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INITIAL RESPONSE OF BIRDS TO SHALE GAS DEVELOPMENT IN A FORESTED LANDSCAPE

A Thesis in

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Nathan R. Fronk

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The thesis of Nathan R. Fronk was reviewed and approved* by the following:

Margaret C. Brittingham
Professor of Wildlife Resources
Thesis Advisor

Matthew R. Marshall
Adjunct Assistant Professor of Wildlife Conservation

W. David Walter
Adjunct Assistant Professor of Wildlife Ecology

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

*Signatures are on file in the Graduate School.

ABSTRACT

Pennsylvania is currently experiencing rapid shale gas exploration, with the focus being on the Marcellus Shale play. Unlike the shallow gas extraction of western Pennsylvania, Marcellus shale development uses much greater quantities of land, water, and other resources. Marcellus shale development is concentrated in two areas within Pennsylvania, the north-central and south-west regions of the state. In the heavily forested north-central part of the state, forest habitat is being cleared and fragmented due to Marcellus shale exploration. North-central Pennsylvania holds the majority of core forest within Pennsylvania and many area-sensitive Neotropical migrant bird species depend on these forests for breeding habitat. Shale gas development in north-central Pennsylvania is of particular concern because of the importance of these forests to a variety of forest specialists. Marcellus shale gas development has created increased levels of fragmentation and edge habitat throughout the region through the creation of pipelines, well pads, and other Marcellus related infrastructure. In order to investigate the effects of Marcellus shale development on bird species, we used a Before-After Control-Impact study design using the newly completed 2nd Pennsylvania Breeding Bird Atlas (PBBA) as before data and as a sampling framework. During the PBBA (2004-2008) the state was divided into BBA blocks measuring ~2,500 hectares per block. Eight point count bird surveys were completed in each block to estimate bird abundance. During the 2011 and 2012 field seasons, points were resurveyed in 37 PBBA blocks, which served as the after data. Additionally, we compared current bird abundance with differing levels of Marcellus shale development at the BBA block (2488.9 ha) level. We created three species habitat guilds to aid in our analysis; synanthropic (or human-associated) species, early successional species, and forest interior species. The synanthropic species showed a significant positive response to Marcellus shale development in the Before-After Control-Impact (BACI) study and had a positive relationship with increasing levels of Marcellus shale development at the block level. The forest interior species guild exhibited a negative response to Marcellus shale development in the BACI analysis and had a weak negative relationship with increasing levels of well pads at the block level. The early successional species guild exhibited no relationship to Marcellus shale development. These results suggest that Marcellus shale development has caused changes in community structure. The initial response of birds to Marcellus development is an increase in human-associated or synanthropic species, which tend to be generalists, which can utilize newly created disturbances. Forest specialists have not shown extensive declines yet. This is most like due to the short time interval since shale development was initiated and the predominately forested landscape, which still persists. Declines in specialist species and an increase in generalist species will result in biotic homogenization throughout the region.

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INTRODUCTION

Marcellus Shale

The Marcellus shale is an organic-rich black shale formation deposited over 390 million years ago, during the Middle Devonian time period (Harper 2008). The shale ranges from southern New York, Pennsylvania, West Virginia, and into western Maryland, a small portion of western Virginia, and eastern Ohio. This layer is estimated to contain 300 trillion cubic feet of gas over its 150,000 square mile range (Johnson 2010). The shale was first discovered in the 1930's but unpredictable flow rates caused gas exploration to halt. It became clear that gas present in the Marcellus shale occurs in pockets and it would not be economically beneficial to extract. With recent technological advances and higher gas prices, the Marcellus shale is now being developed (Harper 2008).

Unlike the shallow gas extraction of western Pennsylvania, Marcellus shale development uses much larger quantities of land and resources. The natural gas in the Marcellus shale is extracted using the process of horizontal drilling. This process involves drilling a horizontal well until the shale is reached. Horizontal drilling allows for the well to be curved so that it will run horizontally (EIA 1993). This pipeline can run horizontally for 1,200 m or more (Harper 2008). This technology allows for up to twelve wells to be placed on a single pad.

Since multiple wells can be drilled on one well pad, the density of well pads in an area is lower than in shallow gas extraction. However, the pad size and space needed to develop Marcellus shale gas wells is larger than that of conventional shallow wells. Wells are drilled on large stone pads, which average 1.25 hectares in size, compared to the shallow gas well pads of western Pennsylvania, which are typically less than 0.4 hectares in size (Johnson 2010). The supporting infrastructure used in Marcellus shale gas extraction also requires a much larger amount of space than that of shallow gas extraction. Pipelines used to transport the natural gas are 61 cm compared to the 5-10 cm pipelines used to transport gas from shallow wells (Johnson 2010). These larger pipelines also require a much larger pipeline right-of-way. A study in Bradford County, Pennsylvania found that pipelines were the major contributor to forest loss and forest fragmentation in the county (Slonecker et al. 2012). The amount of associated infrastructure development averages 2.31 hectares per pad (Johnson 2010). This associated infrastructure may be water retention ponds, pipelines, roads, and any other non-pad development related to Marcellus shale. It is estimated that an additional 8.58 hectares of forest will be indirectly impacted by the creation of forest edge. The total effect of one well pad and associated infrastructure may be 12.14 hectares, when considering indirect impacts of forest fragmentation (Johnson 2010).

With the development of the well pads and accompanying infrastructure, forest habitat is being cleared and fragmented. The placement of Marcellus shale well pads and pipelines in forest habitat reduces core forest habitat and creates new edges. Slonecker et al. (2012) found that the loss of core forest was over twice that of the total forest lost to Marcellus shale development. A review of 2010 aerial photos from the National Agriculture Imagery Program found that 54% of Marcellus shale well pads were placed in forested areas (Drohan et al. 2012). A summary of existing well pads placed in forest cover showed that 23% of well pads were placed in core forest habitat (Drohan et al. 2012).

It is estimated that somewhere between 7,000 and 16,000 well pads will be constructed in Pennsylvania by 2030 (Johnson 2010). This number varies depending on the number of wells per pad and the spacing of the well pads. One of the most concentrated areas experiencing Marcellus shale exploration in Pennsylvania is the north-central region. The north-central portion of

Pennsylvania holds the majority of the core forest present within Pennsylvania and also the least amount of fragmentation (PA DCNR 2004). Overlap between core forest and the Marcellus shale results in high vulnerability for this habitat.

As natural gas exploration in this region increases, forest habitat is predicted to be lost. Johnson (2010) predicted that between 13,678.4 and 33,588.9 hectares of forest may be cleared depending on the intensity of development. While this equates to less than one percent of the state's total forest habitat, where development is heavy, two to three percent of the local forest habitat may be lost. This is of particular importance in the north-central region where the large tracts of forest provide critical habitat for forest-interior wildlife species (Lloyd et al. 2005).

Importance of Pennsylvania for Forest Bird Species

Many area-sensitive bird species depend on the contiguous forests of north-central Pennsylvania for breeding habitat. For example, Pennsylvania is considered to be one of the most important states for breeding Scarlet Tanagers *(Scientific names,* Appendix A*)*. Approximately 17% of the total nesting population of Scarlet Tanagers resides in Pennsylvania (Rosenberg and Wells 1995, Rosenberg and Wells 2000). The north-central region holds the highest diversity of forest-interior bird species within Pennsylvania (Goodrich et al. 2002, Wilson et al. 2012). Black-throated Blue Warbler, Black-throated Green Warbler, Northern Goshawk, and Broad-winged Hawk, all listed as Species of the Greatest Conservation Need, also breed in this region (Pennsylvania Game Commission and Pennsylvania Fish and boat Commission 2005).

Effect of Forest Fragmentation on Forest Birds

In the forests of north-central Pennsylvania, gas development tends to fragment forests by introducing openings and corridors within a forested landscape. Small and Hunter (1988) found higher rates of nest predation in a heavily forested landscape that was fragmented primarily by roads, power lines, and streams. They also suggested that nest predators used both power lines and roads as travel corridors.

The effect of forest fragmentation on songbirds has been a concern of avian ecologists for many years (Robbins et al. 1989, Faaborg et al. 1995, Robinson et al. 1995). Many Neotropical migrant populations are declining, in part, due to habitat fragmentation occurring on their breeding grounds (Robinson et al. 1995, Fraser and Stutchbury 2004). Fragmentation can reduce the abundance and diversity of Neotropical migrant forest songbirds, even in a heavily forested landscape (Askins 1994). As fragmentation increases, levels of brood parasitism and predation may also increase eventually leading to population declines (Chalfoun et al. 2002, Falk et al. 2011).

In addition, fragmentation may cause some edge-sensitive species to display “edge avoidance”, a negative reaction, possibly caused by decreased nest success, decreased suitable habitat, and increased numbers of conspecifics (Bollinger and Switzer 2002). Decreases in breeding success due to habitat fragmentation overtime can cause breeding densities to decrease throughout the landscape (Rosenberg et al. 1999). While there is much known about many contributors of forest fragmentation, little is known about the effects that Marcellus shale development will have on bird communities. Some species of forest-interior birds are already experiencing declines throughout their range due to habitat fragmentation (Robinson et al. 1995, Fraser and Stutchbury 2004).

The response of species to edge habitat depends on both the characteristics of the species and the characteristics of the edge habitat. A species is predicted to increase in abundance at the edge if the edge habitat provides specific resources that are concentrated at the edge of the habitat or the adjacent habitat contains resources that are not available elsewhere (Ries and Sisk 2004, Ries et al. 2004). Marcellus pads are made of stone, which does not serve as habitat for most bird species. Therefore, the predicted edge response to Marcellus shale well pads would be negative, even for species that traditionally utilize edge habitats (Ries et al. 2004). Due to the hard edges created by Marcellus shale gas exploration additional forest loss and fragmentation, may have a significant negative impact on the forest-interior and area-sensitive bird species.

Effect of Oil and Gas Development on Songbirds

There are few studies that have looked at the effect of oil and gas development on bird populations. Hartzler (1999) conducted a study looking at the effects of shallow gas development on birds in Clear Creek State Forest, located in northwestern Pennsylvania. He found that both species richness and Shannon’s diversity index were higher for well sites than control sites as species that used smaller openings were more abundant at well sites (Hartzler 1999).

McGunegle (2009) investigated the effects of shallow oil and gas well development on breeding birds in the Allegheny National Forest using data from the 1st Pennsylvania Breeding Bird Atlas. Results showed over 42 % of the variability in total edge could be attributed to oil and gas development. However, McGunegle (2009) found no significant relationship between oil and gas development and abundance of birds within avian guilds. She concluded that the large scale and short time period of the study may not have allowed her to detect any significant effect. Bird responses to habitat changes may take a number of years or even decades before a noticeable response can be detected (McGarigal and Cushman 2002).

Research in the Allegheny National Forest focused on how shallow well oil and gas development affects songbird abundance. Findings at a local scale, within 100 m of a well pad, showed a higher abundance of closed canopy nesters at sites with no well pads and an increase in abundance of small-gap nesters and understory nesters at well sites (Thomas 2011). At the landscape scale, which was defined as a 25 hectare block, Yellow-bellied Sapsucker and Chipping Sparrow abundance increased with increasing well density. Red-eyed Vireo abundance was lower with increasing well density. These results again illustrate the point that the effect of a new edge created by oil and gas development will depend on the species and whether the edge provides additional resources. An interesting result was that at both the well site scale and the 25-ha scale, avian communities differed between northern hardwood and oak forests on reference sites with no wells, but at high well densities bird communities were not significantly different (Thomas et al., In Press). This suggests that the species responding positively to the new edge habitat were similar between the two forest types. This process has been termed biotic homogenization and is often associated with human-related disturbances (McKinney and Lockwood 1999).

Most of the studies on natural gas impacts to forest songbirds have occurred in the boreal forests of Alberta, Canada. Machtans (2006) and Villard et al. (2007) both found little effect of gas-related edge habitat on forest songbirds. In Wyoming, roads associated with natural gas development had a negative impact on sagebrush obligate passerines within 100 m of a road (Ingelfinger and Anderson 2004). A study in the Upper Green River Basin of Wyoming found that increasing well density was associated with significant decreases in Sage Sparrow *(Amphispiza belli)* and Brewer’s Sparrow *(Spizella breweri)* abundance (Gilbert and Chalfoun 2011). However, Horned Lark *(Eremophila gramineus)* had a positive response to increasing well density and Sage Thrashers *(Oreoscoptes montanus)* showed no response. Results indicated that regional declines in some sagebrush obligate songbird species may be intensified by increased energy development (Gilbert and Chalfoun 2011).

However, studies from the western United States and Canada are not directly comparable to that of the eastern United States. The prairies and forests of the west are comprised of very different ecosystems than that of the eastern United States, thus the effect of fragmentation on avian species will also differ (Sisk and Battin 2002). Studies from western Pennsylvania are also not directly comparable due to the different footprints left by shallow gas extraction versus Marcellus shale gas extraction.

Effect of Shale Development on Forest Habitat

In addition to new well pads, as Marcellus shale development occurs within a block there are additional and expanded roads and pipelines which in combination with the pads reduces the amount of core forest and forest cover (Figure 1, Figure 2). Well pads, pipelines, gathering lines, and the widening of roads are the most significant contributors to the changes in forest habitat. Other infrastructure such as parking areas and compressor stations contribute less to the overall changes in habitat.

Much of the accompanying infrastructure (e.g. pipelines, gathering lines) are placed along roads. Additionally, roads are enlarged to accommodate the large volume of traffic and heavy machinery needed to extract natural gas. Due to the enlargement of roads and creation of infrastructure, the forest habitat surrounding the roads is being altered or lost (Figure 3, Figure 4).

Research Objectives

We looked at the initial effects of shale gas development on forest bird populations at two temporal scales using the recently completed statewide 2nd Pennsylvania Breeding Bird Atlas (PBBA) as a sampling framework (Wilson et al. 2012). For our first temporal scale, we conducted a Before-After Control-Impact analysis comparing the abundance of individual species and of species guilds in PBBA blocks where shale development has occurred within the past three years (impact) and in PBBA blocks where shale gas development has not occurred (control). In addition, we quantified the number of pads per block and the change in forest habitat for blocks where development occurred. At a second temporal scale, we conducted a gradient analysis, comparing current bird abundance across forested blocks with differing levels of shale gas development. To understand how shale gas development affected forest birds, we investigated the relationship between Marcellus shale gas development and changes in total forest cover and core forest cover.

METHODS

2nd Pennsylvania Breeding Bird Atlas

The PBBA was a comprehensive, statewide survey that documented the occurrence and distribution of breeding birds in Pennsylvania. It was conducted from 2004 to 2008. For the atlas protocol, Pennsylvania was divided into 4,937 individual blocks that each measured ~ 24.92 square km (2488.9 ha). The "block" is the basic survey unit defined by the North American Ornithological Atlas Committee and is defined as one-sixth of a standard U.S. Geological Survey (USGS) 75-minute topographic map (Robbins and Geissler 1990, Brauning 1992). As a component of the PBBA, highly skilled field ornithologists conducted roadside point counts throughout Pennsylvania, with the goal of quantifying bird abundances throughout the state

(Wilson et al. 2012). During the PBBA, most blocks had eight point counts completed within each block. The atlas was concluded prior to any significant Marcellus shale associated development. Thus, bird abundance collected during the atlas can act as a baseline for our study. The roadside bird surveys will be discussed in more detail in the avian sampling section.

Study Design

We implemented a Before-After Control-Impact (BACI) study design (McDonald et al. 2000) to determine the initial effects of Marcellus development on birds. Before-After Control-Impact study designs help to control for environmental changes that affect all sites and the variation between sites. Data from the PBBA, which ran from 2004-2008, served as the before data. We collected data at impact and control blocks throughout our study area in the 2011 and 2012 breeding bird seasons, which served as the after data. Control blocks were blocks where no Marcellus development had occurred. Impact blocks were blocks that had at least one well pad and associated infrastructure. The number of well pads per block ranged from 1 to 16 during the 2011 and 2012 field seasons.

For the gradient analysis, we compared bird abundance during the 2011-2012 breeding bird season across forested blocks with differing levels of Marcellus shale development, utilizing the same eight county study region. Blocks were surveyed to examine the relationship between Marcellus shale development and individual bird species and habitat guild abundances. We investigated the relationship between Marcellus shale development and current levels of forest cover and core forest throughout the landscape. Core forest was defined as the area of forest at least 100 m away from the forest edge (Brooks et al. 2009, Drohan et al. 2012).

Study Area

The Marcellus shale gas reservoir encompasses most of Pennsylvania except the south-east region and a portion of the central region of the state (Figure 5). However, gas deposits are not distributed uniformly and therefore neither is Marcellus shale gas development (Harper 2008). Exploration of the Marcellus shale is concentrated in the south-west and north-central portions of the state. This study was conducted throughout Bradford, Centre, Clearfield, Clinton, Lycoming, Sullivan, Tioga, and Potter counties because they represent areas with large amounts of forest cover as well as high levels of Marcellus shale gas development. At the time of this study, most of the Marcellus related development occurred within Bradford, Tioga, and Lycoming counties (Figure 6). As of November 2012, Pennsylvania Department of Environmental Protection reported that there were 4,326 unconventional well permits in the eight county study region. Bradford County had the most permits per county with 1,835 followed by Tioga County with 861 permits, and Lycoming County with 827 permits.

This area is located within the north central Appalachians ecoregion (US EPA 2007) which has a moderate to humid climate with dense and diverse forest cover (USFS 1994). The climate can be characterized as having cool summers and cold winters. Average annual precipitation ranges from 83.8 to 127 cm per year (Woods et al. 1999).

The vegetation type is predominately northern hardwoods, which consists primarily of sugar maple (*Acer saccharum*), red maple (*A. rubrum*), white ash (*Fraxinus americana*), American beech (*Fagus grandifolia*), northern red oak (*Quercus rubra*), black cherry (*Prunus serotina*), and eastern hemlock (*Tsuga canadensis*). However, Appalachian Oak forests are still present throughout the region, consisting mainly of northern red oak and white oak *(Q. alba)* (Woods et al. 1999).

PBBA Block Selection and Description

Blocks and well location data used in our study were spatially represented in ArcMap 10.1 (ArcMap; Environmental Systems Research Institute, Redlands, CA). Well location data obtained from the Pennsylvania Department of Environmental Protection from 2011 and 2012 were combined with 2010 aerial imagery from the National Agriculture Imagery Program (NAIP) to view well pad locations and forest cover. We then used the PBBA block grid layer to look at well pad locations and forest cover within a block. The eight country study region contained 910 PBBA blocks. We focused our non-random block selection on blocks that were impacted by Marcellus shale development. Road access and development intensity were the two main considerations when selecting blocks. To narrow the selection down to mostly forested blocks, we first located blocks with at least 50% forest cover. We then used the number of well pads per block to choose blocks that represented varying levels of Marcellus shale gas development. As Marcellus shale development occurred in most blocks with road access, control blocks were chosen wherever they could be found.

Selected blocks were ~25 square kilometers or 2,500 hectares in size (Figure 7). They had varying levels of well pad density (0.00-0.64 pads/km^2) and number of well pads per block (0-16) (Appendix B). In the gradient analysis, a total of 36 blocks were used because only 36 blocks had five or more point counts per block. Out of the 36 blocks, 29 were treatment blocks and 7 were reference blocks. In the BACI analysis, 37 blocks were used, 30 impacted blocks and 7 controls (Appendix B). We recorded the number of well pads within each block and used this to classify Marcellus development within a block.

Effects of Shale Development on Forest Habitat

We measured the change in forest habitat and core forest by comparing the change in percent forest cover and core forest to pre-Marcellus shale development percentages (Appendix B). Pre-Marcellus data used 2005 land cover data and after data were calculated with only well pads (not pipelines, compressors, etc.) used to calculate core forest and forest cover within PBBA blocks. Core forest was defined as the area of forest at least 100 m away from the forest edge (Brooks et al. 2009, Drohan et al. 2012). Forest cover was defined as the amount of forest habitat (%) within a block.

Well permit location data from Carnegie Museum of Natural History's Pennsylvania Unconventional Natural Gas Wells Geodatabase was used to locate well pads (Whitacre 2013). If well permits were clustered they were assumed to be one well pad, as several wells can be drilled per pad. We used an average well pad size of 1.8 ± 0.3 ha to represent the amount of disturbance caused by an individual well pad. Average well pad size was calculated from 17 well pads that were measured in the field prior to the start of this research. We used average well pad size because many of the pads occur on private land, which made it impossible to accurately measure a well pad in the field. Furthermore, as Marcellus shale development is such a rapid process, aerial photography was not current enough to be used to calculate well pad size. Since we measured amount of forest loss by using well pads only, the actual amount of core forest and forest cover lost is an underestimate of that total change in forest habitat.

Expanded roads, pipelines, pads, and other infrastructure causes local habitat changes around point count stations, causing forest loss and changes in habitat to occur. To quantify these local changes, we recorded whether any Marcellus infrastructure (expanded roads, pipelines, pads, etc.) was present with 75 m of each point. As the number of well pads in a block increases, so does the amount of accompanying infrastructure. Therefore, as development in a block increases, it is likely that the proportion of points that experience changes in forest habitat will increase. To look at the relationship between the amount of points impacted and well pads per block, we looked at the relationship between the percentage of points with shale gas development within 75 m of a point and the number of well pads per block.

Avian Sampling

We used the same methodology employed during the PBBA, so that results could be directly compared to previous surveys. During the PBBA, a road-based random sampling design was carried out to survey the almost 5,000 blocks that were present within Pennsylvania (Wilson et al. 2012). Point counts were conducted at eight locations per block during the PBBA, with points being separated by at least 400 m. Within our selected blocks, we attempted to repeat each point conducted during the PBBA. Counts were 6 minutes 15 seconds and comprised of five 75 second time bands. These time bands account for species that sing more frequently versus species that sing less frequently. However, we did not utilize the time bands in our analysis, but we kept them in order to keep our methods comparable to the PBBA methodology. Birds were classified as being within or outside 75 meters and whether they were singing, using a non-song vocalization, flying over, or in a flock. Only data on singing males within 75 m were used for these analyses.

Point counts were conducted once at each point from mid-May until the second week in July. Within each block we completed at least five points, with 19 blocks having at least eight points completed per block (Appendix B). In 2011 all points received one visit, however during 2012, 87% of blocks that received a first visit also received a second visit, in attempts to obtain the most accurate estimate of singing males at each point and allow birds a chance to respond to shale gas development. To maximize detections, we did not conduct surveys on days with high winds or rain. We also did not conduct surveys along busy roads or in areas with loud noise due to gas exploration. All point counts were conducted from 0530 to 1030, which is when birds sing most frequently. Furthermore, all observers were trained and competent in detecting all birds that may be encountered. In the 2012 field season, two observers conducted point counts. However, one observer completed all points once with repeated visits being conducted by both observers.

Avian Guilds

We used guilds or groups of birds to determine any broad ecological effects (Holmes et al. 1979, Roberts 1987) because our concerns about the effect of Marcellus shale development on birds was for songbird populations more so than any single species and because the abundance of any single species is generally too low to statistically detect effects. Guilds are created by grouping species that use similar resources in similar ways (Root 1967). Guilds for birds are often based on habitat preference or feeding habits (Holmes et al. 1979). To determine the effects of landscape changes caused by Marcellus shale development on songbirds in north-central Pennsylvania, we created three habitat guilds. We chose habitat guilds because Marcellus shale development impacts habitat structure, thus potentially altering suitability for different species.

The three guilds used were synanthropic species, early successional species, and forest interior species (Appendix C). *Synanthropic species* are defined as species that benefit from anthropogenic resources and land actions (Leu et al. 2008, Johnston 2001). The birds included within this guild have differing relationships to humans from almost obligatory to just a slightly advantageous relationship. The *synanthropic species* included species that are associated with human-caused disturbances (e.g. Brown-headed Cowbird, Blue Jay), human resources, and human development (e.g. European Starling) (Marzluff 2005, Hepinstall 2008). The *early successional* guild included species that depend more on early successional forests (e.g. Chestnut-sided Warbler) than edge habitat. The *forest interior* guild included species that prefer undisturbed, contiguous, mature forest habitat (e.g. Black-throated Green Warbler). Classifications were based on habitat information included in the Birds of North America species accounts (Poole 2005) and personal in-field observations. The PBBA was also used as a guide for classifying birds within guilds (Wilson et al. 2012).

STATISTICAL ANALYSIS

Before-After Control-Impact

We investigated the effect of Marcellus shale development on all three species habitat guilds. The *lmer* function from the *lme4* package in R was used to analyze these data (Bates and Maechler 2012). We used mixed-effects models to conduct repeated measures ANOVAs on the data collected at the point level for habitat guild detections. The points were located within 7 control and 30 treatment (impact) blocks (n =37). The models included time and treatment effects, a fixed time by treatment interaction effect, a random block effect, and a random point within block error effect. The random block and random point within block error effects allowed for us to account for repeated samples within sites and repeated measures over time, thus avoiding pseudoreplication. The interaction effect tests for an effect of well pads being placed on the landscape. The interaction effect examines how the control and treatment blocks changed (McDonald et al. 2000) between pre-Marcellus conditions and after Marcellus development. For all of the models in the BACI analysis, we used a Poisson distribution since the data were left skewed and with many zero counts. The number of detections in the BACI analysis represents the count of birds per point. Well pad density represents the treatment. We also used linear regression to investigate the relationship between the number of well pads per block and the changes in core forest and forest cover. We used statistical programs R (R Statistical Computing Software, Vienna, Austria) and Minitab (Minitab Statistical Software 2010).

Gradient Analysis

We compared amounts of core forest, forest cover, well pads, and the relative abundances of individual species and habitat guilds using linear regression. When examining the relationship between Marcellus shale development, forested habitat, and individual species and guild abundances, relative abundance was used as the response variable while core forest, forest cover, and well pads were used as predictors. Relative abundance was calculated by using the mean number of the maximum birds per point per block. Core forest was the percent of core forest per PBBA block and well pads were the number of well pads per PBBA block. When examining how well pads affected levels of core forest and forest cover, well pads were used as a predictor, while the core forest and forest cover were used as a response variables. We considered results significant at $\alpha = 0.05$ for all analyses at the block level. Only species detected in 50% or more of the blocks were analyzed (n =37). However, in our guild analysis the 50% cutoff did not apply, as we summed the individual counts of each species into one guild count. In blocks that were surveyed in both years we used the second year results, as the birds had one more year to respond to gas development. At points that received two visits during one field season, we used the maximum individuals detected during either visit. We used Minitab version 16 to analyze the block level data.

RESULTS

Bird Community

We observed a total of 124 bird species throughout this study. One hundred five species were observed in 2011, and 119 species were recorded in 2012. The average number of individuals per point in 2011 and 2012 was 12.81 and 12.65, respectively. Throughout the study, the average number of synanthropic birds per point was 3.00, the average number of forest interior birds per point was 5.36, and the average number of early successional birds per point was 2.24. The most common species observed were Red-eyed Vireo, Common Yellowthroat, and Ovenbird. During the 2011 field season, we completed 368 points in a total of 36 blocks. In 2012, we completed 471 point counts in 30 blocks. Out of the 126 species detected throughout our study only 37 species were detected in greater than 50% of the blocks and were included in the individual species analysis.

Effects of Shale Development on Forest Habitat

Only 24 point count stations out of 839 total stations had a well pad within 75 m of the point. While well pads did not always directly change the habitat surrounding points, the infrastructure associated with well pads changed the habitat within 75 m of the point at 30% of the point count stations. As the amount of well pads per block increased, so did the number of points that had shale gas development within 75 m of the point (Figure 8).

The change in the amount of forest cover (%) from pre-Marcellus to current forest conditions had a significant positive relationship with increasing levels of well pads per block (F = 14.0, p= 0.001, Figure 9). Core forest declined with increasing numbers of well pads per block (F = 12.00, p = 0.001, Figure 10).

Before-After Control-Impact

The synanthropic species guild showed a positive interaction between time and treatment for an effect of Marcellus shale development on the number of detections (Table 1, Figure 11). The forest interior species guild (Figure 12) and the early successional species guild (Figure 13) did not show a significant interaction effect, indicating that the number of detections was not significantly affected by Marcellus shale development (Table 1). Thirty-four species were detected in greater than 50 % of the blocks and were included in the individual species analysis (Appendix E). Scarlet Tanager had a significant negative interaction effect, with the number of detections lower in blocks with development, while Cedar Waxwing, Common Yellowthroat, and Chestnut-sided Warbler exhibited positive interaction effects with higher numbers in blocks with development (Appendix E). Eight out of the 13 forest interior species analyzed also showed a lower number of detections in blocks with shale gas development; however they were not statistically significant. The number of detections of 29 species did not differ with development (Appendix E).

Gradient Analysis

Percent of forest cover had a significant negative relationship with increasing levels of well pads per block ($F = 11.6$, $p = 0.002$, Figure 14). We found a significant negative relationship between current levels of core forest and well pads per block ($F = 16.7$, $p < 0.001$, Figure 15). Out of the thirty-seven species that had enough observations to be analyzed individually, we found that nine bird species had a significant positive relationship with core forest and two species had a negative relationship with increasing amounts of core forest (Appendix F).

Only one guild had a significant relationship with well pads. Synanthropic species had a significant positive relationship with well pads ($F = 7.1$, $p = 0.01$, Figure 16). The relative abundance of individuals with the early successional species guild did not have a significant relationship with Marcellus shale development ($F = 0.8$, $p = 0.4$). The forest interior species guild did not have a significant relationship with well pads, however, a weak negative trend could be seen ($F = 3.0$, $p = 0.1$, Figure 17).

Two species had a positive relationship between relative abundance with the number of well pads per block, while no species exhibited a significant negative relationship to the number of well pads per block (Appendix G). Chipping Sparrow ($F = 18.01$, $p < 0.001$) and Common Yellowthroat ($F = 5.61$, $p = 0.02$) both exhibited a positive relationship with increasing levels of Marcellus shale development, while Veery showed a negative relationship to Marcellus shale development ($F = 4.81$, $p = 0.04$)

DISCUSSION

Core forest and forest cover levels- Our study looked at the initial changes in forest habitat from Marcellus shale development and the response of birds to these changes. As the number of well pads increased in a block the amount of forest cover and core forest decreased, indicating that the type of habitat shifted and became more fragmented. Because most of the study blocks had high amounts of forest cover, the development of well pads, pipelines, and other Marcellus shale infrastructure would undoubtedly cause some forest loss. These changes in core forest and forest cover have caused changes in songbird abundance and bird community structure. The most notable change was the increase in detections of synanthropic bird species. Forest-interior species exhibited a weak negative relationship to Marcellus shale development, indicating that these species may be negatively affected by forest loss caused by the creation of Marcellus shale infrastructure.

Effects of Shale Development on Forest Habitat– Due to the large block size and low pad density in many blocks, most of our roadside point counts were not near well pads. Instead the changes we detected were probably associated with changes in the road width and pipeline development. Since the proportion of points with shale gas development within 75 m increased with well pads, well pads act as a proxy for overall development.

Synanthropic species guild- Marcellus related infrastructure typically creates open edge habitat, which may provide foraging and nesting opportunities for some generalist species. As pipelines, gathering lines, pads, and other Marcellus related infrastructure increases, open edge habitat is created. Most bird species included in the synanthropic species guild can be considered forest generalists (O'Connell et al. 1998).

This guild exhibited a strong, positive response to Marcellus shale development in the before-after control-impact study. This guild exhibited a significant positive relationship to Marcellus shale development in the gradient analysis. Pipelines and gathering lines may fit the habitat requirements of some generalist species. Fleming and Schmiegelow (2003) found that generalist species such as American Robin and Chipping Sparrow are more likely to be found on or near wide linear features. Pads, compressor stations, and other non-linear development features may be utilized by these species as well. Manmade structures may provide nesting sites for European Starling, Eastern Phoebe, and American Robin. A study in the Green Mountain National Forest found that American Robin and Cedar Waxwing were more abundant near roads than in the forest interior (Ortega and Capen 2002). Some pipelines, gathering lines, and seismic testing lines may serve as narrow openings through forested habitat

Pipelines may serve as foraging areas for many of the species within this guild including American Robin, Chipping Sparrow, and American Goldfinch. Man-made structures associated with Marcellus development, such as compressor stations, bridges, and even well heads, may provide nesting sites for Eastern Phoebe and American Robin. Other synanthropic bird species such as House Sparrow, Rock Pigeon, and European Starling may also benefit, as some buildings associated with Marcellus gas exploration may provide suitable nesting areas. As Marcellus shale gas exploration increases, habitat shifts will continue to occur, which will benefit habitat generalists and partial human obligates.

Forest interior species guild- We found no time by treatment interaction for this guild, indicating Marcellus shale development has not had a detectable effect on the forest interior species in the initial years of shale gas development. Within in the forest interior guild, twelve species had enough observations to be analyzed individually in the BACI framework. Nine species showed a decrease in detections from before Marcellus shale development; however only Scarlet Tanager was statistically significant. This is of particular concern as Pennsylvania is home to approximately 17% of the worldwide breeding population of Scarlet Tanagers (Rosenberg and Wells 1995).

Out of the 13 forest interior species that were individually analyzed in the BACI framework, 62% of the species showed a decrease in the number of detections in blocks with shale gas development but were not statistically significant. At $\alpha = 0.10$, 31% of the forest interior species would have been considered statistically significant. The general trend in the decrease of detections of forest interior songbirds in blocks with shale gas development shows that these birds are responding negatively to shale gas development. While not statistically significant, this suggests further declines may occur. For instance, Magnolia Warbler detections decreased by 8.34 detections per block, a large decrease, however the effect was not statistically significant at $\alpha = 0.05$.

The forest interior species guild showed a weak negative relationship to Marcellus shale development in the gradient analysis. A variety of factors could explain why either no response or a weak response was seen in the forest interior species guild to Marcellus shale gas exploration. While Marcellus shale development has certainly fragmented some of the forested landscape, percent forest cover remained high in our study blocks. Studies from southern Quebec and southern Ontario also found that forest cover has more of an effect than forest fragmentation in relation to bird distribution on the landscape (Trzcinski et al. 1999). While Marcellus shale gas exploration does decrease forest cover, our study only had two blocks that were under 70 percent forest cover.

Our points were located along pre-existing roadways and by definition edge habitat. Due to the many well pads that went into core forest habitat, our survey methodology may underestimate both the abundance of forest interior species within the block and also the effect of development on these species. A more accurate representation would focus on core forest but unfortunately the use of roadside surveys is not compatible with this. Betts et al. (2007) compared the amount of mature forest within 150 m of Breeding Bird Survey (BBS) routes to the amount of mature forest in surrounding 1° blocks of latitude and longitude from 1974 to 2001. They found that forest loss was more rapid in blocks than along the BBS routes from 1974 to 1985, however in the 1985 to 2001 time period, the rate of change in forest loss along the BBS routes were representative of the rate of change in the degree blocks. Breeding Bird Survey (BBS) data on Blackburnian Warbler abundance showed a decline corresponding to loss in mature forest habitat from 1985 to 2001, but not from 1974 to 1985. This is likely due to the forest loss along BBS routes not accurately representing the total amount of forest loss during the

1985-2001 time period. This indicates that the decline during the 1974 to 1985 time period was underestimated because of the survey's roadside sampling bias (Betts et al. 2007).

As development increases and there is more time between the initial disturbance, some forest interior bird species may show negative responses to Marcellus shale development. Some forest-interior species may exhibit "edge avoidance", a negative reaction, which is possibly caused by decreased nest success, decreased suitable habitat, and increased numbers of conspecifics (Bollinger and Switzer 2002). As fragmentation increases, there is less core forest, which increases the amount of edge in turn creating more possible areas where birds can exhibit edge avoidance.

Early successional species guild- We initially predicted that we would see increases in this guild due to early successional habitat being created by Marcellus shale development. However, we found no detectable response of this species to Marcellus shale development, which is not surprising given the lack of early successional habitat created by shale gas exploration.

Marcellus shale development is often associated with abrupt transitions from forest to pipeline or pad habitat, which is typically grass or stone. This is typically defined as a "hard edge". Pipelines and gathering lines must be devoid of most ground penetrating roots, resulting in non-habitat for early successional species such as Field Sparrow. Yahner (2008) suggested that keeping some habitat structure on developed areas could improve the value of the habitat for early successional bird species.As Marcellus shale gas exploration is rather new to the region, vegetation may not have had time to meet early successional species requirements.

The creation of openings, particularly on the periphery of pads and pipelines, through Marcellus shale exploration may result in habitat for early successional bird species. Openings allow the forest to receive more light, providing new opportunities for plant growth (Murcia 1995). Additionally, the potential for regeneration on these sites may be limited due to current legislation and industry reclamation methods. Several practices limit the amount of regeneration, including seeding of grass to limit erosion, the removal of nutrients due to the total removal of understory plants, and soil compaction (Bayne and Dale 2011).

While early successional habitat is important, the amount of forest surrounding the early successional habitat may also be important. Some early successional bird species may depend on small canopy gaps within the forest rather than large tracts of early successional habitat (Hunter et al. 2001). Species such as Golden-winged Warbler depend on early successional habitat within forested landscape (Bakermans et al. 2011).While understory cuts from seismic testing may serve as a suitable alternative to more natural occurrences, the large pipelines and gathering lines may not be suitable for early successional species.

Conclusions

We found changes in bird communities within north-central Pennsylvania due to Marcellus shale gas development. The synanthropic species guild appears to show the strongest increase in abundance to Marcellus shale development. The synanthropic species guild and forest interior species guild both showed a response to Marcellus shale development at the block level. The synanthropic associated species guild seemed to benefit from Marcellus shale development by taking advantage of a change in habitat due to forest loss associated with shale gas development. The early successional species guild showed no response in abundance related to Marcellus shale development in the BACI analysis. This is probably due to the lack of early successional habitat being created by Marcellus shale infrastructure. The forest interior species exhibited a weak negative relationship between Marcellus development and forest bird guild abundance in the gradient analysis. This guild may be slower to react to changes in changes in the levels of core forest and forest cover at the landscape level or we have not yet reached levels of development that would allow us to notice a detectable change in abundance.

Before-after control-impact studies should probably have a longer time span from before to after conditions, which would give bird communities time to respond to changes in the landscape. Our study had a span of approximately three years from before conditions to after conditions. Changes in vegetation structure may not yet be apparent, especially in slow growing trees and shrubs. This also may not be enough time for bird species to respond to changes in habitat at such large spatial scales. Forest birds in particular may take a long time to respond to changes in forest cover, especially when levels of forest cover are relatively high. Many landscape scale studies may exhibit a time lag effect (Schmiegelow et al. 1997).

There was a significant loss of core forest with increasing levels of Marcellus shale development. As core forest is lost, species that showed significant relationships to core forest would be predicted to exhibit a negative response to Marcellus shale development. Species that had a negative relationship with core forest would likely see increases as Marcellus shale gas exploration increases, depending on what type of habitat is created.

Given expectations of development, we predict in the next 30 years to see synanthropic bird species increase throughout the region while forest interior bird species will show a stronger negative effect of Marcellus shale development. Until early successional habitat is created using different development practices or reclamation, we will most likely not see positive responses from early successional bird species. To reduce potentially negative effects of Marcellus shale development on forest birds, development should be focused on open habitats or areas with prior disturbances. The creation of soft edges and the planting of early successional habitat around pad and pipeline edges could be used to benefit early successional bird species.

LITERATURE CITED

Askins, R. A. 1994. Open corridors in a heavily forested landscape: impact on shrubland and forest-interior birds. Wildlife Society Bulletin 22:339-347.

Bakermans, M. H., J. L. Larkin, B. W. Smith, T. M. Fearer, and B. C. Jones. 2011. Golden-winged Warbler habitat best management practices for forestlands in Maryland and Pennsylvania. American Bird Conservancy, The Plains, VA, USA. pp 26.

Bates, D. and M. Maechler. 2012. lme4: Linear mixed-effects models using S4 classes. R package version 0.999999-0. http://lme4.r-forge.r-project.org/.

Bayne, E. M., and B. C. Dale. 2011. Effects of energy development on songbirds. In Energy Development and Wildlife Conservation in Western North America (D. E. Naugle, Editor). Island Press, Washington, DC, USA.

Betts, M. G., D. Mitchell, A. W. Diamond, and J. Bêty. 2007. Uneven rates of landscape change as a source of bias in roadside wildlife surveys. Journal of Wildlife Management 71:2266-2273.

Bollinger, E. K., and P. V. Switzer. 2002. Modeling the impact of edge avoidance on avian nest densities in habitat fragments. Ecological Applications 12: 1567-1575.

Brauning, D. W. 1992. Atlas of Breeding Birds of Pennsylvania. Pittsburgh University Press, Pittsburgh, PA, USA.

Brooks, R., M. McKenney-Easterling, M. Brinson, R. Rheinhardt, K. Havens, D. O’Brien, J. Bishop, J. Rubbo, B. Armstrong, and J. Hite. 2009. A Stream–Wetland–Riparian (SWR) index for assessing condition of aquatic ecosystems in small watersheds along the Atlantic slope of the eastern U.S. Environmental Monitoring and Assessment 150:101-117.

Chalfoun, A. D., F. R. Thompson III, and M. J. Ratnaswamy. 2002. Nest predators and fragmentation: a review and meta-analysis. Conservation Biology 16:8-19.

Drohan, P. J., M. Brittingham, J. Bishop, and K. Yoder. 2012. Early trends in landcover change and forest fragmentation due to shale-gas development in Pennsylvania: A potential outcome for the northcentral Appalachians. Environmental Management 49:1061-1075.

Energy Information Administration [EIA]. 1993. Drilling sideways: A review of horizontal well technology and its domestic application <http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/drilling_sideways_well_technology/pdf/tr0565.pdf>.

Faaborg, J., M. Brittingham, T. Donovan, and J. Blake. 1995. Habitat fragmentation in the temperate zone. In Ecology and Management of Neotropical Migratory Birds (T. E. Marin and D. M. Finch, Editors). Oxford University Press, New York, NY, USA.

Falk, K. J., E. Nol, and D. M. Burke. 2011. Weak effect of edges on avian nesting success in fragmented and forested landscapes in Ontario, Canada. Landscape Ecology 26:239-251.

Fleming, W. D., and F. K. A. Schmiegelow. 2003. Response of bird communities to pipeline rights-of-way in the boreal forest of Alberta. In The Seventh International Symposium on Environmental Concerns in Rights-of-Way Management. Calgary, Alberta, Canada.

Fraser, G. S., and B. J. M. Stutchbury. 2004. Area-sensitive birds move extensively among forest patches. Biological Conservation 118:377-387.

Gilbert, M. M., and A. D. Chalfoun. 2011. Energy development affects populations of sagebrush songbirds in Wyoming. Journal of Wildlife Management 75:816-824.

Goodrich, L. J., M. C. Brittingham, J. A. Bishop, and P. Barber. 2002. Wildlife habitat in Pennsylvania: past, present, and future. Pennsylvania Department of Conservation and Natural Resources.<http://www.fish.state.pa.us/promo/grants/swg/nongame_plan/

pa_wap_sections/appx2habitat_pt2.pdf>.

Harper, J.A. 2008. The Marcellus Shale-An Old “New” Gas Reservoir in Pennsylvania. Pennsylvania Geology 38:2-12.

Hartzler, I. C. 1999. Effects of pipeline corridors and well clearings on avian species composition and diversity in a forested landscape. Master’s Thesis, Clarion University, Clarion, PA, USA.

Hepinstall, J. A., M. Alberti, and J. M. Marzluff. 2008. Predicting land cover change and avian community responses in rapidly urbanizing environments. Landscape Ecology 23:1257-1276.

Holmes, R. T., R. E. Bonney, Jr., and S. W. Pacala. 1979. Guild structure of the Hubbard Brook bird community: a multivariate approach. Ecology 60:512-520.

Hunter, W. C., D. A. Buehler, R. A. Canterbury, J. L. Confer, and P. B. Hamel. 2001 Conservation of disturbance-dependent birds in eastern North America. Wildlife Society Bulletin 29:440-455.

Ingelfinger, F., and S. Anderson. and 2004. Passerine response to roads associated with natural gas extraction in a sagebrush steppe habitat. Western North American Naturalist 64:385-395.

Johnson, N. 2010. Pennsylvania Energy Impacts Assessment. The Nature Conservancy-Pennsylvania Chapter, Harrisburg, PA, USA.

Johnston, R. F. 2001. Synanthropic birds of North America. In Avian Ecology and Conservation in an Urbanizing World, (J. M. Marzluff, R. Bowman, and R. Donnelly, Editors). Kluwer Academic, Boston, MA, USA.

Leu, M., S. H. Hanser, and S. T. Knick. 2008. The human footprint in the West: A large-scale analysis of anthropogenic impacts. Ecological Applications 18:1119-1139.

Lloyd, P., T. E. Martin, R. L. Redmond, U. Langer, and M. M. Hart. 2005. Linking demographic effects of habitat fragmentation across landscapes to continental source-sink dynamics. Ecological Applications 15:1504-1514.

Machtans, C.S. 2006. Songbird response to seismic lines in the western boreal forest: a manipulative experiment. Canadian Journal of Zoology 84:1421-1430.

Marzluff J.M. 2005. Island biogeography for an urbanizing world: how extinction and colonization may determine biological diversity in human-dominated landscapes. Urban Ecosystems 8:157–177.

McDonald, T. L., W. P. Erickson, and L. L. McDonald. 2000. Analysis of count data from before-after control-impact studies. Journal of Agricultural, Biological, and Environmental Statistics 5:262-279.

McGarigal, K. and S.A. Cushman. 2002. Comparative evaluation of experimental approaches to the study of habitat fragmentation effects. Ecological Applications 12:335- 345.

McGunegle, M. L. 2009. The effects of oil and gas development on forest fragmentation and breeding bird populations in the Allegheny National Forest. Master's Thesis, The Pennsylvania State University, University Park, PA, USA.

McKinney, M. L., and J. L. Lockwood. 1999. Biotic homogenization: a few winners replacing many losers in the next mass extinction. Trends in Ecology and Evolution 14:450-453.

Minitab 16 Statistical Software. 2010. Minitab, Inc. State College, PA, USA.

Murcia, C. 1995. Edge effects in fragmented forests: implications for conservation. Trends in Ecology and Evolution 10:58-62.

O'Connell, T. J., L. E. Jackson, and R. P. Brooks. 1998. A bird community index: a tool for assessing biotic integrity for the Mid-Atlantic Highlands. Report No. 98-4 of the Penn State Cooperative Wetlands Center, The Pennsylvania State University, University Park, PA, USA.

Ortega, Y. K., and D. E. Capen. 2002. Roads as edges: effects on birds in forested landscapes.

Forest Science 48: 381-390.

Pennsylvania Game Commission and Pennsylvania Fish and Boat Commission. 2005. Pennsylvania Comprehensive Wildlife Conservation Strategy. <http://fishandboat.com /promo/grants/swg/nongame_plan/pa_wap_complete.pdf>.

Pennsylvania Department of Conservation and Natural Resources[PA DCNR]. 2004. Pennsylvania's Forest 2004. http://www.dcnr.state.pa.us/forestry/PA_Forests_2004.pdf>.

Pennsylvania Department of Environmental Protection [PA DEP]. 2010. Marcellus Shale Formation. http://www.dep.state.pa.us/dep/deputate/minres/oilgas/BOGM%20 Website%20Pictures/2010/Marcellus%20Shale%20Formation.jpg>.

Pennsylvania Department of Environmental Protection [PA DEP]. 2012. Marcellus Shale Well Inventory by County. <http://www.depreportingservices.state.pa.us/Re portServer/Pages/ReportViewer.aspx?/Oil_Gas/Operator_Well_Inventory_By_County>.

Poole, A. (Editor). 2005. The Birds of North America Online. Cornell Lab of Ornithology Ithaca, NY. <http://bna.birds.cornell.edu/BNA/>. Cornell Laboratory of Ornithology, Ithaca, NY, USA.

R Development Core Team. 2012. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0

Ries, L., R.J. Fletcher, Jr., J. Battin, and T.D. Sisk. 2004. Ecological responses to habitat edges: mechanisms, models, and variability explained. Annual Review of Ecology, Evolution, and Systematics 35:491-522.

Ries, L., and T.D. Sisk. 2004. A predictive model of edge effects. Ecology 85:2917-2926.

Robbins, C.S., D. K. Dawson, and B. A. Dowell. 1989. Habitat area requirements of breeding forest birds in the middle Atlantic states. Wildlife Monographs 103:3-34.

Robbins, C. S. and P. H. Geissler. 1990. Survey Methods and Mapping Grids. In Handbook for Atlasing North American Breeding Birds, (C. R. Smith, Editor). Vermont Institute For Natural Science, Quechee, VT, USA.

Roberts, T. H. 1987. Construction of guilds for habitat assessment. Environmental Management 11:473-477.

Robinson, S. K., R R. Thompson III, T. M. Donovan, D. R. Whitehead, and J. Faaborg. 1995. Regional forest fragmentation and the nesting success of migratory birds. Science 267:1987-1990.

Root, R. B. 1967. The niche exploitation pattern of the blue-gray gnatcatcher. Ecological Monographs 37:317-350.

Rosenberg, K.V. and J.V. Wells. 1995. Global perspectives on Neotropical migratory birds. Conservation in the Northeast: Long-term responsibility vs. immediate concern. Final report to U. S. Fish and Wildlife Service, Region-5, Hadley, MA, USA

Rosenberg, K. V., J. D. Lowe, and A. A. Dhondt. 1999. Effects of forest fragmentation on breeding tanagers: A continental perspective. Conservation Biology 13:568-583.

Rosenbery, K. V. and J. V. Wells. 2000. Global perspectives on Neotropical migratory bird conservation in the Northeast: Long-term responsibility versus immediate concern. USDA Forest Service Proceedings RMRS-P-16.

Schmiegelow, F.K.A., Machtans, C.S., and Hannon, S.J. 1997. Are boreal birds resilient to forest fragmentation? An experimental study of short-term community responses. Ecology 78:1914–1932.

Slonecker, E. T., L. E. Milheim, C. M. Silva-Roig, A. R. Malizia, D. A. Marr, and G. B. Fisher. 2012. Landscape consequences of natural gas extraction in Bradford and Washington

Counties, PA, USA. U.S. Geological Survey Open-File Report 2012–1154.

Sisk, T.D., and J. Battin. 2002. Habitat edges and avian ecology: geographic patterns and insights for western landscapes. Studies in Avian Biology 25:30-48.

Small, M. F. and M. L. Hunter. 1988. Forest fragmentation and avian predation in forested landscapes. Oecologia 76:62-64.

Thomas, E. H., M. C. Brittingham, and S. H. Stoleson. In Press. Conventiaonal oil and gas development affects forest songbirds communities. Journal of Wildlife Management.

Thomas, E. H. 2011. Effects of oil and gas development on songbird abundance in the Allegheny National Forest. Master's Thesis, The Pennsylvania State University, University Park, PA, USA.

Trzcinski, M. K., L. Fahrig, and G. Merriam. 1999. Independent effects of forest cover and fragmentation on the distribution of forest breeding birds. Ecological Applications 9:586 593.

United States Environmental Protection Agency [US EPA]. 2007. Ecoregions of North America. <http://www.epa.gov/wed/pages/ecoregion/na_eco.htm#Downloads>.

United States Forest Service [USFS]. 1994. Ecoregions of the United States. <http://www.fs.fed.us/land/pubs/ecoregions/ecoregions.html>.

Villard, M., F.K.A. Schiemgelow, and M.K. Trzcinski. 2007. Short-term response of forest birds to experimental clearcut edges. The Auk 124: 828-840.

Whitacre, J. V. *2013*. Carnegie Museum of Natural History Pennsylvania Unconventional Natural Gas Wells Geodatabase Carnegie Museum of Natural History, Pittsburgh, PA, USA. < http://www.carnegiemnh.org/science/default.aspx?id=18716 >.

Wilson, A. M., D. W. Brauning, and R. S. Mulvihill (Editors). 2012. Second Atlas of Breeding Birds in Pennsylvania. Penn State Press, University Park, PA, USA.

Woods, A.J., J.M. Omernik, and D.D. Brown. 1999. Level III and IV Ecoregions of Delaware, Maryland, Pennsylvania, and West Virginia. U.S. Environmental Protection Agency, National Health and Environmental Effects Research Laboratory, Corvallis, OR, USA.

Yahner, R. H. 2008. Bird responses to a managed forested landscape. Wilson Journal of Ornithology 120:897-900.

Table 1. Effect of Marcellus shale development on species guilds, includes estimates* and standard errors, z-value, and p-value from the year-pad interactions from the repeated measures ANOVAs for data collected at 37 Pennsylvania breeding bird atlas blocks (25 square km) during the 2011 and 2012 field seasons in north-central Pennsylvania.

Guild	**Estimate ± SE**	**Z-value**	**P-value**
Forest Interior Species Guild	-0.55 ± 0.35	-1.59	0.112
Early Successional Species Guild	0.91 ± 0.57	1.59	0.112
Synanthropic Species Guild	2.26 ± 0.52	4.30	< 0.001

*Estimate is the change in the number of detections attributed to the treatment effect

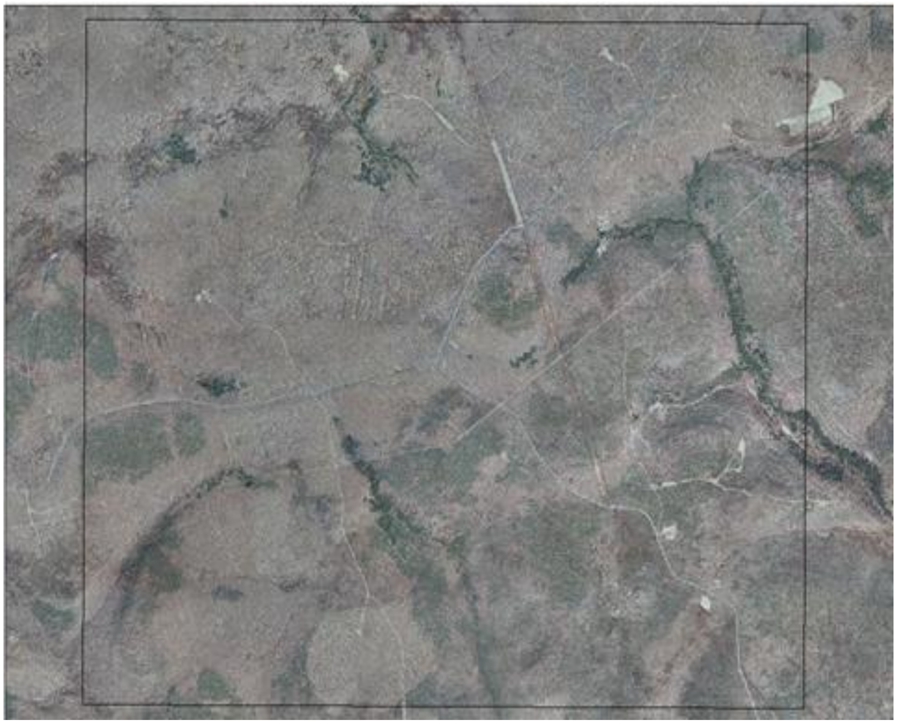

Figure 1. PBBA block, 46C45, in Clearfield County, Pennsylvania before Marcellus shale development. Pre-existing forest roads, power lines, and shallow gas well pipelines exist throughout the block.

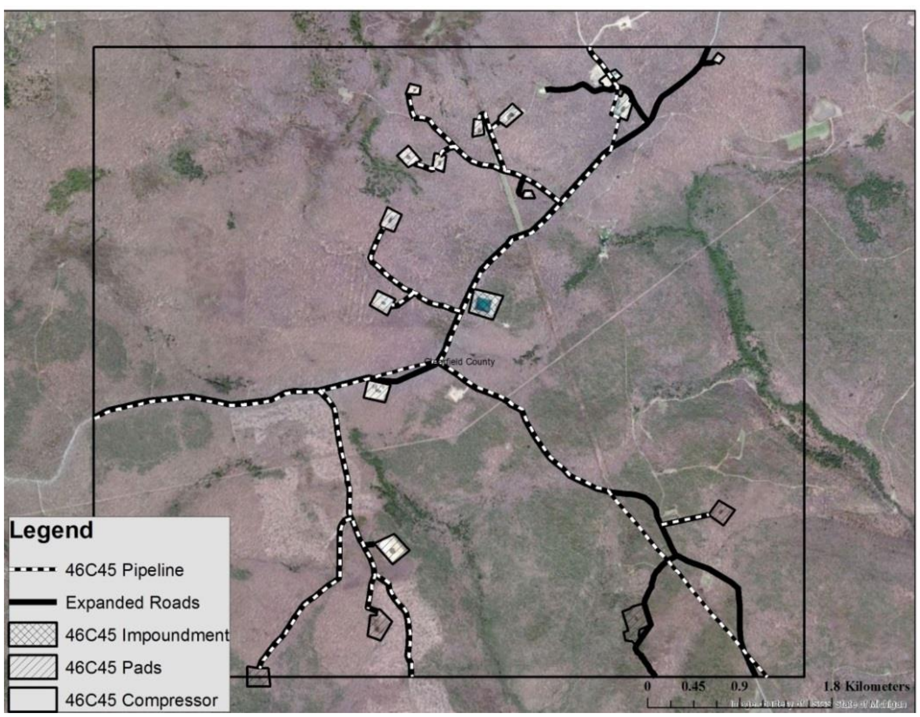

Figure 2. PBBA block, 46C45, in Clearfield County, Pennsylvania at current levels of Marcellus shale development.

Figure 3. A forest road in north-central Pennsylvania without Marcellus shale gas development.

Figure 4. A photo of an expanded forest road and pipeline in north-central Pennsylvania.

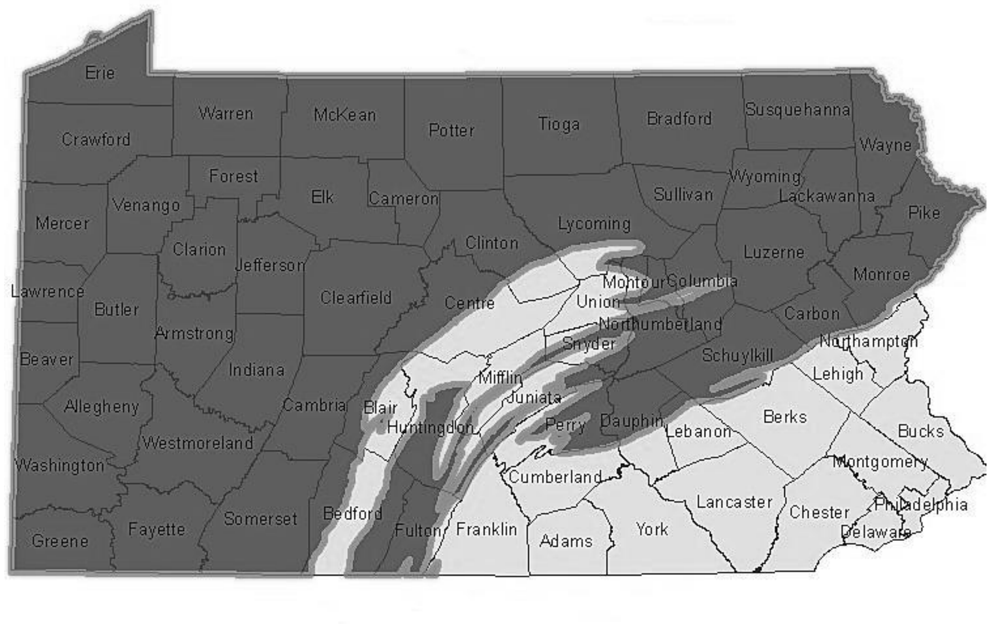

Figure 5. Marcellus shale range map in Pennsylvania (PA DEP 2010). Dark gray represents where Marcellus shale layer is present.

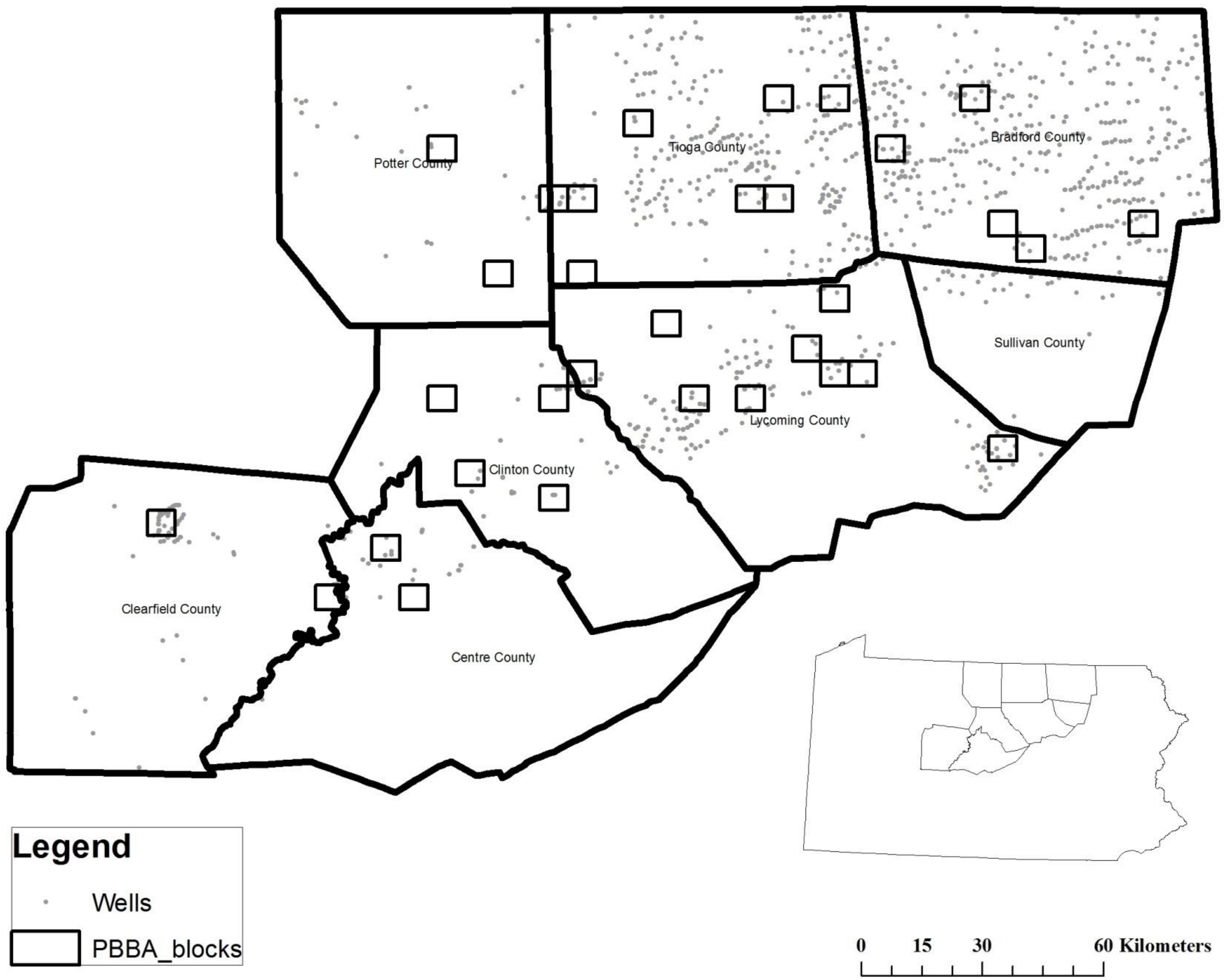

Figure 6. Distribution of wells (PA DEP 2012) and breeding bird atlas blocks (Wilson et al. 2012) surveyed across the eight county region in north-central Pennsylvania in 2011-2012. Subset shows study region within north-central Pennsylvania as of November 2012. Well pads are not to scale.

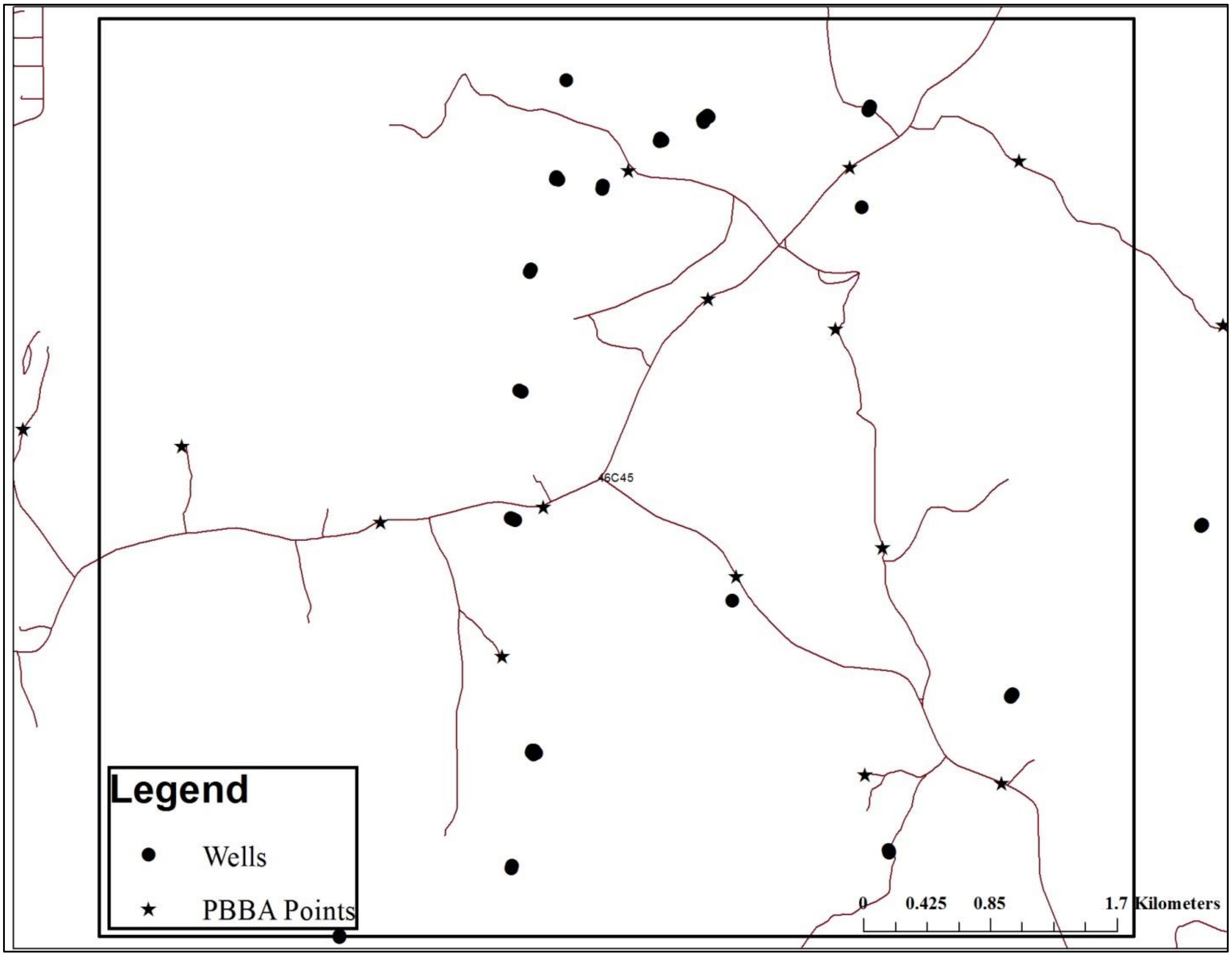

Figure 7. PBBA block, 46C45, in Clearfield County, Pennsylvania, with locations of well pads and available PBBA point count stations.

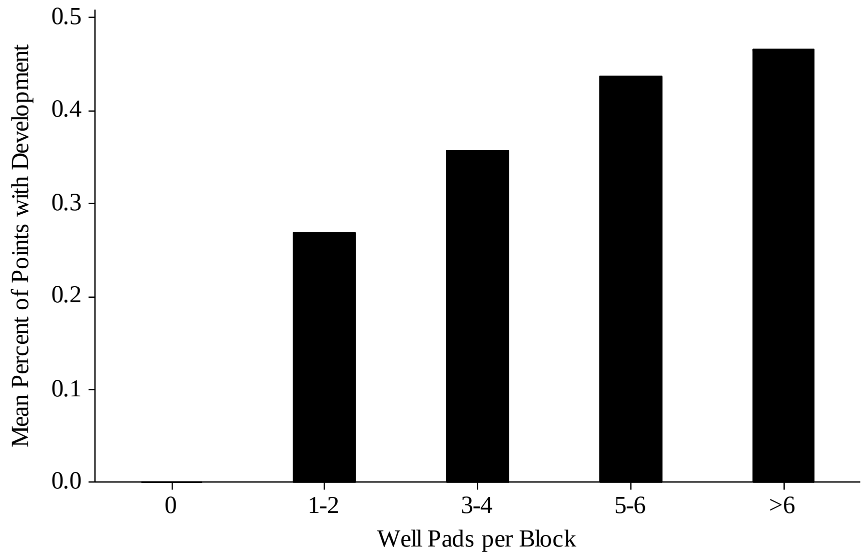

Figure 8. Relationship between the number of well pads per Pennsylvania breeding bird atlas block (25 square km) and the mean percent of points within a block with development (expanded road, pipeline, pad) within 75 m of a point in north-central Pennsylvania during the 2011 and 2012 field seasons.

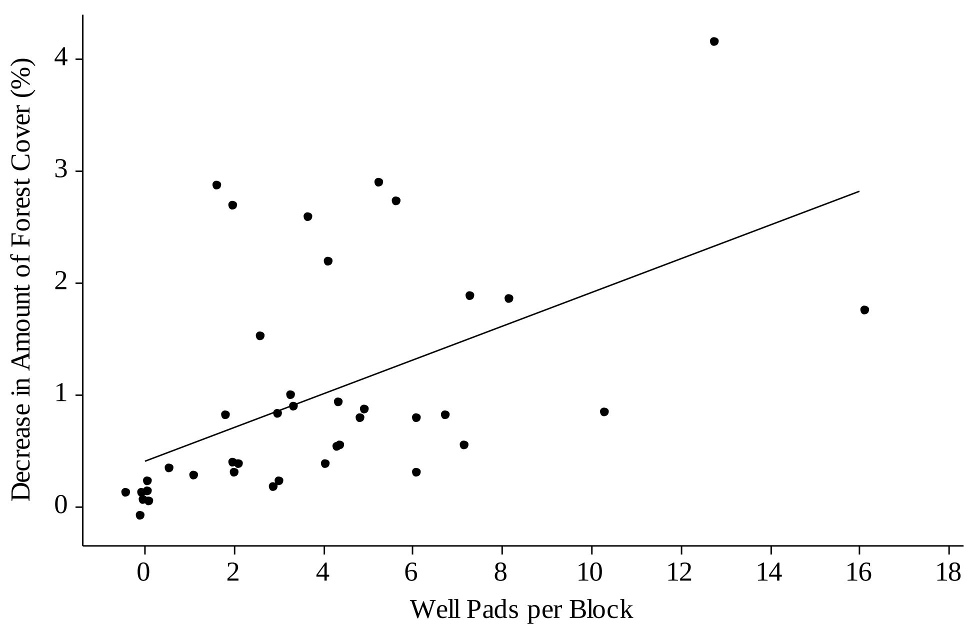

Figure 9. The relationship between the decrease in the amount of forest cover (%) from before (2005) to after (2011-2012) Marcellus shale well pads per Pennsylvania breeding bird atlas block (25 square km) in north-central Pennsylvania (R^2 = 26.9%, F = 14.0, p = 0.001).

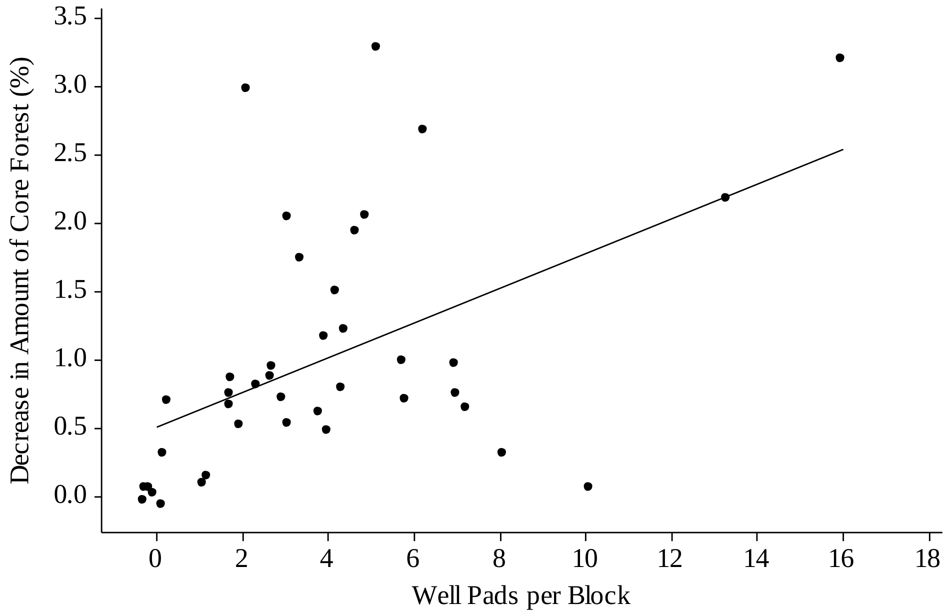

Figure 10. The relationship between the decrease in core forest (%) from before (2005) to after (2011-2012) Marcellus shale development and well pads per Pennsylvania breeding bird atlas block (25 square km) in north-central Pennsylvania (R^2 = 24%, F = 12.0, p = 0.001).

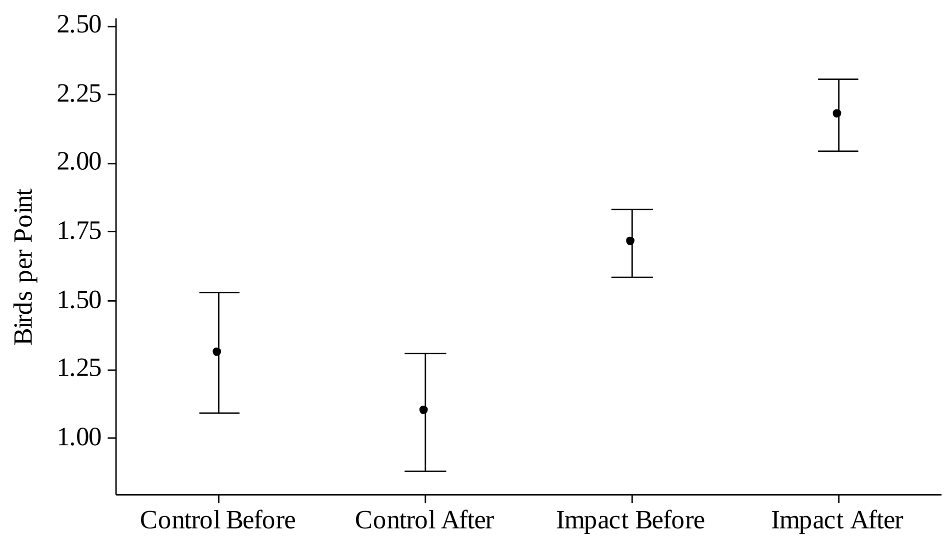

Figure 11. Means of the number of birds per point for the synanthropic species guild at control and impact breeding bird atlas blocks before (2004-2008) and after (2011-2012) Marcellus shale development in north-central Pennsylvania. Bars represent standard errors.

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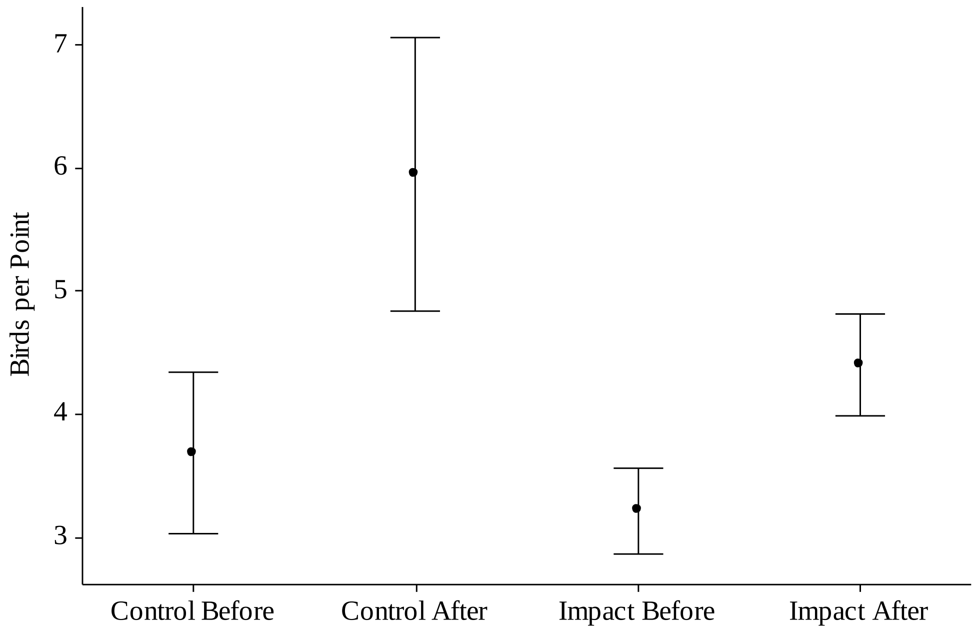

Figure 12. Means of the number of birds per point for the forest interior species guild at control and impact breeding bird atlas blocks before (2004-2008) and after (2011-2012) Marcellus shale development in north-central Pennsylvania. Bars represent standard errors.

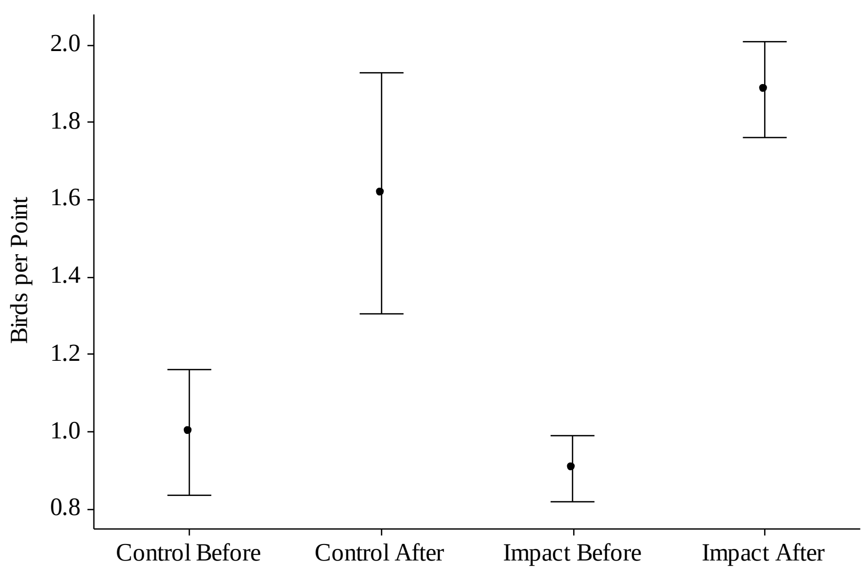

Figure 13. Means of the number of birds per point for the early successional species guild at control and impact breeding bird atlas blocks before (2004-2008) and after (2011-2012) Marcellus shale development in north-central Pennsylvania. Bars represent standard errors.

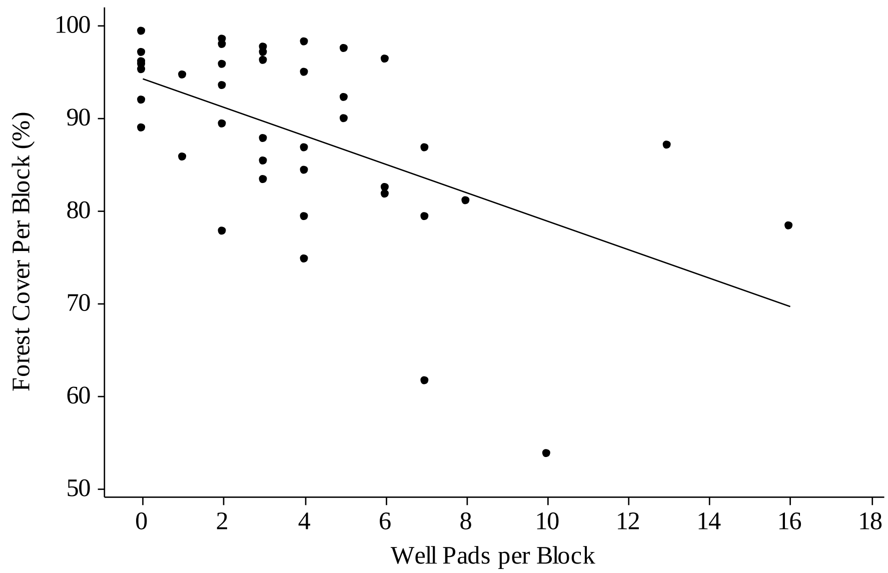

Figure 14. Forest cover (%) had a significant negative relationship with well pads per Pennsylvania breeding bird atlas block (25 square km) during the 2011 and 2012 breeding seasons in north-central Pennsylvania (R^2 = 25.4 %, F = 11.6, p = 0.002).

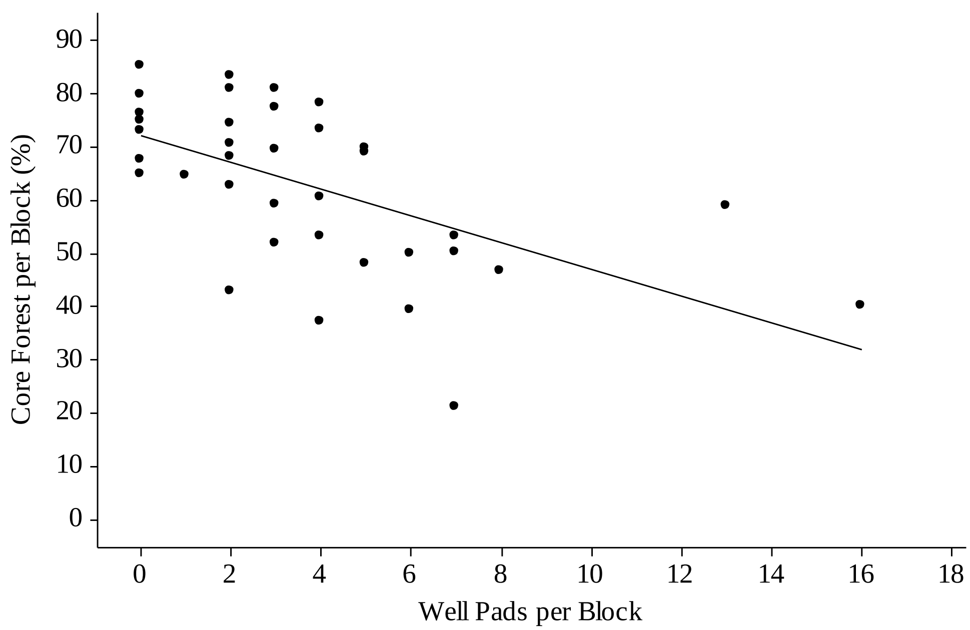

Figure 15. Relationship between well pads per Pennsylvania breeding bird atlas block (25 square km) and core forest during the 2011 and 2012 breeding seasons in north-central Pennsylvania (R^2 = 33.0 %, F = 16.7, p < 0.001).

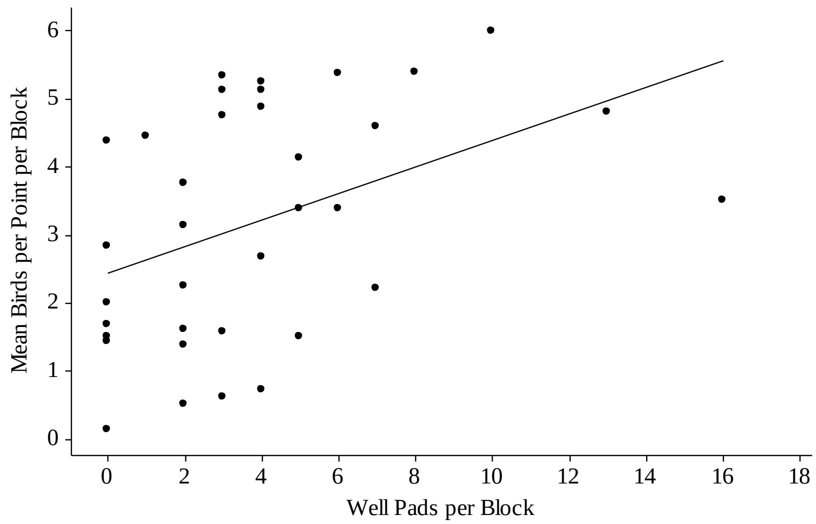

Figure 16. Abundance of individuals in the synanthropic species guild had a significant positive relationship with well pads per Pennsylvania breeding bird atlas block (25 square km) during the 2011 and 2012 breeding seasons in north-central Pennsylvania (R^2 = 17.4 %, F = 7.14, p = 0.01).

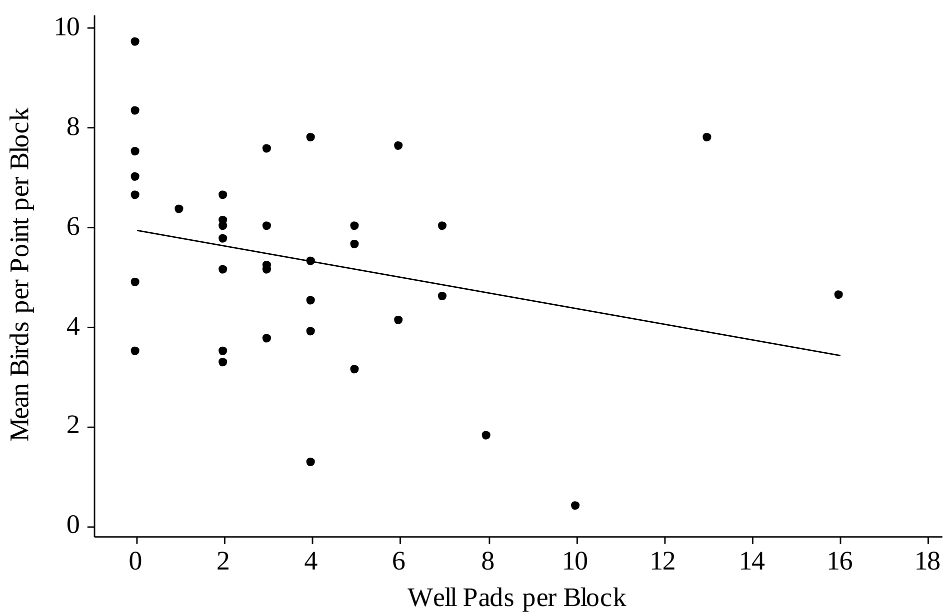

Figure 17. Abundance of the individuals in the forest interior species guild had a weak negative relationship with well pads per Pennsylvania breeding bird atlas block (25 square km) during the 2011 and 2012 breeding seasons in north-central Pennsylvania (R^2 = 8%, F = 3.0, p = 0.1).

Appendix A. Common and scientific names of species observed during roadside point count surveys throughout the eight county study region in the 2011 and 2012 field seasons.

Canada Goose	*Branta canadensis*
Wood Duck	*Aix sponsa*
Mallard	*Anas platyrhynchos*
Common Merganser	*Mergus merganser*
Ring-necked Pheasant	*Phasianus colchicus*
Ruffed Grouse	*Bonasa umbellus*
Wild Turkey	*Meleagris gallopavo*
Great Blue Heron	*Ardea herodias*
Green Heron	*Butorides virescens*
Turkey Vulture	*Cathartes aura*
Cooper's Hawk	*Accipiter cooperii*
Northern Goshawk	*Accipiter gentilis*
Red-shouldered Hawk	*Buteo lineatus*
Broad-winged Hawk	*Buteo platypterus*
Red-tailed Hawk	*Buteo jamaicensis*
Killdeer	*Charadrius vociferus*
Rock Pigeon	*Columba livia*
Mourning Dove	*Zenaida macroura*
Yellow-billed Cuckoo	*Coccyzus americanus*
Black-billed Cuckoo	*Coccyzus erythropthalmus*
Barred Owl	*Strix varia*
Common Nighthawk	*Chordeiles minor*
Eastern Whip-poor-will	*Antrostomus vociferus*
Chimney Swift	*Chaetura pelagica*
Ruby-throated Hummingbird	*Archilochus colubris*
Belted Kingfisher	*Megaceryle alcyon*
Red-bellied Woodpecker	*Melanerpes carolinus*
Yellow-bellied Sapsucker	*Sphyrapicus varius*
Downy Woodpecker	*Picoides pubescens*
Hairy Woodpecker	*Picoides villosus*
Northern Flicker	*Colaptes auratus*
Pileated Woodpecker	*Dryocopus pileatus*
American Kestrel	*Falco sparverius*
Eastern Wood-Pewee	*Contopus virens*
Acadian Flycatcher	*Empidonax virescens*
Alder Flycatcher	*Empidonax alnorum*
Willow Flycatcher	*Empidonax traillii*
Least Flycatcher	*Empidonax minimus*
Eastern Phoebe	*Sayornis phoebe*
Great Crested Flycatcher	*Myiarchus crinitus*
Eastern Kingbird	*Tyrannus tyrannus*
White-eyed Vireo	*Vireo griseus*
Yellow-throated Vireo	*Vireo flavifrons*
Blue-headed Vireo	*Vireo solitarius*
Warbling Vireo	*Vireo gilvus*
Red-eyed Vireo	*Vireo olivaceus*
Blue Jay	*Cyanocitta cristata*
American Crow	*Corvus brachyrhynchos*
Fish Crow	*Corvus ossifragus*
Common Raven	*Corvus corax*
Horned Lark	*Eremophila alpestris*
Tree Swallow	*Tachycineta bicolor*
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*
Bank Swallow	*Riparia riparia*
Cliff Swallow	*Petrochelidon pyrrhonota*
Barn Swallow	*Hirundo rustica*
Black-capped Chickadee	*Poecile atricapillus*
Tufted Titmouse	*Baeolophus bicolor*
Red-breasted Nuthatch	*Sitta canadensis*
White-breasted Nuthatch	*Sitta carolinensis*
Brown Creeper	*Certhia americana*
House Wren	*Troglodytes aedon*
Winter Wren	*Troglodytes hiemalis*
Carolina Wren	*Thryothorus ludovicianus*
Blue-gray Gnatcatcher	*Polioptila caerulea*
Golden-crowned Kinglet	*Regulus satrapa*
Eastern Bluebird	*Sialia sialis*
Veery	*Catharus fuscescens*
Hermit Thrush	*Catharus guttatus*
Wood Thrush	*Hylocichla mustelina*

American Robin	*Turdus migratorius*
Gray Catbird	*Dumetella carolinensis*
Brown Thrasher	*Toxostoma rufum*
Northern Mockingbird	*Mimus polyglottos*
European Starling	*Sturnus vulgaris*
Cedar Waxwing	*Bombycilla cedrorum*
Ovenbird	*Seiurus aurocapilla*
Worm-eating Warbler	*Helmitheros vermivorum*
Louisiana Waterthrush	*Parkesia motacilla*
Northern Waterthrush	*Parkesia noveboracensis*
Blue-winged Warbler	*Vermivora cyanoptera*
Black-and-white Warbler	*Mniotilta varia*
Nashville Warbler	*Oreothlypis ruficapilla*
Mourning Warbler	*Geothlypis philadelphia*
Common Yellowthroat	*Geothlypis trichas*
Hooded Warbler	*Setophaga citrina*
American Redstart	*Setophaga ruticilla*
Cerulean Warbler	*Setophaga cerulea*
Northern Parula	*Setophaga americana*
Magnolia Warbler	*Setophaga magnolia*
Blackburnian Warbler	*Setophaga fusca*
Yellow Warbler	*Setophaga petechia*
Chestnut-sided Warbler	*Setophaga pensylvanica*
Black-throated Blue Warbler	*Setophaga caerulescens*
Pine Warbler	*Setophaga pinus*
Yellow-rumped Warbler	*Setophaga coronata*
Prairie Warbler	*Setophaga discolor*
Black-throated Green Warbler	*Setophaga virens*
Canada Warbler	*Cardellina canadensis*
Eastern Towhee	*Pipilo erythrophthalmus*
Chipping Sparrow	*Spizella passerina*
Field Sparrow	*Spizella pusilla*
Savannah Sparrow	*Passerculus sandwichensis*
Grasshopper Sparrow	*Ammodramus savannarum*
Song Sparrow	*Melospiza melodia*
Swamp Sparrow	*Melospiza georgiana*
White-throated Sparrow	*Zonotrichia albicollis*
Dark-eyed Junco	*Junco hyemalis*
Scarlet Tanager	*Piranga olivacea*
Northern Cardinal	*Cardinalis cardinalis*
Rose-breasted Grosbeak	*Pheucticus ludovicianus*
Indigo Bunting	*Passerina cyanea*
Bobolink	*Dolichonyx oryzivorus*
Red-winged Blackbird	*Agelaius phoeniceus*
Eastern Meadowlark	*Sturnella magna*
Common Grackle	*Quiscalus quiscula*
Brown-headed Cowbird	*Molothrus ater*
Orchard Oriole	*Icterus spurius*
Baltimore Oriole	*Icterus galbula*
House Finch	*Haemorhous mexicanus*
Purple Finch	*Haemorhous purpureus*
Pine Siskin	*Spinus pinus*
American Goldfinch	*Spinus tristis*
House Sparrow	*Passer domesticus*

Appendix B. Pennsylvania breeding bird atlas block (25 square km), year surveyed, number of points completed per block, well pads, change in core forest, current amount of core forest, change in forest cover, and current amount of forest cover from pre-Marcellus conditions to current conditions for blocks surveyed in 2011 and 2012 field seasons. If well pad numbers changed between years the 2012 number is displayed in parentheses. A * indicates that the blocks were only used in the BACI analysis. A ** indicates that the blocks were used only in the analysis of current Marcellus development and bird abundance.

Block	Year Surveyed	Point Counts Completed	Well Pads	Change in Core Forest (%)	Current Core Forest (%)	Change in Forest Cover (%)	Current Forest Cover (%)
34B25	2011	6	0	-0.69	73.07	-0.18	92
34C43	2011/2012	8	6	-0.75	49.92	-0.35	81.71
34D33	2011	8	0	0	85.4	0	97.16
35B54	2012	8	2	-0.69	80.85	-0.39	98.04
35C44	2011/2012	8	5	-3.32	69.76	-0.78	92.24
35C66	2012	6	3	-1.81	51.7	-0.93	83.33
35C74	2011/2012	8	4 (5)	-1.87	68.96	-2.94	89.94
35D44	2012	7	0	0	79.98	0	99.39
36B11	2011/2012	9	1	-0.13	64.51	-0.29	85.84
36B21	2011/2012	8	4	-0.81	37.09	-0.6	74.77
36B26	2012	8	3	-0.86	59.12	-0.85	87.85
36B35	2012	5	7	-0.94	53.16	-0.89	86.8
36C13	2012	8	2 (3)	-2.04	69.63	-1.44	85.3
36C23	2011/2012	10	13	-2.13	58.88	-4.15	87.13
36C31	2012	5	8	-0.26	46.64	-1.76	81.03
36D11	2012	8	4	-0.4	60.47	-0.85	86.82
36D25	2011/2012	8	2	-0.79	70.68	-2.96	89.4
36D43	2011/2012	8	2(4)	-0.58	53.2	-2.49	84.32
37B42	2011/2012	8	6(10)	-0.01	18.44	-0.79	53.62
37C55	2011/2012	8	0	0	74.98	0	96.05
37C76	2011	8	4	-1.26	48	-2.27	79.41
37D52	2011/2012	8	3	-0.98	77.47	-0.91	97.1
46C45	2011/2012	8	14(16)	-3.26	40.21	-1.81	78.3
47D75	2011	8	2	-0.77	42.76	-0.24	77.71
48B21	2011/2012	8	0	0	64.77	0	95.81
48B41	2011/2012	8	3	-0.74	80.93	-0.18	97.66
48C22	2011/2012	8	2	-0.6	62.73	-2.66	93.57
48C43	2012	5	2	-0.82	83.43	-0.27	98.6
48D11	2011/2012	8	3(4)	-1.46	73.37	-0.48	94.99
48D16	2011/2012	8	0	-0.38	67.69	-0.22	88.95
49A46	2011/2012	9	3(4)	-1.15	78.34	-0.42	98.21
49A61**	2012	6	0	0	76.46	0	95.3
49A76*	2011	3	2	-2.91	66.62	-0.87	95.78
49B62*	2011	4	3 (5)	-2.02	56.28	-0.74	97.57

49B72*	2011	3	3(6)	-2.64	80.34	-0.74	96.33
50A14**	2011	7	3	-0.46	68.12	-0.19	96.25
50A25	2011/2012	5	5(7)	-0.69	50.3	-0.49	79.34
50A26	2011/2012	8	1	-0.13	74.55	-0.42	94.64
51B55	2011/2012	8	4(6)	-0.97	39.3	-2.62	82.48

Appendix C. Songbird species habitat guilds[b]

Synanthropic Species	Early Successional Species	Forest Interior Species
Mourning Dove	Gray Catbird	Acadian Flycatcher
Eastern Phoebe	Brown Thrasher	Blue-headed Vireo
American Crow	Chestnut-sided Warbler	Red-eyed Vireo
Blue Jay	Common Yellowthroat	Veery
Eastern Bluebird	Eastern Towhee	Hermit Thrush
American Robin	Field Sparrow	Wood Thrush
European Starling		Cerulean Warbler
Common Grackle		Magnolia Warbler
Chipping Sparrow		Black-throated Blue Warbler
Song Sparrow		Black-throated Green Warbler
Common Grackle		Blackburnian Warbler
Brown-headed Cowbird		Black and White Warbler
American Goldfinch		American Redstart
		Ovenbird
		Hooded Warbler
		Scarlet Tanager
		Dark-eyed Junco
		Rose-breasted Grosbeak

[b] Synanthropic species guild based on definitions by Leu et al. (2008) and Johnston (2001). Early successional and forest interior species guild based on prior knowledge of habitat preferences for each species in north-central Pennsylvania (Wilson et al. 2012).

Appendix D. R code for Before-After Control-Impact analysis

```
library(lme4)

syn<- read.table("synanthropicagg.txt", header = T)
early<- read.table("earlysuccessionalagg.txt", header = T)
forest<-read.table("forestinterioragg.txt", header = T)

species$Time<-as.factor(species$Time)

modelA<-lmer(Count~Density*Time+(1|Block)+(1|Block:Point),family=poisson,data=species,
verbose=TRUE)
```

Appendix E. Effect of Marcellus shale development on species includes estimates* and standard errors, z-values, and p-values for the year-pad interactions from the repeated measures ANOVAs for data collected at 37 Pennsylvania breeding bird atlas blocks (25 square km) during the 2011 and 2012 field season in north-central Pennsylvania. P-values with an asterisk (*) are significant ($\alpha = 0.05$). *Estimate is the change in the number of detections attributed to the treatment effect.

Species	Estimate ± SE	Z	p
Yellow-bellied Sapsucker	3.32 ± 2.30	1.44	0.15
Northern Flicker	-2.21 ± 3.22	-0.69	0.49
Eastern Wood Pewee	-2.16 ± 1.55	-1.39	0.16
Eastern Phoebe	-0.72 ± 3.36	-0.22	0.83
Blue-headed Vireo	-2.96 ± 1.65	-1.80	0.07
Red-eyed Vireo	1.78 ± 0.96	1.86	0.06
Blue Jay	3.79 ± 2.82	1.34	0.18
American Crow	2.42 ± 1.76	1.37	0.17
Common Raven	1.19 ± 1.77	0.67	0.50
Black-capped Chickadee	0.20 ± 1.36	0.15	0.88
House Wren	-1.27 ±2.30	-0.55	0.58
Veery	-2.67 ± 1.82	-1.46	0.14
Hermit Thrush	0.28 ± 2.27	0.17	0.87
American Robin	2.00 ± 1.09	1.84	0.07
Gray Catbird	3.28 ± 2.82	1.16	0.25
Cedar Waxwing	5.82 ± 2.72	2.14	0.03*
Chestnut-sided Warbler	3.57 ± 1.61	2.21	0.03*
Magnolia Warbler	-8.34 ± 4.60	-1.82	0.07
Black-throated Blue Warbler	2.85 ± 2.55	1.12	0.26
Black-throated Green Warbler	-0.12 ± 1.29	-0.1	0.92
Blackburnian Warbler	-0.92 ± 2.71	-0.34	0.73
Black and White Warbler	-0.93 ± 1.90	-0.49	0.62
American Redstart	-0.58 ± 1.56	-0.37	0.71
Ovenbird	-1.25 ± 0.77	-1.63	0.10
Common Yellowthroat	2.80 ± 1.25	2.26	0.02*
Scarlet Tanager	-3.44 ± 1.37	-2.50	0.01*
Eastern Towhee	-1.49 ± 1.06	-1.40	0.16
Chipping Sparrow	2.47 ± 1.35	1.82	0.07
Song Sparrow	2.09 ± 1.16	1.80	0.07
Dark-eyed Junco	1.75 ± 2.28	0.77	0.44
Indigo Bunting	2.02 ± 1.12	1.80	0.07
Red-winged Blackbird	0.59 ± 1.49	0.40	0.69
Brown-headed Cowbird	3.50 ± 2.40	1.45	0.15
American Goldfinch	0.72 ± 1.93	0.38	0.71

Appendix F. Intercept, slope, F-values, and p-values of linear regression with species abundance and guild abundance and the amount of core forest per PBBA block. P-values with an asterisk (*) are significant (α = 0.05).

Species	Intercept	Slope	F	p
Yellow-bellied Sapsucker	-0.01	0.003 (Core)	2.22	0.15
Northern Flicker	0.09	0.0001 (Core)	0.00	0.95
Eastern Wood Pewee	0.02	0.001(Core)	0.94	0.34
Eastern Phoebe	0.05	0.0005 (Core)	0.02	0.68
Blue-headed Vireo	-0.32	0.009 (Core)	11.85	0.002*
Red-eyed Vireo	0.88	0.009 (Core)	2.12	0.154
Blue Jay	0.39	0.003 (Core)	2.76	0.11
American Crow	0.69	-0.006(Core)	4.44	0.04*
Common Raven	0.09	-0.0002 (Core)	0.05	0.82
Black-capped Chickadee	0.23	-0.0005 (Core)	0.06	0.80
House Wren	0.26	-0.002 (Core)	3.25	0.08
Veery	-0.23	0.007 (Core)	7.64	0.009*
Hermit Thrush	-0.18	0.006(Core)	5.39	0.03*
American Robin	1.09	-0.008(Core)	3.31	0.08
Gray Catbird	0.44	-0.003(Core)	2.23	0.14
Cedar Waxwing	0.44	-0.004 (Core)	5.96	0.02
Yellow Warbler	0.41	-0.005 (Core)	9.63	0.004
Chestnut-sided Warbler	0.12	0.004 (Core)	1.37	0.25
Magnolia Warbler	-0.15	0.004 (Core)	9.98	0.003*
Black-throated Blue Warbler	-0.19	0.005 (Core)	5.24	0.03*
Black-throated Green Warbler	-0.27	0.012 (Core)	11.98	0.001*
Blackburnian Warbler	-0.22	0.006(Core)	8.01	0.008*
Black and White Warbler	-0.08	0.003 (Core)	4.57	0.04*
American Redstart	0.01	0.003 (Core)	1.51	0.23
Ovenbird	0.76	0.006 (Core)	0.78	0.39
Common Yellowthroat	1.26	-0.007(Core)	2.56	0.12
Scarlet Tanager	-0.10	0.006 (Core)	11.14	0.002*
Eastern Towhee	0.03	0.005 (Core)	2.45	0.13
Chipping Sparrow	0.78	-0.006 (Core)	2.72	0.11
Song Sparrow	1.32	-0.013 (Core)	7.50	0.01*
Dark-eyed Junco	-0.29	0.01(Core)	15.10	<0.001*
Rose-breasted Grosbeak	0.002	0.001 (Core)	1.48	0.23
Indigo Bunting	0.87	-0.005 (Core)	1.83	0.19
Red-winged Blackbird	1.29	-0.02 (Core)	9.40	0.004*
Brown-headed Cowbird	0.11	-0.0004 (Core)	0.12	0.73

Baltimore Oriole	0.28	-0.003 (Core)	9.15	0.005*
American Goldfinch	0.14	-0.00001 (Core)	0.00	0.99
Edge Species Guild	7.96	-0.08 (Core)	32.4	<0.001*
Early Successional Species Guild	2.24	-0.00 (Core)	0.00	0.99
Forest Interior Species Guild	0.71	0.74(Core)	16.5	<0.001*

Appendix G. Means and standard errors of the relative abundance of individual species and guilds, intercept, slope, F-values, and p-values from linear regression with well pads per block and species and guild abundance in 2011 and 2012 in north-central Pennsylvania. P-values with an asterisk (*) are significant (α = 0.05).

Species	Mean ± SE	Intercept	Slope	F	p
Yellow-bellied Sapsucker	0.20±0.04	0.21	-0.003(Pads)	0.10	0.75
Northern Flicker	0.09±0.02	0.07	0.003(Pads)	0.44	0.51
Eastern Wood Pewee	0.12±0.02	0.11	0.0002(Pads)	0.00	0.97
Eastern Phoebe	0.09±0.02	0.10	-0.004(Pads)	0.54	0.47
Blue-headed Vireo	0.26±0.05	0.33	-0.023 (Pads)	3.32	0.07
Red-eyed Vireo	1.47±0.10	1.29	0.033(Pads)	1.63	0.21
Blue Jay	0.20±0.03	0.18	0.005(Pads)	0.44	0.51
American Crow	0.32±0.04	0.30	0.006(Pads)	0.20	0.66
Common Raven	0.07±0.01	0.06	0.004(Pads)	0.91	0.35
Black-capped Chickadee	0.27±0.03	0.29	-0.006(Pads)	0.37	0.55
House Wren	0.11±0.02	0.12	0.0002(Pads)	0.01	0.98
Veery	0.22±0.04	0.30	- 0.025(Pads)	4.81	0.04*
Hermit Thrush	0.20±0.04	0.24	-0.011(Pads)	0.85	0.36
American Robin	0.62±0.06	0.56	0.013(Pads)	0.47	0.50
Gray Catbird	0.26±0.03	0.26	-0.005(Pads)	0.24	0.63
Cedar Waxwing	0.19±0.02	0.18	0.006(Pads)	0.74	0.40
Yellow Warbler	0.11±0.02	0.10	0.006(Pads)	0.77	0.39
Chestnut-sided Warbler	0.37±0.05	0.32	0.02(Pads)	1.02	0.32
Magnolia Warbler	0.09±0.02	0.11	-0.008(Pads)	2.14	0.15
Black-throated Blue Warbler	0.14±0.04	0.16	- 0.006(Pads)	0.26	0.61
Black-throated Green Warbler	0.40±0.02	0.36	0.009(Pads)	0.36	0.55
Blackburnian Warbler	0.18±0.04	0.24	-0.02(Pads)	2.74	0.11
Black and White Warbler	0.10±0.02	0.13	-0.008(Pads)	1.63	0.21
American Redstart	0.23±0.04	0.25	-0.008(Pads)	0.72	0.40
Ovenbird	1.14±0.10	1.10	0.004(Pads)	0.02	0.89
Common Yellowthroat	0.81±0.07	0.66	0.04(Pads)	5.61	0.02*
Scarlet Tanager	0.28±0.03	0.31	-0.01(Pads)	2.60	0.12
Eastern Towhee	0.36±0.05	0.36	0.0001(Pads)	0.00	0.99
Chipping Sparrow	0.43±0.05	0.23	0.05(Pads)	18.01	< 0.001*
Song Sparrow	0.53±0.08	0.49	0.01 (Pads)	0.32	0.58
Dark-eyed Junco	0.32±0.05	0.36	-0.01(Pads)	0.60	0.45
Rose-breasted Grosbeak	0.10±0.02	0.10	-0.002(Pads)	0.13	0.72
Indigo Bunting	0.54±0.06	0.50	0.007(Pads)	0.16	0.70
Red-winged Blackbird	0.32±0.09	0.32	0.004(Pads)	0.03	0.86
Brown-headed Cowbird	0.08±0.02	0.07	0.005(Pads)	1.06	0.31

Baltimore Oriole	0.55±0.02	0.06	0.003(Pads)	0.35	0.56
American Goldfinch	0.15±0.02	0.15	-0.002(Pads)	0.14	0.71
Synanthropic Species Guild	3.19±0.28	2.44	0.20(Pads)	7.14	0.01*
Early Successional Species Guild	2.24±0.16	2.08	0.042(Pads)	0.88	0.36
Forest Interior Species Guild	5.34±0.34	5.95	-0.16(Pads)	2.95	0.10