1978, Brittingham and Temple 1983). In my study, the majority of brown-headed cowbird encounters occurred within 100m of well pad edges.

Early Successional Species

Thomas (2014) found that early successional species do benefit from shallow gas development and are more abundant near well sites than at control sites. Yahner (2003) and Fink et al. (2006) determined that patch clearcuts and even-age forest stand management practices also attract and increase the amount of suitable habitat for early successional species. I did not find a higher abundance of early successional species near Marcellus edges, in contrast to the aforementioned edge-creating phenomena. Abundance of early successional species was low in northern hardwood habitat with no detectable response to edge. In mixed oak forest, which tends to have a more developed forest understory and more shrubby habitat throughout (Johnson et al. 2009), birds were marginally less abundant near the edge than within the forest interior. While not statistically conclusive, my results suggest that early successional birds may avoid developed edges in areas where shrubby habitat is widely available, such as in laurel-rich mixed oak forest. More study is required to ascertain the validity of that hypothesis, however. What remains clear is that Marcellus development does not appear to be generating early successional habitat

because birds that use that habitat type are not significantly more abundant near well pads. Because Marcellus pads do not attract early successional species, development should not be considered to be the same sort of land treatment as a patch clearcut or shallow gas development. While shallow gas development and patch clearcutting create a pre-successional disturbance matrix that is usable habitat for many bird species, the Marcellus disturbance matrix is little more than a stone lot surrounded by a thin verge of grass. Nevertheless, it may be too early in the process of forest succession following disturbance events related to Marcellus development to observe any real vegetative or habitat changes, either of which could be ecological "drivers" of early successional bird distribution and abundance.

Shrub and ground-nesting species such as the eastern towhee and common yellowthroat were often significantly more abundant in mixed oak habitat than in northern hardwoods. Mixed oak habitat was generally characterized by the presence of multiple oak species and dense, ericaceous-rich understory; mountain laurel and blueberry (*Vaccinium* spp.) were the most common ericaceous shrubs. These shrubs form dense thickets in the forest understory and provide the necessary cover for many ground and shrub-nesting species. Although the abundance of chestnut-sided warblers, shrub-nesting species associated with mixed oak habitat (particularly early successional, shrubby forest), did not differ with habitat type if distance was included in the model, they were more abundant at oak sites than northern hardwood sites if the aggregate points were compared (Appendix B, Table B-2). Even though there was not an increase in shrub cover near edges, many early successional species such as eastern towhees, common yellowthroats, and gray catbirds were occasionally observed foraging in Marcellus-related brush and stump piles near pad edges, particularly in northern hardwood habitat. Sperry and Weatherhead (2010) suggest brush piles may constitute an ecological trap for wildlife because of preferential use by

predatory snakes; the direct effect of increased predation on birds in brush piles is not well-documented or well-understood.

Forest Interior Species

Forest interior bird species largely responded as hypothesized: they declined in abundance near Marcellus pad edges, and encounter frequency was significantly lower at edge points than within the forest interior at reference points. A number of interior species were observed only or primarily outside of 100m from well pad edges. As development occurs, interior species that previously used forested habitat where the pad was constructed largely disappear from the new forest edges and edge-generalist species colonize the newly-created edge habitat. In some cases, as with scarlet tanager, abundance did not differ between the 50m edge point and the interior points. Male scarlet tanagers do, however, visit edges while singing to defend territory, so more study may be needed to assess where tanager nesting occurs relative to edge. Black-throated green warbler mean relative abundance differed significantly between the 150m and 250m points, which suggests edge avoidance for the species continues to a degree beyond what is considered to be core forest surrounding Marcellus pads (≥ 100m from edge). However, relative abundance of most interior species was not statistically distinguishable between the 150m and 250m interior points, and both of these points are within the definition for what constitutes core forest habitat (UConn CLEAR 2013). Many interior bird species, including black-throated green warblers and ovenbirds, were more frequently observed in northern hardwood habitat than in mixed oak habitat.

The forest interior guild tended to be more abundant in northern hardwood forest, probably due to the large number of observations of northern hardwood interior species such as ovenbird (122 observations in all); of species in the guild, only black-throated blue warblers

displayed a clear preference for mixed oak habitat. The site covariate could be influenced by any number of random habitat factors that influence abundance, e.g. land management history, adjacent habitat type, understory vegetation density, and percent canopy cover. Forest interior species response to distance from edge matched the hypothesis of greater abundance within forest interior and reduced abundance in edge forest. Mean relative abundance did not differ significantly between 0m and 50m edge points, therefore suggesting that lower abundance at edge was not solely attributable to direct forest loss at the 0m point.

A biological hypothesis not related to habitat factors as to why interior birds avoid edge habitat is because of heightened susceptibility to nest predation and parasitism at edges. Paton (1994) conducted a literature review and reported both depredation and parasitism rates were higher at edges than within the forest interior, but most edge effects seemed to fade beyond 50m from edge, where evidence became less definitive. Keyser et al. (1998) determined risk of predation is correlated negatively with forest fragment size and that large predator activity, against which songbirds have no defense, increases with decreasing fragment size. King et al. (1998) concluded forest edge creation by clear-cutting leads to increased predator abundance near edges despite the absence of floristic changes at the edge or elevated nest predator populations within clear-cuts; subsequently, rates of both nest parasitism and nest predation were related to distance from edge and landscape-level habitat fragmentation (Donovan et al. 1997). While I did not survey nest predators throughout the course of this study, I did not make any qualitative observations of mammalian nest predators or predator sign near edge, though I did observe American crows, blue jays, and brown-headed cowbirds (all of these being known nest predators/parasites) near edge. Nevertheless, the supposition that returning neotropical migrant songbirds were responding to elevated predation pressure around new pad edges when they first

selected post-development nesting territories seems logically unlikely as a primary mode of explanation for edge avoidance. However, increased rates of nestling predation for ground-nesting birds such as hermit thrush and ovenbird near edges, and increased nest density near edges, suggest that new edges could present an ecological trap and population sink for some species (Flaspohler et al. 2001). I would expect elevated mortality and decreased fecundity near pad edges, or any edge, to provide a partial explanation for the paucity of many interior migrant songbirds near well pads as more time elapses. Considering, however, that most of the well pads I surveyed were ≤ 5 years old, I do not believe local-scale extirpation provides the best explanation for the dearth of interior birds near the edge.

Two broad hypotheses directly relating to habitat change-driven edge avoidance by interior birds are: 1) edge genesis induces vegetative changes that are undesirable for forest interior birds; and 2) habitat change from closed canopy to a forest opening causes territory displacement of and avoidance by interior species. While evidence of vegetative changes due to edge genesis is well-documented within the scientific literature, avian response to those changes is substantially less well-understood. Adventitious branching of trees on edges and increased shrub growth due to increased sunlight exposure provide more foliage layers for avian foraging over time, providing an attractant for edge-associated and woodlot birds but a potential deterrent for interior bird species (Strelke and Dickson 1980, Kroodsma 1984, Murcia 1995). Dispersal of fruit-bearing shrub seeds, particularly invasive shrub seeds, at edges by frugivorous birds leads to increased shrub density at edges (Yates et al. 2004, Flory and Clay 2005, Bartuszevige and Gorchov 2006). However, I did not observe any differences in shrub-related vegetation structure near pad edges except at the 0m point, where approximately one half of the point radius was covered by the pad. The number of large sapling stems did not differ across distance classes.

While vegetative changes can and likely will come to pass due to edge genesis, I believe it is simply too early following development to detect any effect. Absence of significant floral structure differences translates to a low likelihood of vegetation factors being the best explanation for edge avoidance by forest interior species, although it may provide evidence as to why early successional species were not attracted to the edge.

Kroodsma (1984) and Rich et al. (1994) hypothesized forest interior bird abundance decreases near edges because habitat becomes less suitable as continuous forest is fragmented into progressively smaller patches. Ground-nesting interior birds, such as ovenbird, frequently choose large, contiguous forest tracts over smaller tracts because of the plenitude of suitable nesting sites with deep leaf litter and higher food biomass (Burke and Nol 1998). In other words, reduced leaf litter at the Marcellus pad edge could make the nesting habitat unsuitable or undesirable for ground-nesting birds. Van Horn et al. (1995) concluded pairing success is significantly higher for male ovenbirds with territories away from edge; edge-to-interior ratio, percent forest cover over a 5km radius, and total forest area are all highly correlated with pairing success. Furthermore, the creation of forest openings and edge corridors displaces interior bird territories, and corridor limits frequently serve as territory boundaries for singing male songbirds (Bayne 2005*a*, Bayne 2005*b*).

I believe the territory displacement due to unsuitable habitat hypothesis, as posited by Kroodsma (1984) and Rich et al. (1994) best fits my results because I observed declines in forest interior birds near well pads without observing floristic differences between reference points and the 50m pad edge point. Both individually and at the guild level, forest interior species were more abundant at forest interior despite the absence of vegetative changes in forest near the pad edge. Realistic habitat comparisons were made between the 50m, 150m, and 250m distance

classes because the amount of forest and percent forest cover are effectively controlled. While the 0m edge point is partially occupied by the Marcellus pad to capture direct habitat changes brought on by pad installation, the 50m point sustains no direct changes from development activity. Why, then, if the 50m point class encapsulates the same vegetative and habitat features as do the interior points, are forest interior birds using the habitat present near the edge to such a reduced degree?

One potential explanation involves avoidance of the edge due to noise associated with development. While birds may, indeed, avoid the edge while development is occurring, my surveys took place only surrounding inactive well pads. Habib et al. (2007) found 92% of male ovenbirds occupying territories around silent well pads were successful in pairing, and about 30% of the males detected were young males breeding for the first time. Taken together, these results suggest that, while pairing can be successful near well pads, the habitat itself is less desirable as evidenced by the high percentage of inexperienced breeders. Mazerolle and Hobson (2002) determined male ovenbirds arriving early to breeding grounds chose interior habitat over the edge matrix, and were physically larger than birds that selected edge. Selection of interior territories by larger males that arrive early to breeding grounds may suggest that interior birds see edge habitat as undesirable; however, there is no clear biological understanding as to whether or not larger size equates to greater fitness and therefore the securing of "better" territory.

Biotic Homogenization

When interpreted in unison, the avian community analysis results, the guild responses, and the individual species responses provide evidence of an ongoing shift from specialist species to cosmopolitan species inhabiting forest near the newly-created edge: a phenomenon known as biotic homogenization. Homogenization stems from human impacts that decrease habitat

suitability for species with specialized habitat requirements and create habitat for a small number of highly-adaptable ecological generalists. In this way, anthropogenic environmental modifications act as a sort of non-random filter for species able to survive in highly-modified environments (Smart et al. 2006). Devictor et al. (2007) determined avian communities not only become more homogeneous, but also become more unstable and subject to temporal variation in specialist species abundance as habitat perturbation occurs. Although further sampling and analysis will be required to fully assess development effects on avian communities, my results provide some evidence that Marcellus development is leading to biotic homogenization around well pads and in forest habitat within 100m of well pads.

Temporal Variation in Observations

Despite overt similarities between sampling area and forest habitat type during the 2011 and 2012 field research seasons, numerous bird species exhibited large differences in year-to-year encounter frequency which may obscure or dilute some trends in the data. Many of these species were neotropical migrants, which are subject to numerous abundance-changing risk factors during the migratory period. Breeding populations of some neotropical migrant bird species decline when birds are subjected to storm events during ocean-passage phases of migration, and species that breed in eastern North America are at higher risk than species that breed in the west (Butler 2000). Furthermore, yearly populations of vermivorous bird species, including many of the neotropical migrant warblers and vireos, are correlated with yearly variation in lepidopteran larvae (Jones et al. 2003). Abundance of these larvae, which are a primary food source for many birds, is in turn related to the El Nino/La Nina global climate fluctuation pattern (Sillett et al. 2000). Breeding season 2011 was included in the last La Nina climate fluctuation, and food biomass is highest during La Nina years; breeding season 2012

occurred during an El Niño Southern Oscillation (ENSO) neutral period, according to the National Oceanic and Atmospheric Administration. Furthermore, Devictor et al. (2007) determined permanent anthropogenic habitat modification, such as urbanization, can destabilize annual population dynamics of specialist species and make probability of site occupancy unpredictable. While none of these factors can directly explain year-to-year variation in abundance as observed in this study, all of them may hold potential answers as to why variation was so large in some instances. Large amounts of year-to-year variation in neotropical migrant bird populations may obscure stronger trends and dilute the observable distance effect in relation to Marcellus well pads.

Development Effects on Vegetation and Songbird Habitat

Few changes were detected in vegetation immediately surrounding well pads except at points that included the pad or limit of disturbance. I did not analyze measurements by habitat type due to inadequate sample size, but more sampling and analysis could be useful to determine and quantify any naturally-occurring differences between forest vegetation in northern hardwood and mixed oak habitat. Thomas (2011) found avian community structure differed significantly between northern hardwood and mixed oak forest types, and posited that distinct structural characteristics of the two forest types attract different songbird species. Ross et al. (2001) also uncovered differences between avian communities in northern hardwood and oak-hickory forest types; important predictors for avian species richness and abundance included basal area and percent shrub cover. Determining local-scale vegetative differences between habitat types could help to further explain community differences, particularly in terms of how different habitat types regenerate after development has been completed and how bird species respond to regeneration. Because unconventional deep-well oil and gas development is relatively new to

northeastern deciduous forests, little is known about vegetative changes brought on by pad or infrastructure installation. Clearing of litter from the soil surface on the verges of the well pad and increased exposure to sunlight due to canopy thinning are likely to lead to increased growth of grasses and shrubs in the forest understory surrounding pad edges (Murcia 1995). A higher presence of synanthropic bird species such as American robin at newly-created edges may increase the likelihood of establishment of numerous invasive shrub species due to preferential habitat use (Bartuszevige and Gorchov 2006). As time passes and vegetative edge effects take hold, bird communities near well pads are likely to continue to undergo biotic homogenization as more edge and human-associated bird species occupy habitat that has been made marginal for forest interior species. Olden et al. (2004) posited that community function, population stability, and resistance to environmental change are reduced as bird communities become more homogeneous. Future study may be able to shed considerable light on the nature of edge effects on plant communities surrounding Marcellus edges, the penetration distance of those edge effects, and the subsequent effects of floristic structural changes on the structure, abundance, and habitat use of wildlife populations.

Conclusions

Marcellus development is changing forest bird communities in a significant way by creating edge habitat desired by cosmopolitan species. Avian communities in the forest within 100m of well pads were not distinguishable from one another in both forest types, suggesting that biotic homogenization is occurring due to development. Two of the three habitat association guilds responded in a significant manner to Marcellus development. Synanthropic species benefited from development and were most abundant near pad edges; these species were presumably not abundant (if present) in the forest that existed before the land was cleared and the

well pads were installed. Forest interior species responded negatively to Marcellus development and became significantly less abundant near well pads. Early successional species did not exhibit a detectable positive or negative response to development. Abundance was not greater near well pads, therefore development is not creating early successional habitat and should not be considered to be the same land treatment as shallow gas development or a forest clear-cut. Further decline in forest specialist and interior-obligate species, both indicative of healthy forest habitat and bird communities, at the local scale will most likely continue if remediation and mitigation efforts are not given future priority.

Management Implications

As of June 2014, the Pennsylvania Department of Environmental Protection has issued permits for 7620 unconventional oil and gas wells for the seven-county area in which I conducted my research (PADEP 2014). Of these permitted wells, only 2727 have been drilled-about 35% of the current total permitted wells. The drilled wells are distributed between 1293 well pads within the seven-county area for an average of approximately 2 wells per pad (PADEP 2014). Given the average number of wells per pad and the remaining number of permitted wells in the area, an additional 2264 well pads would be required to support the remaining wells. Drohan et al. (2012) reported 33% of current permitted pads in the Susquehanna River Basin, which covers the vast majority of the seven counties in which I conducted research, were allocated to core forest habitat; if this trend continues, then 747 of the 2264 hypothetical new well pads would be constructed within forest interior. Based on a mean size of 2.1 hectares per pad from my results, the new pads would result in the complete loss of 1569 hectares of forest and the fragmentation of many more hectares of core forest; provided more pads and wells will be permitted in the coming years, unconventional gas development on the whole is probably less

than 20% complete in Pennsylvania. As of 2013, more than 600 hectares of state forest have been lost to development; more than 315 hectares of forest have been lost due to well pad development, which constitutes the largest source of forest loss on state forest lands (Devlin 2014).

If development continues to occur at the same rate and without mitigation efforts, then forest-dependent wildlife populations may be negatively impacted statewide by loss and fragmentation of suitable contiguous forest habitat. My results demonstrated negative impacts of Marcellus well pad development at the local scale: by generating edge habitat and fragmenting forests, development decreases habitat suitability for forest-dependent songbirds as evidenced by low abundance of those species near well pads. Unmitigated development at the current rate could therefore result in spillover effects of local-scale impacts and subsequently lead to declines in landscape-level forest songbird populations. Furthermore, my study determined Marcellus development is not creating early successional habitat and is instead simply creating grassy openings and "hard edge," edge not buffered by shrub growth or a multi-layered floral community. Resource developers, regulating bodies, and land managers must work together to ensure energy development is carried out in a responsible way that will not unduly damage forest and wildlife resources.

While the predominance of Marcellus development is occurring on private property, some development is occurring on state-owned lands where managers can, to a degree, influence the outcome of development activity. If public land managers are interested in mitigating development impacts, then they should focus development efforts on already-fragmented forest land to extenuate negative impacts of habitat fragmentation and edge genesis on forest interior birds. Agencies such as the Pennsylvania Game Commission and the Pennsylvania Department

of Conservation and Natural Resources can control where development occurs by leasing only tracts of already-disturbed or otherwise fragmented land, or disallowing new surface disturbance on leased tracts; avoiding additional fragmentation of large core forest blocks will promote healthy avian communities and forests. Wells should be consolidated to a minimum number of pads needed for effective extraction; building fewer well pads will reduce negative impacts of edge genesis and forest fragmentation. Currently, less than 10% of all Marcellus well pads support five or more wells (Drohan et al. 2012). As of 2013, there were 143 well pads on State Forest land supporting a total of 568 drilled wells, or an average of just under four wells per pad (Devlin 2014). Managers should also consider leasing tracts with existing roads that will require minimal expansion and forest disturbance to make stable for development traffic. Consolidating development in already-fragmented areas will allow state forest and wildlife management agencies to take advantage of financial benefits of development while continuing to manage wildlife and habitat in a responsible manner.

Furthermore, if land managers want to create early successional habitat, then they have an opportunity to create that habitat near well pads without having to harvest additional stands of timber; some agencies may wish to retain timber holdings due to reduced value of wood products under current economic conditions. Forest maturation over the last few decades has led to the loss of much early successional habitat and the subsequent decline in game bird species such as ruffed grouse and woodcock (*Scolopax minor*) (Dessecker and McAulay 2001). Instead of an abrupt transition from well pad to mature forest at the limit of disturbance, developers and land managers could work together to create an edge that has been “brushed back” by planting native shrubs and selectively thinning the edge forest to promote shrub growth. Well pad edge would

then constitute early successional habitat that could benefit both game bird and passerine bird species, such as Eastern towhee and golden-winged warbler (*Vermivora chrysoptera*).

An additional benefit of creating gradual forest edges near Marcellus well pads is: forests with gradual edges exhibit fewer edge effects than do forests with abrupt edges. Throughfall deposition of nitrogenous and sulfurous soil pollutants is lessened substantially by vegetation that increases in height from the hard edge to the forest border (Wuyts et al. 2009). Retention of pre-disturbance soil chemistry, structure, and moisture may decrease risk of establishment of invasive plant communities within the forest. Furthermore, because of preferential habitat use by frugivorous birds, invasive plant seeds are most likely to be deposited at edges, thereby altering understory plant community structure (Yates et al. 2004, Flory and Clay 2005, Bartuszevige and Gorchov 2006). If synanthropic and edge associated birds- those most responsible for dispersal of invasive shrub seeds- use the fruits and seeds of native shrubs planted at the gradual edge as a primary food resource, then they may be less prone to venture into areas where invasive shrub fruits and seeds provide the primary food source, thereby reducing the risk of invasive shrub introduction.

Thinning edges and planting native shrubs and grasses will incur some cost to land management agencies, but the benefits of action over inaction outweigh the costs many fold if early successional habitat creation is an immediate goal. However, if land managers want to reduce or stall edge effects without removing thinning edge forest or creating gradual edges at the current time, they could plant evergreen trees such as pines (*Pinus* spp.) and spruces (*Picea* spp.) at the edge to act as a windscreen and light barrier. Reduced wind speeds and decreased sunlight penetration provided by an evergreen barrier should lead to less wind damage,

adventitious branching, understory shrub growth, and soil water loss than would occur in edge forest without the barrier.

If management agencies want to determine and monitor effects of development over time, then study should continue with regard to fragmentation effects on forests, wildlife, and floral communities. My study did not focus heavily upon vegetation factors, but I do not believe sufficient time has yet passed to observe changes due to edge effects; however, Marcellus edges should be monitored for invasive plant establishment over time due to the relatively high risk of invasive plant seed introduction by heavy traffic (Soeder 2010). Marcellus roads and pipelines associated with pads may create more new edge than well pads and may therefore constitute a larger habitat fragmentation risk than pad development *per se*. Roads and pipelines presumably carry the same risk of invasive plant establishment as well pads and will therefore require monitoring, if the wild character and biological integrity of Pennsylvania forest communities are to be maintained.

In addition, research should begin on determining the effects of compressor station noise on bird behavior and abundance to assess how noise associated with gas extraction may affect wildlife populations. Compressor noise has been demonstrated to decrease pairing success of breeding birds and alter breeding population age structure immediately surrounding compressor stations in Canadian forests (Habib et al. 2007). The effects of compressor noise on wildlife in northeastern deciduous forests are currently unknown, as many compressors have only just begun to come online as shale gas transport infrastructure is connected.

Furthermore, effects of development on other taxa should be determined so scientific knowledge can responsibly inform resource development in the future. Predatory mammals not normally associated with edge habitat may forage there if it proves to be a corridor between

desirable habitat types or is adjacent to occupied habitat, producing spillover predation effects on various prey species (Lidicker 1999). Some taxa may be negatively impacted by road expansion and development; amphibians are particularly sensitive to road development because roads present a relatively impermeable movement corridor as opposed to forest-residential edges or forest-open land edges (Gibbs 1998). Adequate study of the aforementioned subjects should help researchers and natural resource managers achieve a relatively complete understanding of the impacts of unconventional gas development in the Marcellus shale region. Understanding impacts will ultimately inform management decisions regarding best practices to minimize deleterious effects on wildlife and habitat, all the while allowing for continued development of an important resource.

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TABLES AND FIGURES

Table 1. Marcellus pad sites by forest type (northern hardwood or mixed oak) and land ownership category (public or private) included in a study of well pad development impacts on forest songbirds in northcentral Pennsylvania, 2011-2012.

	Ownership		
Forest Type	Public	Private	**Total Number of Sites**
Northern Hardwood	5	11	16
Mixed Oak	12	2	14
Total	**17**	**13**	**30**

Table 2. Vegetation measurements and visual estimates recorded in nested sample plots, based on the University of Montana's BBIRD survey protocol (Martin et al. 1997), by distance from the center of point counts conducted during a forest songbird study, northcentral Pennsylvania forest, 2011-2012.

Distance Band		
0m (Point Center)	5m	11.2m
% Canopy Cover	Litter Depth	Tree Stem Counts
% Ground Cover	Shrub Stem Counts	Tree Species ID
Canopy Height	Shrub Species ID	Tree Size Classes
% Dieback	Sapling Stem Counts	

Table 3. Percent land cover by habitat type and buffer radius around well pad center for 30 Marcellus well pad sample sites included in a study of development effects on forest songbirds, northcentral Pennsylvania, 2011-2012.

Land Cover Type	Buffer Radius (km)	N. Hardwood	Mixed Oak	$t_{0.05,28}$	p
		Mean ± S.E.	Mean ± S.E.		
% Road Surface	0.5	13.29 ± 1.82	13.60 ± 3.35	0.08	0.933
	1.0	11.10 ± 1.03	11.88 ± 2.41	0.31	0.755
	5.0	12.03 ± 0.48	11.84 ± 1.07	0.16	0.871
% Forest Cover	0.5	94.37 ± 1.82	96.39 ± 3.10	0.58	0.567
	1.0	94.38 ± 2.07	96.93 ± 2.33	0.82	0.418
	5.0	91.94 ± 1.32	95.28 ± 0.89	2.04	0.051
% Core Forest	0.5	66.92 ± 4.21	70.89 ± 7.28	0.49	0.631
	1.0	71.78 ± 3.47	72.80 ± 5.61	0.16	0.875
	5.0	66.53 ± 2.46	72.42 ± 2.55	1.66	0.109
% Edge Forest	0.5	27.45 ± 2.78	25.50 ± 5.91	0.31	0.759
	1.0	22.60 ± 1.79	24.13 ± 4.34	0.34	0.735
	5.0	25.41 ± 1.20	22.86 ± 1.98	1.13	0.267
% Agriculture	0.5	5.10 ± 1.88	4.14 ± 3.11	0.27	0.788
	1.0	5.05 ± 1.96	3.28 ± 2.33	0.59	0.562
	5.0	7.05 ± 1.19	4.46 ± 0.84	1.73	0.094

Table 4. Individual bird species observed in unidirectional disproportion relative to Marcellus well pad edges in northcentral Pennsylvania forests, 2011-2012. The numbers for broad habitat categorizations (edge associates and forest associates) are sums of observations of the individual species within the group. Species included in the table were not observed at ≥50% of Marcellus pad sites and were not otherwise investigated except in guild analysis[a]; to be included in the table, species had to be observed with ≥80% of the total observations in one distance category (edge or interior).

Group and Species	Total Observations	Edge (0m, 50m)		Interior (150m, 250m)	
		Observations	% of Total	Observations	% of Total
Edge Associates	**91**	**86**	**94.5**	**5**	**5.5**
Mourning Dove	6	6	100.0	0	0.0
House Wren	2	2	100.0	0	0.0
Carolina Wren	1	1	100.0	0	0.0
Brown Thrasher	1	1	100.0	0	0.0
Gray Catbird	11	10	90.9	1	9.1
Chipping Sparrow	13	12	92.3	1	7.7
Field Sparrow	3	3	100.0	0	0.0
Song Sparrow	15	15	100.0	0	0.0
Northern Cardinal	7	6	85.7	1	14.3
Indigo Bunting	15	14	93.3	1	6.7
Common Grackle	3	3	100.0	0	0.0
Brown-headed Cowbird	11	10	90.9	1	9.1
American Goldfinch	3	3	100.0	0	0.0
Forest Associates	**85**	**6**	**7.1**	**79**	**92.9**
Black-billed Cuckoo	1	0	0.0	1	100.0
Ruby-throated Hummingbird	3	0	0.0	3	100.0
Acadian Flycatcher	1	0	0.0	1	100.0
Least Flycatcher	2	0	0.0	2	100.0
Blue-headed Vireo	29	2	6.9	27	93.1
Brown Creeper	3	0	0.0	3	100.0
Veery	27	2	7.4	25	92.6
Blackburnian Warbler	14	2	14.3	12	85.7
Hooded Warbler	3	0	0.0	3	100.0
Magnolia Warbler	2	0	0.0	2	100.0

[a]The complete list of all bird species observed and their habitat association guild assignments can be found in Appendix A.

Table 5. Individual bird species for which large annual differences in number of observations occurred during a study of Marcellus development impacts on forest songbirds, northcentral Pennsylvania, 2011-2012. Values reported for 2011 and 2012 are the number of points where the species was observed (Obs.) and the number of points where the species was not observed (Not Obs.). G and p are the results of a G-test of independence with an alpha-level of 0.05 and 1 degree of freedom.

	2011		2012			
Bird Species	Obs.	Not Obs.	Obs.	Not Obs.	$G_{0.05,1}$	**p**
American Redstart	16	101	0	132	25.41	<0.001
Black-and-white Warbler	28	89	9	123	14.81	<0.001
Blue-headed Vireo	22	95	7	125	11.35	<0.001
Black-throated Blue Warbler	41	76	21	111	12.25	<0.001
Chestnut-sided Warbler	27	90	15	117	6.10	0.013
Eastern Towhee	62	55	38	94	15.24	<0.001
Great Crested Flycatcher	10	107	0	132	15.58	<0.001
Ovenbird	92	25	30	102	82.20	<0.001
Red-eyed Vireo	86	31	57	75	23.85	<0.001
Scarlet Tanager	35	82	12	120	18.04	<0.001
Veery	22	95	5	127	15.28	<0.001
Yellow-bellied Sapsucker	21	96	12	120	4.25	0.039

Table 6. Non-parametric multivariate analysis of variance (NPMANOVA) results for pairwise avian community comparisons within distance from edge and forest habitat type groups surrounding 30 Marcellus sites surveyed during a study of Marcellus development impacts on forest songbirds in northcentral Pennsylvania, 2011-2012. P-values with an asterisk are significant.

Community Comparison	F	p
Aggregate 0m vs 50m	1.918	0.142
Aggregate 0m vs 150m	8.073	<0.001*
Aggregate 0m vs 250m	9.040	<0.001*
Aggregate 50m vs 150m	5.386	<0.001*
Aggregate 50m vs 250m	7.572	<0.001*
Aggregate 150m vs 250m	1.054	>0.999
Northern Hardwood 0m vs Northern Hardwood 50m	1.061	>0.999
Northern Hardwood 0m vs Northern Hardwood 150m	4.859	0.003*
Northern Hardwood 0m vs Northern Hardwood 250m	5.751	0.003*
Northern Hardwood 50m vs Northern Hardwood 150m	3.328	0.020*
Northern Hardwood 50m vs Northern Hardwood 250m	4.115	0.003*
Northern Hardwood 150m vs Northern Hardwood 250m	0.808	>0.999
Mixed Oak 0m vs Mixed Oak 50m	1.461	>0.999
Mixed Oak 0m vs Mixed Oak 150m	5.518	0.003*
Mixed Oak 0m vs Mixed Oak 250m	5.415	0.003*
Mixed Oak 50m vs Mixed Oak 150m	3.560	0.062
Mixed Oak 50m vs Mixed Oak 250m	5.103	0.003*
Mixed Oak 150m vs Mixed Oak 250m	1.449	>0.999

Table 7. NPMANOVA avian community comparisons between distance from edge and forest habitat type groups for 30 Marcellus sites surveyed during a study of Marcellus development effects on forest songbirds in northcentral Pennsylvania, 2011-2012. P-values with an asterisk are significant.

Community Comparison	F	p
Northern Hardwood 0m vs Mixed Oak 0m	0.8395	>0.999
Northern Hardwood 0m vs Mixed Oak 50m	1.612	>0.999
Northern Hardwood 50m vs Mixed Oak 0m	2.389	0.078
Northern Hardwood 50m vs Mixed Oak 50m	2.687	0.104
Northern Hardwood 150m vs Mixed Oak 150m	5.339	0.003*
Northern Hardwood 250m vs Mixed Oak 250m	5.953	0.006*
Northern Hardwood vs Mixed Oak	9.007	<0.001*

Table 8. Mean bird abundance per point count (± standard error) for three habitat association guilds: synanthropic (Synanth), early successional (Early Succ.), and forest interior by distance from Marcellus well pads and forest habitat type from a study of the effects of Marcellus development on forest songbirds in northcentral Pennsylvania, 2011-12. Values are least squares means from Tukey's honestly significant difference (HSD) test at the 95% confidence level. Superscripts indicate Tukey grouping of significant values.

	Mean Per Point Count ± S.E.					
Habitat Guild	0m	50m	150m	250m	N. Hardwood	Mixed Oak
Synanth	0.89 ±0.14[a]	0.69 ±0.12[a]	0.19 ±0.09[b]	0.09 ±0.09[b]	0.51 ±0.07[a]	0.41 ±0.08[a]
Early Succ.	0.51 ±0.21[a]	0.77 ±0.17[a]	0.82 ±0.13[a]	0.93 ±0.13[a]	0.64 ±0.11[a]	0.97 ±0.12[b]
Forest Interior	0.32 ±0.27[a]	0.98 ±0.22[a]	2.82 ±0.17[b]	3.69 ±0.17[c]	2.28 ±0.14[a]	1.62 ±0.15[b]

Table 9. Mean observations per point count for species that occurred at ≥50% of sample sites by distance from Marcellus well pads and forest habitat type from a study of Marcellus development effects on forest songbirds in northcentral Pennsylvania, 2011-12. Species names are four-letter alpha banding codes (Appendix A, Table A-1). Superscript letters indicate Tukey groupings at the 95% confidence level.

	Mean Per Point Count ± SE					
Species	0m	50m	150m	250m	N. Hardwood	Mixed Oak
AMRO	0.17 ±0.05^{ab}	0.26 ±0.05^{a}	0.06 ±0.03^{bc}	0.00^{c}	0.14 ±0.03^{a}	0.10 ±0.03^{a}
BAWW	0.01 ±0.06^{a}	0.09 ±0.06^{ab}	0.11 ±0.04^{ab}	0.22 ±0.05^{b}	0.12 ±0.04^{a}	0.10 ±0.04^{a}
BTBW	0.00^{a}	0.01 ±0.07^{a}	0.31 ±0.05^{b}	0.40 ±0.05^{b}	0.07 ±0.04^{a}	0.28 ±0.04^{b}
BTNW	0.00^{a}	0.02 ±0.09^{a}	0.32 ±0.06^{b}	0.67 ±0.07^{c}	0.23 ±0.05^{a}	0.28 ±0.06^{a}
COYE	0.24 ±0.11^{a}	0.17 ±0.10^{a}	0.30 ±0.07^{a}	0.30 ±0.08^{a}	0.18 ±0.06^{a}	0.32 ±0.07^{a}
CSWA	0.03 ±0.07^{a}	0.05 ±0.06^{a}	0.15 ±0.05^{a}	0.21 ±0.05^{a}	0.07 ±0.04^{a}	0.15 ±0.04^{a}
EATO	0.19 ±0.11^{a}	0.46 ±0.10^{a}	0.37 ±0.07^{a}	0.39 ±0.08^{a}	0.24 ±0.06^{a}	0.49 ±0.06^{b}
HETH	0.00^{a}	0.00^{a}	0.14 ±0.05^{ab}	0.26 ±0.05^{b}	0.13 ±0.04^{a}	0.07 ±0.04^{a}
OVEN	0.06 ±0.09^{a}	0.23 ±0.08^{ab}	0.45 ±0.06^{bc}	0.53 ±0.06^{c}	0.51 ±0.05^{b}	0.13 ±0.05^{a}
REVI	0.20 ±0.09^{a}	0.30 ±0.09^{a}	0.69 ±0.06^{b}	0.67 ±0.07^{b}	0.54 ±0.05^{a}	0.39 ±0.06^{a}
SCTA	0.00^{a}	0.13 ±0.07^{ab}	0.28 ±0.05^{b}	0.24 ±0.05^{b}	0.21 ±0.04^{a}	0.11 ±0.04^{a}

Table 10. Means (± S.E.) for vegetation measurements and habitat characteristics by distance from Marcellus pad edges in northcentral Pennsylvania, 2011-2012. The Fisher's F and p-values are from Minitab general linear models using distance as a predictor. Values with an asterisk are significant ($p<0.05$).

Vegetation Factor	**0m ± SE**	**50m ± SE**	**150m ± SE**	**250m ± SE**	**F**	**p**
Percent Canopy Cover	46.4 ± 2.7	87.9 ± 2.2	92.4 ± 2.3	88.7 ± 2.5	59.6	<0.001*
Mean Litter Depth	7.4 ± 0.9	14.9 ± 0.8	18.2 ± 0.9	15.0 ± 1.0	21.0	<0.001*
Trees <8 cm dbh	0.6 ± 0.8	2.8 ± 0.7	2.0 ± 0.7	1.9 ± 0.8	1.1	0.343
Trees 8-23 cm dbh	6.2 ± 1.3	9.4 ± 1.0	10.2 ± 1.1	7.9 ± 1.1	3.2	0.026*
Trees 23-38 cm dbh	2.7 ±0.5	5.7 ± 0.4	5.8 ± 0.4	5.7 ± 0.5	9.3	<0.001*
Trees >38 cm dbh	0.4 ± 0.2	0.9 ± 0.2	1.2 ± 0.2	1.1 ± 0.2	2.7	0.050
Number of Snags	0.9 ± 0.6	2.1 ± 0.5	0.9 ± 0.6	0.9 ± 0.6	1.3	0.279
Percent Grass Cover	21.6 ± 3.5	9.2 ± 2.8	6.5 ± 3.0	2.4 ± 3.2	5.9	0.001*
Percent Shrub Cover	25.5 ± 6.1	32.3 ± 4.8	28.8 ± 5.2	33.1 ± 5.5	0.4	0.767
Small Sapling Stems (<2.5cm diameter)	17.2 ± 4.9	26.0 ± 3.9	26.2 ± 4.2	30.0 ± 4.5	1.3	0.276
Percent Fern Cover	16.0 ± 5.9	22.1 ± 4.6	23.7 ± 5.0	24.9 ± 5.3	0.5	0.690
Percent Leaf Litter Cover	17.7 ± 6.4	45.5 ± 5.1	62.3 ± 5.5	56.0 ± 5.8	10.4	<0.001*

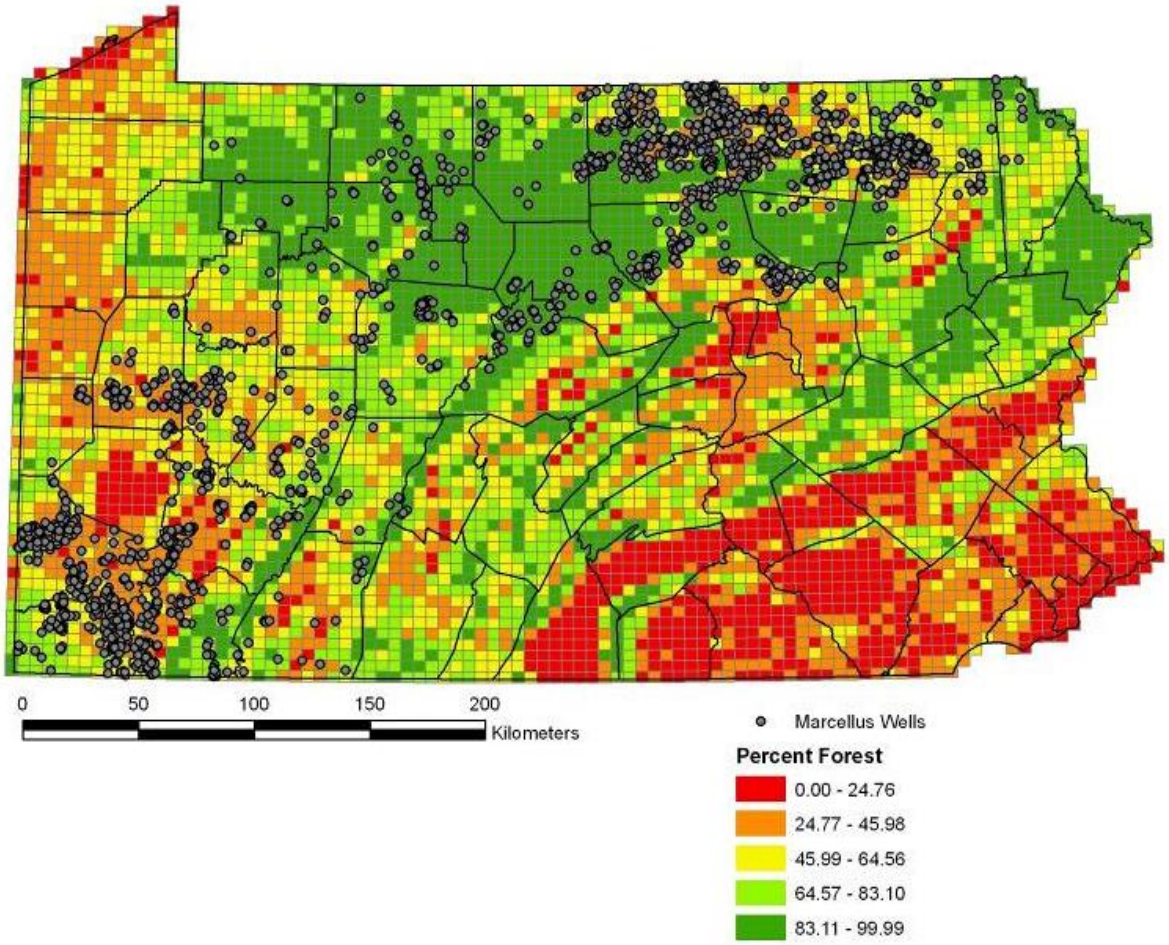

Figure 1. Marcellus well pads and forest habitat in Pennsylvania as of 2012. Percent forest cover is represented by green coloration, and continuous forest is represented by dark hue. Marcellus well pads are represented by grey points.

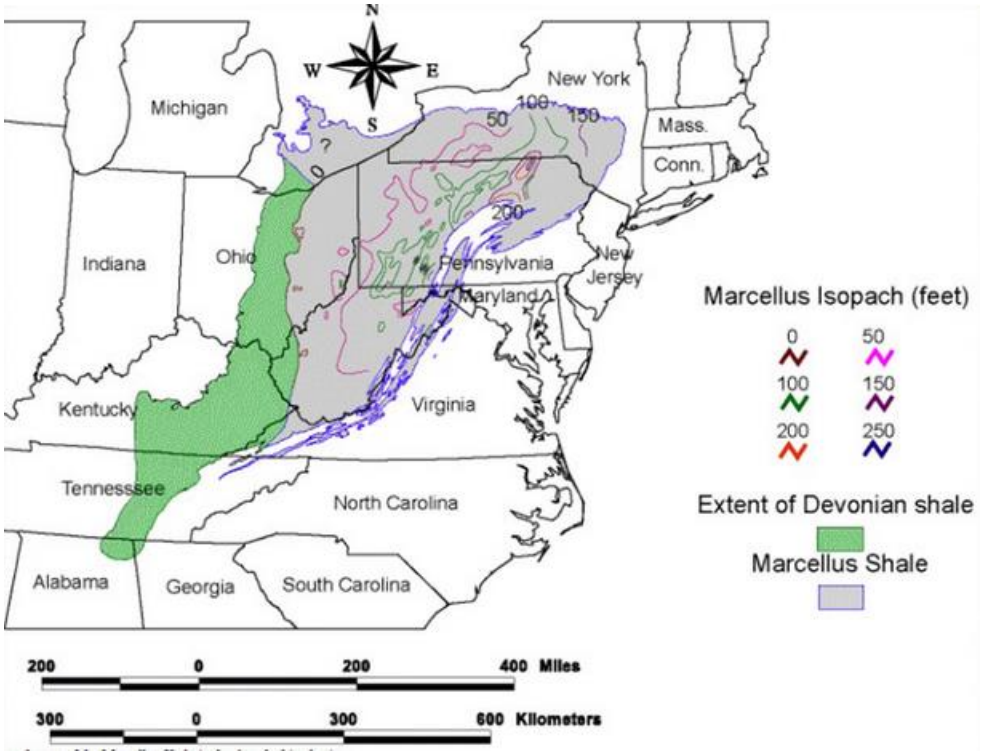

Figure 2. The Marcellus Shale layer of the Mid-Atlantic province of North America is represented by the gray region in the above picture. The outline of the region is based on geological sampling and estimation (Milici 2005). Gradient lines accompanied by numbers on the map represent the mean thickness in feet of the Marcellus Shale layer.

Figure 3. Two Marcellus Shale well pads, shown above outlined in white, in Bradford County, PA. The pads have been surfaced with crushed limestone and are both in the active development stage (MSETC 2010). The upper well pad has a number of water storage ponds located along its upper side.

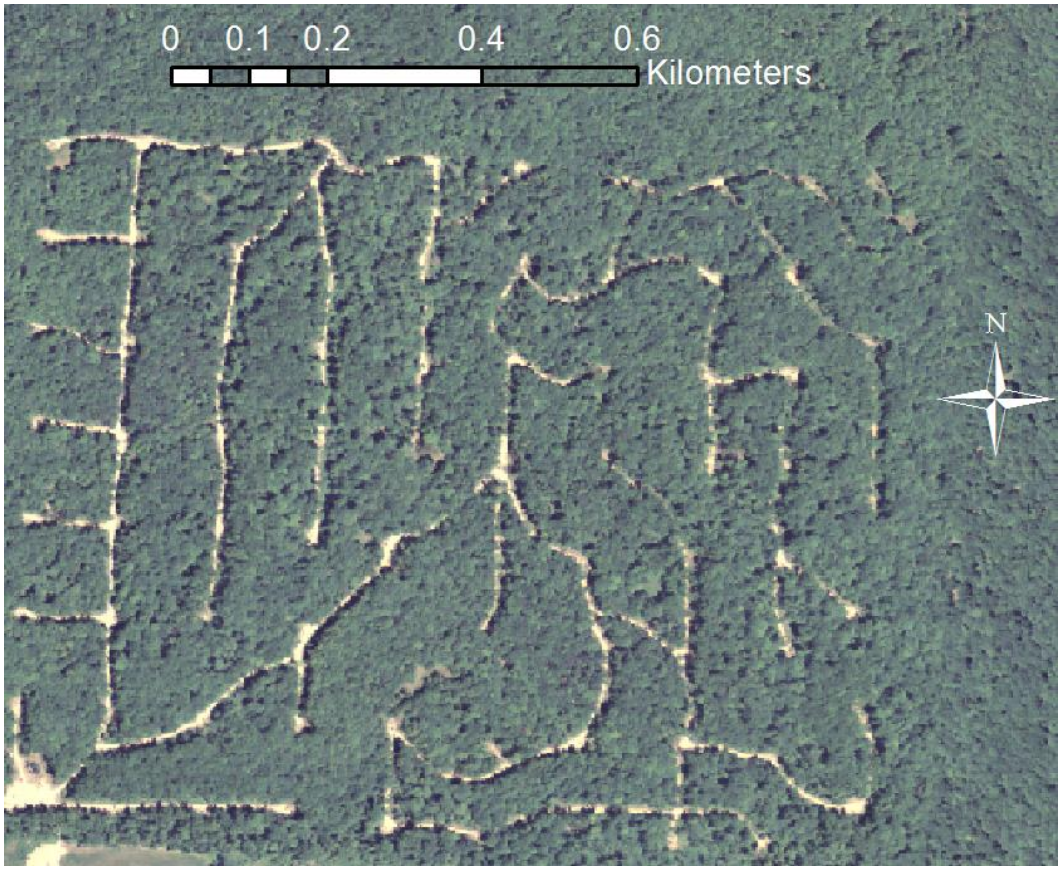

Figure 4. An aerial image of shallow-well, or conventional, oil and gas development in the Allegheny National Forest,Warren County, PA in 2012. Forest fragmentation caused by shallow-well oil and gas development in the Allegheny National Forest in northwest Pennsylvania is characterized by the creation of many small canopy perforations; however, the landscape remains dominated by closed-canopy forest.

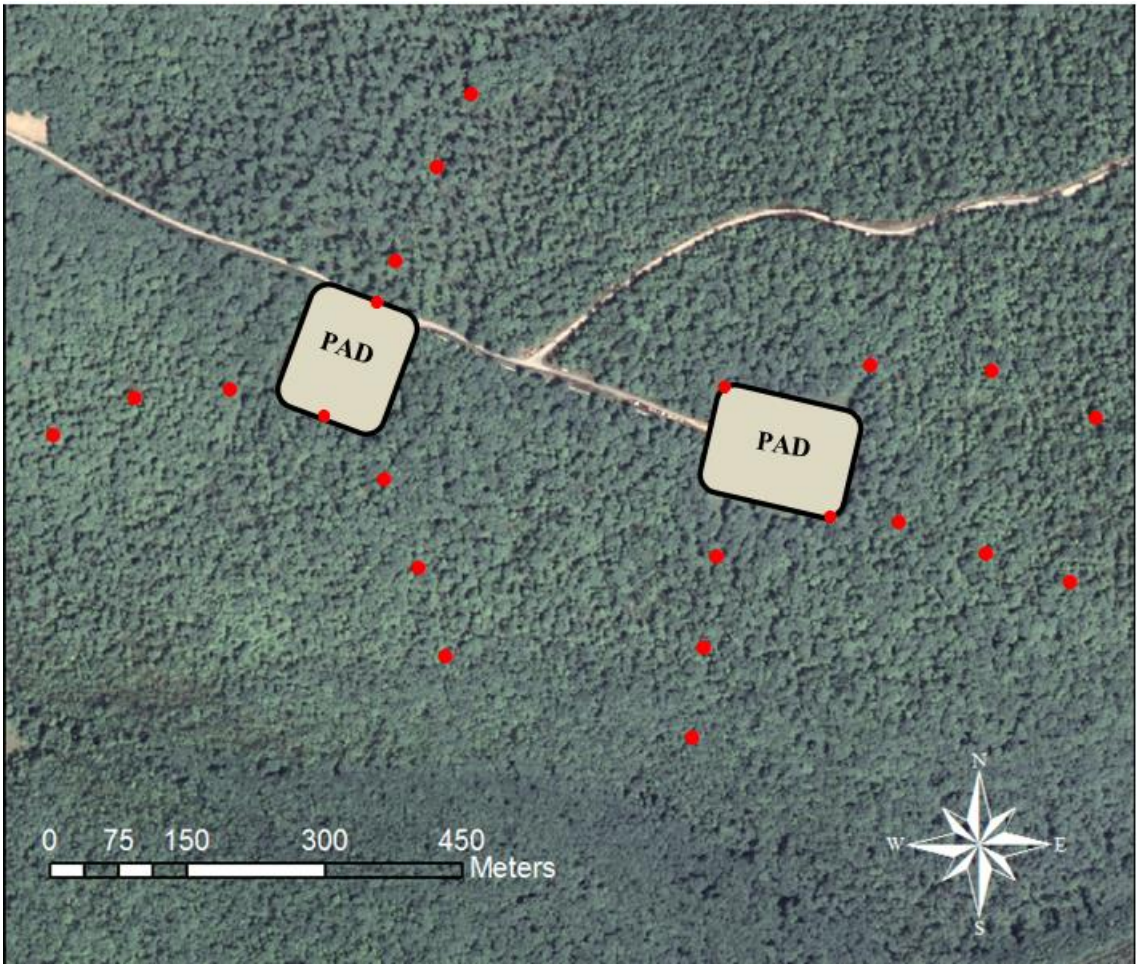

Figure 5. A mapped Marcellus well pad site with two well pads in Lycoming County, Pennsylvania, 2012. "Pads" are Marcellus well pads. Each red point (●) represents a mapped bird point count location of 0m, 50m, 150m, or 250m from the pad edge. Points were selected using aerial imagery and a distance measurement tool in ArcMap Version 10 and sampling arrays were kept separated by at least 150 meters.

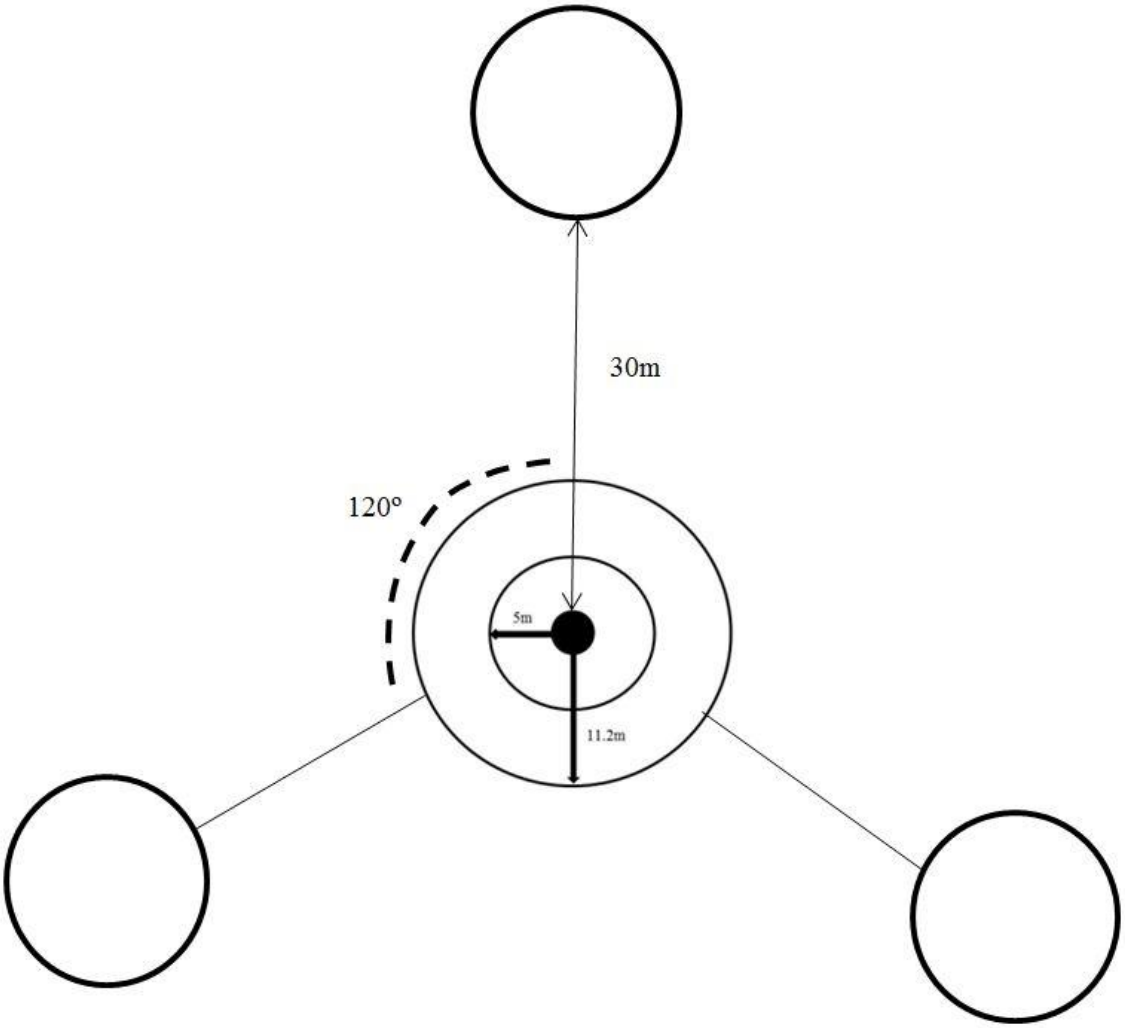

Figure 6. A vegetation sampling array used in the Marcellus study, 2011-2012, in northcentral Pennsylvania. Each array was established at the bird point count center and consisted of four sample plots: one plot at the center, and three outrigger plots 30m from point center. I used a random compass bearing to select the first outrigger plot, and subsequent plots were placed 120º from the first plot.

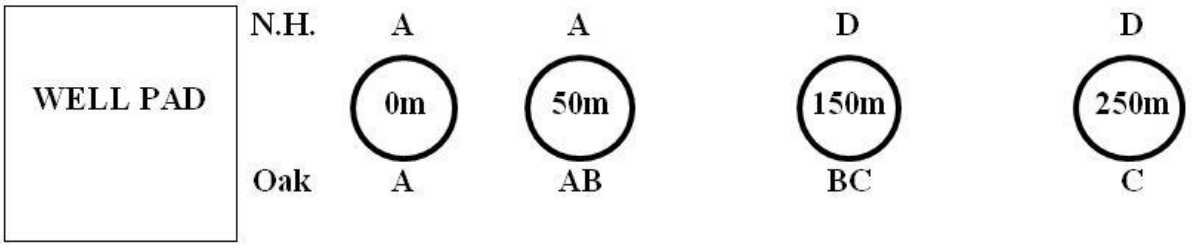

Figure 7. Avian community comparison groupings from non-parametric multivariate analysis of variance by forest type, Northern Hardwood (N.H.) or Mixed Oak (Oak), and distance (m) from Marcellus pad edge from a study on unconventional gas development effects on forest songbirds, northcentral Pennsylvania, 2011-12. Communities sharing letters do not differ.

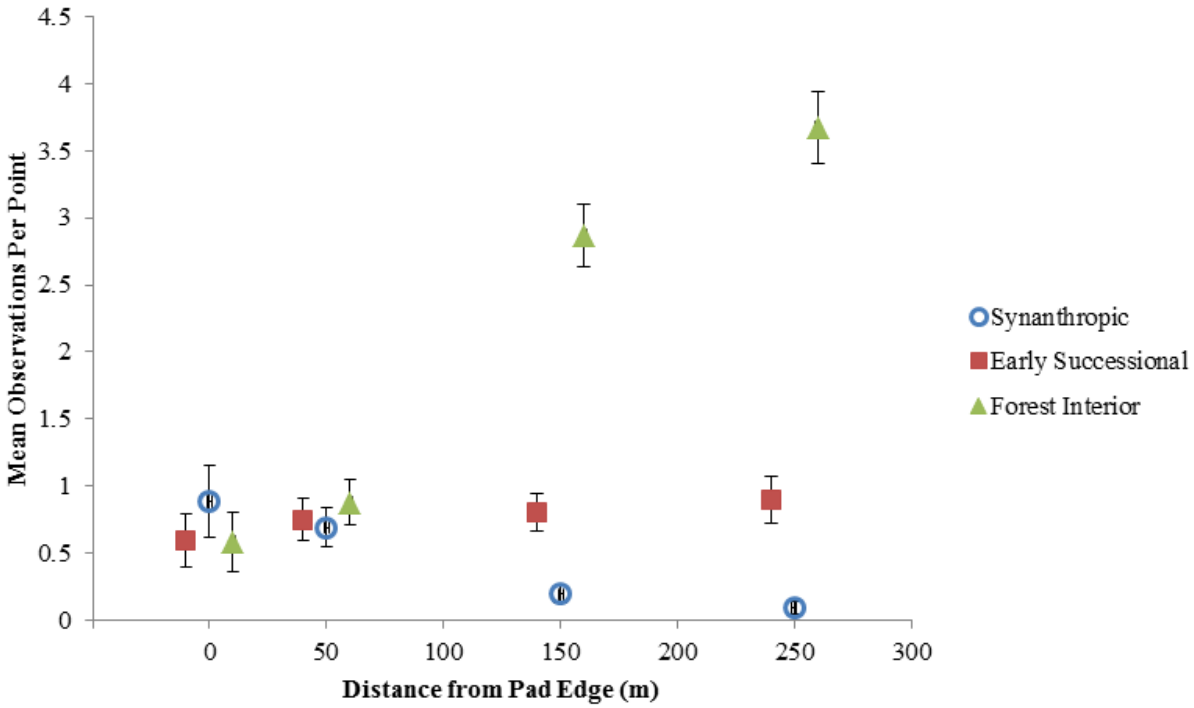

Figure 8. Mean observations of songbird species in habitat guilds per point by distance (m) from the edge of 30 Marcellus well pads in northcentral Pennsylvania forest, 2011-12. Jitter of 10m has been added to forest interior points and jitter of -10m has been added to early successional points to make the figure easier to read and interpret.

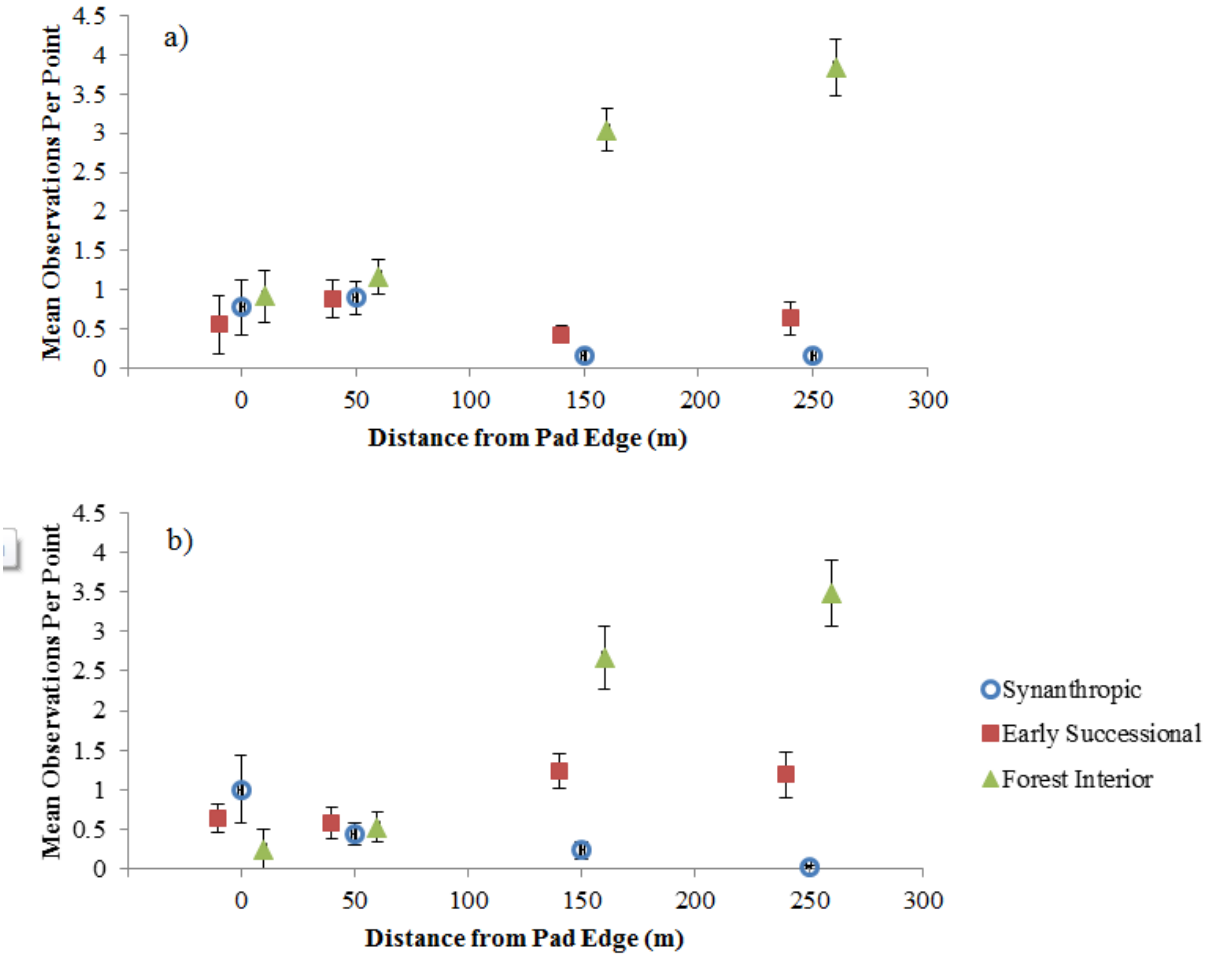

Figure 9. Mean observations of songbird species in guilds per point by habitat type, Northern Hardwood or Mixed Oak, and distance (m) from the edge of 30 Marcellus well pads in northcentral Pennsylvania forest, 2011-12. Plot a) represents means (±SEs) for northern hardwood habitat, and plot b) represents means (±SEs) for mixed oak habitat. Jitter of 10m has been added to forest interior points and jitter of -10m has been added to early successional points to make the figure easier to read.

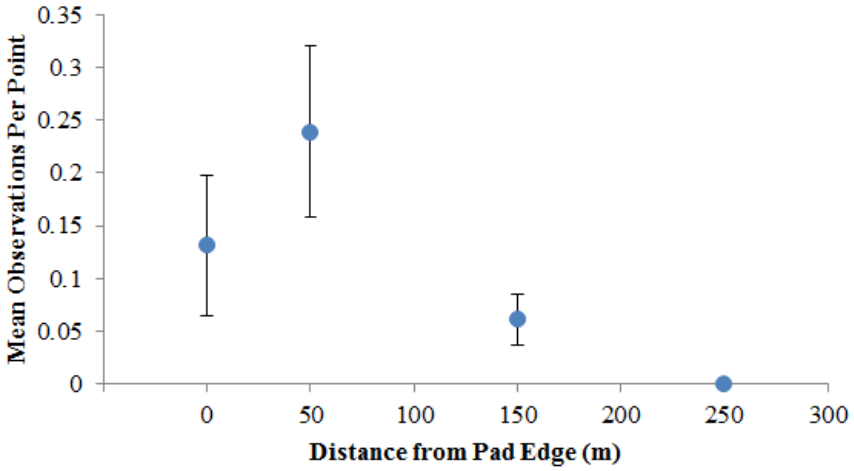

Figure 10. Mean number of American robins observed per point (± SE) by distance (m) from the edge of 30 Marcellus well pads in northcentral Pennsylvania forest, 2011-12. No birds were observed more than 200m from the pad edge within the forest interior.

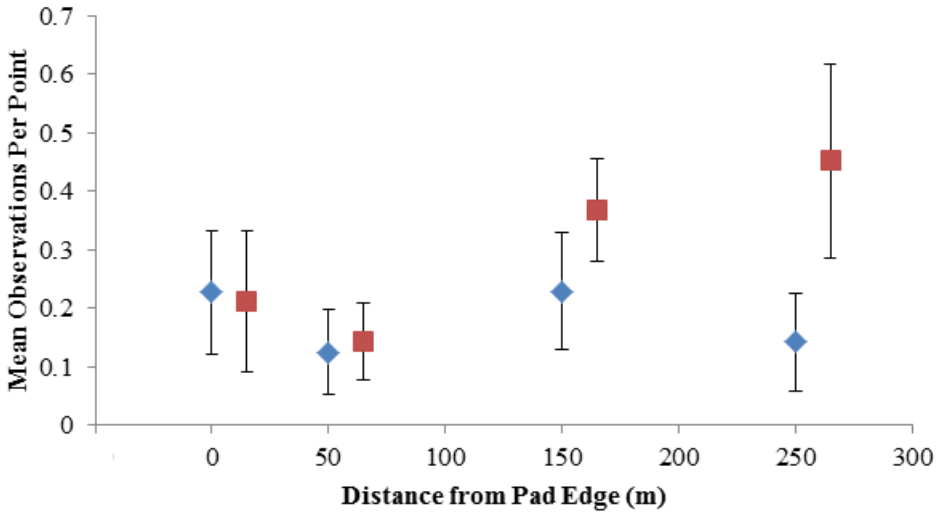

Figure 11. Mean (±SE) number of common yellowthroats observed per point by habitat type and distance (m) from the edge of 30 Marcellus well pads in northcentral Pennsylvania forest, 2011-2012. Diamond markers (♦) represent northern hardwood habitat, and square markers (■) represent mixed oak habitat. Jitter of 10m has been added to mixed oak points to make the figure easier to read and interpret.

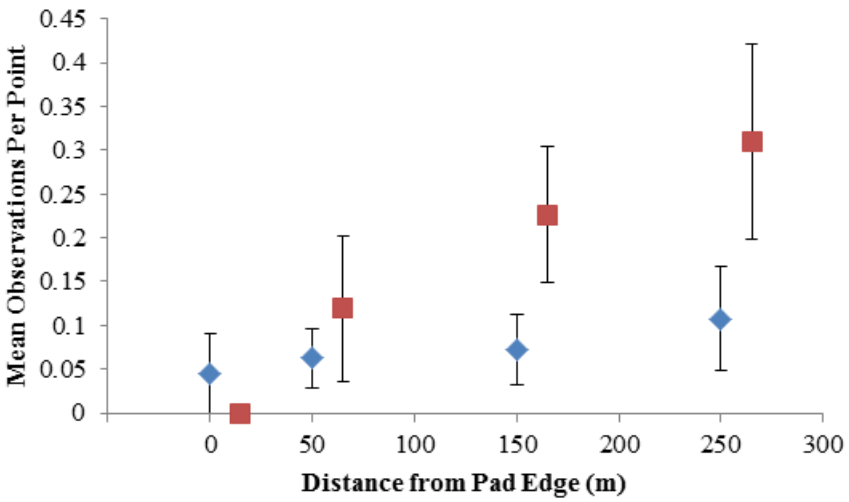

Figure 12. Mean (±SE) number of chestnut-sided warblers observed per point by habitat type and distance (m) from the edge of 30 Marcellus well pads in northcentral Pennsylvania forest, 2011-2012. Diamond markers (♦) represent northern hardwood habitat and square markers (■) represent mixed oak habitat. Jitter of 10m has been added to mixed oak points to make the figure easier to read.

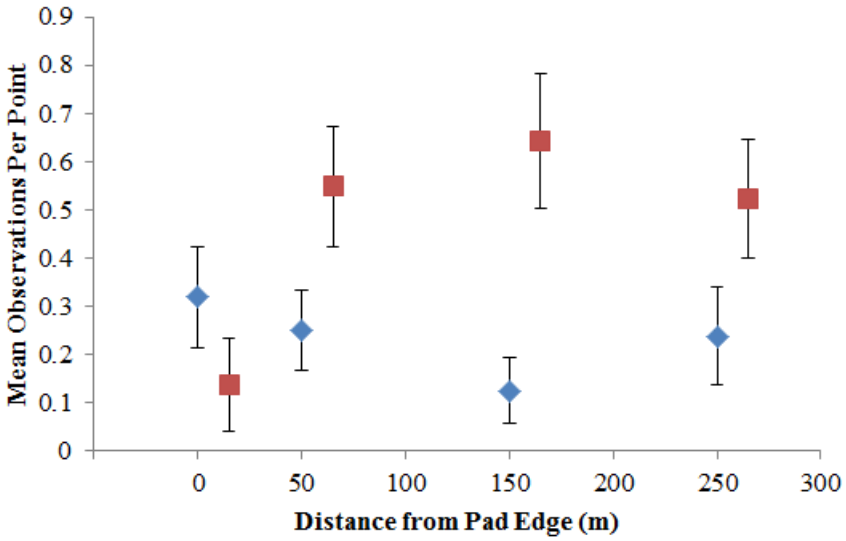

Figure 13. Mean relative abundance (± SE) of Eastern towhees differed by habitat type surrounding Marcellus pads, northcentral Pennsylvania, 2011-12. Diamonds (♦) represent means for northern hardwood habitat, and squares (■) represent means for mixed oak habitat. Jitter of 10m has been added to mixed oak points to make the figure easier to read.

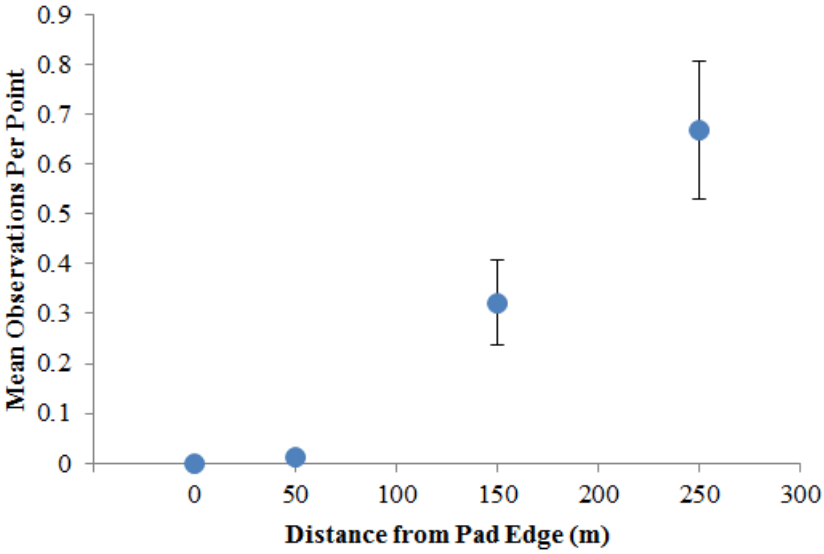

Figure 14. Black-throated green warbler mean observations per point (± SE) versus distance (m) from the edge of 30 Marcellus well pads in northcentral Pennsylvania forest, 2011-12.

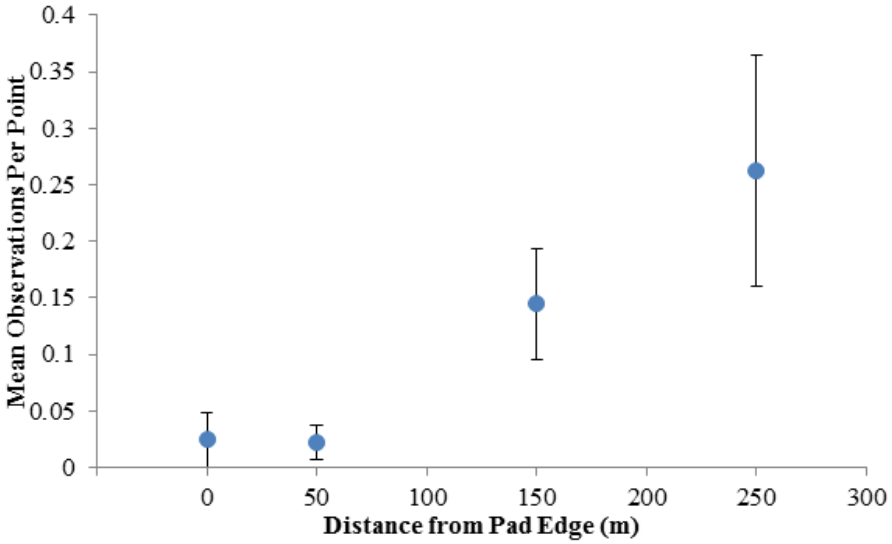

Figure 15. Hermit thrush mean observations per point (± SE) by distance from the edge of 30 Marcellus well pad edges in northcentral Pennsylvania forest, 2011-12.

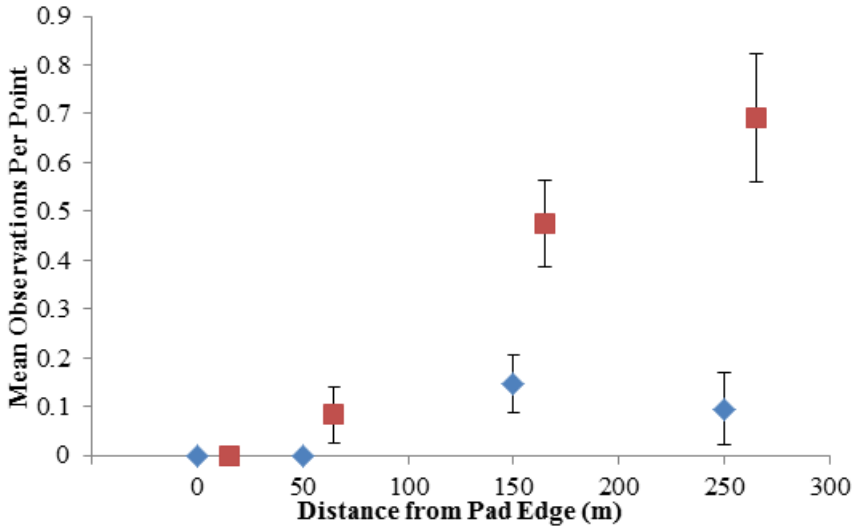

Figure 16. Black-throated blue warbler relative abundance (± SE) relative to habitat type, northern hardwood or mixed oak, and distance (m) from edge of 30 Marcellus well pads in northcentral Pennsylvania, 2011-12. Diamonds (♦) represent means for northern hardwood sites, and squares (■) represent means for mixed oak sites. Jitter of 10m has been added to mixed oak points to make the figure easier to read and interpret.

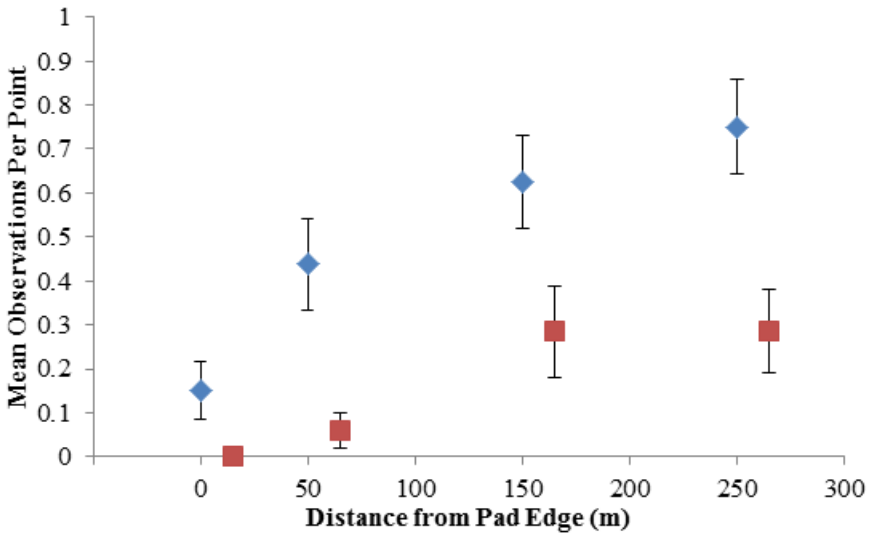

Figure 17. Mean (±SE) ovenbirds observed per point by habitat type and distance (m) from the edge of 30 Marcellus well pads in northcentral Pennsylvania forest, 2011-2012. Diamond markers (♦) represent means for northern hardwood habitat, and square markers (■) represent mixed oak forest type. Jitter of 10m has been added to the mixed oak points to make the figure easier to read and interpret.

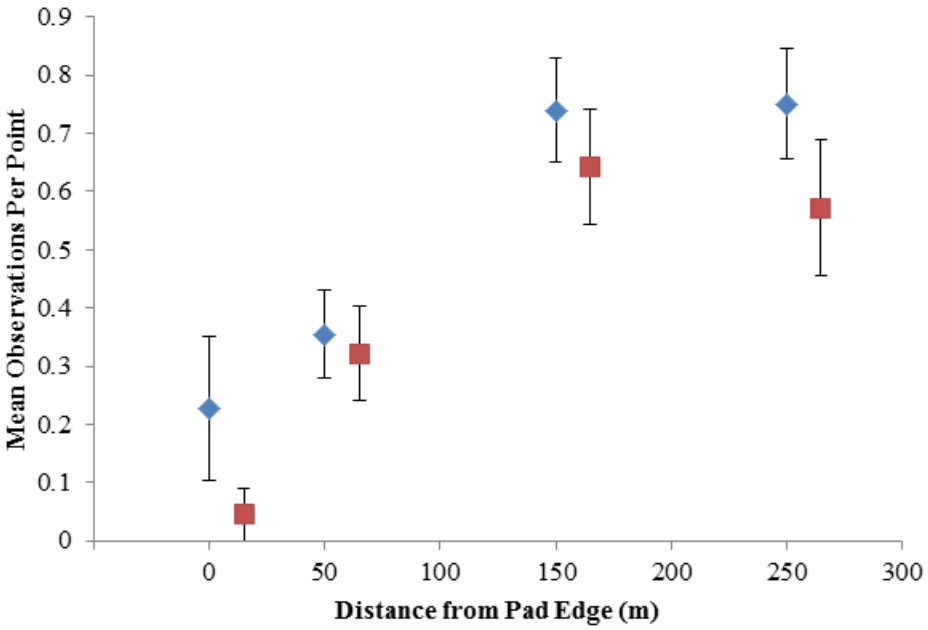

Figure 18. Mean (±SE) red-eyed vireo observations per point by habitat type and distance (m) from the edge of 30 Marcellus well pads in northcentral Pennsylvania forest, 2011-2012. Diamond markers (♦) represent points in northern hardwood forest, while square markers (■) represent points in mixed oak forest. Jitter of 10m has been added to mixed oak points to make the figure easier to read and interpret.

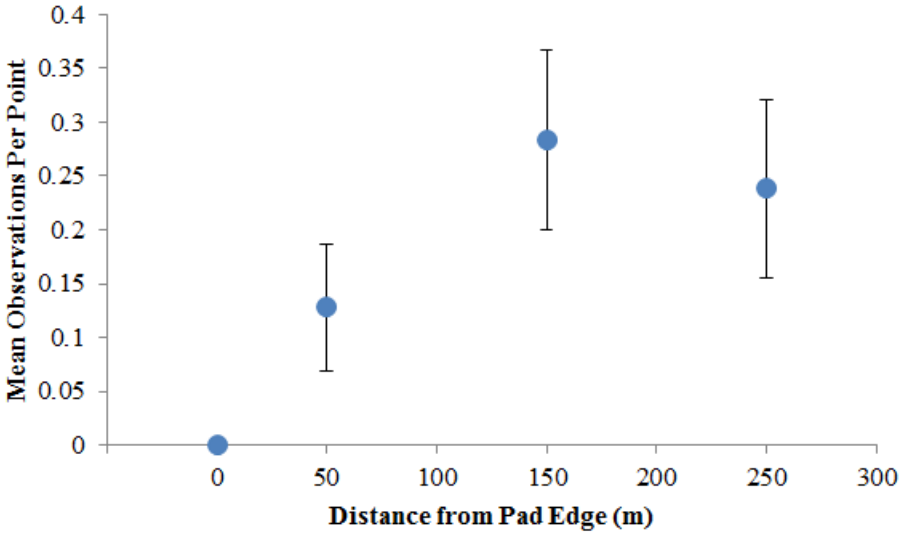

Figure 19. Mean (± SE) number of scarlet tanagers observed per point by distance (m) from the edge of 30 Marcellus well pads in northcentral Pennsylvania, 2011-12.

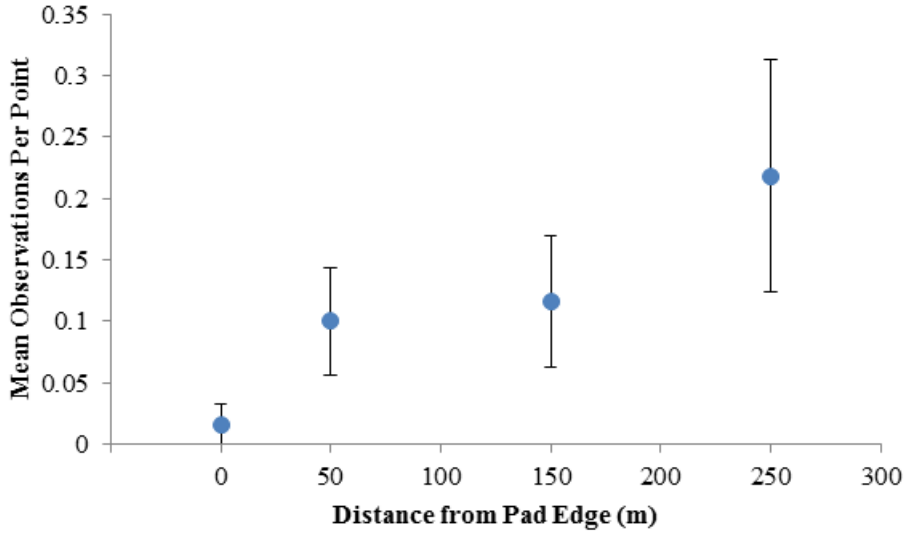

Figure 20. Mean (±SE) number of black-and-white warblers observed per point by distance (m) from the edge of 30 Marcellus well pads in northcentral Pennsylvania forest, 2011-2012.

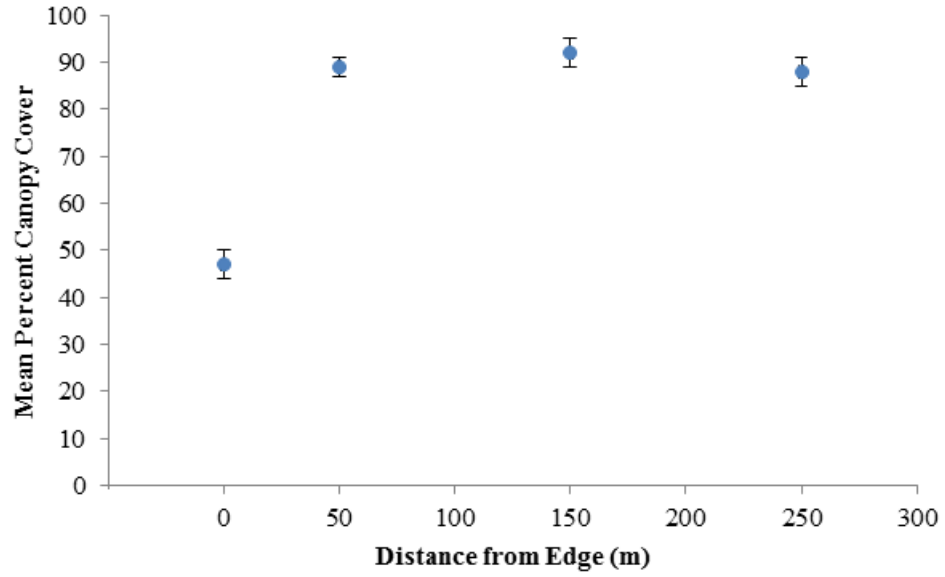

Figure 21. Mean (±SE) percent forest canopy cover by distance (m) from the edge of 14 Marcellus well pads in northcentral Pennsylvania forest, 2011-12.

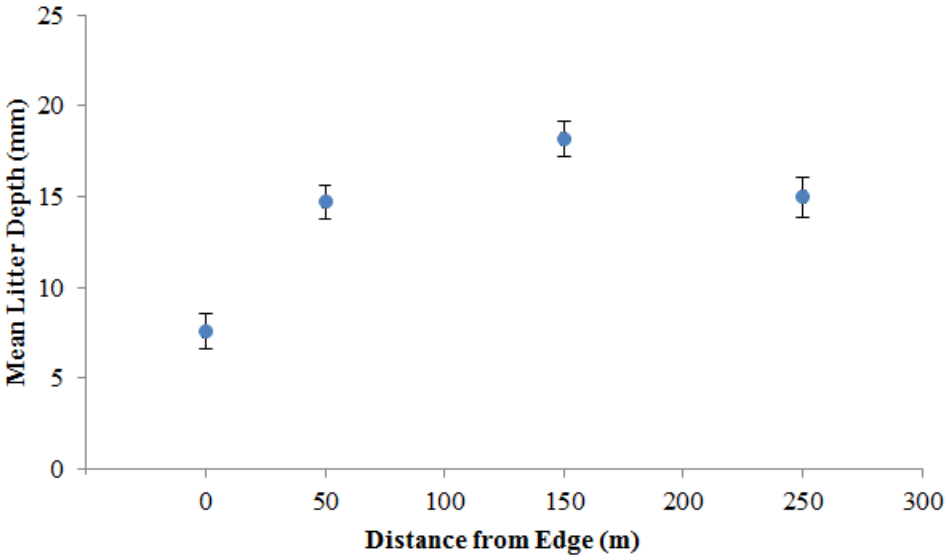

Figure 22. Mean (±SE) leaf litter depth (mm) by distance from the edge of 14 Marcellus well pads in northcentral Pennsylvania forest, 2011-12.

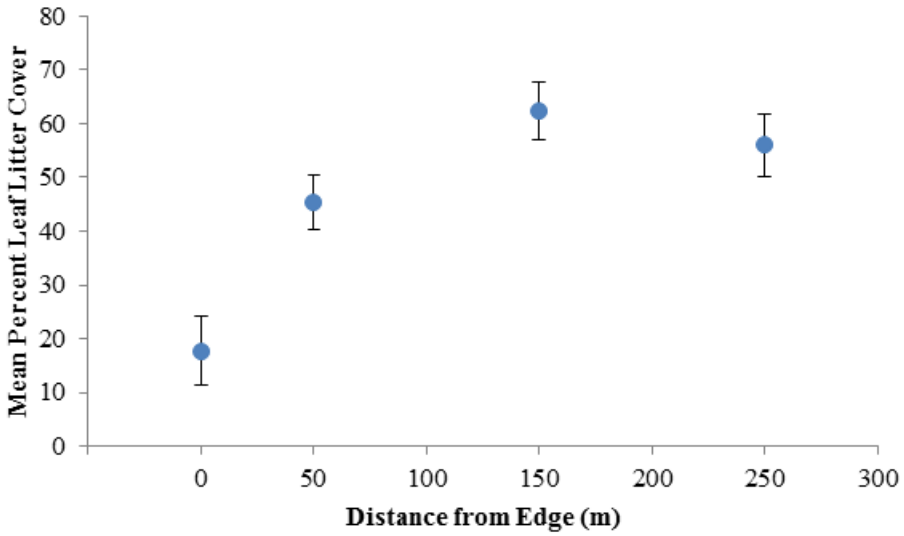

Figure 23. Mean (±SE) percent leaf litter coverage by distance from the edge of 14 Marcellus well pads in northcentral Pennsylvania forest, 2011-12.

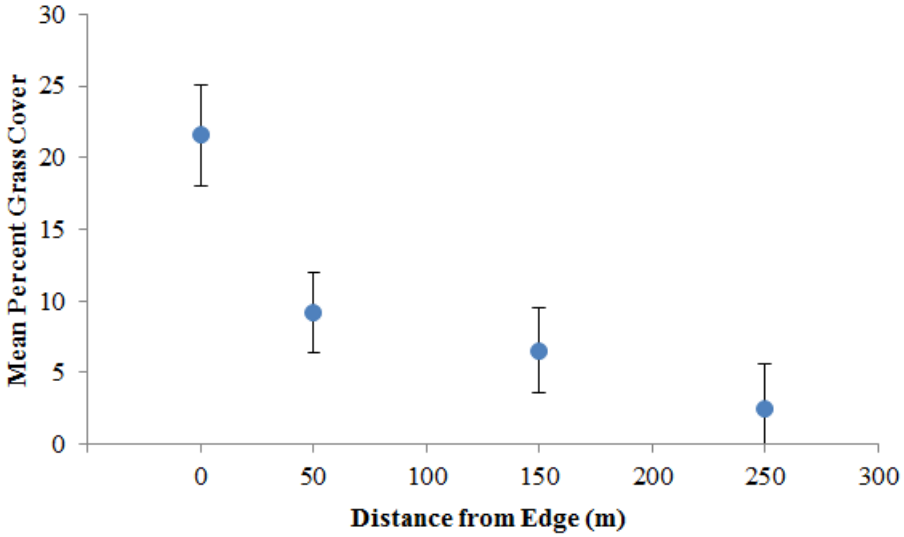

Figure 24. Mean (±SE) percent grass cover by distance from the edge of 14 Marcellus well pads in northcentral Pennsylvania forest, 2011-2012.

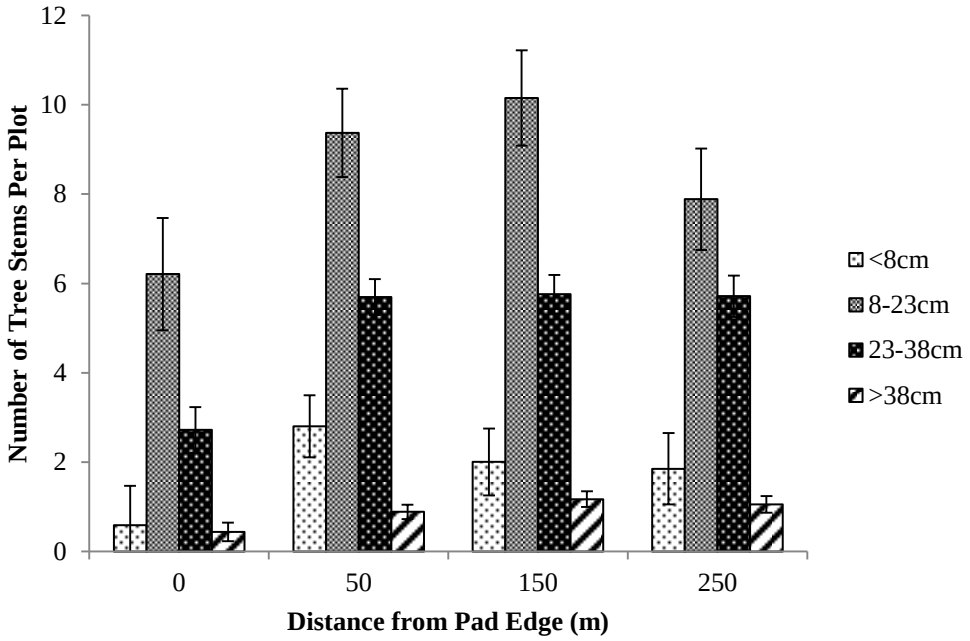

Figure 25. Number of tree stems per vegetation sample plot by diameter at breast height and distance from the edge of 14 Marcellus well pads in northcentral Pennsylvania forest, 2011-12.

APPENDICES

Appendix A. Bird species observed and habitat association guilds.

Table A-1. Passerine and near-passerine bird species detected during point count surveys near Marcellus well pads in northcentral Pennsylvania forest, 2011-2012, and assigned habitat guilds[a]. Species for which a dash (-) appears in the guild column were not assigned to any guild. Species appear in phylogenetic order according to the American Ornithologist Union's taxonomy. Alpha codes are four-letter species codes developed by the Institute for Bird Populations and compiled by Pyle and DeSante (2014); these codes have been used to refer to species in some figures and tables.

Common Name	Alpha Code	Scientific Name	Guild[a]
Mourning Dove	MODO	*Zenaida macroura*	S
Yellow-billed Cuckoo	YBCU	*Coccyzus americanus*	-
Black-billed Cuckoo	BBCU	*Coccyzus erythropthalmus*	-
Ruby-throated Hummingbird	RTHU	*Archilochus colubris*	-
Red-bellied Woodpecker	RBWO	*Melanerpes carolinus*	-
Yellow-bellied Sapsucker	YBSA	*Sphyrapicus varius*	-
Downy Woodpecker	DOWO	*Picoides pubescens*	-
Hairy Woodpecker	HAWO	*Picoides villosus*	-
Pileated Woodpecker	PIWO	*Dryocopus pileatus*	-
Eastern Wood-Pewee	EAWP	*Contopus virens*	-
Acadian Flycatcher	ACFL	*Empidonax virescens*	F
Least Flycatcher	LEFL	*Empidonax minimus*	F
Great Crested Flycatcher	GCFL	*Myiarchus crinitus*	-
Blue-headed Vireo	BHVI	*Vireo solitarius*	F
Red-eyed Vireo	REVI	*Vireo olivaceus*	F
Common Raven	CORA	*Corvus corax*	-
American Crow	AMCR	*Corvus brachyrynchos*	S
Blue Jay	BLJA	*Cyanocitta cristata*	S
Black-capped Chickadee	BCCH	*Poecile atricapillus*	-
Tufted Titmouse	TUTI	*Baeolophus bicolor*	-
Red-breasted Nuthatch	RBNU	*Sitta canadensis*	-
White-breasted Nuthatch	WBNU	*Sitta carolinensis*	-
Brown Creeper	BRCR	*Certhia americana*	F
House Wren	HOWR	*Troglodytes aedon*	S
Winter Wren	WIWR	*Troglodytes hiemalis*	F
Carolina Wren	CARW	*Thryothorus ludovicianus*	S
Eastern Bluebird	EABL	*Sialia sialis*	S
Veery	VEER	*Catharus fuscescens*	F
Hermit Thrush	HETH	*Catharus guttatus*	F
Wood Thrush	WOTH	*Hylocichla mustelina*	F
American Robin	AMRO	*Turdus migratorius*	S
Brown Thrasher	BRTH	*Toxostoma rufum*	E
Gray Catbird	GRCA	*Dumetella carolinensis*	E

Cedar Waxwing	CEDW	*Bombycilla cedrorum*	-
Ovenbird	OVEN	*Seiurus aurocapilla*	F
Common Yellowthroat	COYE	*Geothlypis trichas*	E
Black-and-white Warbler	BAWW	*Mniotilta varia*	F
Black-throated Green Warbler	BTNW	*Setophaga virens*	F
Black-throated Blue Warbler	BTBW	*Setophaga caerulescens*	F
Chestnut-sided Warbler	CSWA	*Setophaga pensylvanica*	E
Blackburnian Warbler	BLBW	*Setophaga fusca*	F
American Redstart	AMRE	*Setophaga ruticilla*	F
Hooded Warbler	HOWA	*Setophaga citrina*	F
Magnolia Warbler	MAWA	*Setophaga magnolia*	F
Canada Warbler	CAWA	*Cardellina canadensis*	-
Eastern Towhee	EATO	*Pipilo erythrophthalmus*	E
Chipping Sparrow	CHSP	*Spizella passerina*	S
Field Sparrow	FISP	*Spizella pusilla*	E
Song Sparrow	SOSP	*Melospiza melodia*	S
Dark-eyed Junco	DEJU	*Junco hyemalis*	F
Scarlet Tanager	SCTA	*Piranga olivacea*	F
Northern Cardinal	NOCA	*Cardinalis cardinalis*	S
Rose-breasted Grosbeak	RBGR	*Pheucticus ludovicianus*	F
Indigo Bunting	INBU	*Passerina cyanea*	-
Common Grackle	COGR	*Quiscalus quiscula*	S
Brown-headed Cowbird	BHCO	*Molothrus ater*	S
American Goldfinch	AMGO	*Carduelis tristis*	S

[a]Guilds based upon knowledge of bird habitat preferences by species supported by Wilson et al. (2012) and Thomas et al. (2014). S=synanthropic, E=early successional, and F=forest interior. Birds with no letter next to name were not placed in any habitat guild.

Table A-2. Non-passerine bird species observed during point count surveys near Marcellus well pads in northcentral Pennsylvania forest, 2011-2012.

Common Name	Order	Scientific Name
Wild Turkey	*Galliformes*	*Meleagris gallopavo*
Sharp-shinned Hawk	*Accipitriformes*	*Accipiter striatus*
Red-shouldered Hawk	*Accipitriformes*	*Buteo lineatus*
Broad-winged Hawk	*Accipitriformes*	*Buteo platypterus*
Red-tailed Hawk	*Accipitriformes*	*Buteo jamaicensis*

Appendix B. Mean (±SE) observations per point and t-tests by habitat type, northern hardwood or mixed oak, for three habitat guilds and individual bird species observed near Marcellus well pads during the 2011 and 2012 breeding seasons, northcentral Pennsylvania forest.

Table B-1. Mean (±SE) observations per point and 2-sample, two-tailed t-tests for three habitat association guilds of passerine birds observed near 30 Marcellus well sites, northcentral Pennsylvania, 2011-2012.

	Mean ± SE			
Guild	N. Hardwood	Mixed Oak	$t_{0.025, 28}$	p
Synanthropic	0.514 ± 0.089	0.274 ± 0.087	1.93	0.056
Early Successional	0.732 ± 0.100	1.063 ± 0.140	-1.98	0.051
Forest Interior	2.520 ± 0.223	2.070 ± 0.260	1.32	0.189

Table B-2. Means and standard errors of observations per point for each bird species observed in two forest types, northern hardwood (n=16) and mixed oak (n=14), surrounding Marcellus well pads during the 2011 and 2012 breeding seasons in northcentral Pennsylvania. The t-statistic is from a 2-sample t-test between relative abundance means by habitat. A dash (-) indicates a lack of observations for the given species. I conducted t-tests of means only for species observed at ≥50% of Marcellus sites (n=30). Where variances between habitat type means were determined to be significantly different by Levene's test, Welch's t-test was used to account for differences in variance[a]. P-values with an asterisk (*) are significant (α=0.05).

	Mean ± SE			
Bird Species	N. Hardwood	Mixed Oak	$t_{0.025,28}$	p
Mourning Dove	0.044 ± 0.021	-		
Yellow-billed Cuckoo	0.013 ± 0.013	-		
Black-Billed Cuckoo	0.005 ± 0.005	-		
Ruby-throated Hummingbird	0.019 ± 0.014	-		
Red-bellied Woodpecker	0.031 ± 0.022	-		
Yellow-bellied Sapsucker[a]	0.174 ± 0.047	0.026 ± 0.020		
Downy Woodpecker	0.021 ± 0.009	0.035 ± 0.016		
Hairy Woodpecker	0.005 ± 0.005	0.034 ± 0.028		
Pileated Woodpecker	0.034 ± 0.021	0.038 ± 0.022		
Eastern Wood-Pewee	0.026 ± 0.021	0.094 ± 0.032		
Acadian Flycatcher	-	-		
Least Flycatcher	-	0.014 ± 0.009		
Great Crested Flycatcher	0.051 ± 0.032	0.030 ± 0.016		
Blue-headed Vireo	0.120 ± 0.039	0.138 ± 0.072		

Red-eyed Vireo	0.533 ± 0.056	0.377 ± 0.052	2.02	0.053
Common Raven	0.023 ± 0.019	-		
American Crow	0.012 ± 0.008	-		
Blue Jay	0.107 ± 0.037	0.063 ± 0.037		
Black-capped Chickadee	0.104 ± 0.041	0.102 ± 0.048		
Tufted Titmouse	0.017 ± 0.012	0.021 ± 0.016		
Red-breasted Nuthatch	-	0.012 ± 0.012		
White-breasted Nuthatch	0.050 ± 0.019	0.012 ± 0.012		
Brown Creeper	-	0.025 ± 0.018		
House Wren	0.014 ± 0.014	-		
Winter Wren	0.021 ± 0.014	-		
Carolina Wren	-	0.006 ± 0.006		
Eastern Bluebird	0.005 ± 0.005	0.009 ± 0.009		
Veery[a]	0.129 ± 0.046	0.008 ± 0.008		
Hermit Thrush	0.143 ± 0.035	0.113 ± 0.048	0.52	0.608
Wood Thrush	0.018 ± 0.010	-		
American Robin	0.125 ± 0.031	0.096 ± 0.029	0.68	0.503
Brown Thrasher	0.007 ± 0.007	-		
Gray Catbird	0.064 ± 0.027	-		
Cedar Waxwing	0.109 ± 0.031	0.063 ± 0.026		
Ovenbird	0.503 ± 0.060	0.168 ± 0.047	4.30	<0.001*
Common Yellowthroat	0.183 ± 0.053	0.303 ± 0.079	-1.28	0.211
Black-and-white Warbler	0.117 ± 0.033	0.083 ± 0.0436	-0.69	0.493
Black-throated Green Warbler	0.240 ± 0.050	0.251 ± 0.056	-0.14	0.889
Black-throated Blue Warbler[a]	0.061 ± 0.026	0.316 ± 0.051	-4.51	<0.001*

Chestnut-sided Warbler	0.072 ± 0.022	0.187 ± 0.054	-2.06	0.049*
Blackburnian Warbler	0.060 ± 0.022	0.041 ± 0.033		
American Redstart	0.062 ± 0.03	0.048 ± 0.033		
Hooded Warbler	-	0.034 ± 0.023		
Magnolia Warbler	0.005 ± 0.005	0.006 ± 0.006		
Canada Warbler	0.010 ± 0.010	0.018 ± 0.018		
Eastern Towhee	0.230 ± 0.065	0.462 ± 0.071	-2.41	0.023*
Chipping Sparrow	0.062 ± 0.020	0.054 ± 0.036		
Field Sparrow	0.018 ± 0.018	-		
Song Sparrow	0.064 ± 0.036	0.063 ± 0.025		
Dark-eyed Junco	0.052 ± 0.021	0.033 ± 0.020		
Scarlet Tanager	0.204 ± 0.038	0.151 ± 0.044	0.92	0.368
Northern Cardinal	0.022 ± 0.016	-		
Rose-breasted Grosbeak	0.047 ± 0.023	0.018 ± 0.012		
Indigo Bunting	0.038 ± 0.017	0.063 ± 0.034		
Common Grackle	0.015 ± 0.010	-		
Brown-headed Cowbird	0.033 ± 0.017	0.045 ± 0.025		
American Goldfinch	-	0.015 ± 0.015		

[a]For species for which the assumption of equal variances was rejected by Levene's test, Welch's t-test was used in place of Student's t-test to account for unequal variances.

Appendix C. Comparisons between northern hardwood and mixed oak forest types.

Table C-1. Means and standard errors of habitat factors at the scale of individual vegetation survey plots for the two forest types: northern hardwood (n=71) and mixed oak (n=23) in 2011 and 2012 in northcentral Pennsylvania forest. Sample sizes are based on by-distance, by-habitat means from 11 northern hardwood sites and 3 mixed oak sites. T-statistics and p-values are the results of a 2-sample, two-tailed Welch's t-test. Due to unequal sample size and the possibility of unequal variances between groups, degrees of freedom were determined via the Welch-Satterthwaite equation. P-values with an asterisk (*) are significant at the level of α=0.05.

	Mean ± SE				
Habitat Factor	N. Hardwood	Mixed Oak	d.f.	$t_{0.025}$	p
Small Trees	1.78 ± 0.41	2.45 ± 0.92	31	-0.65	0.520
Small/Medium Trees	7.59 ± 0.62	11.80 ± 0.99	40	-3.53	0.001*
Medium/Large Trees	5.24 ± 0.30	4.86 ± 0.43	44	0.72	0.477
Large Trees	1.01 ± 0.11	0.63 ± 0.14	51	2.12	0.039*
Snags	0.90 ± 0.20	2.48 ± 0.94	24	-1.60	0.122
% Green	55.85± 2.98	73.51 ± 3.88	49	-3.54	<0.001*
% Grass	11.23 ± 2.06	3.19 ± 1.61	82	3.04	0.003*
% Shrub	20.73 ± 2.09	59.64 ± 5.22	29	-6.78	<0.001*
% Forb	5.58 ± 1.36	0.17 ± 0.11	71	3.95	<0.001*
% Fern	24.21 ± 3.05	15.29 ± 3.98	49	1.75	0.087
% Moss	9.76 ± 1.84	3.36 ± 0.82	90	3.14	0.002*
% Litter	51.69 ± 3.59	32.90 ± 5.96	39	2.65	0.011*
% Natural Woody Debris	8.49 ± 0.63	5.07 ± 0.59	70	3.91	<0.001*
% Rock	4.76 ± 1.08	5.48 ± 1.74	40	-0.35	0.731
% Bare	2.78 ± 0.81	4.22 ± 2.56	26	-0.53	0.603

% Gas-Related Woody Debris	0.68 ± 0.25	0.88 ± 0.66	28	-0.28	0.781
Small Sapling Stems	20.63 ± 1.65	39.74 ± 6.28	25	-2.88	0.008*
Large Sapling Stems	3.41 ± 0.46	3.67 ± 1.21	28	-0.20	0.844
Litter Depth (mm)	14.07 ± 0.87	13.10 ± 0.97	52	0.73	0.471
Canopy Ht. (m)	17.97 ± 0.33	16.25 ± 0.45	45	3.56	<0.001*
% Canopy Cover	78.34 ± 2.59	79.45 ± 3.83	44	0.50	0.622
Low-intensity Dieback (number of stems)	0.27 ± 0.06	0.49 ± 0.09	42	-2.07	0.045*
Moderate Dieback (number of stems)	0.25 ± 0.06	0.56 ± 0.12	34	-2.33	0.026*
Heavy Dieback (number of stems)	0.09 ± 0.03	0.17 ± 0.04	44	-1.64	0.109

Table C-2. Number of vegetation sample points at which given tree species were dominant in the canopy in northcentral Pennsylvania forest surrounding 14 Marcellus well pads, 2011-12.

Species	Number of Plots
Red Maple	138
American Beech	39
Eastern Hemlock	26
Sugar Maple	22
White Pine	19
Black Cherry	19
Red Oak	14
Black Birch	13
White Oak	8
Chestnut Oak	7
Red Pine	4
White Ash	3
Yellow Birch	3
Sassafras	2
Bigtooth Aspen	1
Black Ash	1
Norway Spruce	1
No Overstory Trees	29
TOTAL POINTS	349

Table C-3. Additional results for general linear models of vegetation measurements taken from sampling arrays surrounding 14 Marcellus well pads in northcentral Pennsylvania, 2011-2012. The F and p-values reported are results for distance as a predictor of the given dependent variable. P-values with an asterisk (*) are significant at the level of α=0.05.

	Mean ± S.E.					
Dependent Variable	**0m**	**50m**	**150m**	**250m**	**F**	**p**
Canopy height (m)	16.5 ± 0.5	17.3 ± 0.5	17.9 ± 0.5	17.7 ± 0.6	1.22	0.300
Percent green cover	62.0 ± 5.9	64.9 ± 4.7	54.0 ± 5.0	59.5 ± 5.4	0.89	0.449
Percent forb cover	10.2 ± 2.4	4.2 ± 1.9	2.0 ± 2.0	2.0 ± 2.1	2.89	0.040*
Percent moss cover	1.7 ± 3.2	10.7 ± 2.5	6.5 ± 2.7	12.2 ± 2.9	2.43	0.070
Percent natural woody debris	2.4 ± 1.0	9.2 ± 0.8	9.1 ± 0.9	8.3 ± 0.9	10.61	<0.001*
Percent rock	13.3 ± 1.9	2.2 ± 1.5	3.7 ± 1.6	3.1 ± 1.7	8.06	<0.001*
Percent bare ground	13.8 ± 1.6	0.8 ± 1.3	0.6 ± 1.4	0.3 ± 1.5	17.87	<0.001*
Percent gas woody debris	3.8 ± 0.5	0.0 ± 0.4	0.0 ± 0.4	0.0 ± 0.4	18.86	<0.001*
Large sapling stems (count)	2.9 ± 1.1	4.1 ± 0.8	3.8 ± 0.9	2.9 ± 1.0	0.44	0.722
Low dieback (count)	0.4 ± 0.1	0.5 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	2.51	0.063
Moderate dieback (count)	0.6 ± 0.1	0.3 ± 0.1	0.2 ± 0.1	0.3 ± 0.1	1.51	0.217
Heavy dieback (count)	0.2 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	1.09	0.357

Appendix D. Marcellus study site location, ownership information, and habitat characteristics within a 5km buffer zone.

Table D-1. Marcellus pad site location , ownership information, and survey year for the 30 well pads in my study in northcentral Pennsylvania forest, 2011-2012.

Site	County	Ownership	Habitat Type	Year	Latitude (ºN)	Longitude (ºW)
1	Lycoming	Public	Mixed Oak	2011	41.38209	76.89661
2	Bradford	Private	N. Hardwood	2011	41.60183	76.53460
3	Bradford	Private	N. Hardwood	2011	41.87853	76.34789
4	Lycoming	Private	N. Hardwood	2011	41.43467	76.89995
5	Lycoming	Private	N. Hardwood	2011	41.43369	76.84573
6	Lycoming	Private	N. Hardwood	2011	41.43328	76.83894
7	Clinton	Public	Mixed Oak	2011	41.22032	77.76528
8	Clinton	Public	Mixed Oak	2011	41.19843	77.77958
9	Clearfield	Private	N. Hardwood	2011	41.04347	78.07781
10	Clearfield	Private	N. Hardwood	2011	41.03862	78.06844
11	Tioga	Public	N. Hardwood	2011	41.69311	76.97961
12	Clearfield	Private	Mixed Oak	2011	41.11322	78.40754
13	Clearfield	Private	Mixed Oak	2011	41.11047	78.40224
14	Lycoming	Private	N. Hardwood	2012	41.41251	76.95633
15	Lycoming	Private	N. Hardwood	2012	41.44687	76.83854
16	Lycoming	Private	N. Hardwood	2012	41.44467	76.86422
17	Lycoming	Private	N. Hardwood	2012	41.45664	76.91330
18	Tioga	Public	N. Hardwood	2012	41.69821	76.96511
19	Tioga	Public	N. Hardwood	2012	41.68219	76.95872
20	Tioga	Public	N. Hardwood	2012	41.68236	76.96556
21	Lycoming	Public	Mixed Oak	2012	41.35632	77.49885
22	Lycoming	Public	Mixed Oak	2012	41.39533	77.48766
23	Lycoming	Public	Mixed Oak	2012	41.36596	77.51772
24	Clinton	Public	Mixed Oak	2012	41.23327	77.75763
25	Potter	Public	N. Hardwood	2012	41.72794	78.16843
26	Centre	Public	Mixed Oak	2012	41.07521	77.80079
27	Centre	Public	Mixed Oak	2012	41.07346	77.79659
28	Centre	Public	Mixed Oak	2012	41.06636	77.80602
29	Centre	Public	Mixed Oak	2012	41.05976	77.82678
30	Clearfield	Public	Mixed Oak	2012	41.14394	78.47491

Table D-2. ArcMap land cover statistics within a 5km radius of the 30 Marcellus sites in my study in northcentral Pennsylvania forest, 2011-2012. Road density is kilometers of road per square kilometer or land area

Site	County	Ownership	Road Density (km road/km^2)	% Forest	% Core Forest	% Edge Forest	% Agriculture
1	Lycoming	Public	9.474	93.94	76.74	17.20	17.20
2	Bradford	Private	12.386	92.92	70.92	21.99	21.99
3	Bradford	Private	15.720	76.38	37.82	38.56	38.56
4	Lycoming	Private	10.874	94.46	69.78	24.68	24.68
5	Lycoming	Private	10.007	96.06	74.81	21.26	21.26
6	Lycoming	Private	9.859	96.15	75.83	20.32	20.32
7	Clinton	Public	17.147	97.47	66.37	31.10	31.10
8	Clinton	Public	16.283	97.01	66.31	30.70	30.70
9	Clearfield	Private	13.798	87.13	58.98	28.15	28.15
10	Clearfield	Private	13.421	87.40	60.00	27.40	27.40
11	Tioga	Public	13.570	91.05	61.68	29.36	29.36
12	Clearfield	Private	15.414	91.45	61.83	29.62	29.62
13	Clearfield	Private	16.145	89.97	60.01	29.96	29.96
14	Lycoming	Private	14.018	88.35	61.43	26.92	26.92
15	Lycoming	Private	10.877	96.54	73.69	22.85	22.85
16	Lycoming	Private	10.462	96.17	73.36	22.81	22.81
17	Lycoming	Private	9.935	95.56	74.80	20.75	20.75
18	Tioga	Public	12.643	92.60	64.46	28.14	28.14
19	Tioga	Public	13.045	92.21	64.90	27.31	27.31
20	Tioga	Public	12.927	91.60	64.49	27.11	27.11
21	Lycoming	Public	13.768	97.78	79.27	18.51	18.51
22	Lycoming	Public	10.160	96.63	80.86	15.77	15.77
23	Lycoming	Public	13.863	98.64	79.02	19.63	19.63
24	Clinton	Public	15.091	98.34	70.18	28.16	28.16
25	Potter	Public	8.859	96.51	77.51	19.00	19.00
26	Centre	Public	6.757	96.42	80.70	15.72	15.72
27	Centre	Public	7.132	96.13	79.59	16.54	16.54
28	Centre	Public	6.675	96.24	80.59	15.65	15.65
29	Centre	Public	6.608	96.28	80.27	16.01	16.01
30	Clearfield	Public	11.250	87.56	52.09	35.47	35.47