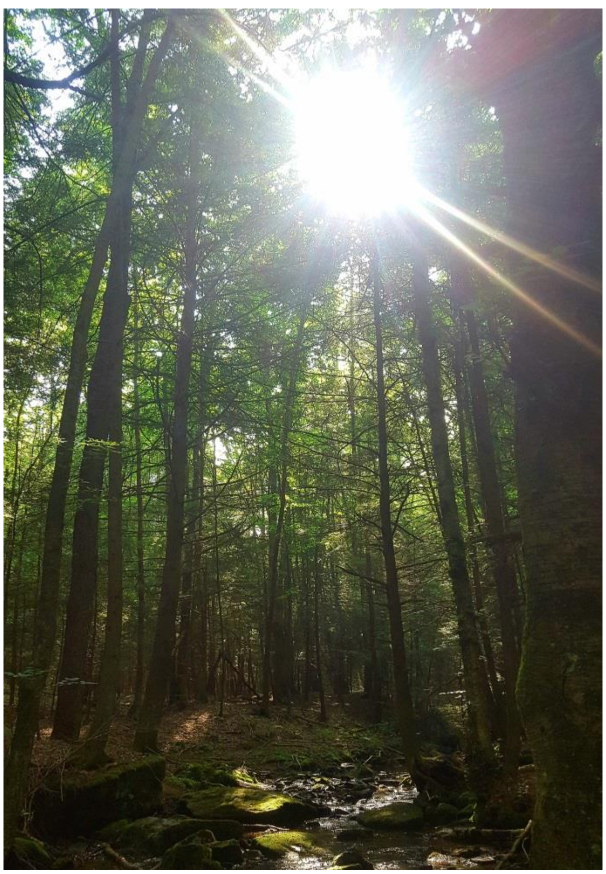
Assessment of High Value Ecological Areas in Pennsylvania's Shale Region Round 2



Assessment and Baseline of High Value Ecological Areas in the Shale Region Round 2

Establishing Baselines for Long-term Monitoring

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Western Pennsylvania Conservancy

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Executive Summary

Background and Approach

Despite the recent slow-down in drilling, there is still considerable concern over potential negative impacts to high quality aquatic and forest ecosystems associated with unconventional natural gas extraction. Development activities associated with well pad, road, and pipeline construction cause direct forest loss, and impacts aquatic habitats through forest clearing, increased impervious surface, erosion and sedimentation activities, and chemical pollution. Pipeline development further threatens wildlife through direct impacts to habitat and indirectly through a suite of edge effects, which function to decrease specific aspects of quality for a specific species.

In 2013, Western Pennsylvania Conservancy (WPC) initiated an ecological assessment of 35 areas of high ecological value thought to be threatened by development activities associated with shale natural gas development. Shale gas activity within the focal areas varied considerably; unconventional wells, as well as pipelines roads, water storage areas, and other infrastructure associated with development, was documented in 15 of the 35 focal areas. Impacts associated with development of shale gas also varied; however, findings, including correlation between water quality parameters and distance to unconventional wells and the community of interior forest birds and human-caused ecological stressors indicated that continued monitoring was needed. In 2016, we returned to the 15 focal areas where unconventional natural gas development activities had been documented to continue aquatic and forest monitoring and answer specific questions about potential influences of development on aquatic and terrestrial ecosystems. Primary targets of our second round of monitoring included water, forests, and landscape fragmentation.

Aquatic monitoring activities for the second round of study included a return visit to 25 of the original locations sampled from 2013-2014, plus 15 additional locations, located closer to well pads. Monitoring activities began in October 2016 at the 25 sites and field work included assessment of biological and chemical components of water quality; at each visit, water samples were collected for laboratory analysis. The15 new points were visited in 2017. Terrestrial monitoring activities, which included breeding bird point counts and a rapid assessment of habitat structure and composition, took place in all 15 focal areas selected for survey in Round 2. Assessment activities included a survey of reference forest conditions in large patches of interior forest with each focal area and forested areas adjacent to unconventional natural gas well pads. Terrestrial assessment activities took place between May-July 2017. In addition to field assessment activities, we assessed landscape fragmentation in Pennsylvania between 2000 and 2017 using available land cover data (National Land Cover Data) and assessed landscape impacts from shale gas development at various scales using data that represented recently developed shale gas-development-related fragmenting features (well pads, pipelines, roads).

Water Monitoring Results

- There were no significant differences in mean values for pH, TDS, conductivity, barium, or strontium between sampling rounds at the 25 sites sampled in both 2013-2014 and 2016-2017 sampling rounds, suggesting sites remained the same with regards to primary indicators of shale gas development pollution.

- As we observed in 2013-2014, several of the sites exhibited values for barium and strontium greater than the average natural (occurrence and (barium: 0.043 mg/l; strontium: 0.06 mg /l) and some were outside of the range of natural occurrence (barium: 0.002 – 0.34 mg/l; strontium: 0.002 – 0.375 mg /l).
- We found, on average, monitoring locations situated nearer to unconventional wells had higher values for TDS, conductivity, strontium, and barium in both spring and fall sampling periods. Conversely, the diversity of sensitive macroinvertebrates, based on the Index of Biological Integrity (IBI), was found to be lower with increased proximity to shale gas wells in both seasons. Monitoring locations with IBI scores less than 50 (impaired) were situated significantly closer to well pads than those with IBI scores over 50. These findings suggest that with decreasing distance from well pads, the quality of the water within aquatic ecosystems decreases.
- Percent agricultural land cover and percent forest land cover within the focal area, as well as Landscape Condition Model (LCM) score were also correlated with increased values for TDS, conductivity, barium, strontium, and IBI indicating that human development stressors (land clearing, distance to roads, percent agricultural land in the watersheds) are also significantly correlated with poor water quality. Other factors, such as the number of wells and number of well pads in a focal area were investigated; however, they were not significantly correlated with IBI score in either season.
- In focal areas where human stressors are prevalent, including shale gas development, our analysis may have detected taxonomic shifts from sensitive taxa to more pollution tolerant taxa. This was particularly apparent in several focal areas and our results merit continued investigation to document the extent of these changes.

<u>Forest Monitoring Results</u>

- Core forest patches within our focal areas were dominated by interior forest bird species, even in areas where agriculture, residential development, and shale gas infrastructure comprise a substantial amount of the land cover.
- Within 150 m of the edge of well pads, roads and pipelines, species of the edge forest and young forest communities thrive, but beyond 150 m, interior forest species are the most prevalent. These findings were consistent across all focal areas and levels of development in the focal areas indicating that even in the most fragmented landscapes we studied, core forest patches function as habitat for interior forest birds.
- Our results suggest that conservation of these remaining habitats is very important, as shale gas infrastructure, along with other forms of anthropogenic development favor edge and young forest species over the interior species that are generally considered to be indicators of high quality forest habitats.
- An interesting observation in our work was an apparent decline in the abundance interior forest bird species across all sites from Round 1 to Round 2 independent of shale gas development. While this may just be annual variation or have been influenced by environmental conditions (e.g. precipitation, high wind), our results may be indicative of a greater trend apparent in Neotropical migrating birds in eastern North America due to outside influences of habitat loss in their wintering range, and collisions with buildings and vehicles. Thus, continued work is needed at our assessment areas to monitor this trend over time.

Fragmentation Analysis Results

- Using available landscape level land cover data (2001, 2006, 2011 National Land Cover Data), we found that while there was a slight increase (1.2%) overall in forest cover from 2000 to 2010, gains in forest cover are mostly associated with new forest land cover in formerly agricultural land, which results in the establishment of young (successional) forest, favored by species of birds that favor forest edges and human-influenced habitats rather than forest interior species.
- We have seen a marked slowdown in the rate of unconventional natural gas infrastructure development in Pennsylvania, from reported numbers of drilled wells as high as 2,000 wells drilled annually in 2011 to less than 400 wells drilled in 2017. Development patterns remain the same, however, with a majority of well pads developed on private land and just over half of the well pads developed on agricultural land. We have seen a slight increase in the percent of well pads developed within forested land cover. Forty-two percent of the shale gas well pads in Pennsylvania were constructed in forested cover types from 2006-2010. This number increased slightly from 2010-2017 with 46% developed in forested land cover.
- Unconventional natural gas development between 2010 and 2017 differed greatly from projections provided in The Nature Conservancy's 2010 report, *Pennsylvania Energy Impacts Assessment*, which predicted 60,000 new wells would be developed in Pennsylvania by 2030. Rather than 48% of the 60,000 projected wells that we would expect to see in the 7 year period, only about 14% had been developed. A smaller number of drilled wells than projected has resulted in many fewer well pads and substantially less fragmentation than originally predicted in the 2010 report; however, the spatial footprint of the observed development may be greater in some areas where development pressure is high, as there are only 2.9 wells per pad on average – fewer than the number of wells per pad in the highest development scenario in TNC's prediction.
- Results suggest that shale gas development in Pennsylvania has reduced the area of large core forests (> 200 ha) by 4.0% through direct loss and conversion of these large core forest patches to "edge" forest. We believe this estimate is conservative, as this figure does not include smaller forest patches (<200 ha) nor does it include loss of forest due to new roads and natural gas gathering lines, which were not available consistently in our data.
- Our landscape analyses investigating fragmentation allowed us to develop a new set of ecologically valuable forest patches for inclusion on the WPC Conservation Blueprint, which guides the Conservancy's land conservation planning activities.

Conclusions and Recommendations

Our continued assessment of aquatic and terrestrial ecosystem quality and landscape condition provides a baseline that can be used to measure land use change over time as sites are developed to produce shale gas, as well as for other development purposes. However, even with 40 monitoring points in 15 focal areas, our aquatic monitoring activities should still be considered small in terms of sample size when trying to ascertain trends in a fragmented landscape. This is also true for the 15 forest interior reference sites and associated well pad monitoring locations. The small sample size of our work influences our conclusions, especially with the variability of conditions and ecological variables across Pennsylvania. Our results, however, demonstrate the value of unfragmented forests and the need for limiting anthropogenic disturbances in our watersheds. Of course, we recommend continued inventory and conservation measures to protect and maintain high ecological value areas.

From this work, as well as the work of other researchers in the Appalachian region, we have a greater understanding of how our natural habitats have changed over the past ten years and specifically, how the development of unconventional natural gas infrastructure has altered forest and stream systems in Pennsylvania. The results will serve as useful for public outreach and education efforts and provide data for policy makers and conservation groups, but more than anything they serve as a solid dataset in a continued effort to monitor ecological conditions of our highest value ecological areas located in regions where shale gas development pressure is a major threat. We believe that specific steps must be taken to limit impacts from shale gas development on aquatic and forest species. These include implementation of best management practices in siting infrastructure and policies limiting development within intact forests and high quality watersheds. These findings may lead to better conservation planning practices at the local level, and specifically may have the greatest chance for improving practices on lands managed by state and federal agencies.

Specifically, we recommend the following:

- Continue/expand assessment of streams sites where levels of barium and strontium are present at higher-than-normal levels. Monitoring should include isotopic analysis of barium and strontium to determine if these elements are present in streams because of unconventional natural gas development, as Marcellus and Utica shale formations tend to have higher levels of barium and strontium than surface geologies.
- Continue long term monitoring in specific watersheds where shale gas well pads have been developed near streams, such as the East Branch of Tionesta Creek to assess direct effects of development as well as cumulative impacts associated with development of multiple shale gas wells in an area, such as in our Buffalo Creek (Washington County) focal area.
- Avoid further loss and fragmentation of the remaining patches of forest, especially patches of high quality unique habitat or sites possessing unique geological characteristics, such as rock outcrops, barrens communities, and limestone-derived soils.
- Prioritize conservation and restoration activities within the remaining large forest patches in more developed landscapes to save and improve what remains of our intact forest ecosystems. Protecting intact forest habitats and minimizing fragmentation should be a goal of state and federal agencies and private land conservancies in Pennsylvania.
- Support efforts for new PAMAP LiDAR imagery. This will enable a detailed comparison of forest cover before and after the first stage of the shale gas boom from 2010 to 2014. A dataset of two periods from PAMAP at the scale available through LiDAR imagery would provide the clearest picture of forest loss and fragmentation statewide from all forms of development including shale gas well development.
- Implement best management practices in infrastructure siting, including colocation of linear infrastructure as recommended in many landscape-level analyses. Minimizing new road development and stream crossings and maintaining and improving riparian buffers will help maintain water quality and interior forest conditions.
- Support public policy that emphasizes maintenance of large unfragmented forest areas and we support policies that limit further fragmentation of large core forest areas in the region.

I. Introduction

Questions on the impacts from shale gas development have come to dominate land conservation and management conversations in Pennsylvania since the first unconventional natural gas wells were drilled in 2002. Estimates of upwards of 60,000 wells drilled by 2030 were thought to be a possibility (Johnson et al., 2010) and by 2011, this looked as if it may be the case as Marcellus Shale natural gas drilling reached nearly 1,900 wells per year (Whitacre and Slyder 2017; PADEP 2018). However, we have not seen the continued rate of drilling and well pad development as originally proposed due to an over-abundance of drilled wells, a lack of transmission infrastructure, and market conditions resulting in low gas prices due to an abundance of available energy resources (Woodall, 201; Cusick, 2017).

Despite the slow-down in drilling, there is still considerable concern over the impacts associated with unconventional natural gas extraction. Development of shale gas causes direct forest loss and impacts surface waters and aquatic habitats through forest clearing, increased impervious surface, and erosion and sedimentation activities associated with well pad, road, and pipeline construction (Johnson et al., 2010; Johnson et al., 2011; Entrekin et al., 2011; Drohan et al., 2012a; Weltman-Fahs and Taylor, 2013; Brittingham et al., 2014). Species and natural communities most vulnerable to these impacts are those with high sensitivity to disturbance and habitat specialists, such as forest interior birds, terrestrial salamanders, and vernal pool communities (Gillen and Kiviat, 2012; Brand et al., 2014; Brittingham et al., 2014; Farwell et al., 2016; Franz et al., 2018). Pipeline development further threatens wildlife through direct impacts to habitat and indirectly through a suite of edge effects, which function to decrease specific aspects of quality for a specific species. (Johnson et al., 2011). In particular, forest edge and young forest-dwelling birds, which thrive in anthropogenic landscapes have increased in forests fragmented by roads and natural gas transmission lines, as well as well pads, staging areas, and other cleared lands (Thomas et al., 2012), whereas forest interior species, which require large tracts of unfragmented and undeveloped mature forest at least 100 m have experienced declines as a result of development activities (Franz et al., 2018). In total, development of well pads, pipelines, and service roads has been shown to reduce core forest by 4% to 12% in heavily forested landscapes of north-central Pennsylvania and the mountains of West Virginia (Farwell et al., 2016; Langlois et al., 2017),

While Pennsylvania has a long tradition of resource extraction, such as coal mining and natural gas and oil development, the location of the most productive “sweet spots” in the shale places the industrial activities associated with shale gas development within primarily rural and forested landscapes that have not experienced this type of development (WPC, 2015). Scientists and conservationists in the region have proposed that species with limited distributions in the region may also be disproportionally impacted by shale gas development activities (Johnson et al., 2010; Gillen and Kiviat 2012;Weltman-Fahs and Taylor 2013; Brand et al., 2014; WPC, 2015). As a result, conservation professionals have called for more baseline data collection (Johnson et al., 2010; Gillen and Kiviat 2012; Brand et al., 2014; WPC, 2015) to assess the current quality of high value biological diversity areas and assessment and monitoring activities to determine the extent of shale gas development impacts and to inform conservation and management activities and landscape planning practices (Benner 2012; Larkin, Stoleson, and Gover 2012).

In 2014, WPC initiated an ecological assessment of areas of high ecological value thought to be threatened by development activities associated with shale natural gas development (WPC, 2015). In 2013 and 2014, we conducted assessment of streams, forests, and rock outcrop ecosystems within 35 high value ecological areas, referred to as "focal areas," situated in the shale region of Pennsylvania. Twenty-five of the 35 focal areas were assessed for forest interior birds, considered indicators of human impacts, 51 stream sites within the 35 focal areas were evaluated for chemical and biological indicators of aquatic ecosystem quality and health, and 5 focal areas were included in the 35 where the condition of rock outcrop ecosystems, home of the rare green salamander, were evaluated as these sites may be negatively impacted by activities associated with construction of natural gas transmission lines.

Through this baseline study, we sought to determine the status of important ecological areas underlain by the Marcellus and Utica Shale. Obtaining baseline data is critical to evaluate the impacts of shale gas development on critical habitats for some of the state's rarest plant and animal species. Assessment of ecological conditions is a first step towards determining impacts from natural gas extraction from deep shale formations and an important component in establishing management strategies and regulations to avoid, minimize, and mitigate for potential impacts. Data from long term monitoring studies are important resources in adaptive management and restoration activities. In our last study, we found that ecological conditions (water quality, forest habitats, rock outcrops) varied considerably among the focal areas, and condition was usually associated with the amount of human development activity, including shale gas development. Shale gas activity within the focal areas varied considerably; unconventional wells, as well as pipelines roads, water storage areas, and other infrastructure associated with development, were documented in 15 of the 35 focal areas.

Results from our assessment of biological and chemical water quality parameters indicated that most sites were of high ecological quality, with a few notable exceptions, such as sites in the Buffalo Creek watershed of Washington County, Pennsylvania, which had 54 wells within our focal area at the time of the work, as well as a legacy of human impacts in the form of agriculture, mining, and residential development. In this focal area, total dissolved solids were substantially higher than in other areas, where agriculture made up nearly 40 % of the land cover. Total Dissolved Solids (TDS) and conductivity were also high in watersheds with more agriculture and developed land cover in comparison to focal areas in heavily forested areas. Across all focal areas, concentrations of barium and strontium in surface waters of focal areas were correlated with the presence of unconventional natural gas activities within the watershed. However, most results of barium and strontium analysis were within the range of natural occurrence and not considered above federal drinking water standards.

From our forest assessments, we found a connection between habitat quality and the bird species, edge and early successional guilds associated with assessment points with greater values of human disturbance. This suggests that with further shale development in our forested landscapes, we will see a shift towards birds common to suburbs and old fields.

There are many causes of these impacts other than shale gas development, including historical land use and coal mining activities; however, it is clear that there is a need for continued research into the extent of impacts from current shale gas development activities. We expect shale gas development to continue in Pennsylvania and that a large majority of the focal areas, identified in previous work will experience some form of development in the form of well pads, pipelines, and other infrastructure, and these assessments will serve as a baseline to monitor change over time, particularly attributable to impacts from shale gas development.

In 2016-2017, we returned to 15 of the original 30 focal areas where well pads, roads, pipelines, and other infrastructure had been developed to support Marcellus and Utica shale gas extraction to resurvey our previously established monitoring aquatic and terrestrial sites. We also established new terrestrial monitoring sites and aquatic monitoring sites closer to well pads to test the hypothesis that forest and aquatic habitat condition improves with distance from shale gas infrastructure in six focal areas represented by 14 new sites that were sampled in Round 2 only. Two new focal areas, Hyner Run and Lick Run, were additionally added for aquatic monitoring in response to shale gas activity in those focal areas. In addition to direct impacts to critical habitat that can be measured in the field, we attempted to investigate trends in fragmentation and development across the state, both at the state and local scale. Due to source data limitations, we do not yet have an up-to-date baseline of landscape fragmentation at a statewide or regional scale. This is essential to provide context for assessments of shale gas development impacts and to compare the relative effects of shale gas infrastructure with other forms of development. The following report describes our approach and findings with particular emphasis on trying to obtain information that is closer to perceived impacts associated with shale gas development.

2. Monitoring Sites

Our initial work in 2013-2014 was conducted within 35 high value ecological areas, referred to as "focal areas," spread across 26 of Pennsylvania's 62 counties (Figure 2.1). The focal areas were situated across the Shale Region of Pennsylvania and were selected because of their ecological value, the quality of aquatic and terrestrial resources, and potential threat from development of shale gas resources (WPC 2015). In 2016, we returned to 15 of the focal areas to continue stream and forest assessment activities where shale gas infrastructure (wells, well pads, roads, pipelines) was present (Table 2.1) .

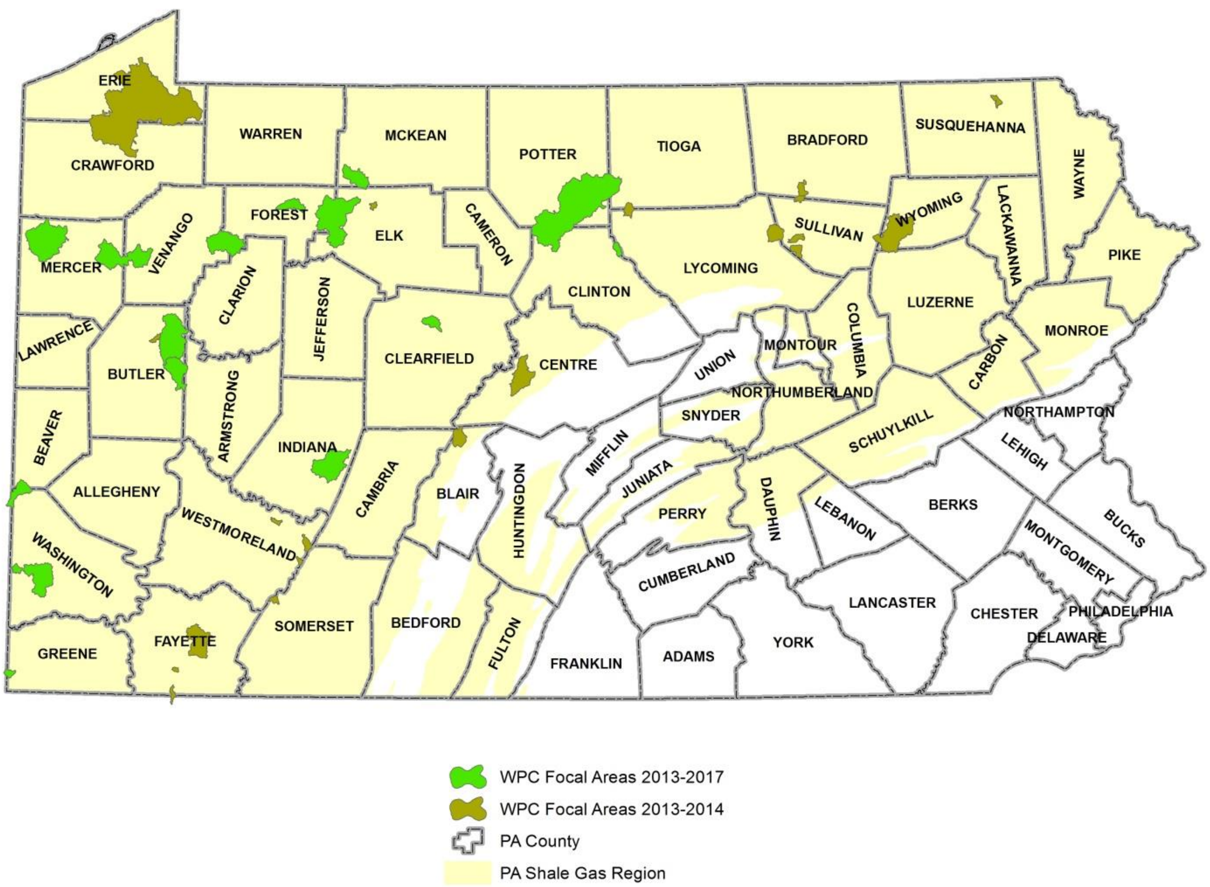


Figure 2.1. Western Pennsylvania Conservancy focal areas 2013-2014, 2016-2017

Table 2.1. Shale gas development activity in Western Pennsylvania Conservancy focal areas (Round 2)

Focal Area Name	Number of Wells	Number of Well Pads	Date of First Well Drilled	Pipeline Density (km/km^2)	Road Density (km/km^2)
Bear Creek	5	5	2007	0.4	1.9
Buffalo Creek–Butler	11	7	2013	0.2	2.0
Buffalo Creek–Washington	82	17	2007	0.7	2.0
EB Tionesta Creek	4	1	2012	0.7	1.8
Harts Run	2	2	2011	1.4	1.8
Hemlock Creek	4	2	2009	0.7	1.0
Hyner Run	24	6	2009	0.7	1.1
Kettle Creek	5	3	2009	0.4	0.8
Kings Creek	1	1	2002	0.2	2.1
Lick Run	38	10	2010	0.0	0.7
Sandy Creek	2	2*	2012	0.5	1.8
Shenango River	2	2*	2013	2.0	2.4
Spring Creek	9	3	2009	1.5	1.1
The Branch	2	2	2009	1.1	1.1
Yellow Creek	2	2	2009	0.3	1.3

*well pads drilled within watershed but outside of focal area

Aquatic Sites

The goals for the second round of sampling were to obtain a third year of data for aquatic sites in focal areas experiencing some level of shale gas development (n = 25 sites within 15 focal areas) in order to compare differences between multiple years. In a subset of these focal areas, we established new aquatic assessment points closer to shale gas development activities (n = 15 sites within 8 focal areas) and are trying to determine if proximity to shale gas wells negatively impacts biological and water quality in these focal areas.

Forest Sites

For forests, we returned to the 15 focal areas where shale gas development activities were observed to determine changes in the interior forest bird community in our interior forest reference sites and establish avian monitoring points within increasing distance bands well pads into the forest.

3. Monitoring Targets

Water

Water quality is affected by a myriad of factors – including development of unconventional natural gas resources (Maloney et al., 2017; Sponseller et al., 2001). Threats from unconventional natural gas development to aquatic ecosystems in Pennsylvania include water withdrawal, erosion and sedimentation, and pollution from flowback and produced water, and waste (Williams et al., 2008; DePhillip and Moberg, 2010; Henley et al., 2010; Johnson et al., 2010; Kargbo et al., 2010; Entrekin et al., 2011; Johnson et al., 2011; Rowan et al., 2011; Drohan and Brittingham, 2012; Maloney and Yoxtheimer, 2012; Weltman-Fahs et al., 2013). Water quality impacts associated with unconventional gas development have been extensively studied in the last decade (Warner et al., 2013) with impacts ranging from methane migration (Vidic et al., 2013), exceptionally high TDS values (Chapman et al., 2012), and impacts to biological resources (Shank and Stauffer, 2014).

Macroinvertebrate Index of Biologic Integrity (IBI) scores, a commonly used indicator of stream health, have been found to be significantly lower in watersheds with shale gas development than in watersheds without development in northeastern Pennsylvania (Lutz and Grant, 2015). Furthermore, barium and strontium, metals that are often associated with shale gas development impacts, have also been found in the feathers of birds in watersheds where shale gas development is occurring at a higher rate than in watersheds without development, suggesting that certain elements accumulate at higher levels on the food chain (e.g. Latta et al., 2015). Many of these threats are also associated with other forms of development (e.g. coal mining, aluminum processing), and it is difficult to separate new impacts to streams from the legacy of mining, oil exploration, and industry without expensive analyses (WPC, 2015). However, correlations exist that warrant further monitoring and analyses to parse out causal relationships. Unconventional natural gas development requires significant amounts of water, uses a suite of chemicals in the extraction process, produces substantial volumes of waste, and disturbs soils and vegetation as infrastructure is constructed. These activities could result in species and ecosystem-level impacts within watersheds where higher amounts of drilling activity are occurring in close proximity to aquatic resources.

Monitoring Methods

Site selection

From 2013 – 2014 WPC conducted water quality assessments at 51 selected sites in 22 focal areas, distributed across the Shale Region of Pennsylvania (Figure 2.1; WPC, 2015). WPC selected 15 of the original 35 focal areas for a second round of water quality assessment activities beginning in Fall 2016. Within the selected 15 focal areas, 25 aquatic sites were chosen for resampling. Twenty-six original sites were abandoned because they were situated in focal areas where unconventional natural gas drilling had not occurred, or were located too far away from shale gas development activities. Those sites that were included in the second round of sampling (n= 25) were sampled in October 2016, March 2017, and again in October 2017. An additional 15 sites were added in March 2017, bringing the total number of sampling sites to 40. The additional sites were added in order to collect data closer to anthropogenic disturbances associated with shale gas development (unconventional natural gas wells). These sites were sampled in Spring and Fall 2017.

Field Methods

Chemical and biological indicators of water quality were collected in the field starting in October 2016 for the 25 sites originally established in the first round of sampling. All sites were visited in April 2017 and again in October 2017. Field measurements included (TDS), phosphates, flow, turbidity, dissolved oxygen (DO), water temperature, pH, alkalinity, conductivity, total dissolved solids turbidity, and nitrates. Grab samples of stream water were also analyzed in a lab to determine the specific conductance, total suspended solids, total dissolved solids, pH, temperature, and the concentration of bromide, chloride, barium, strontium, and manganese. Water samples were analyzed by Environmental Service Laboratories, Inc. (Indiana, Pennsylvania) using approved methods by Pennsylvania Department of Environmental Protection (DEP). Macroinvertebrates were collected in both spring and fall to obtain a complete year of community data; invertebrate community structure may exhibit significant differences with respect to sampling season (Helms et al., 2009; Lenat and Crawford, 1994). The macroinvertebrates communities at all sites were assessed following the DEP In-stream Comprehensive Evaluation (ICE) protocol (PADEP, 2013). Sites selected were wadeable, freestone, riffle-run streams from first to third order. Sampling consisted of six, one minute kicks from riffle areas throughout a 100-meter reach, using a 500-micron mesh D-frame net, and with each kick disturbing approximately one square meter directly upstream of net. We stored the samples in 70 percent ethanol in the field and transported them back to the laboratory for sorting and identification per the ICE protocol. All invertebrates collected as a result of this project were preserved in 70 percent ethanol and stored for future research projects. We sorted, subsampled, and identified all specimens according to ICE protocol. All organisms were identified to the family level with 10% of the identified organisms being selected for quality assurance identification by a qualified professional.

Data Analysis

Water chemistry information and flow were summarized by site, season, and compared among sites and compared to data collected in prior sampling rounds for the 25 sites at which water quality was measured in both sampling rounds. A one-way analysis of variance (ANOVA) was performed in PAST 3.19 to determine significant differences in mean values for the following water quality parameters: pH, TDS (mg/l), conductivity (μS/cm), barium(mg/l), and strontium(mg/l).

Macroinvertebrate Index of Biological Integrity (IBI) was used to evaluate aquatic communities for sampling sites within the 15 focal areas, and by extension, the ecological quality the streams. Macroinvertebrates are known to have varying degrees of sensitivity to pollution, making the more sensitive taxa excellent bioindicators (Helms et al., 2009; Hilsenhoff, 1988). The six metrics in the IBI include total taxa richness, Ephemeroptera + Plecoptera + Trichoptera taxa richness (pollution tolerance values 0-4 only), Beck's Index version 3, Shannon Diversity Index, Hilsenhoff Biotic Index, and percent sensitive individuals (pollution tolerance values 0-3 only). These six metrics were combined to give a total score for the site. Generally speaking, IBI scores are expected to decrease with increased impacts to the stream ecosystem. IBI values less than 50 are considered impaired (PADEP, 2013). A complete description of the IBI can be found in (PADEP, 2013). The following is a description of each of the individual metrics included in the IBI.

1. *Total Taxa Richness* = is the total number of taxa recovered from a subsample.
2. *Ephemeroptera, Plecoptera and Trichoptera Taxa Richness* {Pollution Tolerance Value (PTV) 0-4 only} = a count of the mayfly, stonefly and caddisfly individuals collected in a subsample. Numbers generally decrease with increased stress.
3. *Becks's Index (Version 3)* = weighted count of sensitive taxa of PTV value 0, 1, 2/ Values decrease with increased ecological stress.
4. *Shannon-Weiner Diversity Index* = calculated to measures diversity (the total number of taxa present) and evenness (distribution of total individuals among taxa).
5. *Hilsenhoff Biotic Index* = community composition metric driven by weighted PTV taxa. Value increases with increase in pollution or stress.
6. *Percent Sensitive Individuals* = composition of PTV individuals 0 to 3 only. This number will decrease with increased stress

Additionally, where historic data was available from stream sites in the focal areas, typically from the PA Department of Environmental Protection (DEP) (accessed through Carnegie Museum of Natural History's Macroinvertebrate Water Monitoring Map (https://maps.carnegiemnh.org/macroinvertebrates/, we compared water quality and IBI scores across a longer timeframe, during which shale gas development occurred. This was done specifically at one site (East Branch Tionesta Creek) where shale gas development occurred within the time of sampling activities carried out by DEP from 2005 through 2008 and our two rounds of sampling. We used a one-way analysis of variance (ANOVA) to determine significant impacts on the macroinvertebrate community before and after unconventional natural gas development activities.

Additionally, we investigated relationships between various shale gas development variables (e.g. distance to unconventional natural gas wells) and landscape variables (e.g. percent agricultural land cover in the focal area). The land cover of each of the focal areas, which generally follow watershed boundaries for the assessment points, was determined using Zonal Statistics tools in ArcGIS 10.5 Spatial Analyst extension. Summary statistics relating shale gas development were calculated for each monitoring point [number of wells/well pads in the focal area, distance between wells and monitoring points (meters), distance to nearest well (meters)].

Using the PAST 3.19 statistical software, we performed various statistical analyses to investigate relationships between water quality variables, macroinvertebrate diversity indices (IBI), the unconventional natural gas development activity in the focal area, distance to nearest unconventional well, and land cover. Data were inspected for normality and transformations were made to accommodate non-normality.

Results and Discussion

We first tested for significant differences in mean values (per point) across sampling rounds to assess change in water quality parameters from the first sample round to the second using one way ANOVA. No significant differences in mean values for pH, TDS, conductivity, barium, or strontium were observed between sampling rounds at the 25 sites sampled in both 2013-2014 and 2016-2017 sampling rounds, suggesting sites remained the same with regards to primary indicators of shale gas development pollution (Table 3.1). Inspection of the data suggested that there were no acute pollution events during our sampling activities, which would have been apparent by exceedingly high values for water quality parameters, nor did we observe a rapid degradation in the quality of the water at our sampling locations during this time period. These results were not unexpected as the timeframe of this assessment may still be too short to assess the trends due to development and that the methods used were not intended to provide a continuous measure of water quality variables necessary to determine impact of an acute pollution event.

Table 3.1 Comparison of average values for select water quality parameters among all sites sampled in both sampling rounds – 2013-2014, 2016-2017 (n = 25).

Parameter	*Mean Rnd 1*	*std dev*	*Mean Rnd 2*	*std dev*	*F*	*p*
pH spring	7.0	.73	6.7	.87	1.205	0.278
pH fall	7.4	.58	7.2	.58	1.369	0.248
TDS (mg/l) spring	93.7	83.54	97.6	100.41	0.023	0.880
TDS (mg/l) fall	159.9	134.67	145.8	120.53	0.152	0.698
Conductivity (µS/cm) spring	162.0	144.68	130.2	101.06	0.813	0.372
Conductivity (µS/cm) fall	249.8	202.96	233.1	192.26	0.089	0.766
Barium (mg/l) spring	0.045	0.026	0.042	0.021	0.214	0.646
Barium (mg/l) fall	0.061	0.038	0.059	0.040	0.038	0.847
Strontium (mg/l) spring	0.045	0.026	0.0711	0.072	0.026	0.872
Strontium (mg/l) fall	0.149	0.150	0.134	0.130	0.154	0.697

While there was no observable change detected in water quality parameters for locations between sampling periods, several of the sites exhibited values for barium and strontium greater than the average natural occurrence and [0.043 mg/l, 0.06 mg /l, respectfully (Seiler et al., 1994)] and some were outside of the range of natural occurrence [0.002 – 0.34 mg/l; 0.002 mg/l – 0.375 mg/l, respectfully (Seiler et al., 1994)] (Table 3.2). Additionally, in our previous work, we reported a correlation between elevated levels of barium and strontium and presence of shale gas wells in the watershed (WPC, 2015). These results held true in our second round of sampling with the values for the 40 sites sampled in 2016-2017, which included 15 new sites placed closer to unconventional natural gas well pads.

Table 3.2. Select water quality variables for 40 sites sampled in the second round of water quality assessment activities (2016-2017).

Site Name	Barium mg/l (spring)	Strontium mg/l (spring)	Barium mg/l (fall)	Strontium mg/l (fall)	IBI (spring)	IBI (fall)	Cond. µs/cm (spring)	Cond. µs/cm (fall)	Distance to nearest well (m)	TDS mg/l (spring)	TDS mg/l (fall)
BEAR CK UP	0.061*	0.148*	0.061	0.148*	28.4	33.8	325.0	325.0	3928.3	231.0	231.0
BearCk	0.054*	0.138*	0.070	0.234*	31.3	27.6	309.0	562.5	3222.7	220.0	365.5
N.B. Bear Creek	0.037	0.118*	0.037	0.118*	29.4	18.4	287.0	287.0	2626.5	203.0	203.0
Buff-But-Low	0.064	0.072*	0.126	0.217*	38.9	48.7	173.6	369.0	561.3	124.0	241.5
Buff-But-Up	0.072	0.099*	0.165	0.291*	42.6	43.2	205.0	457.5	2290.8	145.0	300.5
BUFF-WASH-3	0.082	0.226*	0.102	0.308*	37.2	39.7	381.0	548.0	1100.0	270.0	389.0
BUFF-WASH-LAKERD	0.099	0.258*	0.108	0.297*	34.4	18.3	416.0	481.0	600.0	293.0	344.0
Buff-Wash-Low	0.084	0.229*	0.101	0.322*	35.9	42.1	384.0	545.5	730.4	272.0	387.0
Buff-Wash-Up	0.084	0.223*	0.110	0.332*	31.8	45.5	382.0	601.0	455.6	270.0	394.5
EBTC-1	0.042	0.024	0.072	0.050	45.6	48.5	63.1	117.4	7524.7	44.7	78.4
EBTC-3	0.047	0.023	0.131	0.061*	39.8	35.1	69.0	130.0	583.4	50.6	87.5
HARTS-RUN-BIRD	0.028	0.065*	0.057	0.126*	59.4	41.7	137.7	269.0	2725.0	97.7	182.0
HARTS-RUN-QUIET	0.030	0.068*	0.049	0.105*	52.4	58.7	145.1	224.0	951.6	103.0	159.0
Hem-Porc	0.046	0.019	0.053	0.038	57.9	60.8	58.0	123.6	7607.2	41.0	81.5
Hem-Upper	0.050	0.020	0.051	0.035	61.5	52.1	55.7	109.4	7343.8	39.8	71.7
HEM-WAYUP	0.059	0.024	0.064	0.040	51.9	51.5	61.3	124.9	1209.3	43.5	88.6
KettleCrk-Oleana	0.015	0.013	0.019	0.024	63.6	60.4	40.1	58.5	10620.3	28.2	41.4
KettleCrk-Up	0.008	0.010	0.010	0.015	63.2	59.1	28.5	39.5	5915.0	20.2	28.1
Germania Branch Low	0.023	0.018	0.033	0.043	55.9	56.6	58.5	101.0	3641.9	41.6	71.6
Germania Branch Up	0.048	0.030	0.061	0.101*	56.9	57.2	103.5	209.0	1211.8	73.5	148.0
Sliders Branch	0.023	0.014	0.032	0.027	52.2	53.2	46.5	70.3	5645.3	33.1	49.9
Kings-Low	0.026	0.128*	0.036	0.226*	41.5	36.6	305.0	492.5	1146.9	216.0	349.0
Kings-Mid	0.028	0.132*	0.036	0.241*	45.6	45.9	315.0	523.0	2097.0	224.0	370.5
Kings-Up	0.030	0.140*	0.037	0.267*	39.1	41.5	337.0	568.5	1211.8	240.0	402.5
Lick Run	0.035	0.014	0.019	0.015	62.4	51.6	22.5	28.6	953.4	16.0	20.5
Stone Run	0.040	0.015	0.021	0.014	54.8	40.7	22.90	27.40	1973.4	16.3	19.5
R.B. Hyner Run	0.031	0.020	0.04	0.03	44.7	49.8	43.8	53.4	967.5	31.1	37.6
Spring Run	0.04	0.016	0.04	0.02	57.9	59.1	41.3	50.1	701.3	29.3	35.6

Table 3.2, con't. Select water quality variables for 40 sites sampled in the second round of water quality assessment activities (2016-2017)

Site Name	Barium mg/l (spring)	Strontium mg/l (spring)	Barium mg/l (fall)	Strontium mg/l (fall)	IBI (spring)	IBI (fall)	Cond. µs/cm (spring)	Cond. µs/cm (fall)	Distance to nearest well (m)	TDS mg/l (spring)	TDS mg/l (fall)
SC-Bible	0.027	0.046	0.0	0.1*	45.5	39.1	158.7	231.0	5916.5	113.0	152.0
SC-Middle	0.02	0.05	0.0	0.1*	46.2	46.6	185.0	275.5	5883.7	131.0	181.0
Shenango-Upper	0.02	0.05	0.0	0.1*	48.6	44.2	185.0	236.0	5645.3	132.0	152.5
SPC1	0.04	0.02	0.1	0.0	47.4	50.0	37.3	57.5	6249.2	26.6	38.3
SPC2	0.04	0.02	0.0	0.0	57.6	45.4	39.7	62.9	3322.6	28.2	52.1
SPC3	0.04	0.02	0.03	0.02	51.0	48.3	34.9	45.8	4579.9	24.8	32.5
SPC4	0.05	0.01	0.0	0.0	47.5	51.1	31.3	40.9	5140.8	22.2	26.2
TBRCH-LOW	0.04	0.02	0.0	0.0	47.4	52.1	33.6	45.0	5135.6	24.0	36.9
TBRCH-UP	0.05	0.02	0.0	0.0	39.7	44.9	32.2	51.0	1140.0	22.9	34.1
YC Main	0.05	0.21	0.1	0.4	45.3	40.4	224.0	404.0	2542.6	159.0	296.5
YC-MAIN- UP	0.04	0.265*	0.07	0.67**	39.2	15.0	250.0	519.0	1393.2	177.0	370.0
LYC	0.06	0.07	0.1	0.2	47.8	43.8	130.7	349.5	2542.6	92.8	248.0

*indicates value above the average natural occurrence
**indicates value outside the range in natural occurrence
+ indicates value within the focal area

Linear regression models of water quality parameters including barium, strontium, TDS, and conductivity (Table 3.2) and distance between well pads and sampling points indicated that stream monitoring sites near well pads generally exhibited poorer water quality metrics in both spring and fall samples from our second round of monitoring (Table 3.3 and depicted in Figure 3.2 for conductivity).

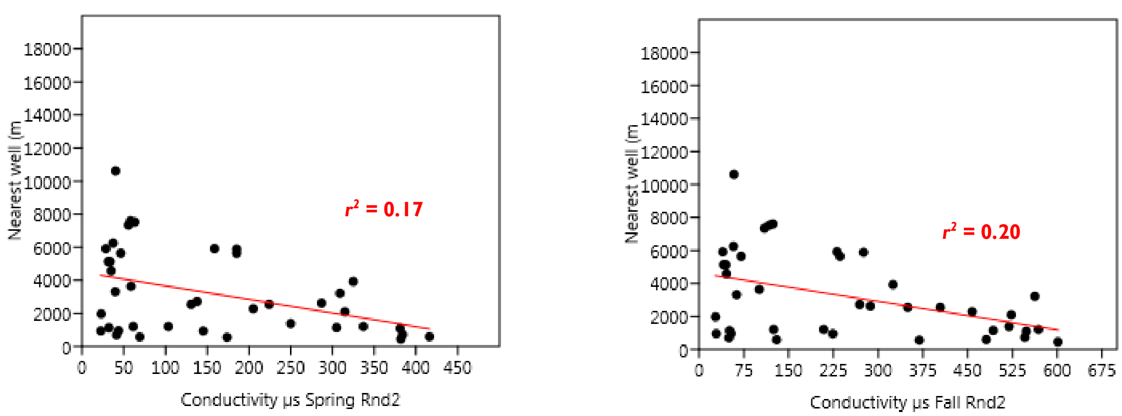


Figure 3.2. Linear regression between conductivity values and distance from sampling site to nearest well pad with trend line and r^2 value given for strength of relationship

Table 3.3. Linear regression between water quality parameters and distance from sampling site to nearest well pad

Parameter	slope	*r2*	*p* value
Barium (spring)	-56552.0	0.20	0.003
Barium (fall)	-2311.0	0.15	0.010
Strontium (spring)	-2609.5	0.22	0.002
Strontium (fall)	-21771.0	0.20	0.004
TDS (spring)	-11.6	0.17	0.008
TDS (fall)	-8.5	0.20	0.003
Conductivity (spring)	-8.2	0.17	0.008
Conductivity (fall)	-5.7	0.20	0.004

Spearman rank correlation was used to compare spring and fall IBI scores versus distance to nearest shale gas well pad as well as other factors, such as percent of the focal area supporting agricultural land cover and percent of the focal area supporting forested land cover. Spring IBI scores showed a significant positive relationship with distance to nearest shale gas well pad (Table 3.4) while fall IBI scores were not significant. We observed significant correlations between landscape variables and IBI as well (Table 3.4).

Table 3.4. Spearman correlation coefficients and p-values for comparisons between spring and fall IBI scores and landscape variables across all survey locations (n = 40).

	%Ag	%Forest	Distance to Unc.Well
IBI Spring: Spearman's ρ	-0.559	0.563	0.410
IBI Spring: p-value	0.0002	0.0001	0.009
IBI Fall: Spearman's ρ	-0.542	0.560	0.280
IBI Fall: p-value	0.0003	0.0002	0.08*

Additionally, using Kruskal-Wallis and Mann-Whitney pairwise tests, we found median distance between wells and sampling sites to be significantly different between sampling sites exhibiting IBI scores of greater than 43 and less than 43 (impaired), recorded in at least one of the sampling periods (spring or fall) (p = .001, Hc = 10.73) with a mean of 1,449.4 m for the lower IBI value sites (IBI <43) and 4,155.7 m for higher quality sites (IBI >43). IBI scores of less than 43 indiacate impared stream status for stream orders 1-3 (DEP, 2013). However, there was no significant difference observed between the two groups with regards number of wells in the focal area or well pads in the focal area, two additional indicators of the level of development activity in the immediate area (p > 0.05). Furthermore, when comparing only the sites exhibiting IBI scores of greater than 43, recorded in both the spring and fall sampling periods, there was no observed correlation between distance (Spearman's p = 0.755, p = 0.07 (spring); Spearman's p = 0..601, p = 0.12 (fall)) suggesting that the highest quality sites in our assessment may not exhibit impacts of the development activities regardless of distance to wells, number of wells/well pads in the focal area.

In addition to a pattern of poorer water quality results with proximity to unconventional natural gas well pads, we also observed a general pattern of lower IBI values and higher values for TDS, conductivity, barium, and strontium within focal areas with greater agricultural land cover and less forest cover

(Tables 3.2, 3.4). Excessive human development, including agriculture, and perhaps the legacy of extractive and industrial activities within the watersheds (eg. surface and deep coal mines) also contributes to the elevated values for all water quality parameters and lower diversity of macroinvertebrate taxa. While our results suggested that shale gas well development may be influencing water quality within our focal areas as water quality indicators tended to be lower with proximity to unconventional well pads, the results are not clear. There may be a naturally high level of barium strontium in surface waters of streams within these particular watersheds, as well as higher TDS and conductivity, or more likely, there is a legacy of pollution from historical coal mining and aluminum processing known to have occurred in some of the areas and current impacts of agriculture and development practices as well. However, it could also indicate direct impacts (pollution from activities at the well pad, leaks from pipelines, below-ground contamination, or illegal dumping (Chapman et al., 2012)) or indirect impacts (use of flowback and produced water for road dust abatement or winter road maintenance (Harrington, 2015)) from shale gas development in the region.

The significant positive correlation in spring IBI vs distance to unconventional wells (and near significance in fall IBI) means that as distances from shale gas wells increase, the IBI scores within streams also increase. This indicates a relationship between anthropogenic development and the biological integrity of aquatic ecosystems, and that shale gas development may be a contributing factor. Other factors, such as percent agricultural land cover and percent forest land cover within the focal area also are correlated with IBI in both spring and fall samples (Table 3.5). Other factors, such as the number of wells and number of well pads in a focal area were investigated; however, they were not significantly correlated with IBI score in either season. Other studies have suggested that unconventional natural gas development activities in streams within more developed landscapes may have a greater impact on aquatic taxa (e.g. Merriam et al., 2018) and our data may point toward this conclusion as well. However, more work needs to be done to determine the exact source of the higher TDS, conductivity, barium, and strontium observed at monitoring points situated closer to shale gas well activity.

Table 3.4. Unconventional natural gas and landscape metrics for all aquatic survey sites (n=40) sampled from 2013-2017

Site Name	Nearest well (m	*Upstream well (m)*	Number of Wells in FA	Number of Well Pads in FA	*%Forest*	*% Ag*
BEAR CK UP	3928.3	None	5	5	78.8	14.2
BearCk	3222.7	5012.02	5	5	78.8	14.2
N.B. Bear Creek	2626.5	1983.3	5	5	78.8	14.2
Buff-But-Low	561.3	8546.6	5	5	78.5	14.5
Buff-But-Up	2290.8	3705.05	5	5	78.5	14.5
BUFF-WASH-3	1100.0	2407.0	82	17	60.3	32.0
BUFF-WASH-LAKERD	600.0	0	82	17	60.3	32.0
Buff-Wash-Low	730.4	758.77	82	17	60.3	32.0
Buff-Wash-Up	455.6	1200.0	82	17	60.3	32.0
EBTC-1	7524.7	4058.92	4	1	83.3	9.7
EBTC-3	583.4	0.0	4	1	83.3	9.7
HARTS-RUN-BIRD	2725.0	1497.43	2	2	88.1	5.5
HARTS-RUN-QUIET	951.6	2332.77	2	2	88.1	5.5

Table 3.4 con't. Unconventional natural gas and landscape metrics for all aquatic survey sites (n=40) sampled 2013-2017

Site Name	Nearest well (m	*Upstream well (m)*	Number of Wells in FA	Number of Well Pads in FA	*%Forest*	*% Ag*
Hem-Porc	7607.2	None	4	2	91.7	6.6
Hem-Upper	7343.8	6943.4	4	2	91.7	6.6
HEM-WAYUP	1209.3	0	4	2	91.7	6.6
KettleCrk-Oleana	10620.3	12530.74	5	3	94.3	4.8
KettleCrk-Up	5915.0	5244.18	5	3	94.3	4.8
Germania Branch Low	3641.9	2854	5	3	94.3	4.8
Germania Branch Up	1211.8	1275.66	5	3	94.3	4.8
Sliders Branch	5645.3	13063	5	3	94.3	4.8
Kings-Low	1146.9	622.15	1	1	70.3	17.8
Kings-Mid	2097.0	3260.05	1	1	70.3	17.8
Kings-Up	1211.8	1275.66	1	1	70.3	17.8
Lick Run	953.4	456.92	38	10	98.7	0.3
Stone Run	1973.4	290	38	10	98.7	0.3
R.B. Hyner Run	967.5	2099.79	24	6	98.4	0.7
Spring Run	701.3	529.89	24	6	98.4	0.7
SC-Bible	5916.5	8585.3	9	3	70.2	18.8
SC-Middle	5883.7	None	9	3	70.2	18.8
Shenango-Upper	5645.3	13063	2	2	47.5	37.4
SPC1	6249.2	8942.22	9	3	98.3	0.3
SPC2	3322.6	5487.54	9	3	98.3	0.3
SPC3	4579.9	None	9	3	98.3	0.3
SPC4	5140.8	None	9	3	98.3	0.3
TBRCH-LOW	5135.6	5899.4	2	2	98.8	0.1
TBRCH-UP	1140.0	0	2	2	98.8	0.1
YC Main	2542.6	None	2	2	72.3	17.5
YC-MAIN- UP	1393.2	0	2	2	72.3	17.5
LYC	2542.6	None	2	2	72.3	17.5

Local Patterns

Investigation into specific focal areas revealed additional interesting patterns and results. One example of where water quality values were surprising was the Yellow Creek focal area, which exhibited high total dissolved solids (TDS) and conductivity readings over the course of the assessment coupled with a correspondingly low abundance and diversity of sensitive macroinvertebrate taxa. These statistics were not surprising given the high percent of agricultural land cover (Table 3.4.). What was surprising was the very high results for barium and strontium, two metals often associated with shale gas development, as Marcellus and Utica shale formations tend to have higher levels of barium and strontium than surface geologies (Chapman et al., 2012), which suggests there may be an influence from the shale gas development activity in the region (Figures 3.3, 3.4). We contacted the Indiana County Conservation District (ICCD) to ask if brine from conventional or unconventional gas wells was applied to dirt and gravel roads in the area and were told that this activity had not been conducted in the region for quite some time (ICCD, personal communication).

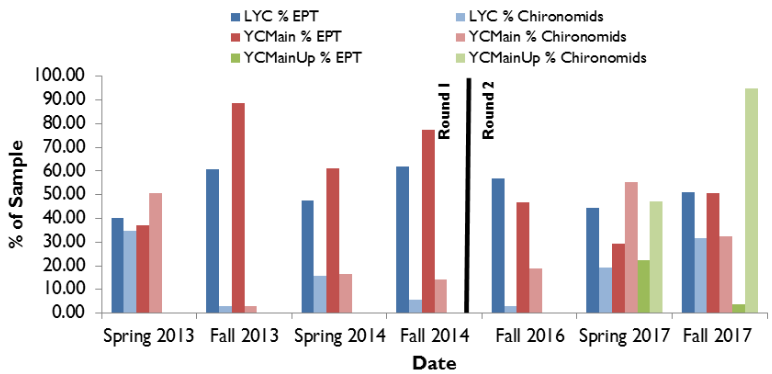


Figure 3.3. Increase in tolerant taxa in the Yellow Creek focal area.

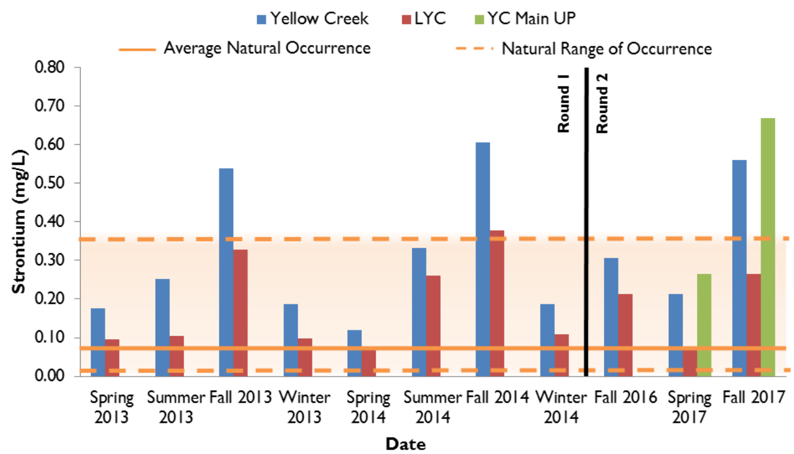


Figure 3.4. Strontium levels in the Yellow Creek watershed, Indiana County, PA from Spring 2013 to Fall 2017.

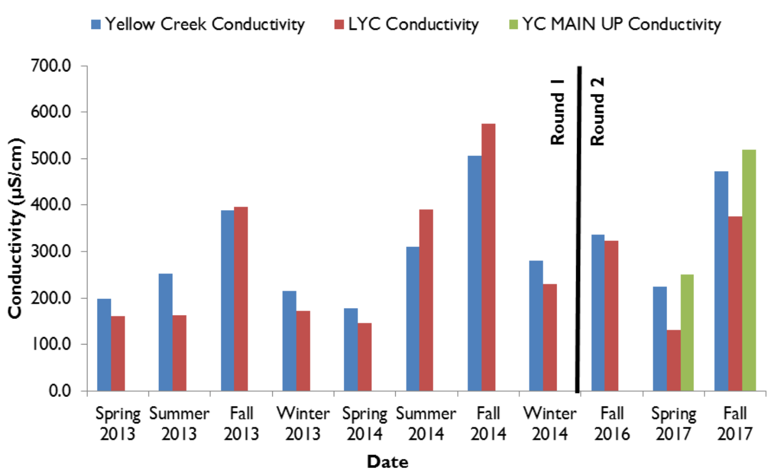


Figure 3.5. Elevated conductivity values mirror strontium levels in Yellow Creek focal area.

A second example of where land use history, land cover, and shale gas development activities are having an impact on water quality is in the Buffalo Creek (Washington County) focal area, where macroinvertebrate metrics recorded indicate depressed biological communities in all sampling locations within the focal area (Figure 3.6).

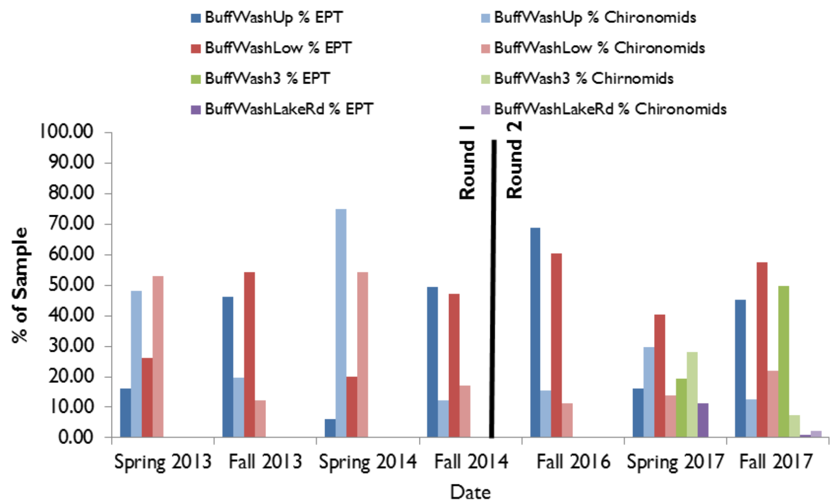


Figure 3.6. Macroinvertebrate metrics showing depressed biological communities in all locations in the Buffalo Creek – Washington County focal area.

In contrast to the Yellow Creek and Buffalo Creek (Washington County) focal areas, the Kettle Creek focal area was nearly 95% forested, one of the most forested focal areas within our assessment (Table 3.4). However, conductivity, barium, and strontium all were higher in the Germania Branch of Kettle Creek, with sampling points established downstream of unconventional natural gas well development in Round 2 sampling. Further, the values for these parameters were twice as high as the sampling location further downstream and at other points in the Kettle Creek focal area (Figures 3.7-3.9). The implications for these higher readings near the wells are not fully understood with regards to the macroinvertebrate community at Germania Branch as IBI scores indicated that these locations were not impaired in either spring or fall assessments (Table 3.2, Figure 3.10). Currently the macroinvertebrate community does not appear to be stressed; however, our data only represents a single year of monitoring and additional sampling needs to occur to determine how the observed values in water quality are impacting the macroinvertebrate community.

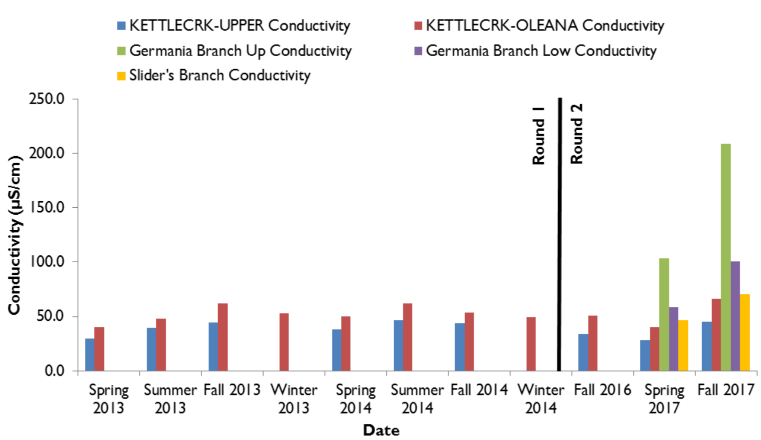


Figure 3.7. Increased conductivity readings closer to unconventional well activity in Potter County, PA.

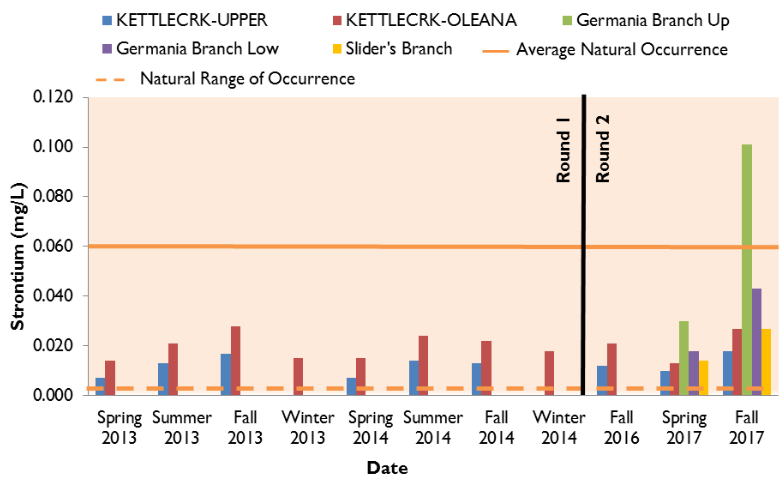


Figure 3.8. Elevated strontium readings in the Kettle Creek focal area.

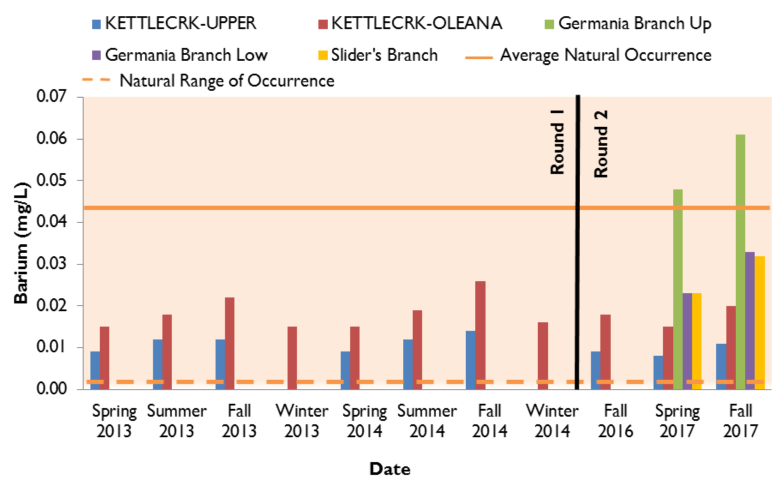


Figure 3.9. Elevated barium readings in the Kettle Creek focal area.

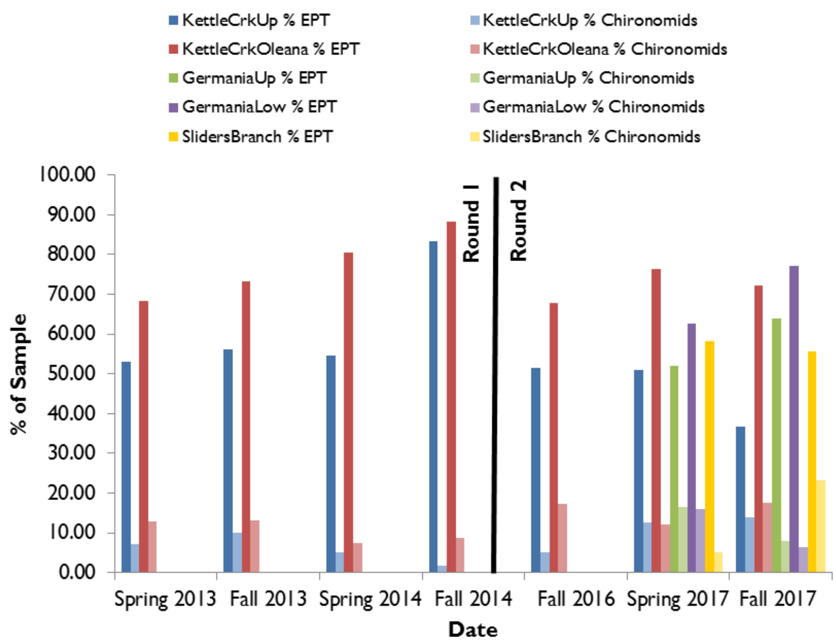


Figure 3.10. Macroinvertebrate communities in the Kettle Creek focal area. High levels of EPT taxa are common in this well forested watershed.

Investigation of macroinvertebrate diversity IBI may have also revealed patterns in stream health following development of shale gas infrastructure. In the East Branch Tionesta Creek focal area, we observed a dramatic difference in IBI scores at three sampling events at point EBTC3, which occurred prior to, and following the development of an unconventional natural gas well pad constructed and drilled in 2012, less than 500 m from the stream. The extended period of sampling was made possible by including data from DEP, which had surveyed in the area in 2005 and 2007 as part of their systematic watershed evaluation, prior to unconventional natural gas development began in the area. Data was access through Carnegie Museum of Natural History's Macroinvertebrate Water Monitoring Map (https://maps.carnegiemnh.org/macroinvertebrates/). Through combining the findings from our work with data from the DEP collected in 2003-2005, our assessment represented three time periods for this one sampling point: before development (collected by PA DEP from 2003-2005), just after development (2013-2014), and five years following development (2017). Our analysis appears to show a shift from a community dominated by sensitive taxa (EPT) according to DEP data to a less tolerating Chironomid-dominated community as indicated by our first round of data collection (2013-2014), which followed the development of a shale gas well pad in 2012; our second round of sampling activities (2017) indicated a recovery of the EPT community several years after shale gas development (Figure 3.11). This decline and subsequent recovery in sensitive taxa may be due to the development of the shale gas well pad upslope (< 500 m) of the stream (Table 3.6) or perhaps something else altogether. Water quality parameters (conductivity, barium, strontium) were generally similar for this sampling point between the two WPC survey rounds (Figures 3.12-3.14).

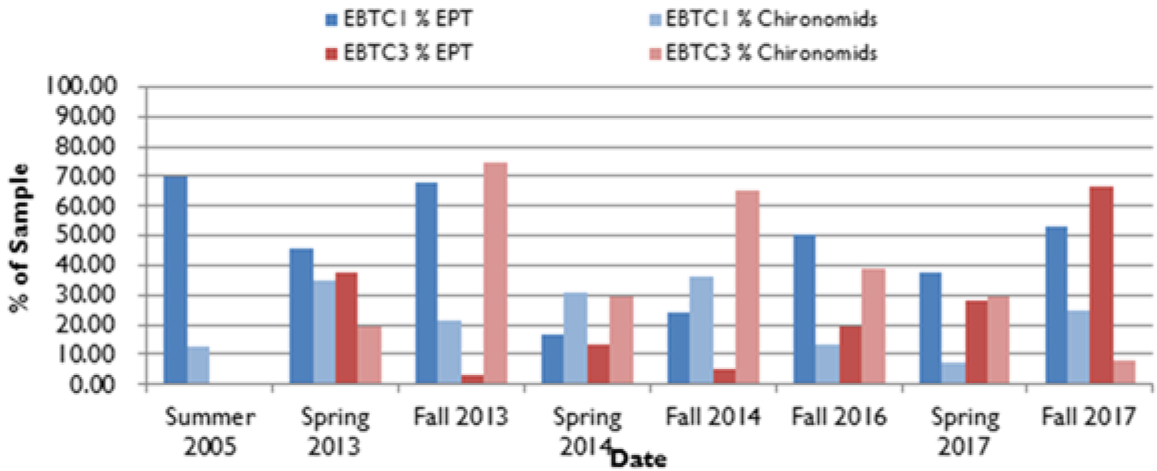


Figure 3.11. Changes in the macroinvertebrate community in East Branch Tionesta Creek focal area. There is a substantial drop in EPT taxa and increase in Chironomid dominance from the DEP data collected in 2005.

Table 3.6. Hilsenhoff, Shannon-Weiner diversity, and Index of Biological Integrity (IBI) indices in the East Branch Tionesta Creek watershed, McKean, Warren, and Elk counties, PA Spring 2013 – Fall 2017.

Index	Spring 2013	Fall 2013	Spring 2014	Fall 2014	Fall 2016	Spring 2017	Fall 2017	Mean	St. Dev.
EBTC1 (B)	4.57	4.08	6.22	5.70	5.46	5.68	4.35	5.15	0.81
EBTC1 (H)	2.20	2.29	2.18	1.87	2.19	2.36	2.38	2.21	0.17
EBTC1 (IBI)	49.70	50.30	44.50	39.20	50.10	42.70	54.30	47.26	5.26
EBTC3 (B)	4.53	5.71	6.30	8.66	5.50	5.63	5.08	5.92	1.33
EBTC3 (H)	2.29	0.93	1.81	1.04	2.01	2.28	2.18	1.79	0.58
EBTC3 (IBI)	46.30	24.10	33.70	29.10	50.10	39.10	39.50	37.41	9.19

While these results may indicate a short-term sedimentation impact and the apparent recovery, more streams need to be studied in this manner to determine if this pattern is consistent following development. This sampling point was the only one in our assessment where we had previously collected data representing predevelopment conditions within a kilometer of the activity.

It should also be noted that conductivity is considerably higher in fall 2013 and 2017 than at any other time during monitoring, which happens to occur at the same time as the only elevated readings recorded at these sites for strontium and barium as well (Figures 3.12 – 3.14). These elevated readings were higher than the recorded means at both sampling locations in the East Branch Tionesta Creek focal area, which were 101.0 µS/cm and 102.4 µS/cm, respectively, for our study period. These values are worth further investigation given their departure from the mean by over two standard deviations.

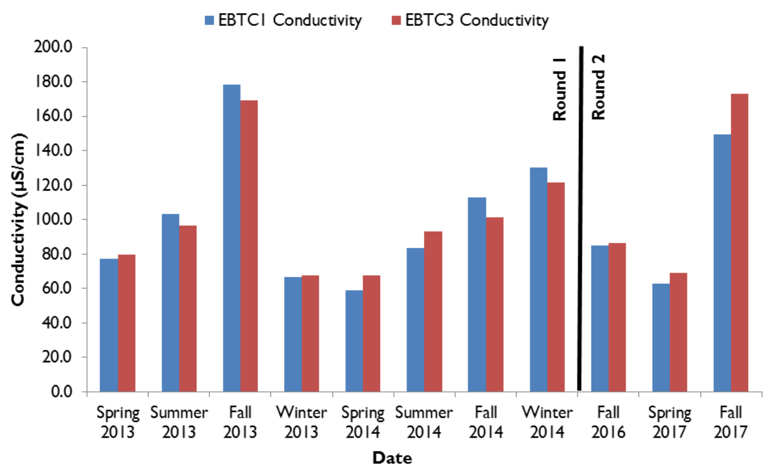


Figure 3.12. Conductivity values in the East Branch Tionesta Creek watershed, McKean, Warren, and Elk counties, PA from spring 2013 to fall 2017.

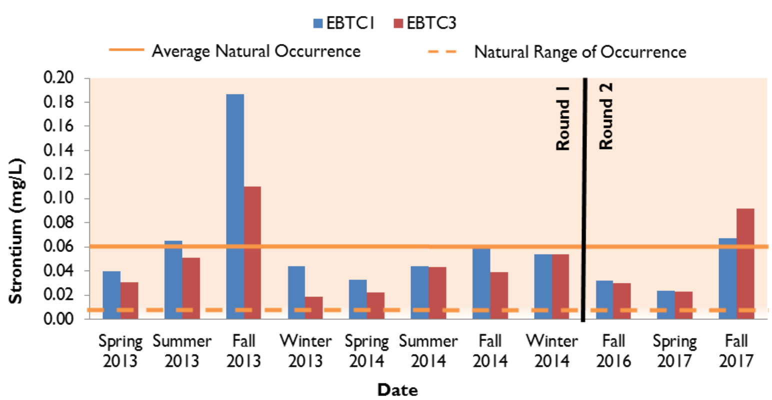


Figure 3.13. Strontium levels in the East Branch Tionesta Creek watershed, McKean, Warren, and Elk counties, PA from spring 2013 to fall 2017.

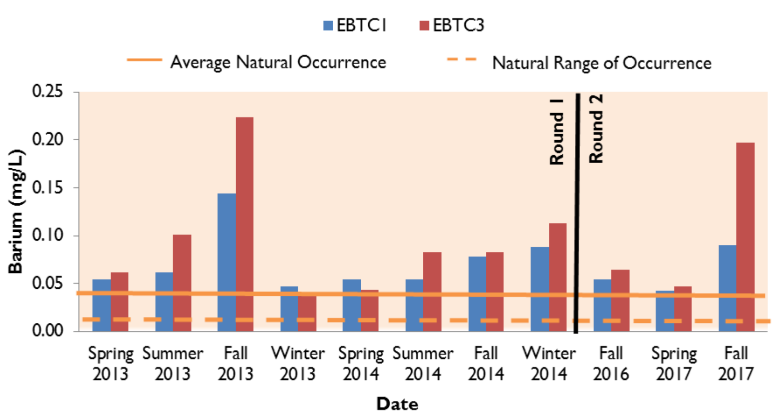


Figure 3.14. Barium levels in the East Branch Tionesta Creek watershed, McKean, Warren, and Elk counties, PA from spring 2013 to fall 2017.

It is widely believed that the cumulative effects of multiple sedimentation events from land clearing and fragmentation from shale gas development will result in an overall decline in the aquatic communities within a watershed over time (Johnson et al., 2010). However, from these findings, while limited in scope, suggests that invertebrate communities may be able to recover after disturbances if other variables remain constant including pH, dissolved oxygen, and water temperature. The ability to document changes over time is important to manage development activities and our findings demonstrate the importance of having both long-term data to assess possible changes at localized sites. Because of these short-term findings, continued monitoring in this watershed is needed to assess impacts over time. Our recommendation is to continue monitoring at this location in particular to gather additional years of data due to the importance of long term data sets to ascertain trends in biological communities (Doods et al., 2012).

Forests

Recent studies in heavily forested regions of Pennsylvania have indicated that gas development has negative impacts on forest interior birds and that as core forest is lost, forest interior birds are replaced by edge habitat species, readily adaptable to anthropogenic disturbance conditions (Barton et al., 2016; Thomas et al., 2014). The current consensus is that the most evident impacts observed from shale gas well pad development on forest plant communities and forest wildlife occur at the local scale, within 100 m of the well site.

Breeding birds are particularly good indicators of human impacts due to their dependence on specific habitat types and characteristics (Bradford et al., 1998; O'Connel et al., 2000). A number of bird species can adapt to human development and habitat conversion, and some even thrive in it – song sparrows, blue jays, and American robins. Other birds are more of habitat generalists, and in Pennsylvania forests there are quite a few species in this category – black-capped chickadees, Carolina wrens, and northern flickers among them. Habitat specialists such as mourning warblers or gray catbirds typically need regular disturbance regimes to maintain their early successional or shrub-dominated habitats. Forest interior-dwelling species of birds (FIDS), which tend to be area-sensitive, require large tracts of unfragmented and undeveloped mature forest (i.e., northern hardwoods, dry-oak heath, etc.) at least 100 m from hard edges like roads, housing developments, well pads, or pipelines.

While environmental contamination (Latta et al., 2015) and nesting survival and productivity (Franz et. al 2017) from development of deep shale gas resources is major cause for concern, we continue to be concerned about the continued alteration of avian communities due to fragmentation and development in forest lands in Pennsylvania. Natural gas development results in direct loss of forest interior habitat (Johnson et al., 2010), and creates a suite of edge effects that negatively impact the forest birds that call it home (Thomas et al., 2014; WPC, 2015).

From 2013-2014, the WPC conducted breeding bird surveys in 25 focal areas in Pennsylvania identified as being threatened by shale gas development (WPC, 2015). Within focal areas, we selected forest interior patches from an analysis of Pennsylvania forest patches (TNC and WPC, 2011) as the sampling unit for bird survey sites on the basis of size, accessibility, and suitability to represent focal areas across the shale play. Consistent with recent research on forest songbird communities (Thomas et al., 2014), we found that forests with fewer disturbances favored forest interior species, whereas forests with greater observed disturbances tended to favor edge or generalist species. Based on our evaluation of current habitat conditions, higher disturbance levels seem to contribute to the homogenization of bird communities across forest types – meaning, that over time, increased disturbance may lead an overall change in bird community diversity and loss of unique forest interior communities (WPC, 2015; Thomas et al., 2014).

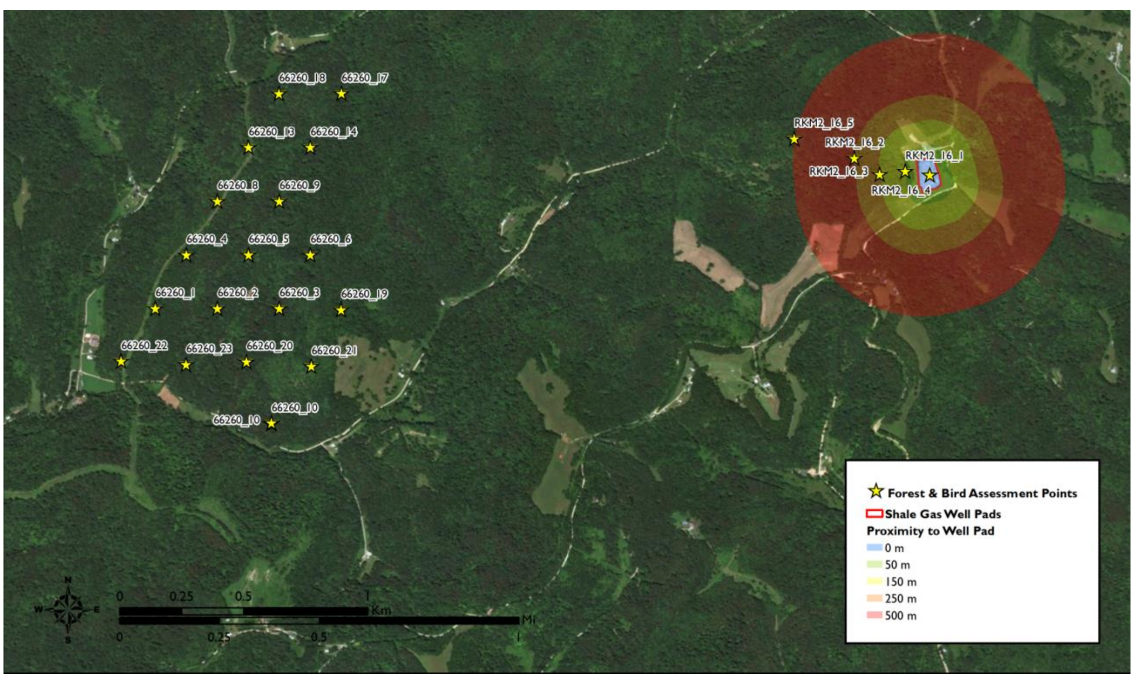
In 2017, we returned to focal areas where shale gas development activities had taken place to continue data collection in our reference forest patches in order to determine if landscape impacts within the focal areas caused by shale gas development negatively impacted forest interior birds and to establish monitoring locations near shale gas infrastructure, namely, well pads, which occurred in 15 of the original 35 focal areas (Figure 2.1) to assess the direct impacts of fragmentation on the forest community.

Monitoring Methods

Site selection

We selected 15 sites representing interior forest reference sites for bird monitoring within the 15 focal areas included in this study. Thirteen of the 15 sites had been visited previously from 2013-2014 as part of WPC's first shale gas assessment activities (WPC, 2015). Reference forest sites in Kings Creek and Yellow Creek were added so that each of the 15 included representative interior forest study areas. In addition to continuing baseline data collection of interior patches, we established assessment sites adjacent to active shale gas well pads to investigate direct impacts of development activities on forest interior species (Figure 3.15).

Figure 3.15. A typical assessment site with reference assessment points, located within interior forest habitat, and well pad assessment points, located adjacent to the well pads and extending into the forest interior within set distance bands (0 m, 50 m, 150 m, 250 m, and 500 m).



Bird monitoring sites were selected from within WPC focal areas using GIS. With the most significant shale gas development impacts for birds and their habitats coming as a result of forest fragmentation and loss, the focus for avian monitoring was placed on important areas for Forest Interior Dwelling Species (FIDS) of birds – those which require large, intact forest patches to maintain healthy populations. Results from the 2nd Atlas of Breeding Birds in Pennsylvania (2012) which indicate areas of high FIDS density were used to select focal areas among the highest 25% in the state, with most ranking among the highest 5-10% in the state.

Within focal areas, forest interior patches from the TNC/WPC analysis of Pennsylvania forest patches (TNC and WPC, 2011) were selected as the unit for baseline bird survey sites on the basis of size, accessibility and suitability to adequately represent focal areas. Using these forest interior patches, all survey points were placed at least 100 m from the forest edge. The Geospatial Modeling Environment (GME) suite of tools was used with R statistical software and ArcGIS to generate non-overlapping survey points spaced at a minimum of 250 m to adequately cover each interior forest patch selected as a survey site (Ralph et al., 1993; Ralph et al., 1995; Hamel et al., 1996; Martin et al., 1997; Heckscher, 2000; Forcey et al., 2006). Points were also stratified, as much as possible, by habitat types as mapped in TNC's Northeast Terrestrial Habitat Classification (NETHC) in GIS (Ferree and Anderson, 2013).

In addition to baseline sites, well pads developed within WPC focal areas were selected as impact study sites. A series of at least 5 non-overlapping points were placed at distance intervals relative to the well pad: 0m, 50m, 150m, 250m, and 500m. The placement of these points was also stratified according to NETHC. Bird surveys across distance classes were used to determine whether or not bird communities and their habitats are changing in response to well pad proximity (Barton et al., 2016).

Point Count Methods

Point count protocols vary considerably in terms of duration and the radius in which birds are counted. The protocol employed here is the one most generally used in recent and current breeding bird studies in the northeast region, accounting for 56% of the studies listed for the region in the USGS Bird Point Count Database (USGS, 2009). This protocol enabled the completion of 15-20 points per survey, depending on travel (walking) time between points as dictated by the navigability of the forest terrain.

Point count surveys were conducted during the height of the avian breeding season in Pennsylvania forests, between 25 May and 15 July (Wilson et al., 2012). At new reference forest sites, each point count location was surveyed twice during the season to account for intra-season variation and variation in bird detectability. Each round occurred during the following periods: 25 May – 18 June (early season) and 19 June – 15 July (late season). Sites having been surveyed 4 times during 2013-2014 were visited just once in 2017. Surveys were completed during the first five hours after sunrise when detection rates are most stable, generally between 0500 and 1000 EST (Ralph et al., 1993; Ralph et al., 1995; Wilson et al., 2012). Weather and wind conditions were recorded during each count following the Beaufort scale and standard weather codes, and no surveys were conducted during high wind conditions (>12 mph), dense fog, steady drizzle, snow, or prolonged rain (Martin et al., 1997).

Surveys at each reference forest point location were 5 minutes in duration, with counts split between an initial 3-minute period and the following 2-minute period. With travel time between point-count locations estimated at less than 15 minutes, this count length maximized the number of survey points across the sample area without compromising the quality of data from a single survey point (Ralph et al., 1995). Well pad point-count duration was 10 minutes with the addition of a 5-10min period and were visited just once during the breeding season.

All birds seen or heard within a 50 meter radius of each point were counted (Buskirk and McDonald 1995, Ralph et al., 1993, Ralph et al., 1995, Martin et al., 1997, Dettmers et al., 1999, Heckscher 2000), and birds were recorded in two subsequent distance bands 50-100m, and beyond 100m to enable density estimates to be made. Birds observed in each of the following categories: flying above the canopy or through habitat and new species encountered between points were recorded separately (Ralph et al., 1995). Singing males were noted to allow breeding population estimates. This bird data enabled abundance and diversity indices to be estimated for each reference site which can then be used to detect changes over time. New survey locations near focal area well pads will allow us to assess direct local scale impacts to forest bird communities.

Vegetation Surveys

Habitat conditions with significance to birds and disturbance was also assessed at each well pad and new baseline survey point following modifications of James and Shugart 1970; Hamel et al., 1996; Martin et al., 1997; and Weber et al., 2006). Vegetation and habitat condition data serves the purpose of tracking changes over time and aids in the detection of development impacts. Vegetation estimates were made for a 25m radius plot and disturbance will be assessed for a 50m radius plot, both centered on the point count location.

At the center of each point count location, elevation, aspect and slope was measured using Trimble GPS, compass and clinometer. Forest cover was classified according NatureServe plots categories: leaf type (broad-leaf, semi-broad-leaf, semi-needle-leaf, needle-leaf, broad-leaf herbaceous, graminoid, pteridophyte), leaf phenology (deciduous, semi-deciduous, evergreen, perennial, annual) and physiognomic type (forest, woodland, sparse woodland, scrub thicket, shrubland, dwarf shrubland, dwarf scrub thicket, sparse dwarf shrubland, herbaceous, non-vascular, sparsely vegetated). If known, community type was recorded according to the Pennsylvania plant community classification (Zimmerman et al., 2012). Each of the following was visually estimated for overstory canopy, mid-story canopy, shrub canopy, and herbaceous canopy: percent canopy cover and dominant species (≥ 40% cover). Maximum height of the dominant tree species in overstory canopy will be measured. Basal area for each point was recorded using a forestry prism (10 Basal Area Factor). The number of standing snags and live cavity trees were recorded within the 25m plot, along with the presence of water. The presence of invasive plant species was noted, and if present, dominant invasive species and estimated percent cover were recorded.

We assessed the condition of the forest through evaluating disturbance type and intensity within the 50m plot. Categorical percent cover (0,<1%, 1-5%, 6-10%, 11-25%, 26-50%, 51-75%, 76-100%) was estimated for infrastructure (paved roads, unpaved roads, power lines, paved trails), ground disturbance (large ditch, small ditch, grading, equipment tracks), vegetation alteration (pine plantation, recent clearcut, logging within 30 years, mowing, grazing, understory removal, deer browse), garbage, and natural disturbance (recent fire, blow downs, tree disease, tree pest, landslide). Disturbances from shale gas development was distinctly noted with an estimate of distance from point count location to activity including well pads, roads, and pipelines.

Forest Bird Data Analysis
Following previous work (WPC, 2015) and avian community assessments in the PA Wilds region of Pennsylvania (Sargent et al., 2017) We assigned each bird species recorded at the reference and well pad sites to one of ten habitat guilds based upon known habitat associations: Boreal Forest, Young Forest, Edge Habitat, Emergent Wetland, FIDS (Forest interior-dwelling species), Forest Generalist, Forested Wetland, Generalist, Grassland, and Wetland. Using 2013-2014 data, we assessed total bird diversity across all 15 reference sites by habitat guild richness and each reference site using habitat guild richness, Shannon diversity (*H'*), and evenness (*E*) (Nur et al., 1999). We determined richness as the cumulative number of bird species recorded at each site in each habitat guild. Shannon diversity is an index which accounts for both the number of species and their abundance and is used as a gauge of ecological condition. Evenness is another index which isolates the distribution of abundances across all species at a site (Nur et al., 1999).

We estimated the abundance of bird species at both the habitat guild level and at the individual species level and determined habitat guild abundance as a percentage of the overall abundance or number of detections across sites and within each site. To eliminate variation in observer abilities, double-counting possibilities, and other biases, we only used counts made within 100 m of each point location for abundance estimates. We estimated mean abundance and density for each survey year and across years for all sites and for each site individually. We based mean abundance on the maximum number of detections for each species per sample unit (i.e., point count area within a 100 m radius), and averaged them across all survey points at each site. We also calculated bird species detection frequency based on presence/absence across all points at each site within each year.

At well pad sites, we applied similar methods to estimate bird habitat guild abundance and richness at each of the five proximity classes: 0 m, 50 m, 150 m, 250 m, and 500 m. We then compared mean abundance and richness per point across these classes to assess how well pad development impacts bird communities near well pads and at distances more similar to natural forest (interior) conditions. All previous studies of this nature have been conducted in mostly unfragmented landscapes. Our study serves to answer questions of well pad development across areas that may include existing landscape fragmentation. Given this, our sampling design took care to isolate proximity influence of well pads versus other existing fragmenting features (e.g. roads, buildings, etc.). We acknowledge the difficulty in establishing this isolated assessment of well pad disturbance impacts, but feel confident that for all proximity classes except the farthest distance of 500 m, due to number and scale of other existing disturbance features in focal areas, we overall succeeded in this isolated evaluation (see below *Bird Response to Well Pads*).

All statistical analyses were performed using the PAST 3.19 statistical software. Data were inspected for normality and transformations were made to accommodate non-normality.

Results and Discussion

Bird Diversity 2017
We detected 88 bird species across 277 point locations at forest reference sites in 15 focal areas during our 2017 surveys. All habitat guilds were consistent with 2013 surveys and as in 2013, the highest richness was found in the Forest Interior guild, making up 38% of all species (Figure 3.16).

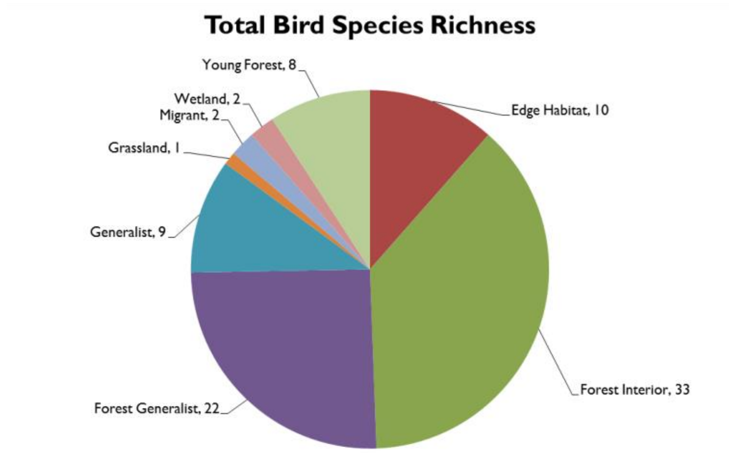


Figure 3.16. Bird species richness by habitat guild across all reference sites within 15 focal areas surveyed in 2017 (n =277).

Bird Abundance 2017

Forest interior birds dominated (>50% total abundance) reference site bird communities across all but one focal area (Figure 3.17, Table 3.7). Spring Creek was the only area where disturbance bird abundance was greater than forest interior bird abundance (44% vs 48%), but is also a site where a significant amount of disturbance from timber harvesting has occurred since 2013-2014. Forest interior bird abundance exceeded 70% at just five focal areas.

With a high level of shale gas activity, Lick Run still had a high total abundance of disturbance birds (40%), a slight increase from 2013, but also had an increase in forest interior bird abundance from 2013, pushing their total abundance to 55%. Spring Creek, The Branch, and Lick Run were the only focal areas where disturbance bird abundance totaled more than 20%.

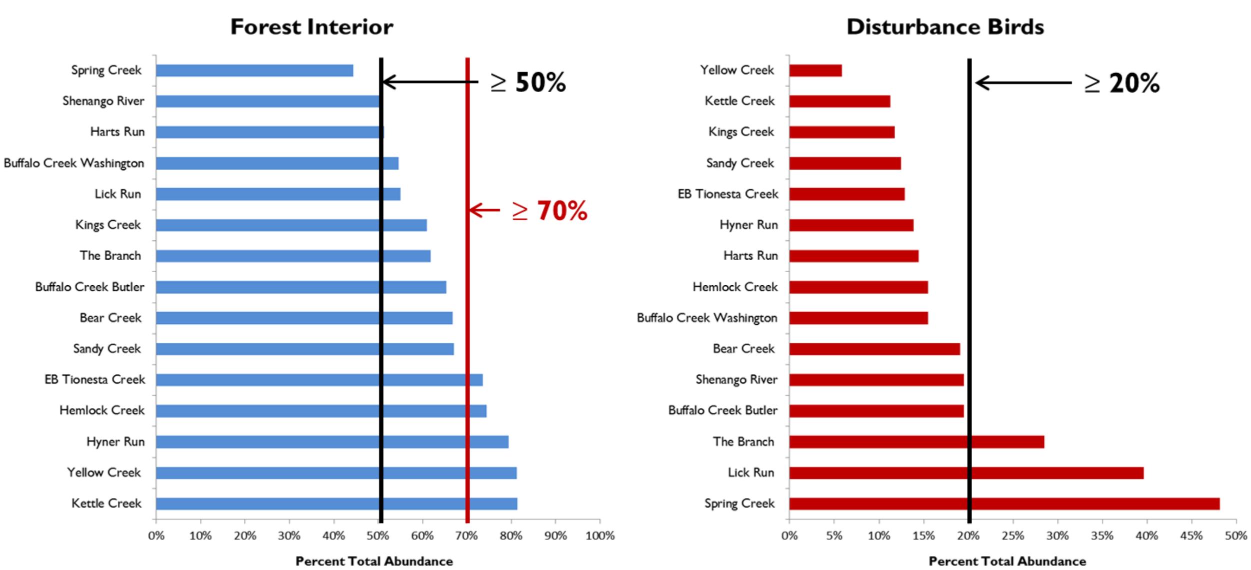


Figure 3.17. Percent total abundance as proportion of total detections by site for forest interior birds (FIDS) and disturbance-associated birds (Edge Habitat and Young Forest).

Table 3.7. Individual bird species mean2017 relative abundance across all reference survey locations (n=277) with standard error.

Species	2017 Mean RA	2017 SE (+/-)
Acadian Flycatcher	0.27	0.04
Alder Flycatcher	0.01	0.01
American Crow	0.09	0.04
American Goldfinch	0.01	0.01
American Redstart	0.16	0.03
American Robin	0.15	0.02
Barred Owl	0.01	0.01
Baltimore Oriole	0.02	0.01
Black-and-white Warbler	0.14	0.02
Black-capped Chickadee	0.12	0.02
Blue-gray Gnatcatcher	0.03	0.01
Brown-headed Cowbird	0.09	0.02
Blue-headed Vireo	0.19	0.03
Blackburnian Warbler	0.24	0.03
Blue Jay	0.27	0.04
Brown Creeper	0.03	0.01
Black-throated Blue Warbler	0.25	0.03
Black-throated Green Warbler	0.55	0.05
Broad-winged Hawk	0.00	0.00
Blue-winged Warbler	0.05	0.02
Carolina Chickadee	0.03	0.01
Carolina Wren	0.03	0.01
Canada Warbler	0.04	0.01
Cedar Waxwing	0.28	0.12
Cerulean Warbler	0.04	0.01
Chipping Sparrow	0.01	0.01
Chimney Swift	0.01	0.01
Common Merganser	0.00	0.00
Common Yellowthroat	0.24	0.03
Chestnut-sided Warbler	0.27	0.04
Dark-eyed Junco	0.05	0.01
Downy Woodpecker	0.06	0.02

Table 3.7 con't. Individual bird species mean2017 relative abundance across all reference survey locations (n=277) with standard error.

Species	2017 Mean RA	2017 SE (+/-)
Eastern Kingbird	0.00	0.00
Eastern Phoebe	0.01	0.01
Eastern Towhee	0.44	0.05
Easter Wood-Pewee	0.11	0.02
Field Sparrow	0.01	0.01
Great Blue Heron	0.01	0.01
Great Crested Flycatcher	0.01	0.01
Golden-crowned Kinglet	0.00	0.00
Gray Catbird	0.10	0.02
Hairy Woodpecker	0.07	0.02
Hermit Thrush	0.08	0.02
Hooded Warbler	0.50	0.08
House Wren	0.01	0.01
Indigo Bunting	0.17	0.04
Kentucky Warbler	0.05	0.01
Least Flycatcher	0.01	0.01
Louisiana Waterthrush	0.04	0.02
Magnolia Warbler	0.15	0.03
Mourning Dove	0.06	0.01
Mourning Warbler	0.01	0.01
Northern Cardinal	0.18	0.04
Northern Flicker	0.05	0.01
Northern Parula	0.02	0.01
Northern Rough-winged Swallow	0.00	0.00
Ovenbird	0.84	0.07
Pileated Woodpecker	0.02	0.01
Rose-breasted Grosbeak	0.26	0.03
Red-bellied Woodpecker	0.13	0.02
Red-eyed Vireo	1.75	0.14
Red-tailed Hawk	0.01	0.01
Ruby-throated Hummingbird	0.00	0.00
Ruffed Grouse	0.00	0.00
Red-winged Blackbird	0.01	0.01

Table 3.7 con't. Individual bird species mean2017 relative abundance across all reference survey locations (n=277) with standard error.

Species	2017 Mean RA	2017 SE (+/-)
Scarlet Tanager	0.45	0.04
Song Sparrow	0.06	0.02
Swamp Sparrow	0.00	0.00
Swainson's Thrush	0.01	0.01
Tennessee Warbler	0.01	0.01
Tufted Titmouse	0.31	0.06
Veery	0.10	0.03
White-breasted Nuthatch	0.07	0.02
Worm-eating Warbler	0.03	0.01
Winter Wren	0.04	0.01
Wood Thrush	0.25	0.03
Yellow-billed Cuckoo	0.03	0.01
Yellow-bellied Sapsucker	0.09	0.02
Yellow Warbler	0.04	0.02
Yellow-rumped Warbler	0.02	0.01
Yellow-throated Vireo	0.02	0.01
Yellow-throated Warbler	0.01	0.01

Reference Sites Comparison (2013-2014 and 2017)

Table 3.8, below, represents a quantitative comparison of individual species abundance and frequency from 2013-2014 to 2017. We were able to compare mean abundance and frequency for 85 species recorded during point count surveys within 100 m radius of 190 survey points across 10 focal areas. Five focal areas surveyed in 2017 were not included in our 2013-2014 sampling and were excluded from this comparison. As a measure of comparison, we calculated percent change in abundance, average number of singing birds detected per point, and change in frequency, number of points at which singing birds were detected.

Table 3.8. Comparison of bird species mean abundance, with standard error, and frequency from 2013-2014 to 2017 across 10 focal areas sampled during both project phases (n=190).

Species	2013-2014 Mean RA	±SE	2017 Mean RA	±SE	RA Change	2013-2014 Max Freq	2017 Freq	Freq Change
Acadian Flycatcher	0.49	0.06	0.22	0.04	**-55%**	0.27	0.17	**-37%**
Alder Flycatcher	0.01	0.01	0.00	0.00	**-100%**	0.01	0.00	**-100%**
American Crow	0.06	0.02	0.12	0.06	109%	0.02	0.04	75%
American Goldfinch	0.02	0.01	0.01	0.01	**-33%**	0.02	0.01	**-33%**
American Redstart	0.53	0.05	0.18	0.03	**-66%**	0.30	0.15	**-51%**
American Robin	0.47	0.05	0.13	0.03	**-73%**	0.26	0.11	**-59%**
Barred Owl	0.01	0.01	0.01	0.01	0%	0.01	0.01	**-50%**
Baltimore Oriole	0.01	0.01	0.00	0.00	**-100%**	0.01	0.00	**-100%**
Black-and-white Warbler	0.48	0.04	0.21	0.03	**-57%**	0.31	0.18	**-40%**
Black-billed Cuckoo	0.02	0.01	0.00	0.00	**-100%**	0.02	0.00	**-100%**
Black-capped Chickadee	0.32	0.04	0.06	0.02	**-82%**	0.17	0.05	**-70%**
Blue-gray Gnatcatcher	0.08	0.02	0.02	0.01	**-75%**	0.05	0.02	**-56%**
Brown-headed Cowbird	0.08	0.02	0.09	0.03	13%	0.06	0.06	9%
Blue-headed Vireo	0.37	0.05	0.13	0.03	**-64%**	0.23	0.13	**-45%**
Blackburnian Warbler	0.33	0.04	0.21	0.04	**-37%**	0.24	0.17	**-27%**
Blue Jay	0.61	0.07	0.26	0.04	**-58%**	0.26	0.17	**-33%**
Brown Creeper	0.04	0.01	0.01	0.01	**-71%**	0.03	0.01	**-67%**
Brown Thrasher	0.02	0.01	0.00	0.00	**-100%**	0.01	0.00	**-100%**
Black-throated Blue Warbler	0.65	0.06	0.31	0.05	**-52%**	0.35	0.23	**-33%**
Scarlet Tanager	1.12	0.05	0.42	0.05	**-63%**	0.64	0.33	**-49%**
Broad-winged Hawk	0.03	0.01	0.00	0.00	**-100%**	0.02	0.00	**-100%**
Blue-winged Warbler	0.06	0.02	0.06	0.02	9%	0.03	0.04	33%
Carolina Chickadee	0.07	0.03	0.01	0.01	**-86%**	0.03	0.01	**-67%**
Carolina Wren	0.04	0.02	0.03	0.01	**-25%**	0.02	0.03	50%
Canada Warbler	0.15	0.03	0.06	0.02	**-62%**	0.08	0.04	**-50%**
Cedar Waxwing	0.19	0.04	0.28	0.17	47%	0.09	0.09	0%
Cerulean Warbler	0.13	0.03	0.06	0.02	**-54%**	0.07	0.04	**-43%**

Table 3.8 con't. Comparison of bird species mean abundance, with standard error, and frequency from 2013-2014 to 2017 across 10 focal areas sampled during both project phases (n=190).

Species	2013-2014 Mean RA	±SE	2017 Mean RA	±SE	RA Change	2013-2014 Max Freq	2017 Freq	Freq Change
Chipping Sparrow	0.06	0.02	0.02	0.01	**-75%**	0.05	0.02	**-70%**
Common Grackle	0.01	0.01	0.00	0.00	**-100%**	0.01	0.00	**-100%**
Cooper's Hawk	0.01	0.01	0.00	0.00	**-100%**	0.01	0.00	**-100%**
Common Yellowthroat	0.58	0.05	0.25	0.04	**-58%**	0.33	0.21	**-37%**
Chestnut-sided Warbler	0.56	0.06	0.30	0.05	**-46%**	0.26	0.18	**-32%**
Dark-eyed Junco	0.25	0.04	0.03	0.01	**-88%**	0.14	0.03	**-81%**
Downy Woodpecker	0.07	0.02	0.07	0.02	8%	0.04	0.07	86%
Eastern Kingbird	0.01	0.01	0.00	0.00	**-100%**	0.01	0.00	**-100%**
Eastern Phoebe	0.04	0.02	0.01	0.01	**-88%**	0.02	0.01	**-67%**
Eastern Towhee	1.39	0.08	0.52	0.06	**-63%**	0.58	0.35	**-39%**
Eastern Wood-Pewee	0.27	0.03	0.08	0.02	**-69%**	0.18	0.08	**-54%**
Field Sparrow	0.03	0.01	0.02	0.01	**-50%**	0.02	0.02	0%
Great Blue Heron	0.01	0.01	0.01	0.01	0%	0.01	0.01	**-50%**
Great Crested Flycatcher	0.06	0.02	0.01	0.01	**-92%**	0.05	0.01	**-89%**
Gray Catbird	0.13	0.03	0.11	0.03	**-17%**	0.07	0.08	7%
Hairy Woodpecker	0.12	0.02	0.04	0.02	**-65%**	0.07	0.04	**-50%**
Hermit Thrush	0.19	0.03	0.07	0.02	**-64%**	0.11	0.05	**-50%**
Hooded Warbler	0.88	0.07	0.57	0.11	**-35%**	0.45	0.30	**-34%**
House Wren	0.00	0.00	0.01	0.01	n/a	0.00	0.01	n/a
Indigo Bunting	0.28	0.04	0.19	0.05	**-32%**	0.17	0.13	**-22%**
Kentucky Warbler	0.14	0.03	0.05	0.02	**-67%**	0.11	0.05	**-57%**
Least Flycatcher	0.04	0.02	0.00	0.00	**-100%**	0.02	0.00	**-100%**
Louisiana Waterthrush	0.08	0.02	0.03	0.02	**-69%**	0.07	0.02	**-77%**
Magnolia Warbler	0.13	0.03	0.14	0.03	4%	0.09	0.12	22%
Mourning Dove	0.09	0.02	0.05	0.02	**-47%**	0.07	0.05	**-31%**
Mourning Warbler	0.02	0.01	0.02	0.01	33%	0.01	0.02	50%
Northern Cardinal	0.32	0.04	0.17	0.05	**-46%**	0.19	0.13	**-33%**

Table 3.8 con't. Comparison of bird species mean abundance, with standard error, and frequency from 2013-2014 to 2017 across 10 focal areas sampled during both project phases (n=190).

Species	2013-2014 Mean RA	±SE	2017 Mean RA	±SE	RA Change	2013-2014 Max Freq	2017 Freq	Freq Change
Northern Flicker	0.21	0.03	0.05	0.02	**-77%**	0.12	0.05	**-61%**
Northern Parula	0.01	0.01	0.03	0.02	500%	0.01	0.02	300%
Ovenbird	1.81	0.08	0.86	0.09	**-52%**	0.73	0.58	**-20%**
Pileated Woodpecker	0.06	0.02	0.01	0.01	**-82%**	0.04	0.01	**-71%**
Purple Finch	0.02	0.01	0.00	0.00	**-100%**	0.01	0.00	**-100%**
Rose-breasted Grosbeak	0.62	0.05	0.23	0.03	**-63%**	0.33	0.21	**-37%**
Red-bellied Woodpecker	0.15	0.03	0.14	0.03	**-10%**	0.12	0.13	9%
Black-throated Green Warbler	0.83	0.06	0.56	0.06	**-32%**	0.43	0.39	**-10%**
Ruby-throated Hummingbird	0.04	0.01	0.01	0.01	**-88%**	0.03	0.01	**-80%**
Ruffed Grouse	0.03	0.01	0.01	0.01	**-80%**	0.02	0.01	**-67%**
Red-winged Blackbird	0.00	0.00	0.01	0.01	n/a	0.00	0.01	n/a
Red-eyed Vireo	2.29	0.08	1.81	0.20	**-21%**	0.90	0.82	**-9%**
Song Sparrow	0.07	0.02	0.03	0.01	**-64%**	0.05	0.03	**-44%**
Sharp-shinned Hawk	0.01	0.01	0.00	0.00	**-100%**	0.01	0.00	**-100%**
Swamp Sparrow	0.02	0.01	0.00	0.00	**-100%**	0.02	0.00	**-100%**
Tennessee Warbler	0.00	0.00	0.01	0.01	n/a	0.00	0.01	n/a
Tufted Titmouse	0.28	0.04	0.33	0.08	19%	0.16	0.20	23%
Veery	0.43	0.05	0.11	0.03	**-74%**	0.23	0.07	**-67%**
White-breasted Nuthatch	0.33	0.04	0.05	0.02	**-86%**	0.18	0.05	**-74%**
White-eyed Vireo	0.01	0.01	0.00	0.00	**-100%**	0.01	0.00	**-100%**
Worm-eating Warbler	0.03	0.01	0.03	0.01	0%	0.03	0.03	0%
Wild Turkey	0.03	0.02	0.00	0.00	**-100%**	0.02	0.00	**-100%**
Winter Wren	0.07	0.02	0.04	0.02	**-38%**	0.04	0.04	**-13%**
Wood Duck	0.01	0.01	0.00	0.00	**-100%**	0.01	0.00	**-100%**
Wood Thrush	0.81	0.08	0.19	0.03	**-76%**	0.38	0.16	**-58%**
Yellow-billed Cuckoo	0.11	0.02	0.04	0.01	**-65%**	0.07	0.04	**-46%**
Yellow-bellied Sapsucker	0.32	0.04	0.11	0.03	**-66%**	0.19	0.09	**-50%**

Table 3.8 con't. Comparison of bird species mean abundance, with standard error, and frequency from 2013-2014 to 2017 across 10 focal areas sampled during both project phases (n=190).

Species	2013-2014 Mean RA	±SE	2017 Mean RA	±SE	RA Change	2013-2014 Max Freq	2017 Freq	Freq Change
Yellow Warbler	0.03	0.01	0.04	0.02	17%	0.02	0.02	33%
Yellow-rumped Warbler	0.01	0.01	0.03	0.01	150%	0.01	0.02	300%
Yellow-throated Vireo	0.03	0.01	0.02	0.01	**-50%**	0.02	0.02	0%
Yellow-throated Warbler	0.01	0.01	0.01	0.01	0%	0.01	0.01	0%

The overall trend was a widespread decrease in both abundance and frequency, as 67 bird species decreased in abundance by 10% or more and 64 bird species decreased in frequency by 9% or more. Due to some of these species being quite uncommon in our dataset, we chose to focus on just bird species which were detected across at least 15% of survey points during both sampling periods. This group included 17 bird species: 12 Forest Interior birds, 3 Young Forest birds, one Forest Generalist, and one Edge Habitat species. Tufted titmouse, a Forest Generalist, was the only species with an increase in abundance (19%) and an increase in frequency (23%), while all other species showed a negative change.

The largest negative change was seen in the long distance Neotropical migrant and Forest Interior breeding wood thrush, with a 58% decrease in frequency and a 76% decrease in abundance (Table 3.8). In fact, 14 of the 17 bird species in this comparison were long distance migrants and all but the common yellowthroat, were also Forest Interior birds. Rounding out the top five species with the greatest negative change in abundance was American redstart at -66%, and three species at -63%: scarlet tanager, rose-breasted grosbeak, and eastern towhee. After wood thrush, the greatest negative change in frequency was found in American redstart (-51%), scarlet tanager (-49%), and black-and-white warbler (-40%).

These results certainly offer us more questions than answers. Even though we cannot say unequivocally that bird populations are declining in these focal areas, there may be several factors contributing to the decreases we see in our 10 site sub-sample. First, our original baseline included an additional survey visit which was not done during 2017 surveys. It is possible that weather, different observers, and annual variation all contributed to some of these negative changes. But it should also be noted that many of the species with the greatest losses are also some of the most easily detectable birds, like the wood thrush which is a frequent, loud singer detectable from distances of 200 m. Likewise, wood thrush has become a prime example of a common Neotropical migrant in decline at the continental scale, as a result of forest habitat loss and fragmentation both here on the breeding grounds and on wintering grounds in Central America (Evans et al., 2011). Many of our Forest Interior breeding birds are long distance migrants and face the same perils of forest loss in both Northern and Southern hemispheres. Not only are they losing habitat coming and going, but also these birds suffer immense direct mortalities annually from building window collisions and outdoor cats (Loss et al., 2014; Loss et al., 2015).

The most significant conclusion from this component of our assessment is that more investigation is needed. Long-term monitoring is just that – long-term, and in order to further understand whether or not forest birds are declining across these focal areas, we will need to commit more resources to continue monitoring and building this dataset over the coming years. With additional surveys and analysis, we should begin to see a clearer picture of these trends in abundance and frequency.

Bird Response to Well Pad Development

We surveyed birds and plant communities at 31 well pads sited in forest habitat across 13 WPC focal areas. Well pads sited in non-forest within focal areas were not considered for surveys. WPC's Sandy Creek and Shenango River focal areas did not contain well pads within a forested landscape context. Well pads were distributed across private and public land ownership, with nearly 40% located on private lands. Survey point locations were distributed evenly around well pads according to five distance bands from the well pad perimeter: well pad center or 0 m (n = 31), 50 m (n =31), 150 m (n=34), 250 m (n=35), and 500 m (n=37).

We examined how forest birds responded to the well pad disturbance by focusing on the diversity, or species richness, and abundance of each of three habitat guilds: forest interior birds (FIDS), Edge Habitat species, and Young Forest species. We first tested for significant differences in mean richness (per point) across each bird habitat guild as proximity to well pad changed using Kruskal-Wallis and Mann-Whitney pairwise tests, when appropriate. Mean richness significantly differed across proximity classes for FIDS ($p<0.001$, $H_c = 30.96$) and Edge Habitat ($p = 0.002$, $H_c = 17.07$) guilds but not for Young Forest birds ($p = 1.00$, $H_c = -93.62$). Figure 3.18 graphically depicts the nature of these differences and Table 3.9. indicates significance values for pairwise comparisons for FIDS and Edge Habitat birds.

Mean richness of Young Forest birds, those associated with dense vegetation and successional states, was highest at 150m from the well pad, but did not vary significantly across all proximity classes. Mean richness of Edge Habitat birds, those most adaptable to anthropogenic disturbance, was significantly higher at the well pad ($\bar{x} = 3.34$, SD = 1.13) when compared to all other proximity classes (Table 3.9, Figure 3.18). Mean FIDS richness showed the inverse relationship with reduced diversity at the well pad and at 50m. While FIDS richness was not significantly different between 0m and 50m, FIDS richness was significantly higher when each of these classes was compared to farther proximity classes (Table 3.9). FIDS richness increased steadily with increasing distance from the well pad to a maximum ($\bar{x} = 5.66$, SD = 2.24) at 250 m. No significant difference was found among comparisons of 150 m, 250 m, or 500 m classes, indicating that 150 m is likely the distance from a well pad disturbance near which FIDS diversity returns to a natural level.

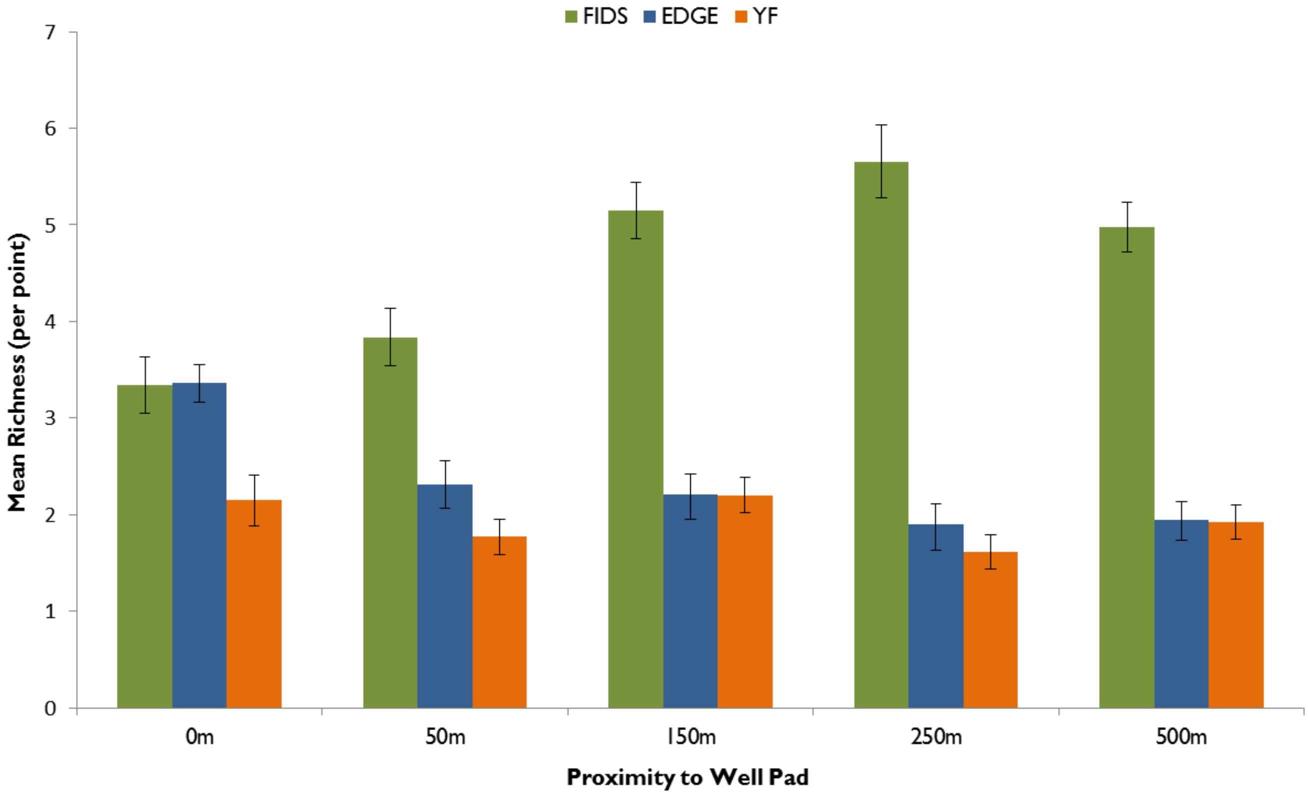


Figure 3.18. Mean number of bird species richness, by guild, recorded across all well pad survey locations (n=168), grouped by proximity to well pad disturbance. Standard error bars are shown.

Table 3.9. P-value results of Mann-Whitney pairwise comparisons of bird species richness by habitat guild across well pad proximity groups. Shaded p-values indicate significance.

Comparison	EDGE	Higher Richness	FIDS	Higher Richness	YF	Higher Richness
0m vs 50m	0.001	0m	0.256	--	--	--
0m vs 150m	0.003	0m	>0.001	150m	--	--
0m vs 250m	>0.001	0m	>0.001	250m	--	--
0m vs 500m	>0.001	0m	>0.001	500m	--	--
50m vs 150m	0.930	--	0.003	150m	--	--
50m vs 250m	0.219	--	0.001	250m	--	--
50m vs 500m	0.467	--	0.004	500m	--	--
150m vs 250m	0.322	--	0.346	--	--	--
150m vs 500m	0.521	--	0.698	--	--	--
250m vs 500m	0.563	--	0.201	--	--	--

We looked for significant differences in bird habitat guild abundance across the well pad proximity classes using Kruskal-Wallis and Mann-Whitney pairwise tests. All three guilds showed significant differences in abundance as distance increased from the well pad; Edge Habitat ($p<0.001$, Hc= 48.71), FIDS ($p<0.001$, Hc= 68.06), and Young Forest ($p=0.001$, Hc= 16.3). Edge Habitat species were most abundant at 0 m and decreased rapidly as distance from the well pad increased (Figure 3.20). Edge Habitat species thrive at the well pad, with nearly five times as many individuals detected when compared to 150m away. At 500m from the well pad, the average abundance of this group of birds is reduced to just 12.5% of what is found at the well pad. FIDS showed an opposite pattern with their lowest abundance found at the well pad (0 m) and reaching their highest abundance at 250 m with similar abundance found at 500 m. FIDS abundance at the well pad was just 13.5% of what was found at 250m into surrounding forest with a substantial increase in abundance from 50 m to 150 m from the well pad. Young Forest bird abundance was highest at 50 m followed by 0m and decreased from 50 m to 500 m. Generally, these differences were found to be significant through pairwise comparisons (Table 3.10).

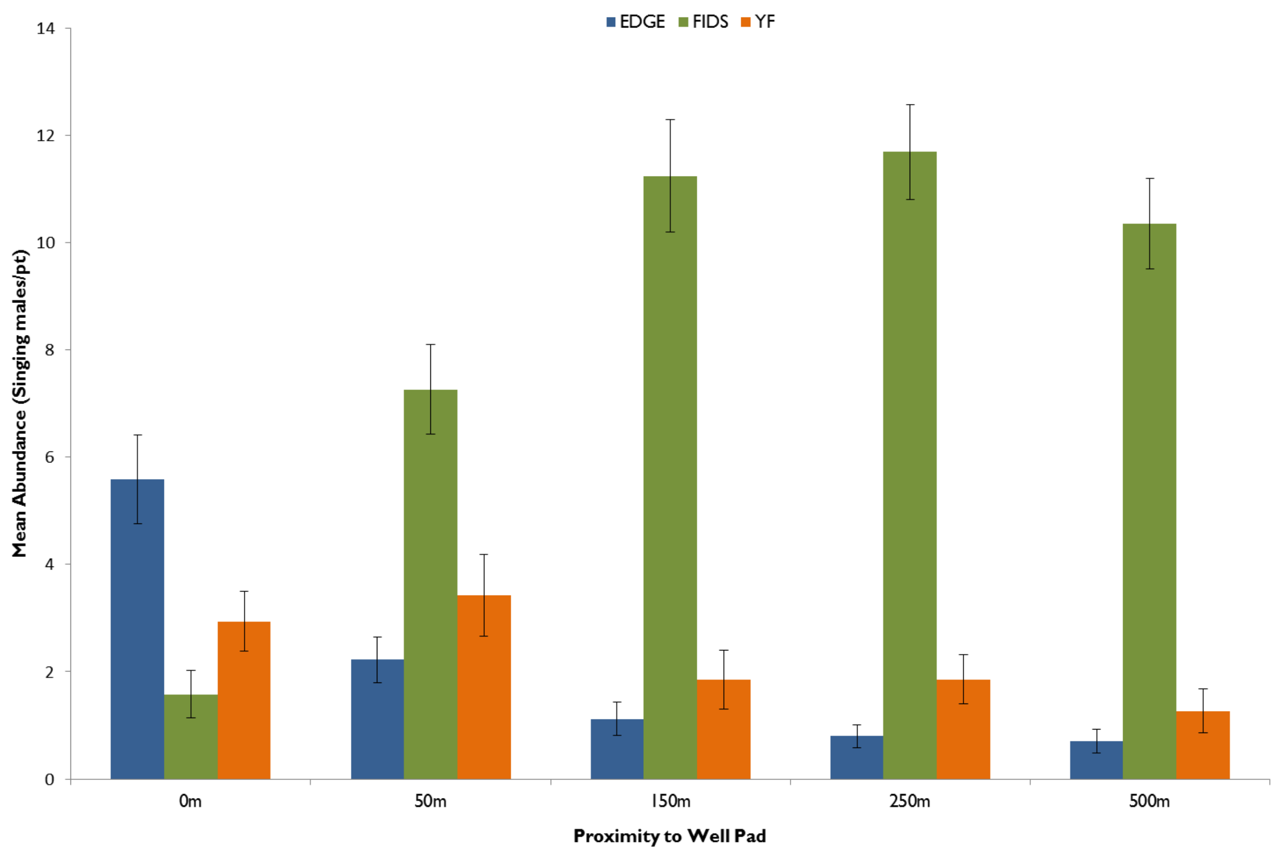


Figure 3.20. Mean bird abundance as singing males per point, limited to 100 m radius of survey point, grouped by guild across all well pad survey locations (n=168), classified by proximity to well pad disturbance. Standard error bars are shown.

Table 3.10. P-value results of Mann-Whitney pairwise comparisons of bird abundance by habitat guild across well pad proximity groups. Shaded p-values indicate significance.

Comparison	Edge Habitat	Higher Abundance	Forest Interior	Higher Abundance	Young Forest	Higher Abundance
0m vs 50m	0.001	0m	>0.001	50m	0.699	--
0m vs 150m	>0.001	0m	>0.001	150m	0.026	50m
0m vs 250m	>0.001	0m	>0.001	250m	0.071	0m
0m vs 500m	>0.001	0m	>0.001	500m	0.001	0m
50m vs 150m	0.007	50m	0.006	150m	0.015	50m
50m vs 250m	0.001	50m	0.001	250m	0.035	50m
50m vs 500m	>0.001	50m	0.014	500m	0.001	50m
150m vs 250m	0.714	--	0.552	--	0.472	--
150m vs 500m	0.298	--	0.674	--	0.325	--
250m vs 500m	0.473	--	0.263	--	0.074	--

Edge Habitat bird abundance was significantly higher at both 0 m and 50 m when compared to farther proximity classes equated to more natural or undisturbed forest conditions. Conversely, FIDS abundance was significantly higher at 150 m or greater when compared to proximity classes nearest the well pad and having the highest levels of shale gas disturbance. Finally, Young Forest bird abundance was significantly higher at 50 m versus farther proximity classes and was significantly higher at 0m compared to the two farthest distance bands (Table 3.10).

Fragmentation

Prior to European settlement, forest covered more than 90 percent of the area that became Pennsylvania (Goodrich et al., 2003). Current estimates suggest that forest cover today is approximately 58 percent of the state, comprising an area of 6.8 million hectares (16.9 million ac) (McCaskill et al,. 2009; Albright, 2016). Although forest still dominates as the majority land cover in Pennsylvania, the forest cover that remains is largely fragmented, with less than half the overall forest composition comprised of core forest (Goodrich et al., 2003).

Fragmentation of contiguous forested landscapes into smaller, isolated tracts has an effect on plant and animal distribution and community composition. Large forest patches that become fragmented, or split into pieces, result in forest islands that may lack habitats that existed in the original tract, or may be smaller than the minimum area required by specific species (Lynch and Whigham, 1984). Along with a reduction in total forested area, forest fragmentation creates a suite of edge effects which can extend 1,000 feet into the remaining forest patch (Forman and Deblinger, 2000). The area classified as edge forest is composed of a zone of altered microclimate and contrasting community structure distinct from the interior or core forest (Matlack, 1993). Edge effects include increased light intensity, reduced depth of the leaf-litter layer, and altered plant and insect abundance (Yahner, 1995; Haskell, 2000; Watkins et al., 2003). Additionally, a number of studies have shown that the nesting success of forest interior songbirds is lower near forest edges than in the interior, due to increased densities of nest predators, brood parasites, and changing environmental conditions (Faaborg et al., 1995, Manolis et al., 2002).

Unconventional natural gas development has been shown to directly contribute to forest loss and fragmentation across the mid-Atlantic region (Farwell et al., 2016; Langlois et al., 2017). On average, approximately 3.6 hectares (8.8 ac) of forest are cleared during well pad development due to pad development and the construction of other associated infrastructure such as roads, pipelines, and water impoundments. Approximately 8.6 additional hectares (21.2 ac) of forest per well pad are impacted by indirect effects due to the creation of new edge forest. In all, approximately 12.1 hectares (30 ac) of forest may be impacted either directly or indirectly due to the development of a single well pad (Johnson et al., 2010)

At the time of this analysis (July 2017), there were nearly 11,000 unconventional natural gas wells developed in the Marcellus Shale formation within Pennsylvania (DEP, 2018; Whitacer and Slyder, 2017), situated on well pads at varying densities across the state. Development of well pads, pipelines, compressor stations, and roads have resulted in thousands of hectares of disturbance to forested habitats, and even more impacts associated with edge effects and loss of wild character. Forests and streams in the Appalachian Region are expected to continue to experience substantial impacts from the development of infrastructure needed to support the unconventional natural gas activity occurring within the Marcellus and Utica Shale Formations (Johnson et al., 2010; Johnson et al., 2011; Brittingham et al., 2012; Drohan et al., 2012; Drohan and Brittingham 2012; Slonecker et al., 2013; DCNR, 2016; Evans and Kiesecker 2014; Farwell et al., 2016; Langlois et al., 2017).

During this project, WPC assessed change in forests and natural habitats in Pennsylvania over the past 15 years associated with development and energy production. Through this project, we used different landscape-level assessment methods to evaluate habitat fragmentation at multiple scales and with the results, investigate changes to our most valuable ecological areas.

We set out to determine the following:

- Patterns in Shale Gas Development
- Patterns in Landscape-level Fragmentation in Pennsylvania
- Patterns in Local Fragmentation
- Update to WPC's Forest Condition Assessment
- Relationship of Landscape Variables and Results from Field Studies

Patterns in Shale Gas Development

Gas development represents a significant threat to intact interior forest areas in the Appalachian region (Johnson et al., 2010; Drohan et al., 2012; Brittingham et al., 2014; Thomas et al., 2014; Farwell et al., 2016; Langlois et al 2017; Franz et al., 2018). Projections by TNC for the Pennsylvania Energy Impacts Assessment indicated that a majority of future wells in the northern tier of Pennsylvania were projected to be drilled on forest land – primarily within large tracts of interior forest (Johnson et al., 2010).

The Pennsylvania Energy Impacts Assessment (Johnson et al., 2010) proposed that 60,000 wells would be developed in Pennsylvania between 2010 and 2030 based on the steady development of one new well per month by 250 horizontal drill rigs that were estimated to be available for operating in the state during this time period (Johnson et al., 2010). Assuming steady annual development, this would result in the construction of 3,000 new wells per year between the period of 2010 and 2030. The projected increase in wells was estimated to require between 6,000 and 15,000 well pads, depending on the number of wells drilled on each pad. Johnson et al., 2010 proposed three scenarios of development impact, a low development scenario (6,000 well pads) suggesting 10 wells per pad and requiring the lowest number of new well pads and least landscape-level disturbance of all scenarios; a medium development scenario (10,000 well pads) suggesting 6 wells per pad; and a high development scenario (15,000 well pads) suggesting 4 wells per pad, and requiring the highest number of new well pads and greatest landscape-level disturbance of all scenarios.

Seven years out from the 2010 projections, and assuming steady annual development, we would expect that 42.5% of projected wells be developed by July 2017, our cutoff date for the data used in these analyses. Based on these projections, the expected 25,500 wells would require 2,550; 4,250; or 6,375 well pads respective of low, medium, or high development scenarios.

Now that several years have passed since the Pennsylvania Energy Impacts Assessment was written, we sought to update our understanding of current patterns in shale gas development, investigate the impact of landscape level disturbance, and revisit the projections posited by the Pennsylvania Energy Impacts Assessment to compare current patterns of Marcellus Shale natural gas development to early trends and future projections.

Methods

While unconventional natural gas wells are tracked by the Pennsylvania DEP, the well pads, and associated infrastructure are not. In GIS, we estimated the footprint of unconventional gas well pads in Pennsylvania as of July 1, 2017 through a process described in Drohan et al. (2012) and using Carnegie Museum of Natural History's Unconventional Natural Gas Well dataset (Whitacer and Slyder, 2017) for well location. Active and developed well sites were identified by choosing wells that were classified as "drilled" or "producing." A visual spot check confirmed that this was the most effective query to isolate well pads while excluding wells that had been permitted, but never developed. The approximate well pad footprint was derived by buffering each well site by 50 m and dissolving the overlapping buffers. These buffers were then converted to centroid points. The centroid points were buffered by 63.19 m to create an area of 1.3 ha (3.1 ac), the average spatial disturbance footprint of a Marcellus Shale well pad (Johnson et al., 2010).

Following Drohan et al. (2012), we determined the dominant land cover in which each of the pads was constructed by overlaying the pad center points on 2010 NLCD imagery. To determine patterns in land ownership of well pads within our focal areas, we overlaid the derived well pad layer on a layer representing the combined lands owned and managed by state and federal agencies and private conservation organizations (USGS, 2016).

To compare TNC's shale gas development projections with actual development since 2010, we calculated the number of shale gas wells developed between January, 2010 and July, 2017 and compared these numbers to the different scenarios presented in Johnson et al., 2010. Additionally, using GIS, we compared the spatial distribution of developed well pads to the predicted location of well pads suggested by Johnson, et al., 2010.

Results and Discussion

Well Development Trends

As of July 2017, there were nearly 10,000 Marcellus Shale gas wells in Pennsylvania (PA DEP 2018; Whitacre and Slyder, 2017; FracTracker 2018), found on an estimated 3,376 well pads (Figure 3.21). Where the Marcellus Shale formation underlies Pennsylvania, well pad density varied across the state, ranging from as low as 0.04 well pads/100 km^2 in Bedford County to nearly 20 well pads/100 km^2 in Susquehanna County (Figure 3.22). Annual construction of new wells and well pads decreased substantially from nearly 2,000 wells and 600 new well pads in 2011 to just 425 wells and 62 new well pads developed in 2016 (Figure 3.21).

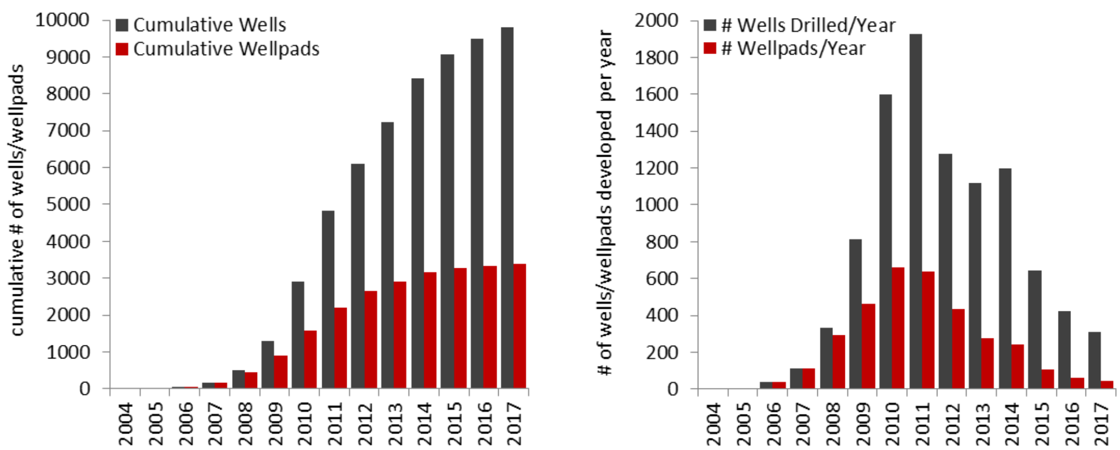


Figure 3.21. Cumulative shale gas wells/well pads developed and number of shale gas wells/well pads developed annually, July 2017.

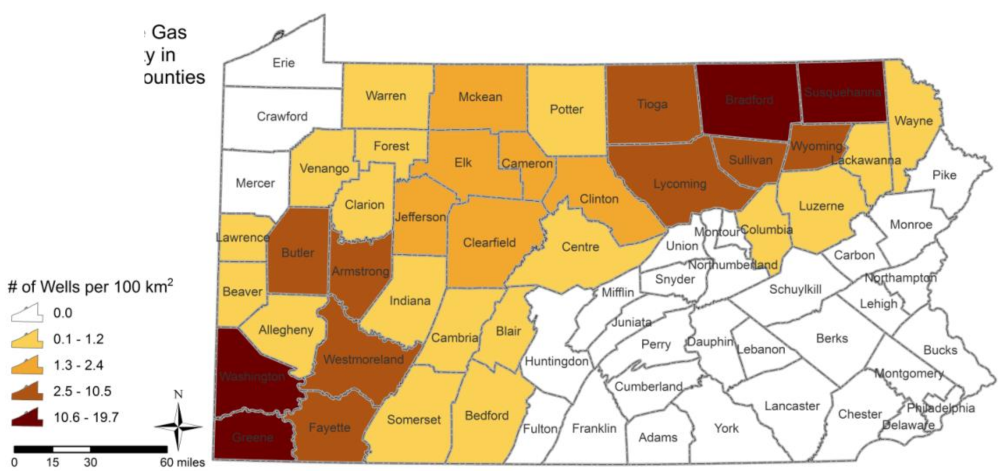


Figure 3.22. Well pad density (#wells/100 km^2) in Pennsylvania

As the cumulative number of drilled wells has increased, the number of well density per well pad has increased from an average of 2 wells per pad in 2010 (Johnson et al., 2010) to an average of 2.9 wells per pad in 2017. The lower density of wells per well pad observed during initial Marcellus Shale development was due to the practice of drilling companies moving quickly from one lease to another to test productivity and to secure as many potentially productive leases as possible (leases typically expire after 5 years if there is no drilling activity) (Johnson et al., 2010). Still, in July 2017, nearly 42% of well pads in Pennsylvania contained just one well. Twenty-two percent of well pads contained 5 or more wells and 2% of well pads contained 10 or more. The highest number of producing and/or drilled wells per well pad in Pennsylvania was 17 (Whitacre and Slyder, 2017), but with the inclusion of permitted wells, the number of wells per pad could range up to 20, or even higher, in the future (Litvak, 2018).

The landscape context of shale gas well development in Pennsylvania showed similar trends to our findings in 2015, as well as findings by Drohan et al. (2012). We found that 53.5% of well pads have been developed on agricultural land and 44% of well pads have been developed on forest land (Figure 3.23). A total of 26.4% (890 out of 3,376) of well pads have been developed within core forest.

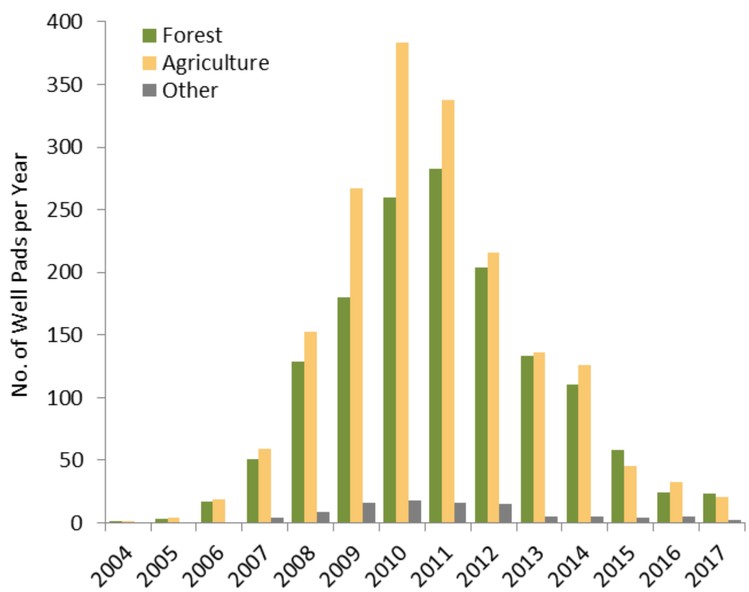


Figure 3.23. Number of well pads developed within different land use classes by year.

Nearly 92% of well pads have been developed on private land, and 8% developed on state lands (Figure 3.24); again, similar to Drohan et al., (2012) who reported approximately 90% of existing well pads at that time were developed on private land. A recent study of fragmentation impacts of shale gas development in Lycoming County, Pennsylvania, found that the density of well pads on private land was significantly greater than on state owned land (Langlois et al., 2017). While land clearing at well pad sites was found to be similar between state and private land ownership, the authors found that loss of core forest due to shale gas infrastructure on private land was more than double the amount of core forest loss on land managed by state land management agencies (Langlois et al., 2017).

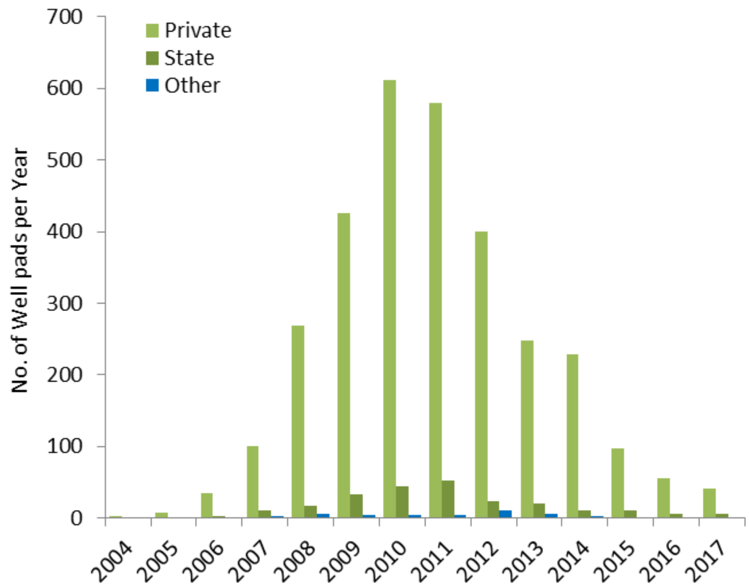


Figure 3.24. Number of well pads developed on private versus state lands by year.

Comparison to 2030 Projections

We found substantial differences in the development of shale gas wells between 2010 and 2017 from the projections suggested by The Nature Conservancy in the 2010 Pennsylvania Energy Impacts Assessment (Johnson et al., 2010). Based on TNC's 2010 projections, we would have expected to see 25,500 new Marcellus Shale wells developed between the period of January 2010 and July 2017. Instead, we found that only 8,499 new wells were drilled during this time period, just 33% of the expected, and only 13% of the original total that was projected for the year 2030. The substantially lower than predicted rate of well development was principally due to an overabundance of energy resources that have caused gas prices to decrease, making the large expenses associated with unconventional natural gas development unfavorable for profitable gas extraction (McAllister, 2015; Woodall, 2016; Cusick, 2017; Sisk, 2017).

It is difficult to say whether or not the landscape impacts from shale gas development will play out as predicted by TNC, even with the slow-down in development. We estimated the total number of well pads developed in Pennsylvania between 2010 and 2017 was 2,463. At this point, the number of new well pads developed was just below what TNC predicted in the low development impact scenario after seven years since the projections were made (assuming a consistent rate of development). Although the number of new well pads was lower than what would have been developed by 2017 in all three proposed development scenarios (2,550, 4,250, 6,375 – numbers based on TNC's low, medium, high development impact scenario), the average density of wells per well pad in 2017 (2.9 wells per pad) was markedly lower than the number of wells used to predict the number of well pads in the low development impact scenario, which predicted a per well pad density of 10 wells per pad (the medium and high well density was 6 and 4 wells per pad, respectively). This lower number of wells per well pad indicates a greater degree of well pad development than what was expected in 2010, and therefore, although the amount of unconventional natural gas well development and development of well pads was substantially lower than projected for the period between 2010 and 2017, the landscape level fragmentation impacts of shale gas development may actually be higher than what we would expect in the original high development impact scenario proposed by TNC where only 4 wells were developed on each pad). This has major implications about potential large scale fragmentation that could occur if Marcellus Shale gas activities begin to accelerate and the industry continued to develop new well pads with an average of 2.9 wells per pad.

When investigating the spatial distribution of well pads we found that by July 2017, nearly half of all well pads in Pennsylvania (48.6%) are situated within 1 km from another well pad. Despite a fewer number of drilled wells than was expected, this clustered spatial distribution of these wells suggests that local fragmentation may still be higher than anticipated in areas where the greatest intensity of development has occurred. While we may not see 60,000 wells drilled in the Marcellus and Utica Shale region of Pennsylvania by 2030 as originally predicted, we may still see the landscape impacts associated with very intense development in heavily developed areas, and perhaps a greater impact than anticipated in some areas unless infrastructure is carefully sited to minimize forest loss (e.g. Eshleman and Elmore, 2013: The Pennsylvania Wilds Planning Team, 2013; TNC, 2015).

Most intense development of the Marcellus and Utica Shale has occurred in the Northeastern and Southwestern regions of Pennsylvania, where several counties have experienced substantially greater development of well pads than projected by TNC (Figure 3.25). For example, TNC models used in the 2010 assessment projected that within Susquehanna County, a total of 234 well pads would be developed under the low development scenario by 2030. Instead, 346 well pads have already been constructed. At least one well pad was developed in each county where well pads were projected to be developed in all 2030 development scenarios. However, significantly lower levels of development were observed within the central part of the state and in the Laurel Highlands, causing overall well pad development to be lower than expected based on TNC's projections.

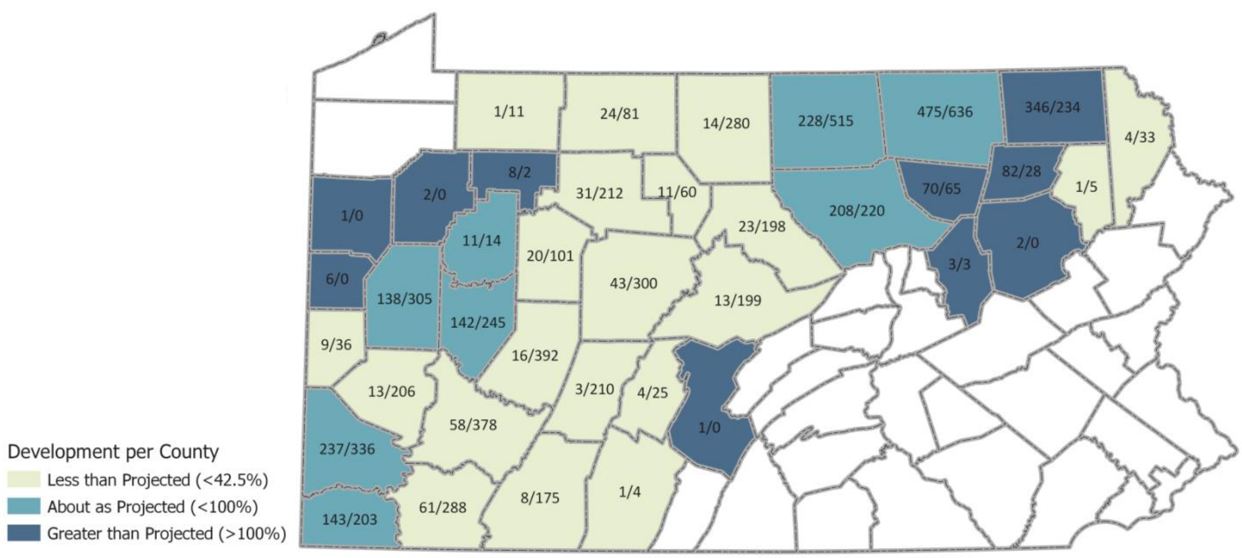


Figure 3.25. Number of wells developed per county in Pennsylvania compared with 2030 projections in Johnson et al., (2012). Data from the Carnegie Museum of Natural History Pennsylvania Unconventional Natural Gas Wells Geodatabase (v.2017-Q2) (Whitacre and Slyder, 2017).

While we found that some local areas and specific regions across Pennsylvania may be experiencing greater impacts due to a low number of wells drilled per well pad and closer well pad spacing than what was used to model landscape impacts in the PA Energy Impacts Assessment, it is too early to tell if these early trends in development will continue into the future, especially with the rapid pace of technological advancement increasing the ability to increase well numbers on individual pads and development of longer horizontal wells. Further, changing practices in the industry, such as changes in leases (e.g. consolidation of lease ownership) and there no longer being a need to quickly drill a vertical well to hold a lease (Johnson et al., 2010), will most certainly contribute to the future spatial pattern of well pad development.

It is clear that the number of unconventional natural gas wells and the number of well pads was different than expected in 2010 during the early years of the shale gas boom. The number of wells drilled on the well pads also differed. Location of well pads also differed considerably than predicted – as nearly 50% of the wells were found within 1 km of each other, not as suggested by the model used by TNC. Well pad location, though, appears to be driven by private land ownership and the Industry's practice of developing pads and drilling wells to hold leases "by production." Thus, a landscape containing a higher density of individual landowners (mineral rights owners) would presumably contain a greater number of well pads within that landscape. Density is not always greater on private lands as demonstrated by a number of our focal areas (e.g. Lick Run, Hyner Run), where wells pads are within 0.8 km (0.5 miles) from each other and situated on the tops of ridges, where it appears as if they were sited in the only suitable location. Local geology or other site specific variables (i.e. topography, presence of existing infrastructure, presence of wetlands and waterways) most certainly contribute to siting of well pads. The landscape impacts of this development should be continued to be monitored to assess the change in development trends over time and to compare these trends to the predictions made in 2010.

Landscape-level Fragmentation

Regional variation in forest cover, land management policy, and development patterns influence the estimates of the landscape impact from infrastructure development. For this report, we attempted to quantify forest loss and fragmentation due to shale gas development across Pennsylvania. Hoping to include a release of a new National Land Cover Data (NLCD) layer, we proposed to look at the change in natural land cover (forest, shrubland, and wooded wetlands) from a period of time before gas exploration (circa 2006) until now. Unfortunately, we were challenged by the lack of up-to-date landscape-level data for land cover and land use in Pennsylvania, as the NLCD data layer representing the 2015 landscape during our grant period was not available. Therefore, we were resigned to explore other methods to quantify the level of fragmentation and loss of forest in Pennsylvania, primarily relying on estimated spatial footprints of well pads and pipelines, which were "burned-in" to the most recent NLCD (2010).

Methods

We used the circa 2001, 2006, and 2011 NLCD layers as the base land cover for our analyses (Jin et. al. 2011). To reduce potential classification errors, the original NLCD classes were grouped into four broad categories, including natural cover, water, agricultural, and development (Table 3.11).

Table 3.11. Grouping of land cover classes into four main categories.

Category	NLCD Cover Type	
Natural cover	41	Deciduous Forest
	42	Evergreen forest
	43	Mixed Forest
	52	Shrub/Scrub
	90	Woody Wetlands
	95	Emergent Herbaceous Wetlands
Water	11	Open Water
Agriculture	71	Grassland/Herbaceous
	81	Pasture/Hay
	82	Cultivated Crops
Development	21	Developed, Open Space
	22	Developed, Low Intensity
	23	Developed, Medium Intensity
	24	Developed, High Intensity
	31	Barren Land

The height of the shale gas boom in the Appalachian Region (circa 2010-2014), as indicated by unconventional well development data) was not captured by the NLCD because the most recent data available to us at the time of this study included land cover prior to 2011. Further, the resolution of Marcellus Shale gas well pads was typically too small to be detected in the 30 m NLCD layers. Therefore, we used the well pad data layer that we created (see section above for methods) and purchased pipeline data (Hart Energy 2016) to consider forest loss and fragmentation due to the development of well pads and pipelines. To account for potential land clearing created for the pipeline right-of-ways, transmission pipelines were given a 45-m buffer (Johnson et al., 2010). Smaller pipelines (gathering and distribution lines) were not considered fragmenting features as they are often estimated to be no more than 15 m wide (Johnson et al., 2011) and were often not visible during spot checks on aerial imagery. Furthermore, gathering and distribution line data were inconsistently represented in our pipeline dataset resulting in possible underestimates of fragmentation in some areas. Compared to available street and railroad data, natural gas transmission data suffers from issues of incompleteness and accuracy. Therefore, we made efforts to remove pipelines that were planned, but not yet constructed or seemed to be inaccurately mapped.

Following development of the pipeline and well pad datasets, we used methods similar to the USGS (Slonecker et al., 2013) and Penn State University researchers (Langlois et al., 2017) to add well pad and pipeline datasets to the NLCD layers to provide layers more realistic to shale gas development conditions in July 2017. Unlike Langlois et al., (2017), we did not account for gathering and distribution pipelines or roads, as these data were either inconsistently represented in our datasets or were difficult to associate with shale gas development, exclusively, and thus our estimate is a much more conservative representation of fragmentation.

Using the 2001, 2006, 2011, and 2011+ gas infrastructure NLCD layers, we assessed the change in forest fragmentation classes using the Landscape Fragmentation Tool (LFT v2.0) developed by University of Connecticut (Vogt et al., 2007). This tool was used to map the types of fragmentation present across natural cover of each focal area. For the purposes of this analysis, we used natural cover as defined above to represent habitat and water, agricultural, and developed classes were considered fragmenting land covers. Although the width of 'edge effects' varies by species or issue being studied, we assumed an edge width of 100 m, a distance that is often used for general purpose analyses (Drohan et al., 2012).

Natural land cover was classified into four main categories following Vogt et al., 2007 (Figure 3.26) and compared for each NLCD dataset and our NLCD 2011+ dataset that included our shale gas infrastructure features. The resulting dataset included the following:

- Core pixels were any natural cover pixels that were more than 100 m from the nearest fragmenting pixel. Core pixels were further classified into three patch sizes, based on summaries of the relevant scientific literature:
    - Small core patches had an area of less than 100 hectares (250 ac)
    - Medium core patches had an area between 100 hectares and 200 hectares (250 – 500 ac)
    - Large core patches had an area greater than 200 hectares (500 ac)
- Patch pixels were within a small natural cover fragment that did not contain any core forest pixels, and were, most likely, completely degraded by the edge effect.
- Perforated and edge natural cover were within 100 m of fragmenting pixels but were part of a patch containing core pixels:
    - Edge pixels were along the outside edge of the natural cover patch
    - Perforated pixels were along the edge of small natural cover gaps

Figure 3.26. Representation of fragmentation categories identified by Vogt et al.,2007.

We used FRAGSTATS v4 (McGarigal et al., 2012) software to determine additional landscape fragmentation metrics for all Pennsylvania Counties. Percent forest cover, mean forest patch area, area weighted mean patch area, forest largest patch index, and forest edge density were calculated within each Pennsylvania County using the 2001, 2006, and 2011 NLCD well pad layers. The difference between values in 2001 and 2006, 2006 and 2011 was calculated for each metric in each county so as to indicate changes that occurred over the decade. The four landscape metrics that we chose to include were meant to complement one another so as to provide a diverse analysis of fragmentation. The four landscape metrics were:

- Percent forest cover provided a measure of the percentage of landscape that was comprised of forest, which offered insight into overall forest area and how it was changing.
- Mean forest patch area/area weighted mean patch area provided a measure of the total area of forest patches divided by the total number of patches, offering an indication of fragmentation of forest patches.

- Largest patch area provided a measure of the percentage of the landscape comprised by the largest patch of forest and indicated how the size of the largest patch of forest within each county changed over time.
- Edge density provided a measure of the length of edge of all forest patches within a county divided by the county area. Although edge density provided insight into patch shape and fragmentation, without other metrics, it would have been difficult to distinguish whether higher values were caused by fragmentation or complexity of patch shape.

The inclusion of all four metrics in our analyses provided a more complete representation of how Pennsylvania forests were changing during the 2001-2011 decade and again accounting for recent shale gas infrastructure.

Results and Discussion

According to our analysis of the original NLCD data, the total area of natural land covers within Pennsylvania experienced little change during the decade between 2001 and 2011, increasing slightly by 1.2% over this period. Additionally, a static representation of forest fragmentation metrics across Pennsylvania counties revealed expected results. Counties that contained a greater area of developed land, particularly in Southeast Pennsylvania and Southwest Pennsylvania, had less forest land cover, and included metric values that were more indicative of forest fragmentation, including low forest patch area, low largest patch index, and high edge density (Figure 3.27). Northern counties within the region that is often referred to as the Pennsylvania Wilds because of its lack of development, have a substantially higher percentage of forest land cover, and metric values indicating less forest fragmentation.

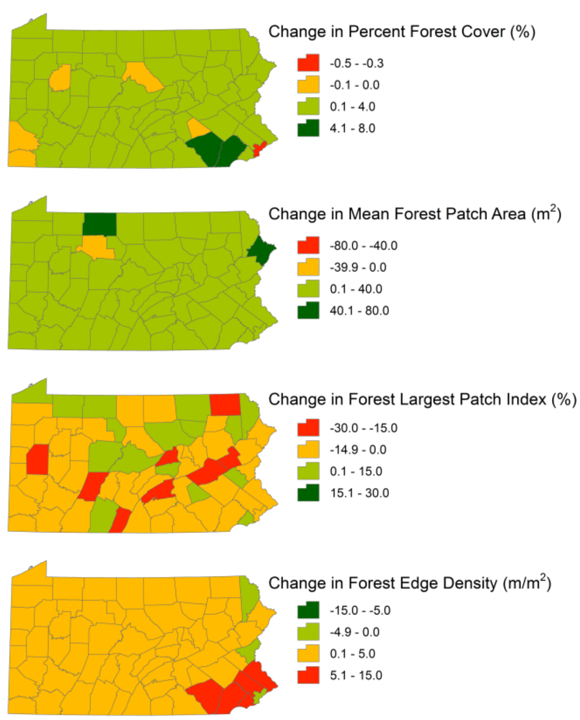


Figure 3.27. Change in forest cover from 2001-2011 based on NLCD data following well pads developed prior to 2011.

In our comparison between the 2011 NLCD layer and the 2011+ NLCD layer that included shale gas infrastructure, we estimated that the total acreage of large core forests (>200 hectares, >500 ac) decreased from 3,541,457 hectares to 3,398,535 hectares (8,751,131 ac to 8,397,963 ac) (4.0%) following the removal of shale gas wells and pipelines. Similarly, other researchers have used real-life measurements on a smaller scale to estimate forest loss due to the development of well pad and pipeline infrastructure (Johnson et al., 2011; Slonecker et al., 2013; Langlois et al., 2016) and have suggested substantial forest loss due to development. In areas that have a high amount of core forest and high pipeline density, the conversion from core to edge forest may be very high.

After accounting for shale gas infrastructure, we also found that the average size of the forest patches decreased by 142.3 ha (351.6 ac) from 1,468.3 ha (3,628.2 ac) to 1325.9 ha (3,276.6 ac) (9.6%) across the region; however, in the comparison of mean patch size between the two datasets, the differences was not significant. Counties such as Greene, Potter, Clinton, McKean, Elk, and Tioga, which contained a large area of core forest and where pipelines were most prevalent, have experienced the greatest forest loss impacts, all having lost between 44,51.5 and 84,98.4 ha (11,000 and 21,000 ac) of core forest (Figure 3.28). We detected an increase of 68,458.2 ha (169,164 ac), or 3.4%, in edge forest due to the included shale gas well pads and pipelines.

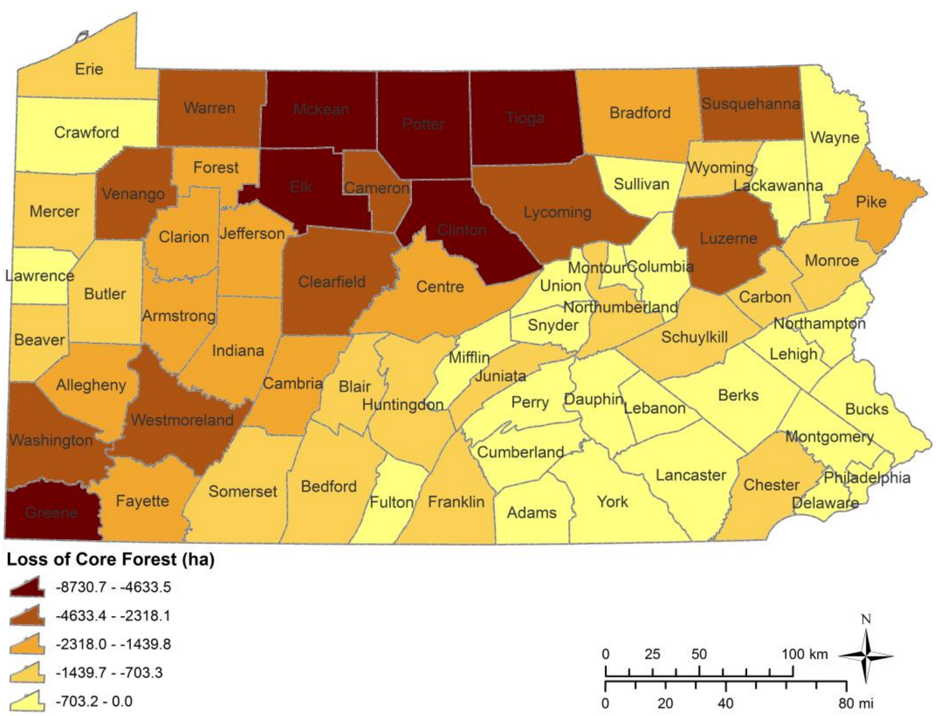


Figure 3.28. Core forest loss (ha) due to well pads and pipelines in Pennsylvania by county.

Regional variation in forest cover, land management policy, and construction patterns influence the estimates of landscape impacts from infrastructure development. Additionally, specific landscape fragmentation and analysis methods vary across studies. However, our findings of 4.0% forest loss seem to be within the range of results from other studies in the region – suggesting that core forest loss due to shale gas infrastructure development may be between 4% and 12% (Farwell et al., 2016; Langlois et al., 2017). We did not attribute the percent loss in core forest to pipelines or well pads, but it was clear that the loss of core forest due to development of linear infrastructure features, such as pipelines, outweighed the impact of well pad construction, as discussed by Johnson et al., 2011 for Pennsylvania as a whole and reported in site specific studies from West Virginia (Farwell et al., 2016) and Lycoming County, Pennsylvania (Langlois et al., 2017). Both Farwell and Langlois used a combination of modeled and hand-digitized data representing fragmenting features layers (roads, pipelines, and well pads), Langlois et al. (2017) calculated a percent core forest loss due to pipelines and roads associated with shale gas development as causing a 3.2% loss in core forest since shale gas development began.

Local Forest Fragmentation

Research on impacts of construction of gas well pads and infrastructure (e.g., roads, pipelines) on forest cover and bird communities has shown that development has contributed to substantial losses of forest cover and increases in edge density (Farwell et al., 2016; Langlois et al., 2017; Franz et al., 2018). Farwell et al. (2016) found that development of shale gas infrastructure contributed to an overall 4.5% loss in forest cover within heavily forested areas in West Virginia, and resulted in a loss of 12.4% core forest and a 51.7% increase in forest edge density. Even small reductions in the amount of core forest have been correlated with a decline in habitat quality for specific interior forest species (Franz et al., 2018). To assess the change in core and edge forest in our focal areas, we re-assessed the land cover of each of our 15 focal areas in GIS that had been investigated in our 2015 report (WPC, 2015).

Methods

Using the base natural cover dataset as prepared above as a starting point, we corrected mapping and classification errors. First, the natural cover grid was converted to a polygon feature class. Next, we determined the current forest cover for each focal area in GIS based on the existing land cover data (2011 National Land Cover Dataset) and available aerial imagery available in ArcMap (Sources: Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community), and adjusted boundaries to match the edges of the natural cover as seen in the imagery. All digitizing was completed at a scale of 1:5,000. This produced a map of forest cover at a scale appropriate for the focal area.

As with the statewide fragmentation assessment above, we assessed forest fragmentation by using the Landscape Fragmentation Tool (LFT v2.0) developed by University of Connecticut (Vogt et al., 2007) to map the types of fragmentation present across the natural cover of each focal area. We assumed that the edge width was 100 m. Although the width of 'edge effects' varies with the species or issue being studied, we assumed an edge width of 100 m, a distance that is often used for general purpose analyses. Forests were classified into Core, Patch, Perforated, and Edge.

Following determination of the patch statistics for each focal area, the percent of each focal area considered "core forest" and "edge forest" were compared between the two dates of analysis (2015 and 2017) for the 15 focal areas experiencing shale gas development.

In addition to the fragmentation statistics presented above, we calculated road density (km/km^2) and pipeline density (km/km^2) within each focal area using the Line Density tool in ArcGIS. The mean density for both roads and pipelines were summarized for each focal area as well as each physiographic section. Road density was not re-calculated as new road data were not available through ESRI Street Map.

Results and Discussion

The 15 focal areas ranged in size from 10.5 km^2 to 517.5 km^2 and natural cover ranged from 47% to 99% with a mean of 82.0%, (sd = 16). Water covered the smallest percentage of each focal area, with development and agricultural making up a larger percentage of each focal area. Figure 3.29 presents the percentage of each land cover type calculated in 2017 for the subset of the 15 focal areas in this study. Focal areas differed considerably in the amount of forest cover and other land cover/land use depending on which physiographic section there occurred in. For example, focal areas in the Northwestern Glaciated Plateau, Pittsburgh Low Plateau, and the Waynesburg Hills typically had higher percentages of agriculture and development, reflecting the development history of the region; whereas focal areas situated in the Deep Valleys and High Plateau sections. Lick Run, located in Clearfield County at the eastern edge of the Pittsburgh Low Plateau, was an exception, and exhibited a high degree of forest cover. Forests of this region of the Pittsburgh Low Plateau often appear to share forest cover characteristics with the forests of the Deep Valleys and High Plateau due to their distance from more developed regions as well as similarity in physiographic factors (steep slopes and narrow valleys).

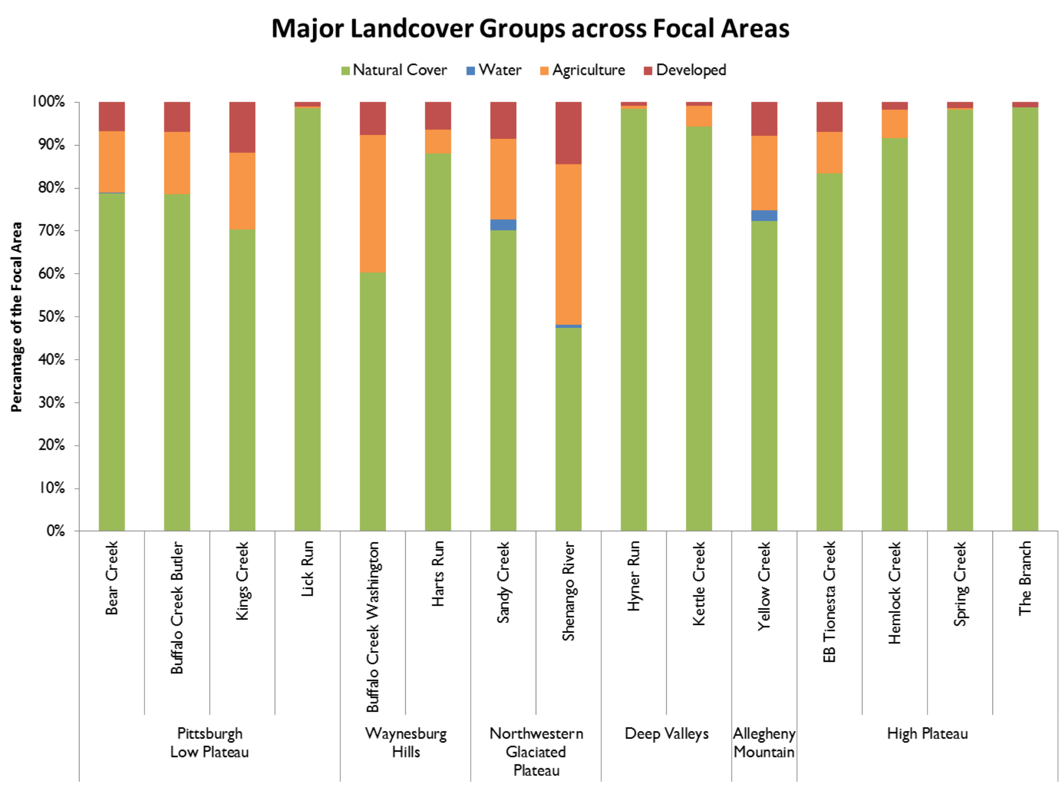


Figure 1.29. Land Cover distribution within each of 15 focal areas by Physiographic Section.

Forest fragmentation values (percent of core forest vs edge forest) ranged considerably by physiographic section with focal areas in the Allegheny Mountains, Deep Valleys, and High Plateau consistently exhibiting a higher percent of core forest (> 200 hectares) and lower percent edge, whereas focal areas in the Northwestern Glaciated Plateau, Pittsburgh Low Plateau, and Waynesburg Hills had relatively low scores for core forest and higher scores for Edge (Figure 3.30).

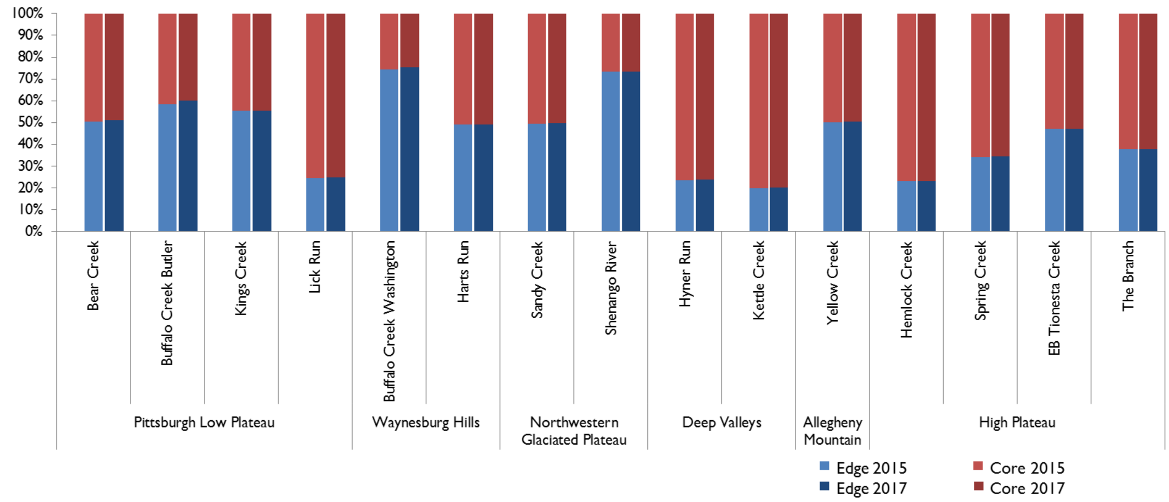


Figure 3.30. Comparison of focal area fragmentation (amount of edge forest vs core forest) of forests in WPC focal areas between 2015 and 2017.

Focal areas changed minimally from 2015 to 2017 (average core forest loss of 0.22%, sd = 0.47%) with greatest losses of core forest observed in the Buffalo Creek Washington (-1.8%), Buffalo Creek Butler (-1.53%), and Bear Creek (-0.50%). Conversely, the percent of edge forest increased in all three focal areas. Bear Creek also experienced loss of core forest due to development of a new surface coal mine within the focal area. Three additional focal areas experienced substantial pipeline development, Harts Run, Kings Creek, and Shenango River; however, this was not captured by available aerial imagery.

Mean road density within the focal areas ranged from 0.45 km/km^2 to 2.44 km/km^2 in 2015 and focal areas within in the more developed and/or agricultural areas of the Glaciated Northwestern Plateau, Waynesburg Hills, and Pittsburgh Low Plateau exhibited the greatest density of roads within the 15 WPC focal areas (WPC, 2015). Because ESRI has not completed an update of the ESRI Street Map data layer, we could not appropriately measure the change in pipeline density over this time.

Comparing the pipeline data released by Hart Energy used in our 2015 assessment with their most current release of pipeline data indicated a marked change in several focal areas. Mean pipeline density within the focal areas ranged from 0.0 km/km^2 to 1.94 km/km^2 in 2015 to 0.0 km/km^2 to 1.99 km/km^2. The greatest changes in density between the two datasets were in the Harts Run and Buffalo Creek Washington focal areas (0.76 km/km^{2}and 0.23 km/km^2, respectively) (Figure 3.31). Both are situated in areas of extremely high shale gas development. Kings Creek, Shenango River, and Bear Creek also experienced a noticeable increase in pipeline density during this time period. Due to the lack of recent aerial imagery, however, some of these impacts were not represented in core forest loss depicted in Figure 3.30 as discussed above.

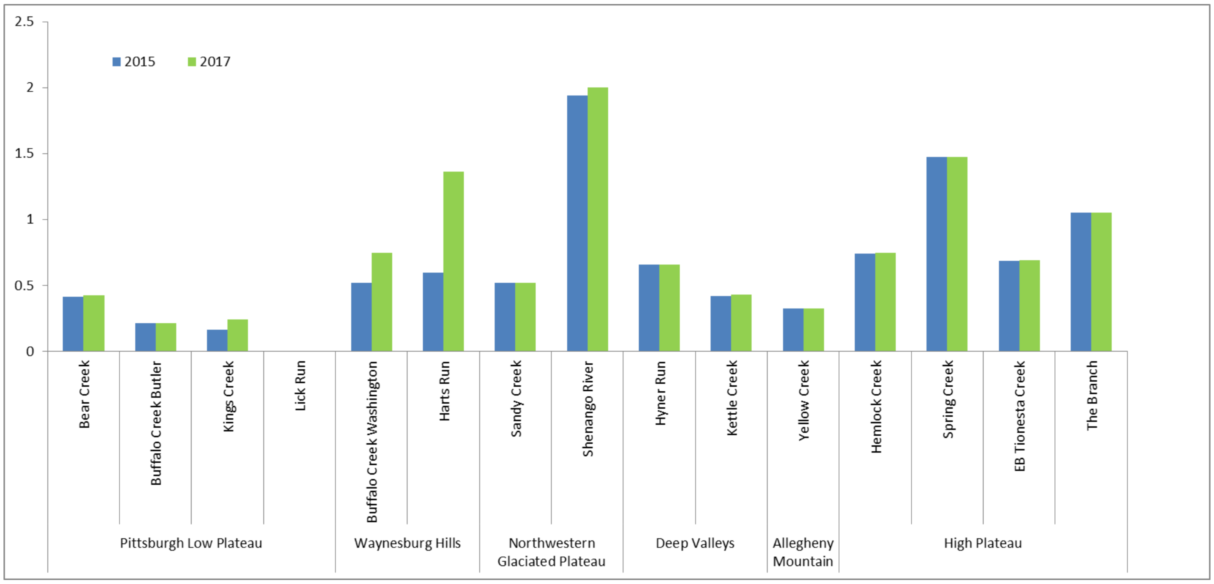


Figure 3.31. Comparison of pipeline density (km/km2) within focal areas between 2015 and 2017.

Forest Condition Assessment

As part of this project, we updated the WPC's Forest Conservation Analysis (FCA), originally completed by WPC and The Nature Conservancy in 2007 using forest land cover data from the NLCD and fragmenting features (e.g. roads, pipelines) in GIS.

Methods

To create the new layer representing forest cover in Pennsylvania, we used the University of Vermont's 2015 Pennsylvania Statewide High-Resolution Tree Canopy dataset produced by the University of Vermont Spatial Analysis Laboratory (UVSAL, 2015). These data represent closed tree canopy based on LiDAR leaf-on imagery acquired in 2006, 2007, and 2008 with supplemental LiDAR imagery from 2010 through the National Agricultural Imagery Program (NAIP). We determined that this dataset was highest resolution and most accurate representation of statewide forest canopy available rather than the lower resolution NLCD. At a one meter resolution, these data refine the way we look at forest patches as contiguous canopy and capture canopy gaps as well as linear forest fragments with great accuracy.

We made two alterations to the UVSAL dataset, both resulting in a "burning-in" of important fragmenting features. We created 1meter resolution 1-bit GRID rasters snapped to the tree canopy raster for both PA DOT State Roads and our estimated shale gas well pads. Using Raster Calculator in ArcGIS 10.4, we removed positive values (Value =1) for each of these two layers from the tree canopy layer to represent on-the-ground canopy removal. As in the fragmentation methods described above, we identified the number of gas well pads in Pennsylvania as of July 1, 2017 through a process described in Drohan et al. (2012) and used data from the Carnegie Museum of Natural History Pennsylvania Unconventional Natural Gas Wells Geodatabase (Whitacer and Slyder, 2017) to identify well pad locations. Well pads were determined by identifying groups of associated wells situated within 50 m of each other. In GIS, overlapping buffers were dissolved and a center point is calculated, representing the center of the well pad (see methods for developing well pads, above). These layers were then removed from the tree canopy data. The resulting tree canopy raster was then converted to a polygon feature class (with polygon simplification to improve spatial representation and performance through reduction of vertices).

Following the delineation of distinct forest patches within the UVM dataset, we attributed large patches of contiguous forest with condition metrics calculated from a "Landscape Condition Model" tool (LCM) for Pennsylvania developed by the PA Natural Heritage Program and produced a map of statewide landscape condition summarized by the new 2017 forest patches greater than 40 hectares (≥100 ac). A full explanation of the LCM technique developed by WPC for the PA Natural Heritage Program is found in Tracey (2018) included in Appendix 1.

The LCM depicts the impacts from a suite of human-caused landscape stressors (e.g. fragmentation features, development, agriculture). Landscape level condition assessments have been demonstrated to effectively estimate ecological integrity of larger ecological units in other regions (Lemly et al., 2011; Grunau et al., 2012; Feldmann and Howard, 2013).

Our model uses 13 input stressors within 4 categories: *Transportation*, *Urban and Industrial Development, Land cover and Land use*, and *Energy Production* (Table 3.12). We assigned a weight (w) to each stressor, from 100 to 600, which was set as its maximum value in the impact footprint. We also set a decay distance, which is the distance at which the stressor no longer had any effect, guided by the previous work of Grunau et al., 2012; Comer and Hak, 2012; Feldmann and Howard, 2013.

Table 3.12. Input themes, function types, variable values, and decay distances for the Pennsylvania LCM (Table from Tracey, 2018).

Input theme	Function type	a	b	c	w	Decay distance
Transportation						
Interstate Highways	y5	5	5	100	300	2000
Major Roads	y3	1	5	100	300	200
Local streets	y3	1	5	100	300	250
Active Railroads	y1	0.5	10	100	500	100
Urban and Industrial Development						
High Intensity Development	y6	10	0.5	100	500	2000
Medium Intensity Development	y2	2.5	2	100	400	300
Low Intensity Development	y2	2.5	2	100	300	300
Land cover and Land use						
Cultivated	y3	1	5	100	300	200
Pasture	y3	1	5	100	300	200
Energy Production						
Abandon Mine Land	y4	2.5	2	100	600	600
Active Gas Wells	y2	2.5	2	100	300	100

The resulting map depicts regions of higher integrity while increasing shades of red indicate lower integrity (Figure 3.32).

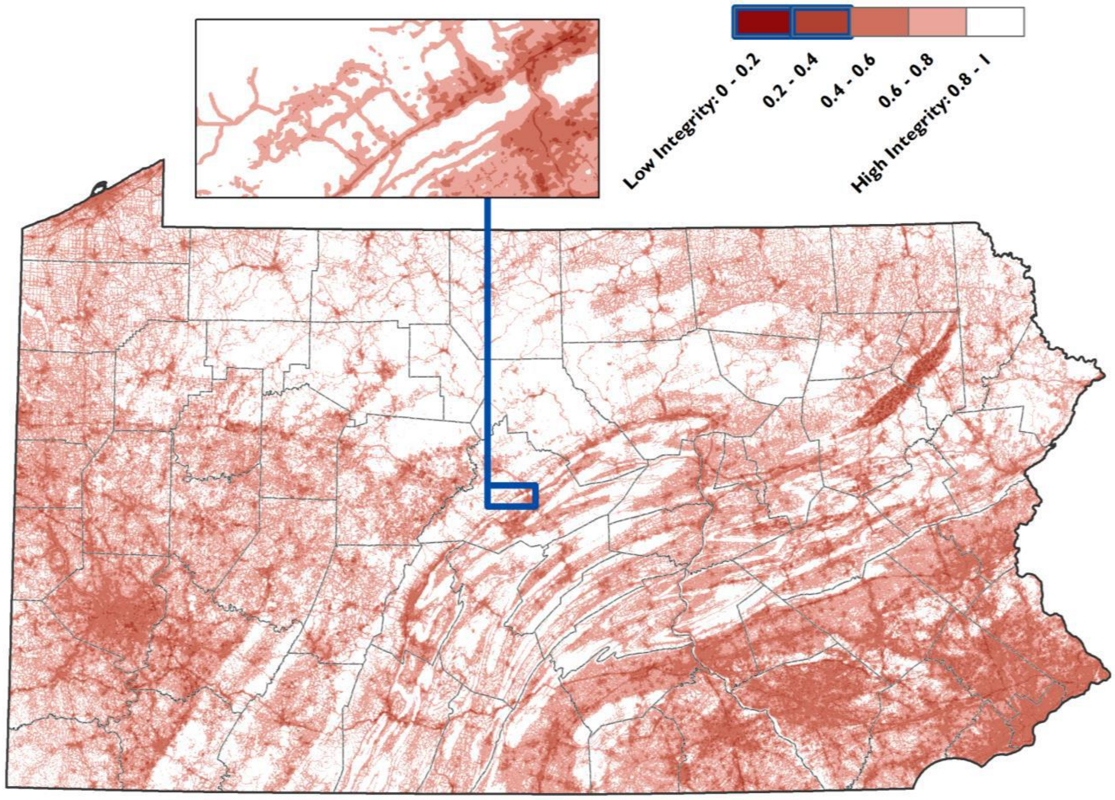


Figure 3.32. Landscape Condition Model. White areas are regions of higher integrity while increasing shades of red indicate lower integrity (Figure from Tracey, 2018).

The mean LCM scores for each forest patch derived from the UVMSL forest canopy dataset created in the process described above, were calculated in ArcGIS using Zonal Statistics tools in ArcGIS 10.5 Spatial Analyst extension, and attributed to the new forest patch layer.

These patches were compared to the results of the forest patch layer developed by TNC and WPC in 2007 (WPC and TNC 2011) and also attributed with several additional landscape statistics indicating geophysical setting, elevation class, ownership and patch statistics. These were then provided to WPC's Land Conservation Program for use in land conservation and prioritization activities.

We also calculated the accumulated mean LCM score for each of the 15 WPC focal areas ArcGIS using Zonal Statistics tools in ArcGIS 10.5 Spatial Analyst extension to investigate the relationship of landscape variables and quality of aquatic and forest monitoring sites.

Results and Discussion

The new WPC Forest Patch layer includes 12.2 million features with a maximum patch size of 80,347 ha (198,541 ac) and a minimum of less than 1 ha. To improve performance and practical use of the dataset, two selections were made from this final layer for use as working forest patch layers: 1) patches ≥ 0.2 hectares, and 2) patches ≥ 40 hectare. Forest patches ≥ 40 hectares total 12,315 while the forest patches 0.2 hectares and above total 335,218 (Figure 3.33). WPC's 2011 Forest Patches included 305,057 features greater than 0.2 hectares total of (WPC and TNC 2011). This increase in patches may be a result of increased fragmentation, but it is also most certainly a result of increased resolution in forest patch data derived from LiDAR in the new assessment.

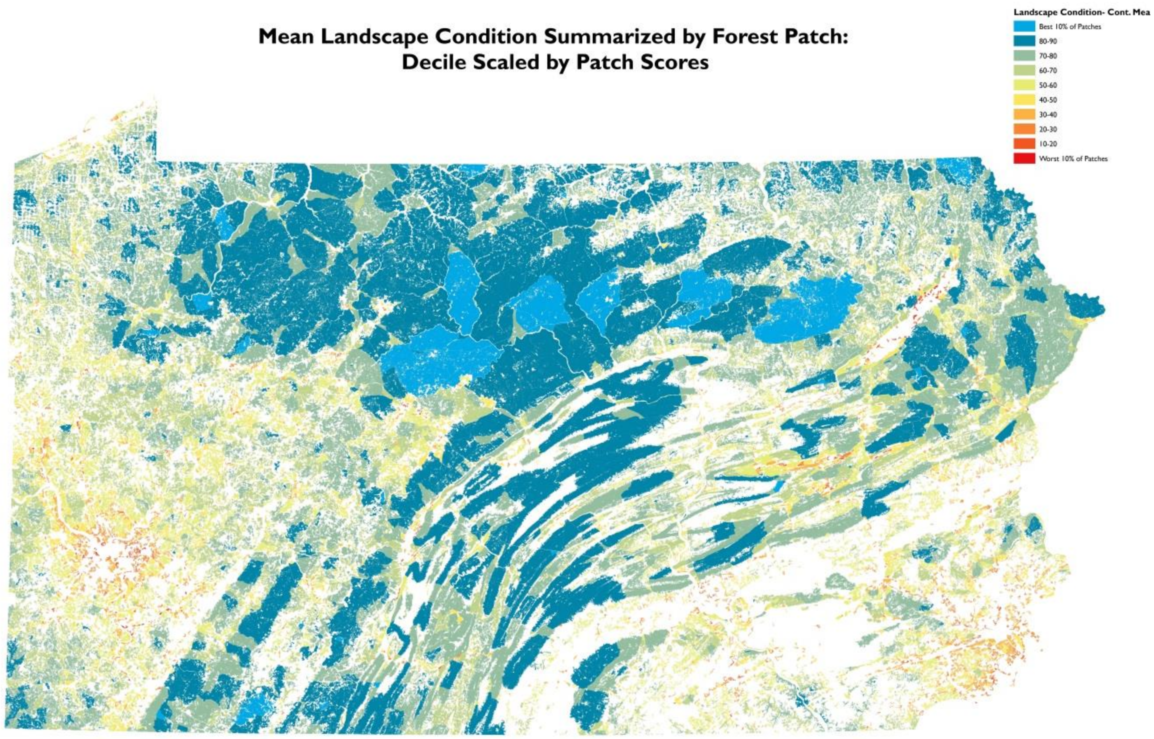


Figure 3.33. Mean land condition values from the WPC Landscape Condition Model summarized by forest patch and decile scaled by mean patch LCM values; i.e. the top decile represents forest patches with the Best Condition values (0-221).

This layer of forest patches was then presented to WPC's Conservation Science and Land Conservation programs for further evaluation and use in landscape evaluation and conservation prioritization and planning.

While the forest patches layer developed through the LCM process identified the forest patches possessing highest ecological context, it may fail to identify small patch ecosystems in highly fragmented landscapes as well as conservation values that may exist independent of our fragmentation features, such as aquatic ecosystems, vernal pool ecosystems, and rock outcrops. Further, selecting patches based on size and landscape context, while appropriate for conservation of intact interior forest habitats required by FIDS and other interior forest species, may not be what is needed to prioritize and select areas where restoration may be most effective in improving resilience of habitats and wildlife populations. Therefore, additional steps must be completed by WPC to select a final set of forest patches as targets for conservation planning. This dataset, however, provides a useful tool to evaluate the landscape condition of specific forested properties within Pennsylvania.

Relationship between Water Quality, Aquatic Macroinvertebrates and Landscape Characteristics

Land cover/land use patterns and anthropogenic disturbance in watersheds are widely accepted as drivers of water quality and aquatic community assemblage (Sponseller et al., 2001). Sensitive taxa, taxa from the orders Ephemeroptera, Plecoptera, and Trichoptera, are used as bioindicators in water quality assessments. Shale gas development has the potential to greatly modify the land cover/land use patterns within watersheds, and our collection of baseline macroinvertebrate data in streams within our focal areas enabled us to investigate links between sensitive taxa and shale gas development activities and land cover/land use patterns in general. We investigated investigate relationship between the biological and chemical parameters of water quality, land use/land cover patterns, and landscape fragmentation within the 15 focal areas studied. Specifically, we were interested in how the diversity of sensitive taxa within streams differed among the focal areas, with respect to land cover/land use and landscape condition of the focal area.

Methods

The land cover of each of the focal areas, which generally follow watershed boundaries and may therefore be used to represent general watershed boundaries for the assessment points, was determined using Zonal Statistics tools in ArcGIS 10.5 Spatial Analyst extension. Summary statistics relating to fragmentation and shale gas development were calculated for each monitoring point (number of wells/well pads in the focal area, distance between wells and monitoring points (meters), distance to nearest upstream well (meters), road density (km/km^2), pipeline density (km/km^2, percent mined lands of the focal area).

Using the PAST 3.19 statistical software, we performed correlation and regression analysis to investigate relationships between macroinvertebrate diversity indices (IBI) and chemical parameters of water quality (conductivity, TDS, pH, and heavy metals), and calculated landscape variables (%agriculture, %forest, distance to nearest unconventional well). We used ANOVA to investigate between groups of monitoring locations based on IBI score (group 1 = IBI > 50 and group 2 = IBI < 50). Data were inspected for normality and transformations were made to accommodate non-normality. Spearman rank correlation was used to compare IBI and landscape variables.

We also we performed regression analysis to determine any relationship between spring and fall macroinvertebrate IBI scores and LCM values.

Results and Discussion

Spring IBI scores showed a significant positive relationship with distance to nearest shale gas well pad (Table 3.13) while Fall IBI scores were not significant*.

Table 3.13. Spearman correlation coefficients and p-values for comparisons between IBI and environmental variables across all aquatic survey locations (n = 40).

	LCM	%Ag	%Forest	Distance to Unc.Well
IBI Spring (sqrt): Spearman's ρ	0.455	-0.590	0.563	0.410
IBI Spring (sqrt): p-value	0.003	-0.00006	0.0001	0.009

IBI Fall: Spearman's ρ	0.350	-0.542	0.560	0.280
IBI Fall: p-value	0.027	-0.0003	0.0002	0.08*

*indicates correlation is not significant ($p<0.05$)

The significant correlation in Spring IBI vs distance to unconventional wells (and near significance in Fall IBI) suggests that as distances from shale gas wells increase, the IBI scores within streams also increase. This indicates a relationship between anthropogenic development and the integrity of aquatic ecosystems, and that shale gas development may be a contributing factor. Other factors, such as percent agricultural land cover and percent forest land cover within the watershed (focal area) also are correlated with IBI in Spring and Fall samples (Table 3.13). Other factors, such as the number of wells and number of well pads in a focal area were investigated; however, they were not significantly correlated with IBI score for either fall or spring surveys.

Investigation into the relationship between water quality and landscape condition of the focal area as well as the immediate area (within 1 km of each assessment point) reinforced our understanding of landscape-level impacts on stream quality. Overall focal area landscape condition values ranged from 0.76 to 0.97, all ranking in the top 30% of values statewide. Five focal areas ranked in the 90th percentile of LCM scores statewide, three focal areas ranked in the 80th percentile, and 7 focal areas were in the 70th percentile (Figure 3.34). These generally showed that more developed (lower LCM value) focal areas contained streams with lower IBI scores and to further investigate the relation of IBI scores and landscape condition, we used a finer-grained analysis, looking at the average LCM scores for a 1 km buffer area surrounding each monitoring point. Condition scores ranged from 0.59 in the Shenango River focal area to 0.98 in the Hemlock Creek focal area (Table 3.14). Average LCM values were sometimes higher or lower than the average condition score for the focal area due to the specific location of the assessment point in relation to fragmenting features. Points that were situated the more developed landscapes tended to have a lower spring IBI score ($r^2 = 0.22$, $p = 0.002$, Figure 3.34, reinforcing the understanding that landscape condition influences the aquatic invertebrate community. Fall IBI values, however, were only weakly correlated with landscape condition and the correlation was not significant ($r^2 = 0.09$, $p = 0.06$).

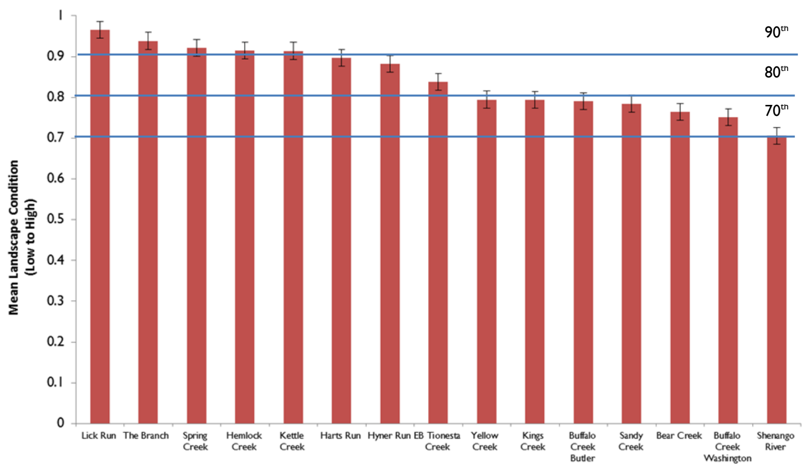


Figure 3.34. Mean Landscape Condition Model values (0=Lowest Integrity, 1=Highest Integrity) across the entirety of each focal area. Standard error bars shown. Horizontal lines represent 70th, 80th, and 90th percentile cutoffs for statewide Landscape Condition values.

Table 3.14. Average Landscape Condition Model value for the 1 km buffer surrounding each WPC water quality assessment point and average IBI score for spring and fall sampling rounds in 2017-2017.

Site Name	*Mean LCM (1km Buffer)*	Spring IBI	Fall IBI
BEAR CK UP	0.83	28.4	33.8
BearCk	0.74	31.3	27.6
N.B. Bear Creek	0.84	29.4	18.4
Buff-But-Low	0.77	38.9	48.7
Buff-But-Up	0.83	42.6	43.2
BUFF-WASH-3	0.67	37.2	39.7
BUFF-WASH-LAKERD	0.84	34.4	18.3
Buff-Wash-Low	0.74	35.9	42.1
Buff-Wash-Up	0.78	31.8	45.5
EBTC-1	0.94	45.6	48.5
EBTC-3	0.82	39.8	35.1
HARTS-RUN-BIRD	0.91	59.4	41.7
HARTS-RUN-QUIET	0.90	52.4	58.7
Hem-Porc	0.86	57.9	60.8
Hem-Upper	0.95	61.5	52.1
HEM-WAYUP	0.99	51.9	51.5
KettleCrk-Oleana	0.88	63.6	60.4
KettleCrk-Up	0.88	63.2	59.1
Germania Branch Low	0.90	55.9	56.6
Germania Branch Up	0.78	56.9	57.2
Sliders Branch	0.93	52.2	53.2
Kings-Low	0.83	41.5	36.6
Kings-Mid	0.97	45.6	45.9
Kings-Up	0.87	39.1	41.5
Lick Run	0.98	62.4	51.6
Stone Run	0.95	54.8	40.7
R.B. Hyner Run	0.93	44.7	49.8
Spring Run	0.92	57.9	59.1
SC-Bible	0.80	45.5	39.1
SC-Middle	0.80	46.2	46.6
Shenango-Upper	0.60	48.6	44.2
SPC1	0.85	47.4	50.0
SPC2	0.94	57.6	45.4
SPC3	0.94	51.0	48.3
SPC4	0.88	47.5	51.1
TBRCH-LOW	0.88	47.4	52.1
TBRCH-UP	0.95	39.7	44.9
YC Main	0.82	45.3	40.4
YC-MAIN- UP	0.86	39.2	15.0
LYC	0.81	47.8	43.8

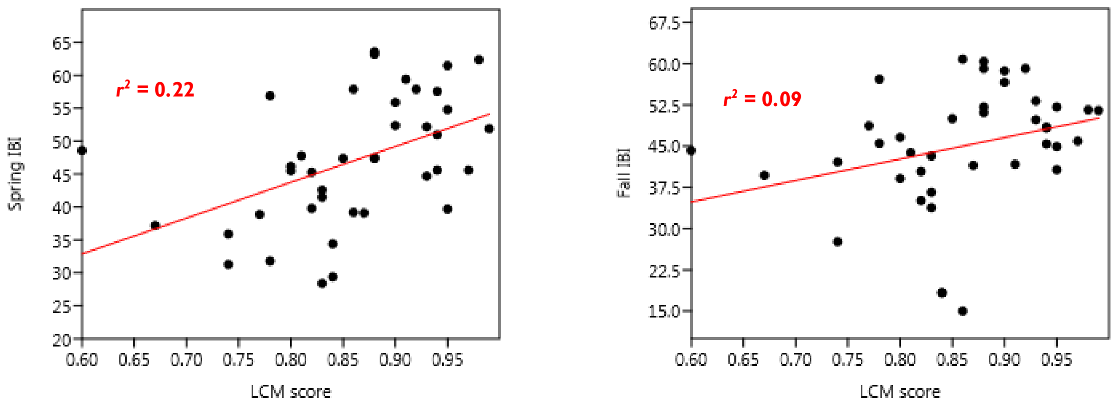


Figure 3.34. Linear regression between mean landscape condition of a 1 km-diameter buffer surrounding each monitoring location and IBI scores obtained in spring and fall sampling rounds in 2016-2017 with trend line and r^2 value given for strength of relationship.

Relationship between Forest Interior Bird Community and Landscape Characteristics

In our previous work (WPC, 2015), we found that our reference sites varied with respect to small-scale human disturbance factors, such as roads, invasive plants, and logging and the accumulation of these anthropogenic disturbance factors was correlated with a greater abundance of bird species comprising the edge and young forest species guilds. The LCM enabled us to investigate relationships of landscape condition values and field data collected at our terrestrial monitoring locations. In this section, we investigated investigate relationship between the bird community and landscape fragmentation within the 15 focal areas studied. Specifically, we were interested in how the abundance and diversity of forest interior species of birds within the reference forest patches differed among the focal areas, with respect to the condition of their surrounding landscape.

Methods

The LCM values were determined for each of 277 bird survey points across 15 focal areas and the entirety of each focal area. These values were assigned using Zonal Statistics tools in ArcGIS 10.5 Spatial Analyst extension. A 200 m buffer was used to represent bird survey areas and overall focal area polygons were used to calculate corresponding focal area values.

Using the PAST 3.19 statistical software, we performed correlation and regression analysis to determine any relationship between forest interior birds and LCM values. As previously defined, we compared interior bird species abundance for 2017 (total singing males) and richness (total number of species) per point against mean Landscape Condition. Data were inspected for normality and transformations were made to accommodate non-normality. While improvements were made using arcsine and square root transformations, data still did not pass tests of normality.

Spearman rank correlation was used to compare FIDS abundance and FIDS richness versus Landscape Condition.

Results and Discussion

Comparing bird and forest monitoring reference sites to overall focal area landscape condition (Figure 3.35), we found 12 reference sites ranked in the 90th percentile with the highest integrity values. Two reference sites fell into the 80th percentile and just one reference site, Bear Creek, ranked in the 70th percentile. Only reference sites for Bear Creek, Kettle Creek, and The Branch had landscape condition values of lower integrity than their overall focal areas values, but even so, these LCM reference site values were within the standard error of the overall focal area values, indicating that condition of reference sites was likely quite similar to that of the focal area as a whole.

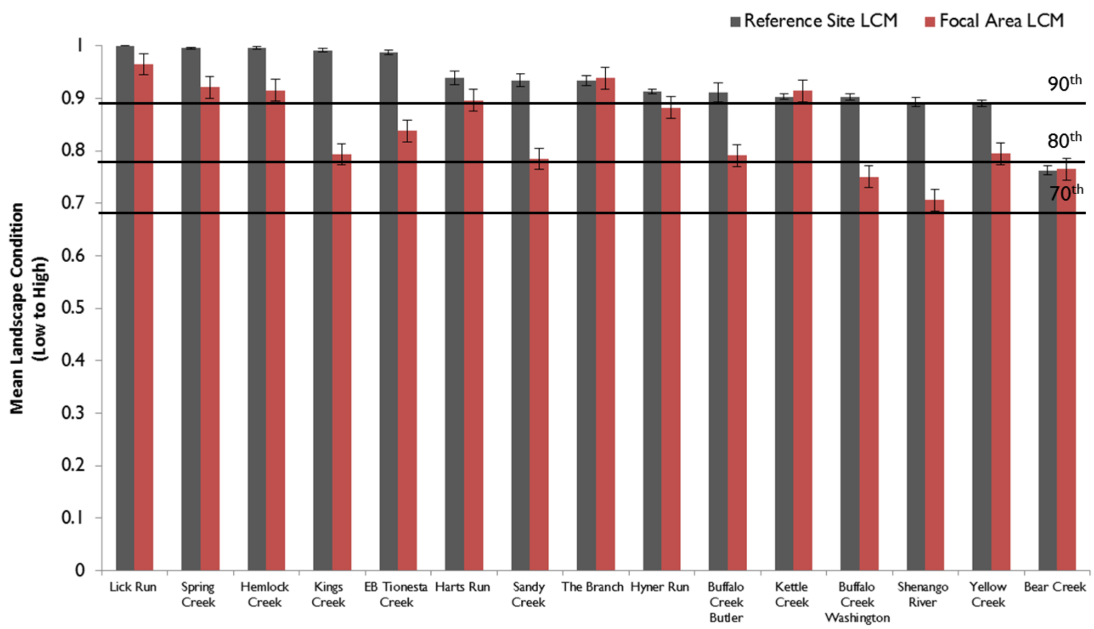


Figure 3.35. Mean Landscape Condition Model values (0=Lowest Integrity, 1=Highest Integrity) for bird and forest reference sites within focal areas (n = 277) and across the entirety of each focal area. Standard error bars shown. Horizontal lines represent 70th, 80th, and 90th percentile cutoffs for statewide Landscape Condition values.

Spearman rank correlation was used to compare FIDS abundance and FIDS richness versus Landscape Condition. FIDS richness showed a nonsignificant correlation with LCM (-0.006, $p = 0.917$), while FIDS abundance had a significant, but small, negative correlation with LCM (-0.174, $p = 0.004$). This means that as landscape condition values increase, FIDS abundance decreases, and this is shown graphically in Figures 3.36 and 3.37. However, this linear regression shows provides very little explanation of the variation in this relationship with an extremely low coefficient of determination ($r^2 = 0.0406$). This indicates that there are other factors contributing to the abundance of forest interior birds.

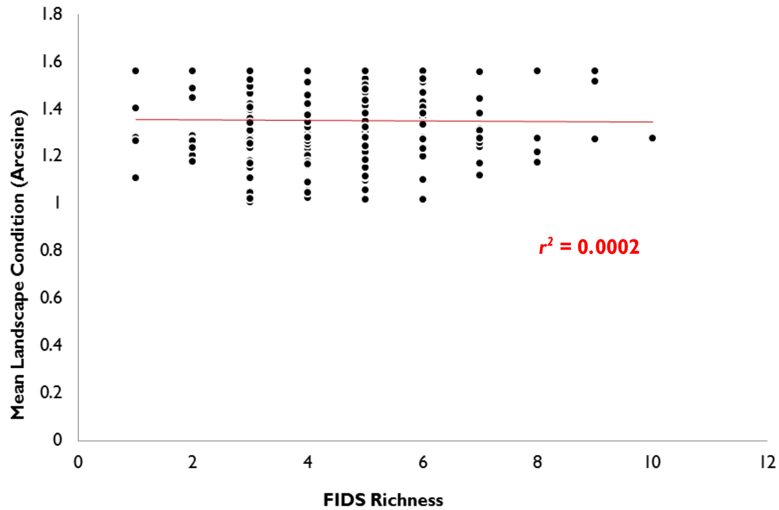


Figure 3.36. Linear regression between mean Landscape Condition (Arcsine transformed) and forest interior bird (FIDS) abundance (square root transformed) with trend line and R2 value given for strength of relationship.

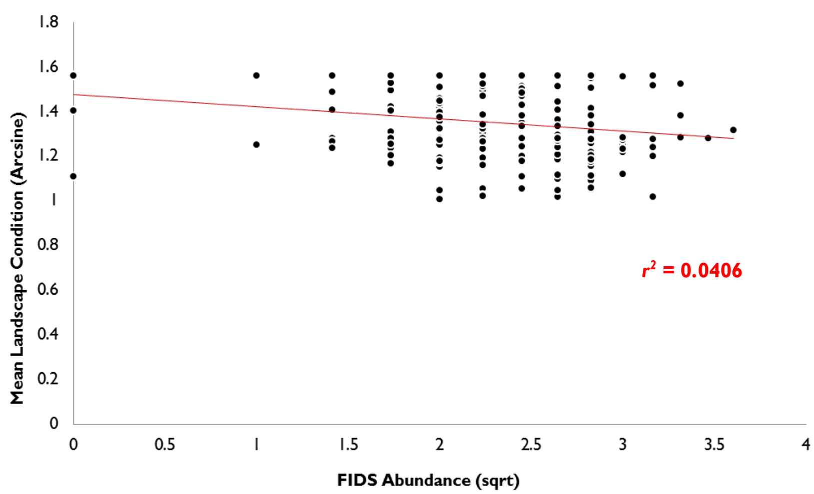


Figure 3.37. Linear regression between mean Landscape Condition (Arcsine transformed) and forest interior bird (FIDS) richness with trend line and r^2 value given for strength of relationship.

To further investigate relationships between landscape context and forest interior birds within our focal areas, we determined fragmentation metric values of core forest, patch, edge habitat, and perforated forest for each reference site bird survey location (n = 277). Again we conducted Spearman rank correlation analysis using both FIDS richness and FIDS abundance across all survey locations. We found no significant correlations ($p > 0.05$) across all comparisons (Table B).

Table 3.15. Spearman correlation coefficients and p-values for comparisons between FIDS abundance and FIDS richness across all survey locations (n = 277).

	Patch	Edge	Perforated	Core Forest
FIDS Abundance (sqrt): Spearman's ρ	-0.032	-0.025	-0.060	0.106
FIDS Abundance (sqrt): p-value	**0.598**	**0.683**	**0.322**	**0.079**
FIDS Richness: Spearman's ρ	0.015	0.043	-0.047	0.031
FIDS Richness: p-value	**0.809**	**0.475**	**0.439**	**0.610**

Figure 3.38 below gives more insight as to why no correlations were found between the landscape fragmentation metrics and forest interior birds. There was very little variation in the fragmentation composition, with Core Forest averaging 91% of the buffered sample area across all survey locations. This points to consistent landscape condition and context across our reference sites and indicates that small-scale disturbances and forest type (i.e. structure and composition) are the more influential drivers of bird habitat guild diversity and abundance within the reference forest patches.

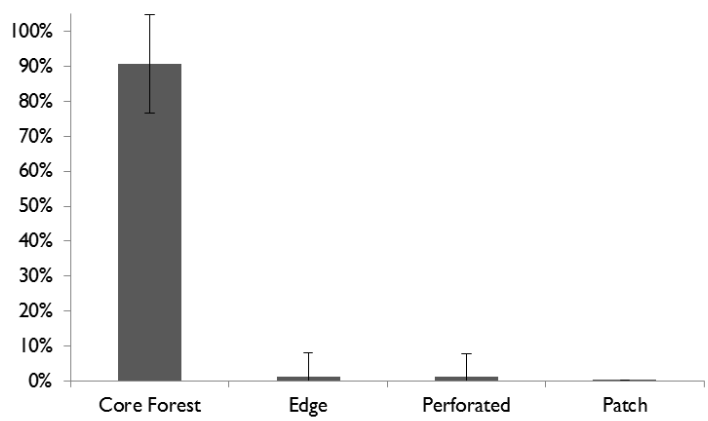


Figure 3.38. Mean percent fragmented forest type (Core Forest, Edge, Perforated, or Patch) across all reference site bird survey locations (n = 277) using a 100m buffer. Standard deviation bars shown.

Our reference sites represent interior forest patches functioning as reservoirs for species requiring core forest habitats. Our results reveal that conservation of these forest patches is still a worth-while activity even in areas of very high development.

4. Conclusions

Shale gas development activities have occurred in and adjacent to all of our focal areas; however, most sites have just begun to be touched by the industry. With the recent rise in shale gas drilling, we expect development to increase in and around our 15 focal areas, especially those situated in southwestern Pennsylvania. Cumulative impacts from shale gas development on these high quality forest and aquatic ecosystems may only be seen following several more rounds of monitoring.

Despite our findings suggesting an influence of shale gas development activities on aquatic ecosystems, such as levels of barium and strontium at the higher end of what is considered "natural occurrence" in the streams of several focal areas, it may still be too early to tell if these impacts are associated with unconventional natural gas development. Our findings may reflect a naturally high level of these metals in these particular watersheds or may indicate a legacy of pollution from historical coal mining and aluminum processing. It could also indicate direct impacts from shale gas development in the region.

Biological indicators of ecosystem quality indicated that streams within all focal areas support a diverse macroinvertebrate community, the foundation for robust aquatic ecosystems. However, there was considerable variation in water quality and diversity and abundance of sensitive macroinvertebrates within our focal areas, most likely a due to differences in land use and historical anthropogenic disturbance. Coal mining, natural gas extraction, forestry, agriculture and development have impacted all of our focal areas in some degree, and none of them can be called "pristine." Sedimentation caused by human development activity negatively affects sensitive species (Wood and Armitage, 1997) and development activities associated with shale gas development (pipelines, well pads, roads), has been shown to increase sediment load in streams (Entrekin et al., 2011). The results of our work indicate that land cover and landscape condition within the focal area greatly influences water quality of the area's streams. The health of streams within heavily forested and higher quality natural areas is high, despite the presence of shale gas development activities. Other studies have suggested that unconventional natural gas development activities in streams within more developed landscapes may have a greater impact on aquatic organisms (e.g. Merriam et al., 2018) and our data may point toward this conclusion as well.

Our estimates of forest change and core forest loss due to pipeline and well pad development is consistent with other landscape-level studies in the Appalachian Region (Farwell et al., 2016; Langlois et al., 2017). In some places, pipelines contribute to nearly 80% of the core forest loss due to shale gas development (Langlois et al., 2017). The loss core forest area within the largest patches (patches > 200 ha) in Pennsylvania due to well pad and pipeline construction may be most concerning, as core forest is considered critical habitat for species of neotropical birds. Conversion of core forest to developed land cover from construction of unconventional natural gas well pads, roads, and pipelines, has been shown to favor bird species associated with young forest and edge habitat, two habitat types closely associated with human-caused disturbances and development, including unconventional natural gas development. Our work, as well as other studies, has shown that natural gas infrastructure leads to changes in habitat that favor species common to early successional, edge, or human-influenced habitats and creates unfavorable habitat for the interior forest birds (Brittingham and Goodrich, 2010; Thomas et al., 2012; Farwell et al., 2016; Barton et al., 2016).

In this study, we found that large forest patches support a robust bird community dominated by interior forest bird species, even within our most-fragmented landscapes. However, even in remote areas, the effects of forest fragmentation stemming from development of unconventional natural gas infrastructure has been found to greatly impact nesting success of certain interior forest bird species (Franz et al., 2018). Because of the presence of infrastructure within and adjacent to our focal areas, and the ever-expanding footprint of well pads and pipelines in our region, it is not clear that our reference forest patches will continue to support the high diversity and abundance of species over time. Continued monitoring will help us determine long-term trends. More importantly, protecting intact forest habitats from additional impacts by avoiding development of existing older-growth forest habitat and improving the quality of remaining forest stands should be a goal of high priority for state and federal agencies and private land conservancies in our region, as well as public landowners of large tracts of forest land. Conservation efforts within intact forest landscapes will greatly benefit interior bird species, which are experiencing declines in abundance across their range due to a variety of factors including habitat loss within their winter range as well as here in Pennsylvania.

Many studies conclude by recommending minimizing impacts of fragmentation through public policy and proactive conservation practices that restrict where wells are drilled or where pipelines are constructed (Johnson 2010; Johnson et al 2011; Drohan et al., 2012). However, siting decisions, especially on private land are complex and policies limiting development on private land may not be attainable. The fragmented nature of subsurface resource ownership has a major influence on where development occurs. Management of natural gas development on state-owned forest land may offer a model for large private landowners in the region. In a landscape-level study of development patterns on public and private lands in Lycoming County, Pennsylvania (Langlois et al., 2017), authors found that forest fragmentation was significantly lower on state-owned forest land than on forest land in private ownership. This is due, in part, to development restrictions (e.g. number of well pads per lease tract) and requirements of infrastructure co-location established in lease agreements, as detailed in leases with the Pennsylvania Bureau of Forestry. Leases with the DCNR also include provisions to control invasive plant species within right of ways and around clearings associated with natural gas development. Langlois et al. (2017) found that pipeline infrastructure was rarely co-located with roads and other right-of-ways on private land. This type of proactive landscape-level planning may only be attainable on lands managed by state and federal land management agencies, as the ownership of forest lands and subsurface mineral rights is extremely fractured and this greatly influences where infrastructure is placed. A study comparing forest fragmentation within the large lease tracts sold by DCNR from 2008-2010 versus private lands of a similar size in Pennsylvania is needed to determine how requirements and restrictions written into the leases affect forest fragmentation. Independent of the questions regarding the degree of fragmentation on public versus private land, from our work, we can make the case that limiting the amount of forest fragmentation will directly benefit interior forest bird species, and that all efforts to further limit landscape fragmentation on private land should be encouraged. While management of shale gas development on state land may be used as a model for other large landowners in the region efforts to reduce or eliminate development all together within large patches of intact interior forest must be considered. Protecting large patches of private forest and controlling subsurface mineral rights will benefit interior bird species. We encourage implementation of practices to limit in the siting of infrastructure as suggested in many landscape-level fragmentation studies (Bearer et al., 2012; Drohan et al., 2012; TNC, 2015; Langlois et al., 2017), but realize that private land requires a greater degree of coordination in planning of shale gas infrastructure than on public land. With larger scale planning and policy solutions so difficult to realize, conservation actions that reduce fragmentation should be of high priority. Land conservation efforts through acquisition of surface and sub-surface development rights, and management of development activities through surface use restrictions should be encouraged. From a private landownership perspective, consolidation of leases and development rights by larger companies may also improve the ability to site infrastructure in a way that limits forest loss and fragmentation. Combining these actions with technological advancements that enable access of the shale gas resources from greater distances a will further reduce forest fragmentation on both state and private land.

Estimates of fragmentation are plagued by the lack of up-to-date, high resolution land cover data and researchers (including the authors of this study) have resorted to using models and estimates to represent forest canopy cover, core habitat, and location of fragmenting or have fallen back on smaller-scale studies to make broader inferences (e.g. Johnson et al., 2010; Slonecker et al., 2013; Farwell et al., 2016; Langlois et al., 2017). Comprehensive high-resolution data is lacking. We had hoped to take advantage of the release of 2015 National Land Cover Data in 2016 or 2017, but the data were not completed. The new NLCD dataset will be available sometime in 2018 or 2019 (USGS, 2016), and these data may be used to investigate overall landscape change from a time period that represented the height of the shale gas boom (2010-2014). We had a higher resolution dataset representing forest canopy (UVSDL, 2015), developed from the PAMAP LiDAR imagery and used it to develop the new forest patches for the WPC Conservation Blueprint. This statewide dataset provides the resolution needed to assess landscape-level fragmentation and these data appeared to capture landscape impacts associated with unconventional natural gas development not apparent on the NLCD. The precision of the LiDAR imagery therefore makes it possible to estimate the loss of canopy cover at a large scale. However, the program was conducted just once, over a three year time period (2006-2008) and, like the 2010 NLCD, the imagery was produced before most of the unconventional wells were drilled in Pennsylvania, missing the height of the shale gas boom.

From this work, as well as the work of other researchers in the Appalachian region, we have a greater understanding of how our natural habitats are changing due to the development of unconventional natural gas infrastructure. The results may serve as useful for public outreach and education efforts and provide data for policy makers and conservation groups, but more than anything they serve as a solid baseline in a continued effort to monitor ecological conditions of our highest value ecological areas located in regions where shale gas development pressure is a major threat. Analysis of the data may have uncovered additional questions, and therefore we strongly recommend continued field assessment to provide answers to these questions. However, we believe that shale gas development is having an effect on the composition of forest birds and aquatic organisms in the region. At minimum, by altering habitat characteristics of forest and aquatic ecosystems may lead to shifts in the composition of important wildlife species. These findings will allow us, as well as our conservation partners, to make specific, science-based recommendations on management actions and policies to avoid and minimize impacts to Pennsylvania's most critical habitats, high value ecological areas, and important wildlife and plant species.

Specific conservation recommendations for aquatic and forest ecosystems include:

- Continue/expand assessment of streams sites where levels of barium and strontium are present at higher-than-normal levels, Monitoring should include isotopic analysis of barium and strontium to determine if these elements are present in streams because of unconventional natural gas development, as Marcellus and Utica shale formations tend to have higher levels of barium and strontium than surface geologies. In order to curtail practices that may negatively affect water quality, a mechanism, or "pollution pathway" needs to be established.
- Continue long term monitoring in specific watersheds where shale gas well pads have been developed near streams, such as the East Branch of Tionesta Creek to assess direct effects of development as well as cumulative impacts associated with development of multiple shale gas wells in an area, such as in our Buffalo Creek (Washington County) focal area. These data are needed to develop regulations that moderate the number of well pads, miles of pipeline, and roads in watersheds supporting a high diversity of important plant and animal species.
- Avoid further loss and fragmentation of the remaining patches of forest, especially patches of high quality unique habitat or sites possessing unique geological characteristics, such as rock outcrops, barrens communities, and limestone-derived soils. Management and restoration activities to minimize the effect of direct and indirect impacts of forest fragmentation will minimize cumulative impacts of shale gas and other human developments.
- Prioritize conservation and restoration activities within the remaining large forest patches in more developed landscapes to save and improve what remains of our intact forest ecosystems. Protecting intact forest habitats and minimizing fragmentation should be a goal of state and federal agencies and private land conservancies in Pennsylvania.
- Support efforts for new PAMAP LiDAR imagery. This will enable a detailed comparison of forest cover before and after the first stage of the shale gas boom from 2010 to 2014. A dataset of two periods from PAMAP at the scale available through LiDAR imagery would provide the clearest picture of forest loss and fragmentation statewide from all forms of development including shale gas well development.
- Implement best management practices in infrastructure siting, including colocation of linear infrastructure as recommended in many landscape-level analyses (Bearer et al., 2012; TNC, 2015; DCNR, 2016). Minimizing new road development and stream crossings and maintaining and improving riparian buffers will help maintain water quality and interior forest conditions. Site planning tools to identify routes for pipelines and roads that minimize landscape fragmentation, such as TNC's LEEP planning tool (TNC, 2015), may help to avoid impacting large patches of interior forest.
- Support public policy that emphasizes maintenance of large unfragmented forest areas and we support policies that limit further fragmentation of large core forest areas in the region.

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Appendix. A Landscape Condition Model for Pennsylvania