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"Fence-line" contrast soundscape study of forested lands in Allegany State Park and Allegheny National Forest: Is there an impact of oil and gas development on an eastern forest soundscape?

Kasey Lynne Osborne
kosborne@outlook.com

"FENCE-LINE" CONTRAST SOUNDSCAPE STUDY OF FORESTED LANDS IN ALLEGANY STATE PARK AND ALLEGHENY NATIONAL FOREST: IS THERE AN IMPACT OF OIL AND GAS DEVELOPMENT ON AN EASTERN FOREST SOUNDSCAPE?

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Kasey Lynne Osborne
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Dr. Anne Axel, Committee Chairperson
Dr. Jayme Waldron
Dr. Shane Welch

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APPROVAL OF THESIS

We, the faculty supervising the work of Kasey Lynne Osborne affirm that the thesis, *"Fence-line" contrast soundscape study of forested lands in Allegany State Park and Allegheny National Forest: Is there an impact of oil and gas development on an eastern forest soundscape?*, meets the high academic standards for original scholarship and creative work established by the Master of Science in Biological Sciences and the College of Science. This work also conforms to the editorial standards of our discipline and the Graduate College of Marshall University. With our signatures, we approve the manuscript for publication.

Dr. Anne C. Axel, Department of Biological Sciences   Committee Chairperson   Date

1 June 2017

Dr. Jayme L. Waldron, Department of Biological Sciences Committee Member   Date

1 June 2017

Dr. Shane Welch, Department of Biological Sciences   Committee Member   Date

1 June 2017

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DEDICATION

I would like to dedicate this work to my parents, Debra and Dennis Osborne, for being my first introduction to the natural world, supporting me in all of my endeavors, and always being the greatest source of reason, wisdom, guidance, and love I could ever hope for.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

“Natural resources”—an inclusive term indiscriminate of splendor or conservation status – require proper management, be it for forest, oil, water, wildlife, or even soundscapes. The soundscape, or all sounds (biophony, anthrophony, geophony) characterizing an area, is both an ecological monitoring tool and a resource itself—a component of the landscape. As energy demands surge, the oil/gas region of the Appalachian Plateau adjusts to unconventional extraction concurrent with traditional drilling operations. Energy development leaves enduring spatial footprints on the landscape, such as fragmentation from well-pad matrices. Soundscape patterns may not be as readily observed as visual cues, but their analysis can reveal temporal landscape changes and ecological integrity. This study examined the soundscape of a contiguous eastern deciduous temperate forest located across the “fence-line” of a federally-managed forest (Allegheny National Forest, PA), an area with ongoing energy development, and a state-managed park (Allegany State Park, NY), an area without energy development. Using comparable sites in each state, I deployed ten Wildlife Acoustics SM2 recorders (Wildlife Acoustics 2013) in a north-south line across the PA-NY border. The devices recorded for one minute every thirty minutes, and these data were collected every two months. The indices used reveal how complex or uniform the sound is, the ratio of biophony relative to anthrophony, and ultimately show how biodiversity may wane in response to ecosystem health. The literature generally finds higher biophony and acoustic complexity in undisturbed areas, which the undeveloped NY sites are predicted to reflect. The expected results imply that the infrastructure, land disturbance, and compromised natural soundscape associated with energy development can negatively impact wildlife occupancy, communication, reproductive success, vegetation composition, and ecological integrity as represented by acoustic niches in the soundtope.

Incorporating soundscapes into modern landscape assessment ensures comprehensive and informed natural resource management. Results indicated a significant difference between the two forest management plans in only the acoustic complexity index in the full dataset; this could be explained by a lack of temporal distinctions in the full analysis, an influx of species associated with edge on lands with energy development, or the omission of the 2017 dawn chorus data. Homogeneity of variance was detected in the ACI for the NY sites at dawn chorus, meaning the ACI values between sites in NY were not significantly different; however, heterogeneity of variance was detected for the AEI and NDSI.

CHAPTER 1

INTRODUCTION

The "New World" of America astounded early surveyors with the land's variform and abundant natural resources—from great and sturdy trees, wide, flowing rivers, bounteous feathered and furred game, to untapped energy just below fruitful soil. She remains a natural resource hub, with the stewardship of her lands perpetuating abundance to the current day. However, the coexistence of both scenic horizons rich with life and resources vital to human civilization has not been attained without a balancing act. Sustainably using natural resources while promoting economic and societal growth is the key to continued enjoyment of nature and services for generations to come. However, this balance is contentious and complicated to both determine and implement. The political climate of natural resource management is increasingly impassioned as both public environmental awareness and energy demands surge (USDE 2005); this discord is particularly evident in the Allegheny Plateau. Pennsylvania is the home to many thriving historical and modern energy industries as well as its namesake, "Penn's Woods", which makes the state the second-most forested in the northeast (Smith, Miles, Perry, and Pugh 2009).

Energy Development Background

The Allegheny National Forest (ANF), covering Pennsylvania's Elk, Forest, McKean, and Warren counties, is entrenched in the history of energy extraction, for it is but 40 miles away from Titusville, PA, where the first commercial oil well, the Drake well, in the United States was drilled in August 1859 (Ross 1996). The oil fields of Bradford, PA supplied an astounding 90% of the entire world's oil demand into the early 1900s (Fettke 1938). Since this historical explosive phase in energy exploration, Pennsylvania has remained a chief source of domestic energy products, including coal, natural gas, and oil. Many of the oil fields beneath the ANF are still producing today, with new wells between 1986-2005 increasing four-fold (Thomas, Brittingham, and Stoleson 2014; USFS 2007b, 2008). Further, in the past decade, a new layer of fuel, namely the Marcellus shale, in the Allegheny Plateau has become newly accessible in the advent of unconventional drilling techniques such as high-volume hydraulic fracturing and horizontal drilling, wherein the shale is fractured to release gas (Brittingham, Maloney, Farag, Harper, and Bowen 2014; Engelder and Lash 2008; Drohan, Finley, Roth, Schuler, Stout, Brittingham, and Johnson 2012; Slonecker, Milheim, and Roig-Silva 2012).

Pennsylvania residents own approximately 76% of the land developed for shale-play, non-residents own 7%, and the Commonwealth owns 17%, leading to booms in the regional economies of those towns near the developed sites (Kelsey, Shields, Ladlee, and Ward 2011). In 2009, around 24,000 new jobs and $3.1 to $3.2 billion in new income came into Pennsylvania (Kelsey et al. 2011). State agencies, including the Pennsylvania Game Commission and Department of Conservation and Natural Resources, have also reaped the economic benefits of owning mineral rights in shale-play regions, receiving millions of dollars toward their agency missions (Kelsey et al. 2011; Drohan, Finley, et al. 2012).

Since the mid-2000s, Pennsylvania has undergone rapid landscape change to accommodate the influx of this new energy development. According to the Pennsylvania Department of Environmental Protection (PA DEP), the agency tasked with managing energy resources, the number of historical and modern well reports amount to around 325,000 wells drilled since 1859 (PA DEP 2011), with about 51,000 unconventional and conventional wells formed in the past decade, per the PA DEP’s self-reporting system records (PA DEP 2017). Numbers obtained from this system can have an element of ambiguity to them due to the nature of self-reporting by energy companies, the variety in types of wells and operations, historical and modern production, and the inclusion of permitted and future wells (Drohan, Finley, et al. 2012).

Conventional wells and unconventional Marcellus shale wells often exist in the same area, though they regularly have different spatial footprints (Drohan, Finley, et al. 2012; Drohan, Brittingham, Bishop, and Yoder 2012; Johnson 2010). The abundant conventional wells are shallow and typically one ha or less, but occur in clusters over large swathes of land (Slonecker et al. 2012; USFS 2007a). Traditional wells outnumber Marcellus shale operations, though the latter have a footprint anywhere between two and twelve ha, and are comprised of well pad matrices and substantial infrastructure (PA DEP 2011; Drohan, Brittingham, et al. 2012). However, the horizontal wells employed for Marcellus shale, which can reach 2,438 m in subterranean length and, thus, access a wider area for gas, can result in fewer overall wells drilled (Drohan, Finley, et al. 2012). While the peak of the current Marcellus shale drilling has passed and new drilling permit applications have presently slowed, the potential short- and long-term impacts eastern forests will experience are not yet well understood, for research has been unable to keep up with the expanding gas exploration (Thomas et al. 2014, Drohan, Brittingham, et al. 2012); however, effects can be partially predicted by studying similar landscape disturbance in ecosystems from other anthropogenic processes (Brittingham et al. 2014).

This study examined the effects of general (conventional and unconventional) natural gas extraction on eastern deciduous forests by analyzing and comparing the soundscapes in sites in a state park without energy development and a national forest with energy development.

Ecological and Ecosystem Impacts

Civilization depends on functioning, interconnected ecosystems for many daily items, or goods and services: food, water, living space, medicines, building materials, recreation, aesthetics, energy, and countless other products and activities. An ecosystem's health is often defined and assessed in terms of its ecological integrity and condition, which are intricate qualities encompassing features such as the ecosystem's ability to reach its natural biological potential, its ability to recover following disturbance, how stable its patterns are, and the diversity, composition, and functions of the species and communities it supports and sustains (Karr and Dudley 1981; Karr, Fausch, Angermeier, Yant, and Schlosser 1986; Parkes and Lyon 2006).

As with any large-scale anthropogenic disturbance, the opportunity for compromised ecological integrity is increased (Noss 1990; Drever, Aitken, Norris, and Martin 2008; Parrish, Braun, and Unnasch 2003; Andreasen, O'Neill, Noss, and Slosser 2001; Jones and Pejchar 2013). Many types of disturbance and landscape change occur with energy development, including forest fragmentation and clearing; access roads and road systems; well pads and associated well matrices; vertical and horizontal drilling operations; gathering and main transmission lines; construction machinery; compressor stations; freshwater and flowback water storage ponds; equipment storage areas; pipelines; increased human traffic and occupancy for site maintenance; and other anthropogenic disturbances (Drohan, Brittingham, et al. 2012; Slonecker et al. 2012;). Habitat alteration, particularly linear clearings used for roads and pipelines, can have marked impacts on habitat and inhabitants, such as edge effects, barrier effects, and road mortality (Laurance and Yensen 1991; Laurance, Goosem, and Laurance 2009; Fahrig 2003; Murcia 1995; Brittingham et al. 2014; Segers and Broders 2014).

Because natural gas development in the Allegheny Plateau, and specifically on the ANF, is frequently in forested areas (Ritters et al. 2002), core forest habitat (>100 m from edge) (Abrahams, Griffin, and Matthews 2015; Souther et al. 2014) is often compromised by fragmentation. Core habitat is particularly critical on the ANF, because it harbors most of the remaining interior forest in Pennsylvania (USFS 2007b). Fragmentation also alters forest patch size and isolation, solar penetration, and temperature, moisture, and other abiotic elements, which in turn affects biotic components, such as making way for expanding invasive plant species (Brittingham et al. 2014; Mortensen, Rauschert, Nord, and Jones 2009; Harper et al. 2005).

Beyond landscape changes, the great quantity of fresh water required for hydraulic fracturing and the possible emission of contaminants may occur, as well (Drohan, Finley, et al. 2012; Slonecker et al. 2012). Each well undergoing hydraulic fracturing requires between 11 and 30 million liters of water; as the well produces gases, surrounding groundwater mixes with the pumped water, leading to possible contamination of groundwater. Temporary dams can affect flow regimes and temporal aquatic status, changing systems from lotic to lentic, or ephemeral to perennial (Brittingham et al. 2014).

Wildlife Impacts

Being the only national forest in the state, and a large, contiguous one at that, means the ANF supports a great diversity of forest wildlife, particularly forest-interior species including neotropical migrant songbirds and species of concern (Thomas et al. 2014; Steele, Brittingham, Maret, and Merritt 2010). Because continuous and core forest is often fragmented to make way for natural gas and oil development, forest-interior specialists, particularly songbirds, can suffer from the loss of these areas. Nesting recruitment and mortality of birds can occur when development coincides with breeding season (Wilgenburg, Hobson, Bayne, and Koper 2013).

Pipelines and access roads create linear corridors in the forest, which can either serve as a barrier or an avenue of invasion (Laurance et al. 2009). Movement can be impeded or facilitated;

the latter often being the case with predatory or invasive mammals and birds such as the brown-headed cowbird (*Molothrus ater*) (Brittingham et al. 2014), leading to higher predation rates (Bayne, Boutin, Tracz, and Charest 2005). Species interactions, distribution, occupancy, abundance, and movement patterns can all be altered from the introduction of linear fragmentation (Laurance et al. 2009; Brittingham et al. 2014).

Despite the lack of literature pertaining to amphibians and unconventional gas development, forest-dwelling amphibians can suffer deleterious effects from forest fragmentation, particularly in community diversity and abundance (Gibbs 1998; Cushman 2006; Bell and Donnelly 2006; McCracken and Forstner 2014). Amphibians associated with a moist microclimate, detritus, and coarse woody debris, such as Plethodontidae, the woodland salamanders, can be negatively impacted by the artificially sustained successional habitat left by gas wells and the increased salinity associated with roads and fracturing water (Moseley, Ford, Edwards, and Adams MB 2010; Russell, Wigley, Baughman, Hanlin, and Ford 2004). Species whose ranges largely overlap or are even restricted to the areas underlain by the shale-play are most at risk (Gillen and Kiviat 2012) due to increased number of access roads and amphibians' poor dispersal abilities (Moseley et al. 2010; Storfer 2003).

Chronic noise pollution from natural gas development and production and oil wells can negatively affect wildlife (Francis and Barber 2013; Barber, Crooks, and Fristrup 2010; Barber et al. 2011; Blickley, Blackwood, and Patricelli 2012; Proppe, Sturdy, and St. Clair 2013). While the development and drilling process can take several months to years, the production period and compressor stations can contribute to anthropogenic sound for many years beyond this timeframe (Brittingham et al. 2014). Many taxa rely on sound to communicate, be it for mating, territorial establishment, awareness of predation or prey, inter- and intra-specific interaction, or other uses.

The long-term source of noise pollution in energy development is compressor stations, which can cause acoustical masking leading to site avoidance, altering avian communities, and negatively affecting species abundance, pairing and reproductive success, and prey-predator interactions (Brittingham et al. 2014; Francis and Barber 2013; Blickley et al. 2012).

Unlike the sparse research conducted in the eastern forests, the sagebrush ecosystem in the western US has experienced both extensive oil and gas development and associated research. Most of these studies are conducted primarily on the greater sage-grouse (*Centrocercus urophasianus*), which is treated as an umbrella species for those in the region (Brittingham et al. 2014; Lendrum, Anderson, Long, Kie, and Bowyer 2012; Blickley et al. 2012). Concurrent with gas exploration in Wyoming, the sage-grouse population has decreased substantially over the past several decades, indicating a negative association with gas development (Rowland, Wisdom, Suring, and Meinke 2006). Mule deer habitat selection, density, and migration routes were all found to be impacted by unconventional gas development (Sawyer, Kauffman, and Nielson 2009; Lendrum et al. 2012). While the sagebrush ecosystem is not directly comparable to the eastern temperate forest, similar patterns can exist in response to the same disturbance types.

Inversely, many wildlife species associated with edge and early successional habitat can be associated with natural gas development, where canopy removal and forest fragmentation are common. Diversity and species richness of small mammals and reptiles can be improved by the introduction of edge habitat and canopy removal (Moseley et al. 2010; Russell et al. 2004; Menzel, Ford, Laerm, and Krishon 1999; Ross et al. 2000; Greenberg 2001; Kjoss and Litvaitis 2001). Game species may flourish from properly managed natural gas openings transformed into wildlife openings (Moseley et al. 2010).

Soundscapes

Understanding interactions of human-natural systems at different scales requires assessing ecosystem health with a modern and comprehensive approach that takes advantage of innovative ecological monitoring tools (Pijanowski, Farina, Gage, Dumyahn, and Krause 2011; Dumyahn and Pijanowski 2011). One of these relatively recent tools is acoustic ecology, or soundscape assessment, which combines elements from landscape ecology, bioacoustics, community ecology, and engineering (Gasc, Francomano, Dunning, and Pijanowski 2017). A "soundscape" (Pijanowski and Farina 2011; Schafer 1977) is an entity regarded as the collection of all the sounds that exist in a certain landscape, such as a forest, city, desert, marine reef, and so on. These sounds are assembled into three classifications: biophony, geophony, and anthrophony (Pijanowski and Farina 2011). Biophony is the sound emitted from living organisms, often as the communication of birds, amphibians, insects, mammals, and other fauna. Geophony includes abiotic environmental sounds, like rainfall, flowing water, thunder, wind, earth, and rustling leaves. Anthrophony refers to sounds generated by humans or human-related activities, such as trucks and cars, planes, sirens, construction machinery, and other anthropogenic sources. These distinct categories, fluctuating over time and space, unite to form a single soundscape, which is a distinct object that reflects the informative properties of the items comprising it (Farina, Lattanzi, Malavasi, Pieretti, and Piccioli 2011a; Bedoya, Isaza, Daza, and López 2017), and is considered a natural resource—something to be conserved, as well (Pilcher 2010; Krause and Ellen 2001).

The use of sound to assess landscape change and ecological integrity is growing as a modern monitoring tool within the realm of landscape ecology (Farina and Belgrano 2004; Brown and Williams 2016; Truax and Barrett 2011). While soundscape ecology certainly integrates and builds upon parallel fields, unlike the humanities/species-centric and behavioral approach of bioacoustics and acoustic ecology, soundscape ecology largely follows the tenets of landscape ecology (Turner 1989). The field emphasizes the spatial-temporal patterns of sound with respect to biophony, geophony, and anthrophony (Villanueva-Rivera, Pijanowski, Doucette, & Pekin 2011; Bormpoudakis, Sueur, and Pantis 2013), while maintaining bioacoustics' conservation ethic (Pijanowski, Farina, Gage, et al. 2011). Landscape change has traditionally been studied in single snapshots by visual observations (Farina and Belgrano 2004) like surveys; however, soundscape studies capture information over temporal (and spatial) spectrums, reflecting landscape-level shifts in pattern and process (Dumyahn and Pijanowski 2011; Matsinos et al. 2008). While analysis of sonic facets in the environment may initially seem abstract, the soundscape contains quantifiable properties: acoustic composition, temporal and frequency patterns, spatial variability, and acoustic interactions (Pijanowski, Villanueva-Rivera, Dumyahn, Farina, Krause, Napoletano, Gage, and Pieretti 2011; Villanueva-Rivera et al. 2011; Smith and Pijanowski 2014). The acoustic patterns of a soundscape can reflect the biological diversity that exists in an area by way of signatures or occupation of sound frequency ranges, the levels of complexity of sound signals, and other quantifiable properties of collected audio, while explaining ecological and evolutionary processes as manifested in sound (Mazaris, Kallimanis, Chatzigianidis, Papadimitriou, and Pantis 2009). A diversity in frequencies used by organisms in acoustic and temporal space can be explained by the "acoustic niche hypothesis" (Krause 1987), wherein acoustic space (i.e. frequencies) within the soundscape represents a vital limited resource for species much like physical space.

The biophony portion of the soundscape is especially representative of a habitat's ecology, as it is what carries all communication from wildlife. Birds are a major biophonic presence, and beyond being a main contributor to biophony, birds are also considered indicators of ecosystem health due to traits that make them an excellent study taxon: high trophic positions, low reproductive rates (Maurer 1999; Hausner, Yoccoz, and Ims 2003), high detectability, existing literature, their presence over many landscape types and levels of vegetative structure (Furness and Greenwood 1993; Bradbury et al. 2005; Drever et al. 2008), response to vegetative structure (Eglington, Noble, and Fuller 2012), and their many life history traits and habitats (Chace and Walsh 2006; Canterbury, Martin, Petit, Petit, and Bradford 2000). Many birds are gregarious and exhibit coordinated vocalizations within and between species groups in order to convey information to both like-species and intruders (Mazaris et al. 2009; Gasc et al. 2017). Amphibians are also a major natural sound contributor; because they are often quite sensitive to any nuanced changes in their immediate environment, amphibians are considered ecological indicators of sustainable forest management (Moseley et al. 2010; Welsh and Droege 2001).

Because continuous, passive long-term monitoring of landscapes is both feasible and potentially informative with soundscape ecology, I used this method to investigate what, if any, differences in the soundscape occur between two adjacent forest sites with different natural gas management regimes (Deichmann, Hernandez-Serna, and Delgado 2017). This study examined the soundscape of two forest treatments (energy development in Pennsylvania, and no energy development in New York) using the following acoustic indices: Acoustic Complexity, Normalized-Difference Sound, and Acoustic Evenness. I hypothesized the Pennsylvania sites, with forest more fragmented than its NY counterpart, would have lower acoustic complexity, higher acoustic evenness, and a lower biophony-to-anthrophony ratio.

MATERIALS AND METHODS

Study Area

The study area was a contiguous forest in northcentral Pennsylvania, the Allegheny National Forest, extending into southern New York in the Allegany State Park. A large-scale timber industry and subsequent recovery of forest caused a species composition change from beech and hemlock to a dominance of black cherry, red maple, and sugar maple; though, there are old-growth virgin forest patches in the Allegheny National Forest (USFS 2007a; Slonecker et al. 2012). Natural gas extraction has a long history in this region and the more recent Marcellus shale extraction dots the landscape, as well.

The “fence-line” premise of this study is the political, shared boundary of the states of Pennsylvania and New York. The Allegheny National Forest in Pennsylvania is geared toward natural resource use; it is regularly logged for timber and has experienced extensive historical and current energy development, particularly natural gas and oil, whereas the Allegany State Park in New York is ordered toward recreational use by park visitors, and has only two isolated natural gas well pads, not located near the study area. The study area for the Allegheny National Forest was heavily forested, relatively remote with some residential areas nearby, and contained access roads, hiking trails, snowmobile trails, and well pad footprints with associated matrices of pads, oil lifts, and compressor stations. The Allegany State Park study area did not have any energy development, but the forest was marked with roads, cabins, camping sites, cleared areas and meadows, a reservoir, park shops, hiking trails, and other features with a general appeal to recreational visitors.

The disparate management goals and surface-mineral rights ownership of the two states provide a unique stage for a fence-line contrast study, which examines two contiguous landscapes undergoing different management regimes (Hongslo 2015). The biophony in these areas is dominated primarily by birds, but also includes insects and amphibians.

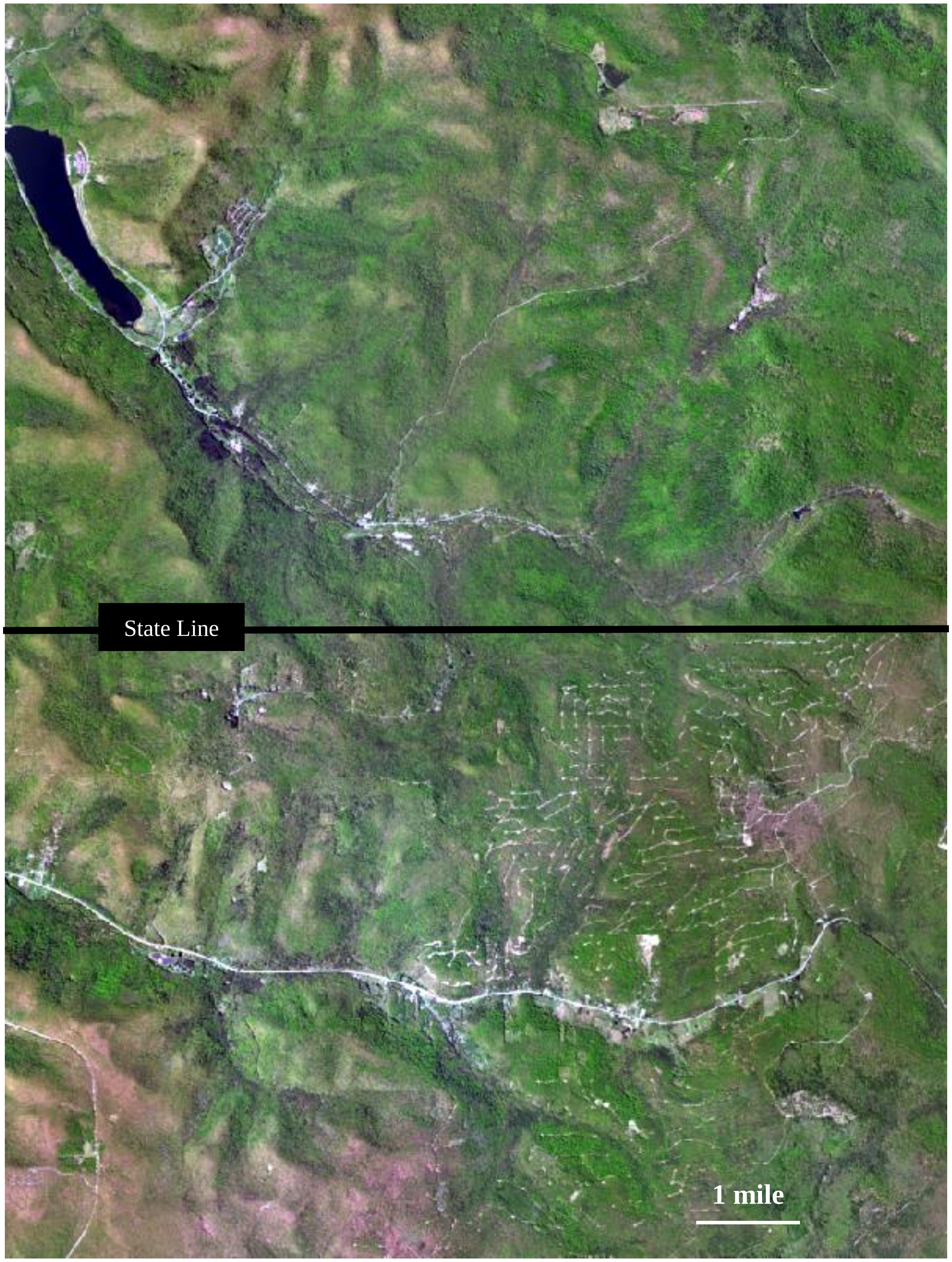

Figure 1. Map of study area

A mosaic of four tiles from the National Agriculture Imagery Program, depicting the Allegheny National Forest and Allegany State Park in May 2015 (USGS 2015).

Soundscape Recorders

I deployed Wildlife Acoustics Song Meter SM2+ (Wildlife Acoustics 2012) autonomous acoustic recorders in the study area in June 2016 and collected acoustic samples until March 2017. I programmed the devices to record for one minute every thirty minutes, though gaps existed from malfunctions, depleted memory or battery, or temporary displacement of one recorder. I used a sampling rate of 22,050 Hz, mono-right channel, and recorded in waveform audio file format (WAV).

Recorder Placement

To ensure comparable conditions and keep the fence-line component relevant, I restricted my study area in Pennsylvania to the northern extent of the forest. All sites in Pennsylvania were in the northwestern corner of McKean County, approximately ten km west of the city of Bradford. The New York sites were clustered in the southwestern portion of Cattaraugus County. The Pennsylvania forest is managed for energy development, and the New York forest management plan does not contain energy development. I arranged the recorders along a rough north-south line perpendicular to the PA-NY boundary with respect to a disturbance gradient (Gibbs 1998; Fischer and Lindenmayer 2006; Joo, Gage, and Kasten 2011; Kleist, Guralnick, Cruz, and Francis 2017; Pieretti and Farina 2013); nine of these sites were situated in an area of approximately 26 km^2 (4,920 hectares), while the tenth was the sole recorder placed at a hydraulic fracturing site located ten km south of the main study area. In both treatment areas (non-energy and energy development), I affixed the recorders to trees of 60 to 80 cm diameter at breast height by wire and about 3.5 to 4 m above the ground.

I named the recorders AF#, the pound sign signifying Allegheny Forest Unit Number. Units 1 through 5 were in the Allegheny National Forest (PA, energy development), and units 6 through 10 were in the Allegany State Park (NY, no energy development) (Table 1). I initially used a random point generator for recorder placement, and I adjusted recorder position in the field in response to surface ownership, travel concerns, and degree of forest cover. I used a comparable mix of land uses within the umbrella of either treatment, including forest away from the edge, forest proximate to trails and roads, and near buildings. I placed each recorder approximately 25 to 50 m from the forest edge.

Table 1. Recorder Locations
Recorder locations including the state (therefore forest management plan), specific latitude and longitude, elevation in feet, and the general description of the environment immediately surrounding the recorder.

Recorder	State	Coordinates	Elevation	Location Description
AF01	PA	N41.99573, W78.7869,	641 feet	near a compressor station which was activated for 4 hours every 72 hours
AF02	PA	N41.948292, W78.793037	628 feet	forest near an isolated access ro
AF03	PA	N41.982575, W78.800574	644 feet	forest patch near a recently-cleared well pad which is situated off a separate access road than the other proximate sites
AF04	PA	N41.967187, W78.816071	629 feet	forest off the main access road 2A, near an oil lift
AF05	PA	N41.859123, W78.824274	646 feet	about 6 miles south of the other ANF sites, in a forest patch near a recently-cleared unconventional well pad
AF06	NY	N42.015347, W78.822596	474 feet	steep woody hillside above a recreational campsite
AF07	NY	N42.009687, W78.800621	493 feet	woody patch off the main road, behind a wastewater complex, near a creek

AF08	NY	N42.02185, W78.848804	421 feet	off a forest hiking trail called “Bear Rock Trail”
AF09	NY	N42.028701, W78.808908	557 feet	in a woody valley called Tornado Alley, across a stream
AF10	NY	N42.045217, W78.777411	687 feet	off a main park road, in an isolated forest patch adjacent to a meadow

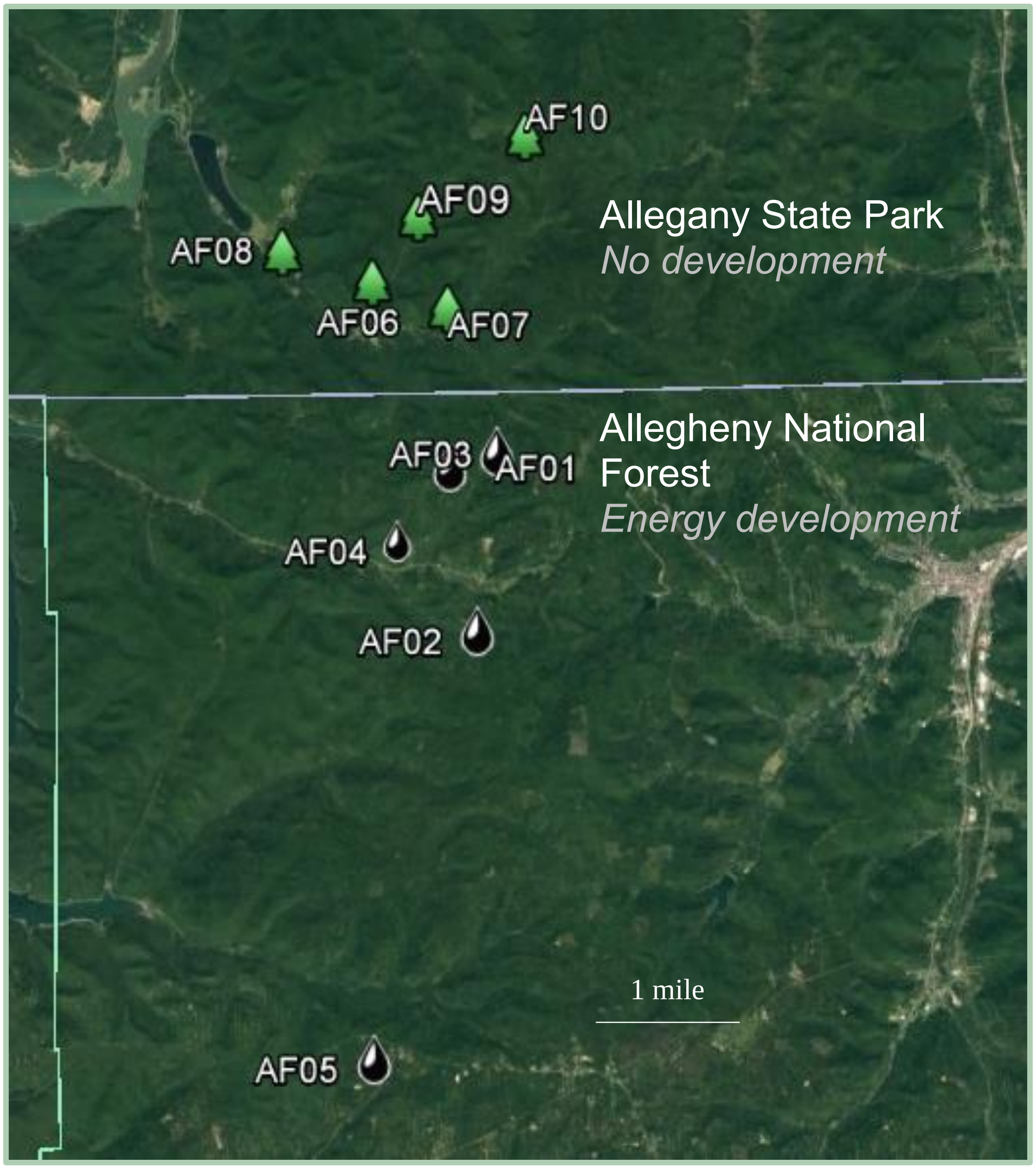

Figure 2. Recorder locations map

A map of recorder locations in the Allegheny National Forest (AF01-05) and Allegany State Park (AF06-10). Imagery is from Google Earth in June 2015 (Google Earth Pro 2006).

One recorder, AF04, was temporarily displaced, as the tree to which it was attached was logged for a timber sale. The attendants to the sale dismounted the recorder and placed it on the ground within the site, so the data from the expected time of dismount (mid-December) to the point when its batteries failed were retained, so I deemed the affected audio files as still appropriate to the site. I did not reinstall the recorder until late March, so January, February, and March data are missing for this site. The recorder was reinstalled near its original location. The recordings from unit AF09 were subject to excessive background noise from either the gain settings or the recorder's location near a stream, so I removed it from the data analysis. Many of what were likely the optimum locations of recorder placement for this study, particularly in the ANF, were inaccessible either due to private surface ownership or were avoided in deep forest to make the recorder retrieval feasible in winter months where transportation was limited and difficult. Further, the PA areas that may be more representative of widespread energy landscape are more southern than the study area, but would likely not be comparable to the NY portion of the forest.

Acoustic Indices

To prepare the data, faulty or empty WAV files were omitted from the dataset. Then, I calculated the Normalized-Difference Sound Index, Acoustic Complexity Index, and Acoustic Evenness Index on each sample. I calculated acoustic indices in the R Statistical Program (R Core Team 2015) using packages tuneR (Ligges, Preusser, Thieler, and Weihs 2015) and Soundecology (Villanueva-Rivera and Pijanowski 2015). Again, I removed AF09 recordings from both the full dataset and the dawn chorus subset because background noise was excessive due to either the gain setting inadvertently configured too high or the recorder being placed next to the stream.

Normalized-Difference Sound Index

The Normalized Difference Soundscape Index (NDSI) was developed by the Remote Environmental Assessment Laboratory (REAL) at Michigan University (Kasten, Gage, Fox, and Joo 2012). The NDSI is a measure of the ratio of biophony relative to anthrophony, ranging from -1 (pure anthrophony) to +1 (pure biophony). The frequency level of anthrophony is system-specific, though it occurs in many peri-urban systems at <2,000 Khz (the frequency of automobiles, motor boats, mowers, etc.) For this reason, the default range of anthrophony of NDSI in the soundecology package is 2,000.

Some recorders had disproportionately high anthrophony values due to their placement near mechanical sound sources, so I needed to determine site-specific minimum and maximum frequency thresholds for anthrophony and biophony by sampling 40 spectrograms for each recorder. Anthrophony thresholds ranged from 1,500–4,000 Hz and biophony thresholds were 4,000–11,000 Hz.

Acoustic Complexity Index

I used the Acoustic Complexity Index (ACI) (Pieretti and Farina 2013; Pieretti, Farina, and Morri 2011) to help discriminate between sounds that do not share the inherent patterns of biophony, particularly geophonies and anthrophonies. High values of this index represent temporal variability in the amplitude/intensity of signals as would be seen in a soundscape with many different bird species across multiple frequencies and across the length of the sample. Low values, on the other hand, represent constant frequency and amplitude values as would be seen in a soundscape filled with engine noises (Pieretti, Farina, and Morri 2011; Farina, Pieretti, and Piccioli 2011).

The output of ACI combines the complexity of sound over both temporal and frequency spectrums, and can be used as an acoustic signature of a specific soundscape at a given time. The ACI uses the summation of the absolute difference of adjacent intensity values based on the user-defined temporal interval; I set the temporal step to five seconds, which is the default in the package.

Acoustic Evenness Index

The Acoustic Evenness Index (AEI) (Villanueva-Rivera et al. 2011) is analogous to species evenness. The audio dominance and occupancy per each frequency band are calculated and represented as the Gini coefficient, wherein a value of zero is perfect unevenness and one is total evenness. Evenness can fluctuate greatly over time, with higher evenness generally indicative of less diversity represented in the spectrogram, and low evenness signifying a greater number of entities producing auditory signals, and thus, higher species richness (Sueuer, Farina, Gasc, Pieretti, and Pavoine 2014; Ström 2013). Choral times, such as dawn and evening, generally appear less even with many call types occurring at once (Fuller, Axel, Tucker, and Gage 2015; Pijanowski, Farina, Gage, et al. 2011). A low evenness score suggests a high-quality habitat due to variation in sound activity (thus low acoustic evenness), particularly in mid- and high-frequencies typical of avian calls, whereas sparse avian communities can be indicated by low AEI variation and a high overall score (Fuller et al. 2015).

Statistical Analyses

I calculated hourly means for each acoustic index sample (24 values per day per site) over the full sampling period June 2016–March 2017. I then subset the dataset to include only those values during the dawn chorus (5–8 AM) within the last half of the 2016 avian breeding season (June and July) (Farina, Ceraulo, Bobryk, Pieretti, Quinci, and Lattanzi 2015). There were 58,131 hourly samples in the full dataset (after removal of the AF09 recordings) and 1,000 samples in the dawn chorus dataset. Through transformation, I achieved normality in the AEI and ACI indices.

Mixed Models

I treated each hourly mean value as a repeated sample instead of an independent observation (Gutzwiller and Riffelll 2007) and performed statistical analyses in the R Statistical Program (R Core Team 2015).

I used nlme, the R Statistical Program package, (Pinheiro, Bates, and DebRoy 2015), to first assess relationships between each of the three indices and the forest treatments (energy development in PA and no energy development in NY) with two generalized least squares (GLS) tests fit to a linear regression model: the first without correlation or weights as a reference point, followed by one with weights (hour) to account for heterogeneity within sites (Zuur, Ieno, Walker, Saveliev, and Smith 2009). After comparing Akaike information criterion (AIC) scores between the two GLS models, the latter was determined to perform better, meaning the assumption that variance is homogenous was rejected, ruling out the validity of an analysis of variance (ANOVA) repeated measures. An ANOVA with repeated measures was considered, but the dataset, beyond being too large to yield informative results in this way, failed to meet model assumptions—homogeneity of variance, and independence—leading to a high likelihood of Type I error in determining significance.

I then performed a mixed-effects (random and fixed) model relating each index to forest management type fit by restricted maximum likelihood estimation (REML) without a covariance structure, followed by another mixed-effects model including an auto-regressive autocorrelation structure (AR-1). The covariance structure with the hour of day was used to account for temporal autocorrelation, since the samples were not independent (Gutzwiller and Riffell 2007). The fixed effects were the acoustic index and forest treatment, and the random effects were the hour and site per treatment. Based on AIC model selection, the mixed model with AR-1 autocorrelation outperformed the GLS and the mixed model without autocorrelation. The same model selection procedure was done for both the full dataset and the dawn chorus subset. Below is the final model used, where "state" is the forest treatment, "index" is the acoustic index, "dataset" is the data, and "hour" is the hour of day count per recorder:

=lme(index ~ state, data=dataset, random = ~1| site, method='REML', correlation = corAR1(form= ~hour), na.action=na.exclude)

Fligner-Killeen Test for Homogeneity of Variance

Initial results from analysis of the full dataset suggested little difference in hourly means by site, but there appeared to be rather significant differences in variance within and between sites. Therefore, I ran a Fligner-Killeen test for homogeneity of variance between and within sites for both the full dataset and the dawn chorus subset (Donnelly and Kramer 1999).

RESULTS

Mixed Model

The best mixed effects model included autoregressive (corAR1) covariance structure. Acoustic complexity was significantly higher/lower in the energy landscape (PA) than in the forest landscape (NY). There was no significant difference in acoustic index values between the forests of different management (i.e. NY and PA) for acoustic evenness or biophony-to-anthrophony ratio (24 hours per day over the full period) (Table 2). There was no significant difference in acoustic index values between the forests for any of the acoustic indices for the dawn chorus subset (June and July 2016) (Table 3).

Table 2. Model Results for Full Dataset
A summary of the statistical output of candidate models: GLS1 (Generalized Least Squares), GLS2 (Generalized Least Squares with weights and random intercept), RE (Mixed Effects with no covariance structure), and corAR1 (Mixed Effects with covariance/correlation structure by hourly sequence).

Model	Index	Estimate	Estimate	Standard Error	D.F.	*t-value*	*p-value*	AIC
GLS1	NDSI	Intercept	0.149	0.002	58100	65.320	<0.001	59100
		State	0.062	0.003		19.431	<0.001	
	ACI	Intercept	-6.971	0.000	58100	-24400	<0.001	-182000
		State	-0.005	0.0004		-12.217	<0.001	
	AEI	Intercept	0.423	0.001	58100	289	<0.001	7590
		State	-0.099	0.002		-45.854	<0.001	
GLS2	NDSI	Intercept	0.149	0.002	58100	61.962	<0.001	54500
		State	0.107	0.003		34.447	<0.001	
	ACI	Intercept	-6.971	0.0003	58100	-23300	<0.001	-186000
		State	-0.004	0.0003		-8.970	<0.001	
	AEI	Intercept	0.413	0.001	58100	281	<0.001	4580
		State	-0.122	0.002		-59.862	<0.001	
RE	NDSI	Intercept	0.143	0.123	58100	1.163	0.246	33800
		State	0.0701	0.185	7	0.378	0.716	
	ACI	Intercept	-6.971	0.003	58100	-2150	<0.001	-183000
		State	-0.005	0.005	7	-0.988	0.356	
	AEI	Intercept	0.419	0.070	58100	5.953	<0.001	-12900
		State	-0.094	0.106	9	-0.889	0.403	
corAR1	NDSI	Intercept	0.143	0.123	58100	1.162	0.246	-28100
		State	0.070	0.185	7	0.379	0.716	
	ACI	Intercept	-6.971	0.0007	58100	-9030	<0.001	-232000
		State	-0.005	0.001	7	-4.547	0.0027	
	AEI	Intercept	0.419	0.070	58100	5.952	<0.001	-52400
		State	-0.094	0.106	7	-1.284	0.889	

Table 3. Model Results for Dawn Chorus Subset
A summary of the statistical output of candidate models: GLS (Generalized Least Squares), RE (Mixed Effects with no covariance structure), and corAR1 (Mixed Effects with covariance/correlation structure by hourly sequence).

Model	**Index**	**Estimate**	**Estimate**	**Standard Error**	**D.F.**	***t-value***	***p-value***	**AIC**
GLS	NDSI	Intercept	0.604	0.019	900	31.152	<0.001	864
		State	-0.283	0.026		-10.914	<0.001	
	ACI	Intercept	-6.927	0.002	900	-3160	<0.001	-3050
		State	-0.004	0.003		-1.292	0.199	
	AEI	Intercept	0.397	0.009	900	42.843	<0.001	-458
		State	0.022	0.013		1.732	0.085	
		State	-0.125	0.001		-92.825	<0.001	
RE	NDSI	Intercept	0.603	0.171	891	1.042	0.0004	70.9
		State	-0.283	0.229	7	-1.236	0.257	
	ACI	Intercept	-6.927	0.009	891	-769	<0.001	-3150
		State	-0.004	0.012	7	-0.312	0.764	
	AEI	Intercept	0.397	0.058	891	6.80	<0.001	-752
		State	0.022	0.078	7	0.274	0.792	
corAR1	NDSI	Intercept	0.603	0.171	891	3.532	0.0004	-29
		State	-0.285	0.229	7	-1.248	0.256	
	ACI	Intercept	-6.927	0.009	891	-773	<0.001	-3270
		State	-0.004	0.012	7	-0.309	0.766	
	AEI	Intercept	0.397	0.059	891	6.781	<0.001	-805
		State	0.397	0.079	7	0.281	0.787	

Fligner-Killeen Test for Homogeneity of Variance

Boxplots of hourly mean acoustic values revealed high variability within and between sites both NDSI and AEI (Figures 3–5). The Fligner-Killeen test for homogeneity of variance (Donnelly and Kramer 1999) supported information in the boxplots indicating acoustic evenness and ratios of biophony-to-anthrophony were variable within and between the site level. On the other hand, acoustic complexity values were homogeneous within and between sites for the dawn chorus subset (Table 5), but the pattern did not hold true for the full dataset (Table 4, Figures 6–8).

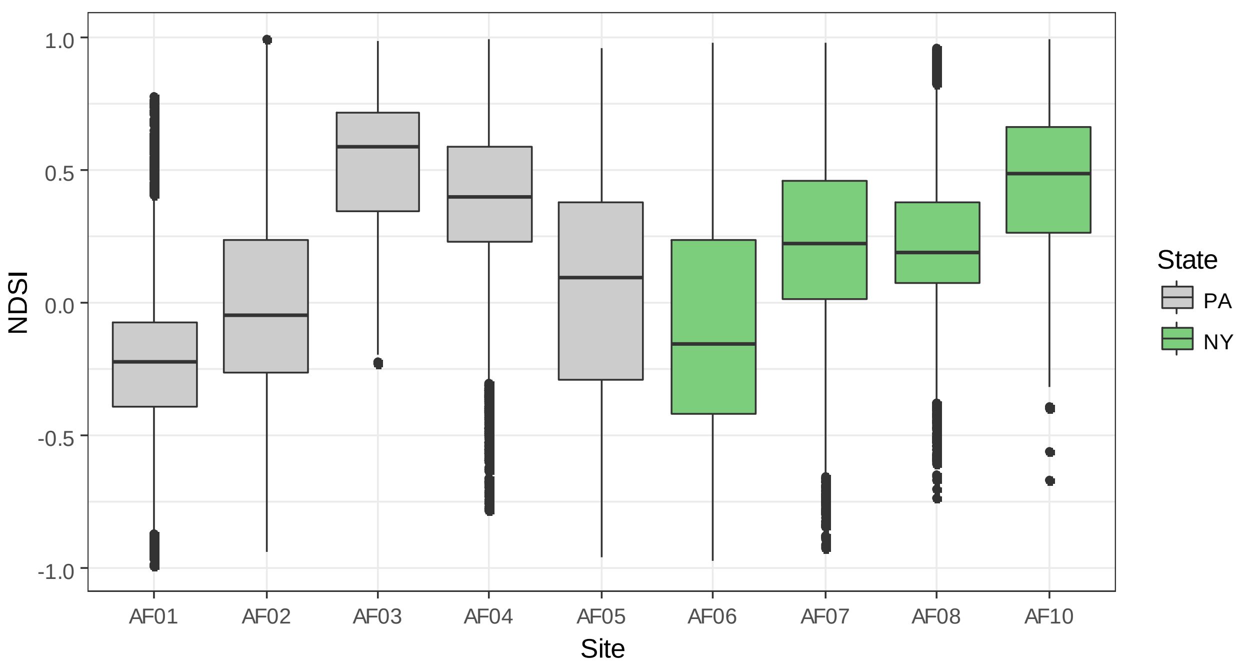

Figure 3. Normalized Difference Sound Index by Site
Boxplots of the NDSI index per each recorder. Pennsylvania sites (AF01–05) contain energy development and New York (AF06–10) do not.

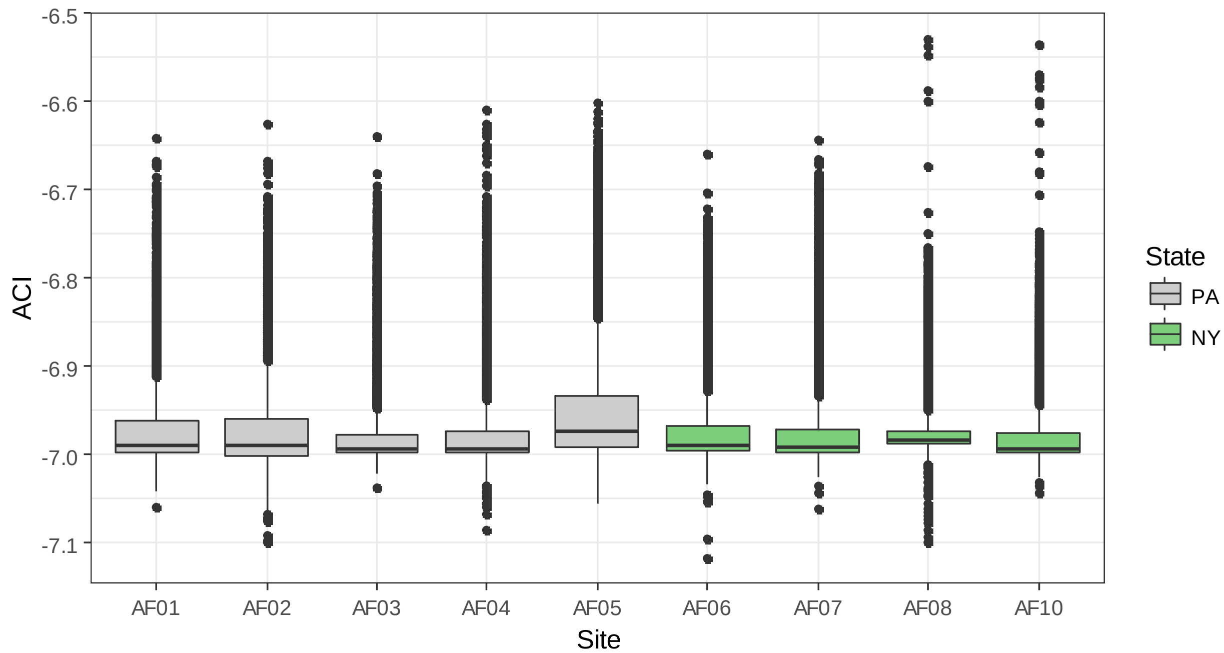

Figure 4. Acoustic Complexity Index by Site
Boxplots of the ACI index per each recorder. Pennsylvania sites (AF01–05) contain energy development and New York (AF06–10) do not.

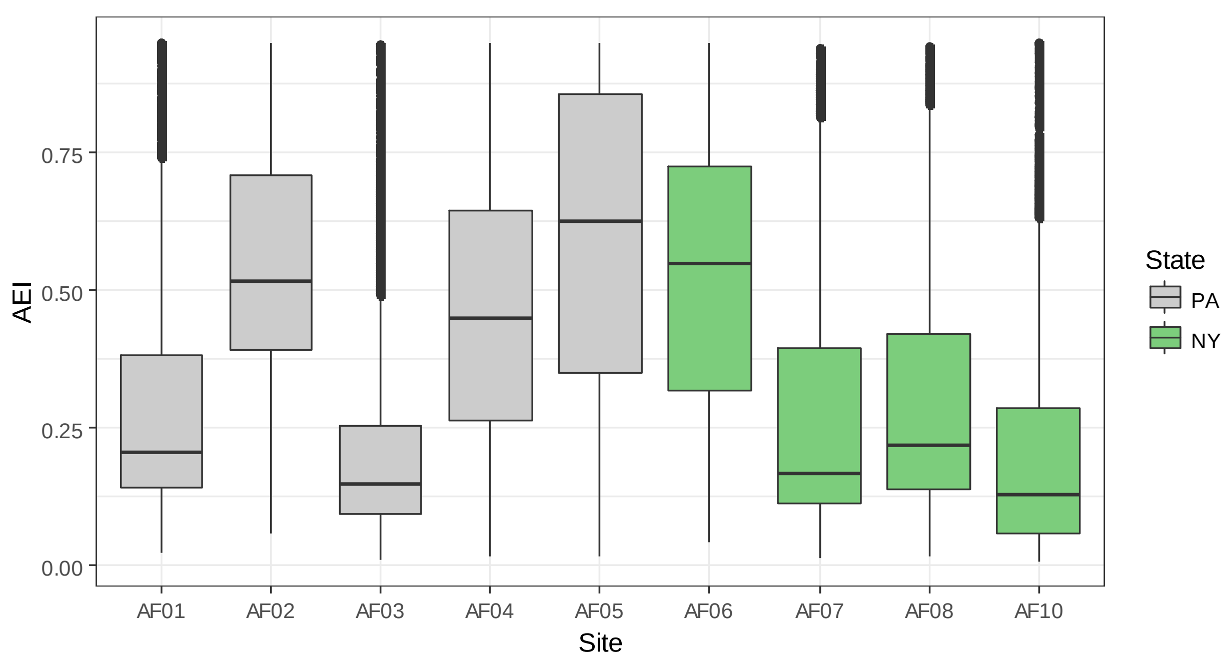

Figure 5. Acoustic Evenness Index by Site
Boxplots of the AEI index per each recorder. Pennsylvania sites (AF01 –05) contain energy development and New York (AF06 –10) do not.

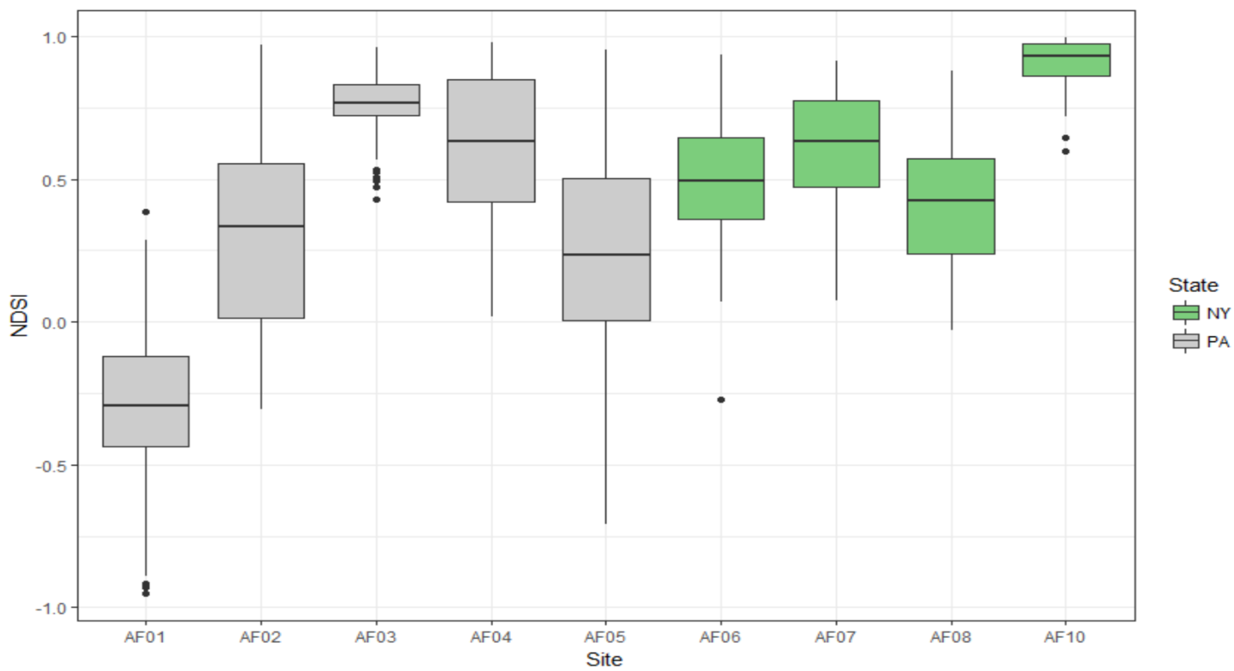

Figure 6. Normalized Difference Sound Index by Site (dawn chorus)
Boxplots of the NDSI index per each recorder. Pennsylvania sites (AF01 –05) contain energy development and New York (AF06 –10) do not.

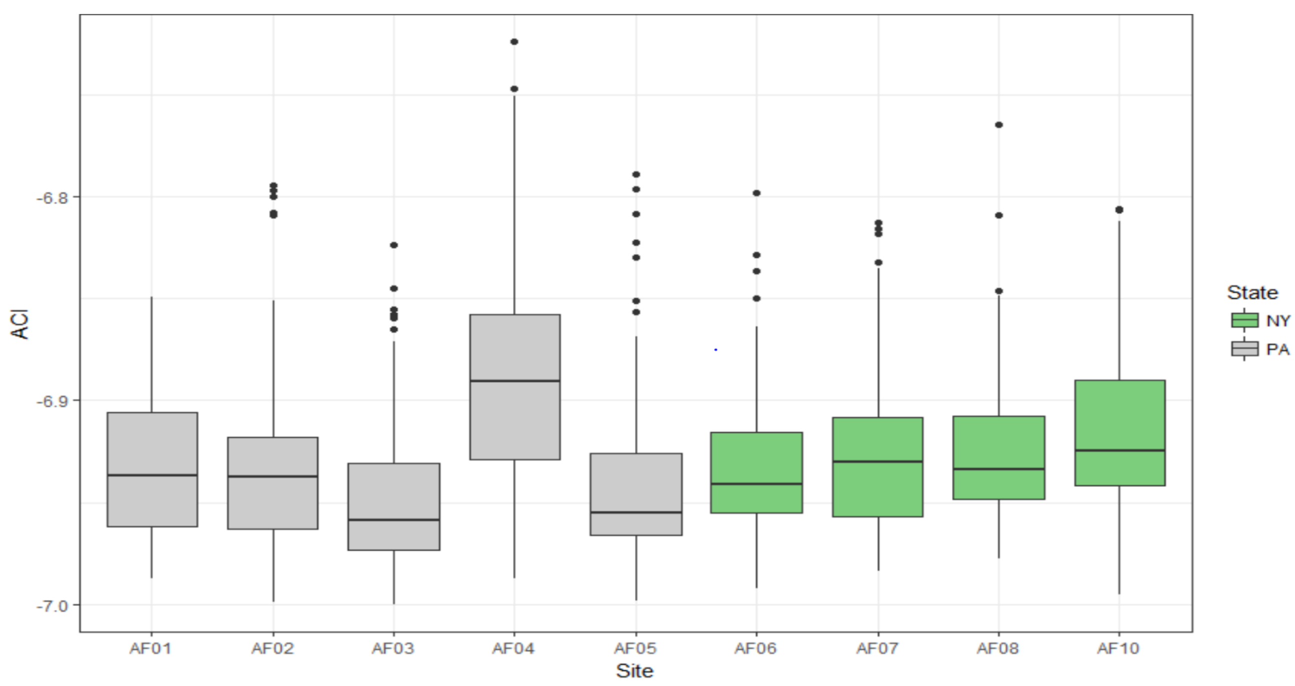

Figure 7. Acoustic Complexity Index by Site (dawn chorus)
Boxplots of the ACI index per each recorder. Pennsylvania sites (AF01 –05) contain energy development and New York (AF06 –10) do not.

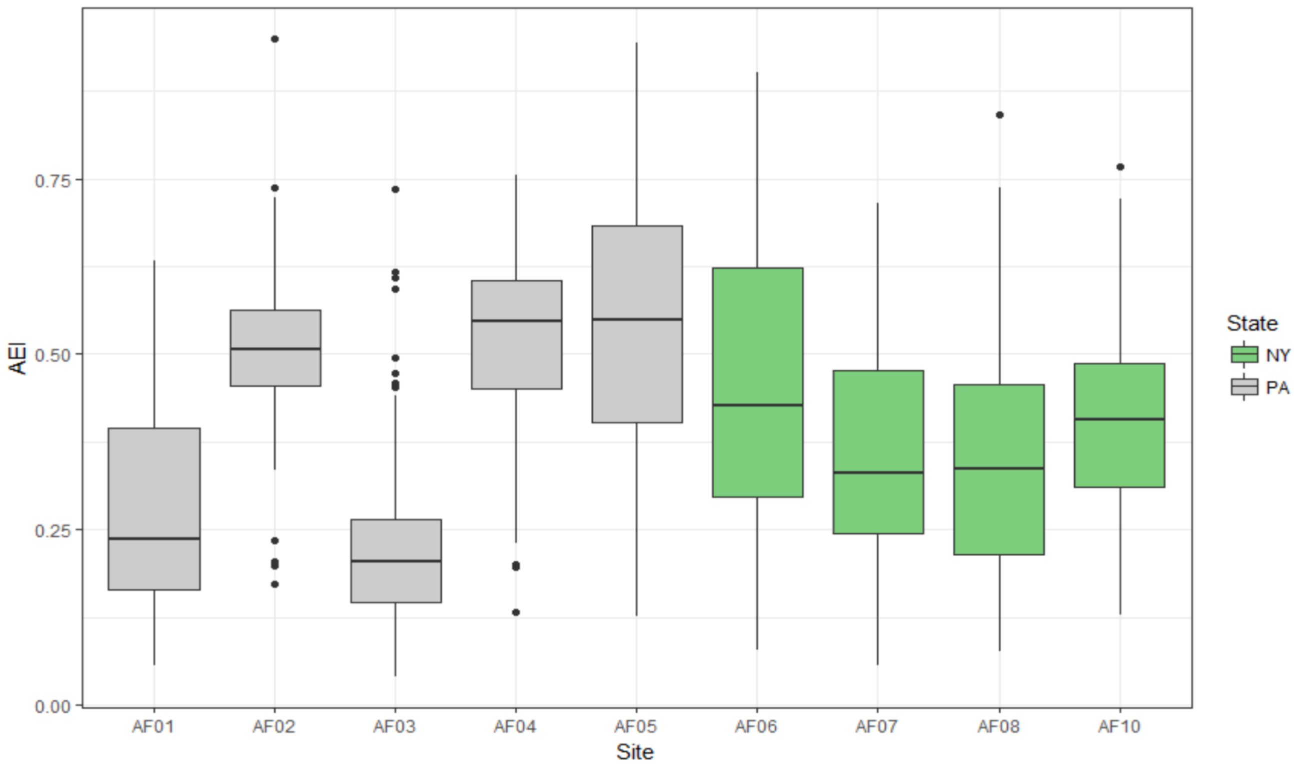

Figure 8. Acoustic Evenness Index by Site (dawn chorus)
Boxplots of the AEI index per each recorder. Pennsylvania sites (AF01–05) contain energy development and New York (AF06–10) do not.

Table 4. Results of Fligner-Killeen Test for Homogeneity of Variance for Full Dataset
A summary of the statistical output of Fligner-Killeen variance test in the full dataset.

Index	By	Chi-Squared	*D.F.*	*p-value*
NDSI	Sites	4420	8	< 2.20e-16
	PA	2430	4	< 2.20e-16
	NY	1850	3	< 2.20e-16
ACI	Sites	3860	8	< 2.20e-16
	PA	2240	4	< 2.20e-16
	NY	288	3	< 2.20e-16
AEI	Sites	12500	8	< 2.20e-16
	PA	7500	4	< 2.20e-16
	NY	4030	3	< 2.20e-16

Table 5. Results of Fligner-Killeen Test For Homogeneity of Variance for Dawn Chorus
A summary of the statistical output of Fligner-Killeen variance test in the dawn chorus dataset.

Index	By	Chi-Squared	*D.F.*	*p-value*
NDSI	Sites	203	8	< 2.20e-16
	PA	94.5	4	< 2.20e-16
	NY	65.6	3	3.65e-14
ACI	Sites	41.2	8	1.96e-06
	PA	30.4	4	3.99e-06
	NY	6.30	3	0.0981
AEI	Sites	146	8	< 2.20e-16
	PA	106	4	< 2.20e-16
	NY	29.9	3	1.42e-06

DISCUSSION

While the New York sites were expected to show higher biophony-to-anthrophony ratios, higher acoustic complexity, and lower acoustic evenness, there was only a significant difference in mean hourly acoustic complexity in the full dataset. No significant differences existed in any index in the dawn chorus subset. The variance of the NY ACI values were homogenous, but the variance of the AEI and NDSI values were heterogenous, meaning the sites within NY varied significantly for these indices.

The full dataset (June to 2016 to March 2017) was analyzed first without any temporal separation. Then, I also analyzed a separate subset to explore patterns at dawn chorus over a portion of the bird breeding season (June and July 2016) to compare biophony between sites at a particularly acoustically active period of time. Appendix B, a series of heatmaps for each index of the full dataset, illustrates how greatly the values change over the course of a year. In temperate deciduous forests, most organisms are vocally active in the spring and summer months, and in the morning and evening choruses, making these more biologically relevant time periods (Gasc et al. 2017; Farina, Lattanzi, Malavasi, Pieretti, and Piccioli 2011; Gutzwiller and Riffell 2007; Fuller et al. 2015; Pijanowski, Farina, Gage, et al. 2011). Further analysis may yield more distinct patterns by extending the window of the breeding and summer season by including the May and June 2017 data, as the dawn chorus dataset in this written study includes only June and July 2016.

The biophony-to-anthrophony ratio derived from the NDSI gives the proportion of biological sound to anthropogenic sound. Despite differences in noise, traffic, and fragmentation between the two forest areas, there were largely no differences in hourly means of acoustic indices tested. There was a difference in levels of anthrophony between sites, but when anthrophony levels are accounted for in the NDSI, levels of biophony are surprisingly similar between sites. Many wildlife species are enticed by or associated with energy development due to synanthropy, edge effects, early successional habitat, or linear corridor use (Alverson, Waller, and Solheim 2010; Moseley et al. 2010; Harper 2007), so this may account for similar levels of biophony. The NDSI boxplots for the full dataset illustrate variance between sites within each state but little pattern between the two states. Some PA sites had particularly high levels of anthrophony, such as AF01 which was near a compressor station, but some were biophony-heavy sites such as AF03, which was near a recently cleared well pad which likely captured both meadow and forest edge vocal activity and was isolated from significant anthropogenic sound sources. Similar patterns existed in New York, where AF06, which was on a steep, woody hillside overlooking a recreational campsite, had lower biophony and a greater range. Placed in a similar landscape to AF03, AF10, which was in a wooded area near a meadow, likely contained sounds both from the forest edge and meadow, leading to overall higher biophony levels.

Furthermore, because the assigned thresholds for anthrophony overlapped low-frequency animal calls, such as anurans, the NDSI could be underestimating biophonic information that exists in a lower frequency. Inversely, anthropogenic sounds that occupy a higher frequency could be miscategorized as biophony.

In the biophony-to-anthrophony ratio results in the dawn chorus subset, the difference was still statistically insignificant, but biophony levels were consistently higher and with less variation in New York than in Pennsylvania; this pattern indicates all sites in New York experience greater biophonic activity in the dawn chorus than those in Pennsylvania, where sites showed lower, moderate, and more sporadic dawn choral activity. When considering the dawn chorus subset, the New York sites may be more conducive to avian occupancy and vocal activity.

The acoustic complexity index differentiates between sounds which contain features of human-generated noise (such as the drone of a car or plane) and the temporally varied sounds of animal calls—particularly associated with avian calls (Pieretti et al. 2011). In a spectrogram, a low ACI score, such as for a file with a compressor sound, will be represented by a block with no peaks over temporal or intensity scales, whereas one for a bird call would include erratic peaks and valleys as typical for biophonic noise. For the full dataset, the ACI values were significantly different between the two forests. In the dawn chorus subset, no significant differences exist, likely because the communities of vocalizing avians were similar between the two states. However, the ecological value of certain avian species (those that may be considered ecological indicators) is not taken into account in the index. Species that are simply more abundant or call more loudly are those that will be registered (Gage, Wimmer, Tarrant, & Grace 2017; Fuller et al. 2015). Because NDSI relies on manual thresholds within which all sounds are the defined category, ACI might be best for landscapes that have a relatively constant level of drone noise so that the more complex biophonic sounds may be recognized.

While hourly mean acoustic indices did not vary substantially between sites in the dawn chorus, the variation between sites in NY seemed to be consistently less than those in PA, meaning the NY sites may be consistently higher in biological integrity across sites (Donnelly and Kramer 1999). Sites within NY exhibited homogeneity of variance in acoustic complexity. Unlike the ACI values in the PA sites, the vocal acoustic complexity values in NY sites were more consistent between sites. Because ACI largely represents avian vocalizations, the homogenous ACI values in the NY sites mean the soundscape and, by extension, landscape has consistent levels of acoustical complexity and contains a steadier level of avian songs than the PA sites.

No difference existed between the acoustic evenness values between states for either the full dataset or the dawn chorus subset. Lower acoustic evenness indicates greater species richness due to many frequency bands being occupied, theoretically by different species. NY generally had low acoustic evenness in all sites except AF06, which had a higher evenness value and a wider spread. The PA sites, however, had visually distinct differences in evenness, with AF01 and AF03 being low and AF05 being high with a wide range. The low evenness in AF01 is interesting because the site was near a compressor station and also had a low biophony-to-anthrophony ratio. Perhaps the sound and edge habitat attracted a variety of vocalizing species. Alternatively, perhaps the compressor noise was miscategorized as biophonic vocalizations. While there was no significant homogeneity of variance within states and between sites for AEI, the apparent variance between sites in PA is much greater than those in NY, meaning the species richness varies across the landscape in PA, likely in response to shifts in landscape features associated with energy development, and remains relatively constant in NY. Higher species richness or diversity also means increased biotic interactions like predation, brood parasitism, and competition (Brittingham et al. 2014).

This study examined energy development as a whole, including both the more abundant conventional well areas and unconventional together on a landscape—as they often occur together. So, the soundscape analysis cannot necessarily be attributed to either one type of energy development, but a combination of the two in spatial distribution, depending on their distance and area of effect.

The data for most recorders were replete with outliers and significant spreads. The seasonal (spring versus winter) and hourly (dawn versus midnight) cycles in sound sources and animal abundance can vary significantly over different time periods. Sampling hourly mean acoustic indices across 24-hour periods of many months may obscure sound patterns by averaging sound across seasonal and diel periods. Further, the periodic but severe noise from the compressor station may be affecting some averages.

In Pennsylvania, state and federal government can own the surface rights, while private individuals own mineral rights, so implementing standard best management practice compliance across the ANF can be difficult (Slonecker et al. 2012). The ANF may be federal land, but 93% of the subsurface mineral estate is privately owned, and, upon the establishment of the forest, and after the Weeks Act of 1911, which permitted federal government to purchase private land, the Forest Service concluded that the separation of surface and mineral rights would not impede the enforcement of its mission statement, although mineral rights take primacy over surface rights (USFS 2007b). However, public ownership of surface rights, particularly in areas with private (or public) energy development, can give way to innovative research that strikes a balance between mitigation, economic growth, and ecological health.

Since the forests of Pennsylvania are estimated to have once dominated the great majority of land, and with current estimates at a substantial 61% of total land area (USFS 2011), forest resources are a vital focus for both policymakers and stakeholders, including agencies, numerous industries, nature enthusiasts, hunters, and anyone who may use or be affected by forest resources. Ideal regulations should be friendly to both ecology and economy, striking a balance between conservation and industry that is often difficult to achieve. While the purpose of state parks—such as the case with the New York segment—is typically oriented toward recreation, national forests bear the motto “Land of Many Uses” (USFS 2011). This phrase entails a more multifaceted approach to land management in order to sustainably support anything from wildlife habitat, watershed protection, and wood products, to hunting and recreational opportunities. The breadth of factors both influencing and influenced by forests and forest-related activities and products is outside the scope of this study, but sustainability is a comprehensive practice that requires a collective mission and collaboration by disparate entities. Common sense management practices can benefit from incorporating information generated by emerging ecological monitoring tools, such as soundscape ecology.

Wildlife in energy landscapes with compressor noises might benefit from noise-abatement strategies. For areas such as site AF01 with recurring compressor noise and other areas with likewise noise pollution that hinder wildlife communication and habitat integrity, a possible noise-abatement strategy could include noise-reducing walls. Widespread compressor stations may not be quelled completely by these walls, but their area of effect would most likely be reduced across the landscape (Francis, Paritsis, Ortega, and Cruz 2011).

Natural gas forest openings are not necessarily negative introductions for all wildlife, as they can serve as wildlife openings. As stated, many reptiles and small mammal populations increase in diversity and species richness (Moseley et al. 2010; Russell et al. 2004; Menzel et al. 1999; Ross et al. 2000; Greenberg 2001; Kjoss and Litvaitis 2001) due to edge habitat and canopy removal. Managed wildlife openings and early-successional vegetation are beneficial for game species like the eastern wild turkey (*Meleagris gallopavo*), American black bear (*Ursus americanus*), ruffed grouse (*Bonasa umbellus*), American woodcock (*Scolopax* minor), and white-tailed deer (*Odocoileus virginianus*) (Moseley et al. 2010; Kammermeyer and Moser 1990; Parker, Kammermeyer, and Marchington 1992; DeGraaf and Yamasaki 2003; Litvaitis 2001). Passerines such as eastern meadowlarks (*Sturnella henslowii* Audubon), field sparrows (*Spizella pusilla* Wilson), and other songbird species (Moseley et al. 2010) can also take advantage of these openings and successional habitat with enhanced habitat heterogeneity, foraging, and nesting habitat (Parker et al. 1992; DeGraaf and Yamasaki 2003; Northrup and Wittemyer 2013). These concepts can also explain the high levels of biophonic influence in the energy development sites.

However, natural gas clearings and their road networks can result in forest fragmentation which negatively affects forest-interior species associated with core, continuous forest like neotropical migrant songbirds (Thomas et al. 2014; Steele et al. 2010), forest-dwelling herpetofauna and species with poor dispersal abilities like many amphibians (Moseley et al. 2010; Gibbs 1998; Cushman 2006; Bell and Donnelly 2006; McCracken and Forstner 2014), juvenile dispersal, opens the way for invasive species and subsequent competition with indigenous species, and can pose as an ecological trap “to which individuals of a species are attracted but in which they cannot reproduce" (Fischer and Lindenmayer 2007; Battin 2004; Drohan, Brittingham, et al. 2012).

Furthermore, taking the opportunity to make these natural gas clearings into ecological assets will require surface management that focuses on reducing soil compaction (Moseley et al. 2010), and improving species composition and vegetative structure of the surrounding plant communities (Harper 2007; DeGraaf and Yamasaki 2003). Further research examining the effects of increasing cover materials like coarse woody debris, rocks, and vegetation, and how the natural gas openings are maintained to possibly benefit wildlife, should be conducted.

The Allegheny National Forest hosts a unique blend of beauty and utility, and while examining temporal landscape change and the potential associated ecological impacts, landscape disturbance has been an integral force in the historical and current development and maintenance of eastern forests, and Pennsylvania is no exception. The condition and growth status of forests in Pennsylvania are not static, but in constant flux from use of ecosystem services, as the ANF has been both a main source of timber and energy (Flaherty and Flaherty 2014; Cho et al. 2015). Current forest composition and ecological conditions are merely a result of over a century of continued natural resource use.

Future Considerations

Again, including the May and June 2017 data with the current 2016 dawn chorus data may reveal more distinct model results. Because soundscape ecology is a new and growing field, current acoustic indices are being improved and new indices are being developed, so using other metrics may examine other aspects of the soundscapes and offer new insights. Taxonomic discernment in the soundscape—thus, including bioacoustics analysis—or field surveys can help determine if the biophony sources are from species that indicate ecosystem health, or are associated with poor habitat (Sueur et al. 2014; Towsey, Wimmer, Williamson, Roe 2014). Finally, forest metrics such as canopy cover, distance to road, and basal area can be incorporated as covariates in the two forest management regimes.

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APPENDIX A: OFFICE OF RESEARCH INTEGRITY APPROVAL LETTER

MARSHALL UNIVERSITY.
www.marshall.edu

Office of Research Integrity

April 27, 2017

Kasey Osborne
627 11th Avenue 1/2
Huntington, WV 25701

Dear Ms. Osborne:

This letter is in response to the submitted thesis abstract entitled *"Fence-line" Contrast Soundscape Study of Forested Lands in Allegany State Park and Allegheny Notional Forest: Is there an Impact of Oil and Gas Development on an Eastern Forest Soundscape.* After assessing the abstract, it has been deemed not to be human subject research and therefore exempt from oversight of the Marshall University Institutional Review Board (IRB). The Code of Federal Regulations (45CFR46) has set forth the criteria utilized in making this determination. Since the information in this study does not involve human subjects as defined in the above referenced instruction, it is not considered human subject research. If there are any changes to the abstract you provided then you would need to resubmit that information to the Office of Research Integrity for review and a determination.

I appreciate your willingness to submit the abstract for determination. Please feel free to contact the Office of Research Integrity if you have any questions regarding future protocols that may require IRB review.

Sincerely,

Bruce F. Day, ThD, CIP
Director

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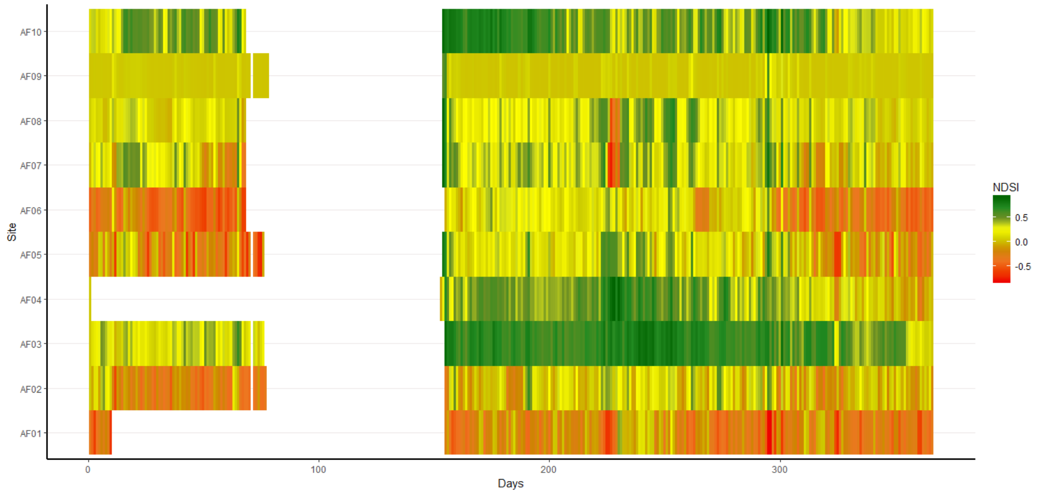
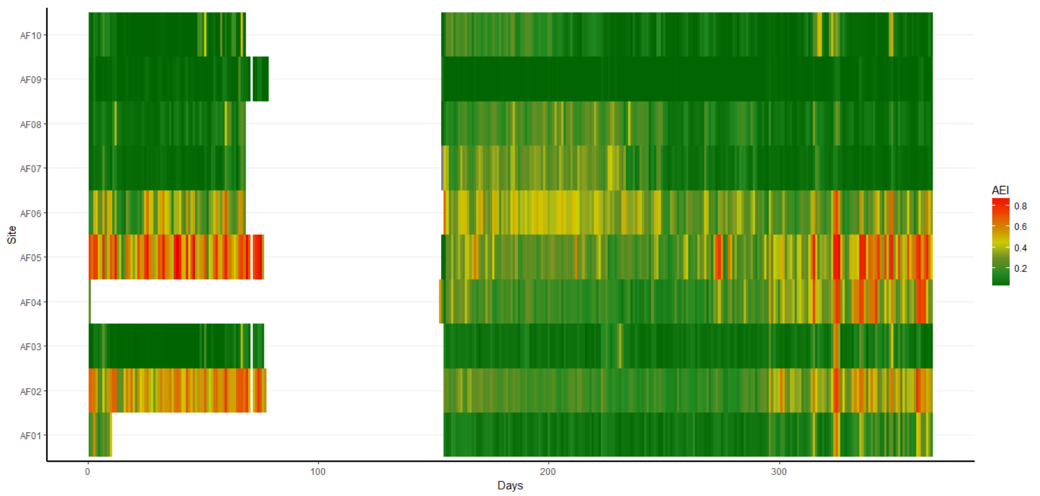
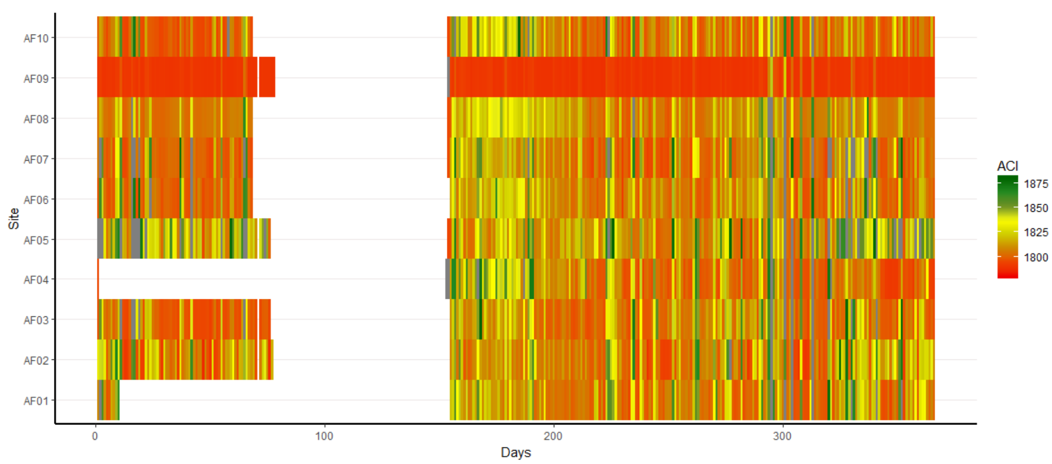
APPENDIX B: ACOUSTIC INDEX HEATMAPS







APPENDIX X: VITA

Curriculum Vitae

KASEY L. OSBORNE
196 Maple Street
Carmichaels, PA 15320
724.833.4305
kosborne@outlook.com

EDUCATION

M.A. candidate, Professional Writing and Editing, 2019
West Virginia University, Morgantown, West Virginia

M.S. candidate, Biological Sciences, 2017
Certificate: Geospatial Science Information
Marshall University, Huntington, West Virginia
Advisor: Anne C. Axel, PhD
Program GPA: 4.0/4.0
NASA West Virginia Space Grant Consortium Fellow

B.S., Wildlife and Fisheries Resources, 2015, Summa Cum Laude
Minor: Conservation Ecology
West Virginia University, Morgantown, West Virginia
Advisor: Amy Welsh, PhD
Program GPA: 4.0/4.0, Overall: 3.92/4.0

RELEVANT COURSEWORK

Renewable Resources Policy and Governance; History of the English Language; Editing; Professional Writing; Human Dimensions in Natural Resources Management; Effective Public Speaking; Remote Sensing/GIS Modeling; Applied GIS in Natural Resources; Statistics; Quantitative Ecology; Advanced Wildlife and Fisheries Techniques; Herpetology; Mammalogy; Restoration Ecology; Conservation Genetics; Limnology; Silviculture; Dendrology; Fisheries Management; Conservation Ecology; Wildlife Ecosystem Ecology

PROFESSIONAL EXPERIENCE

August 2017 – Current
English Teaching Assistant, **West Virginia University,** Morgantown, WV

- English composition

August 2017 – Current

Digital Publishing Assistant Editorial Assistant
Dissertation: Soundscapes Research, **Marshall University**, Huntington, WV
"Fence-line" contrast soundscape study of forested lands in Allegany State Park and Allegheny National Forest: Is there an impact of oil and gas development on an eastern forest soundscape?
Supervisor: Cheryl Ball, PhD, Assistant Professor of English, West Virginia University

- Thesis project is fence-line contrast soundscape study of contiguous forest in Pennsylvania and New York with different energy development policies

2009 – Current (Casual)
Clerical Assistant, **Tri-County Insurance Agency**, Carmichaels, PA
Supervisor: David Hockenberry, Owner

- Develop advertisement and manual literature
- Manage financial/insurance accounts
- Conduct insurance claims/quotes inspections
- Graph building and property layouts
- Practice customer service

April 2016 – May 2017
NASA WVSGC Graduate Fellowship
Dissertation: Soundscapes Research, **Marshall University**, Huntington, WV
"Fence-line" contrast soundscape study of forested lands in Allegany State Park and Allegheny National Forest: Is there an impact of oil and gas development on an eastern forest soundscape?
Supervisor: Anne Axel, PhD, Assistant Professor of Biological Sciences

- Thesis project is fence-line contrast soundscape study of contiguous forest in Pennsylvania and New York with different energy development policies
- Will present research at the 2017 United States – International Association of Landscape Ecology conference, "People, Places, Patterns: Linking Landscape Heterogeneity and Socio-Environmental Systems" in Baltimore, MD

August 2015 – May 2017
Biological Sciences Teaching Assistant, **Marshall University**, Huntington, WV
Supervisor: Susan Weinstein, Lab Coordinator

- Responsible for singly teaching several sections of an assigned lab course
- Grade lab data sheets and lab reports

2016 Summer
Education Assistant, **Greene County Parks and Recreation/Penn State University Extension**, Waynesburg, PA
Supervisor: Pam Blaker, Greene County Parks and Recreation Department

- Assisted Pennsylvania State University Extension Service educators with summer programs

February 2016 – June 2016
Bioacoustics Research Assistant, **Marshall University**, Huntington, WV
Supervisor: Jayme Waldron, PhD, Assistant Professor of Biological Sciences

- Responsible for using the bioacoustics software Raven to automate gopher frog call detection in sound data

January 2015 – May 2015
Phenology Research Assistant, **West Virginia University Natural History Museum**, Morgantown, WV
Supervisor: James Anderson, PhD, Program Coordinator and Professor of Wildlife and Fisheries Resources

- Worked with graduate student and group of academics/professionals on the West Virginia Climate History Project
- Investigated and compiled data sources for phenological information
- Developed outreach materials
- Conducted literature and herbarium research
- Phenology data entry
- Responsible for project planning

2014 Summer
Technical Writing Intern, **Information Technology Services**, WVU, Morgantown, WV
Supervisor: Jessika Thomas, PhD, JD, Director of Business Relationships and Customer Support

- Work with planning and design teams to create templates and content for new software documentation (wvOASIS)
- Performed software testing to determine accuracy
- Edited existing documentation and Knowledge Database

March 2013 – February 2014
Wildlife Biology and Education Intern, **Pennsylvania Game Commission**, Southwest Regional Office, Bolivar, PA
Supervisor: Joseph Stefko, Wildlife Education Supervisor (retired)

- Responsible for using a culvert trap to bait, trap, process, and release black bears (sedation, identification tattoos/ear tags, radio collars, milk tooth extraction, and body dimensions)
- Gained certification and taught several teacher workshops
- Used radio telemetry and GPS units
- Trapped (corral) and processed (age, sex) Canada geese
- Worked with Wildlife Services in Oral Rabies Baiting Program
- Responsible for trailering equipment to various programs
- Operated stations in firearm training or wildlife/habitat lectures
- Participated in habitat projects
- Responsible for trail and firing range maintenance
- Manned bear den and check stations

2012 Summer
Engineering, Scientific, and Technical Intern, **Pennsylvania Department of Environmental Protection**, California, PA

Supervisor: Matthew Cavanaugh, MSI Specialist

- Used ESRI ArcGIS to digitize mine maps and populate spatial information
- Scanned and entered mine maps into Pennsylvania Underground Mine Map Inventory System
- Performed wetland and other fieldwork with biologists, MSI inspectors, and consultants
- Inspected well pads

2009 –2011 Winter
Seasonal Laborer, **Panhead Stone & Trucking**, Carmichaels, PA
Supervisor: Lynn Cunningham, Owner

- Responsible for the local removal of snow and salt application for walkways, buildings, properties, and roads

2010 Summer
Camp Counselor, **Greene County Parks and Recreation**, Greensboro, PA

- Helped run the activities of the summer day camp

TEACHING EXPERIENCE/Certifications

- Graduate Teaching Assistant for English Composition, West Virginia University
- Graduate Teaching Assistant for BSC 105: Human Biology and BSC 104: Biology for Non-Majors, Marshall University
- Education Assistant for Pennsylvania State University Extension summer programs
- WVU Undergraduate Teaching Assistant for FOR 140: Natural Resources of West Virginia Taught/certified in teacher workshops: Project WILD, Wonders of Wetlands, Wild about Bears, Orienteering
- Conducted bluebird box/biology programs, mammal pelt lectures, radio telemetry and bear demonstrations, wetland/habitat restoration
- Youth Field Days; NWTF Women in the Outdoors; firearm/shooting sports safety and training
- Student Mentor through Society for Conservation Biology
- Supervised the Special/Rotation Exhibit for Carnegie Museum of Natural History: interactive learning aimed at children

PROFESSIONAL SOCIETIES

- Society for Technical Communication
- The Wildlife Society, National, WVU Student Chapter, Pennsylvania State Chapter
- International Association for Landscape Ecology
- Society for Conservation Biology

VOLUNTEER/OUTREACH

- Carnegie Museum of Natural History Special Exhibit; room supervisor
- Avian Conservation Center of Appalachia; avian husbandry/rehabilitation
- Pennsylvania Game Commission

- Society for Conservation Biology Student Mentor
- Writing Tutor

REWARDS AND RECOGNITION

- NASA West Virginia Space Grant Consortium Graduate Fellowship $12,000 (2016-2017)
- Pennsylvania State University Extension Outstanding Contributions (2016)
- West Virginia University Summa Cum Laude
- Alpha Natural Resources Scholarship, $6,000 (2011-2015)
- WVU Blue and Gold Scholarship, $12,000 (2011-2015)
- H. Phillip Berthy Scholarship, $1,000 (2014)
- Chingos Foundation Scholarship, $2,500, (2013)
- Pennsylvania Game Commission Wildlife Conservation Award (2012)
- Pennsylvania State Envirothon, $1,000
- Greene County Envirothon (2), $500

REFERENCES

Advisor
Anne C. Axel, PhD
axel@marshall.edu
Assistant Professor of Biological Sciences
Marshall University

Academic
Shane Welch, PhD
shwelch@marshall.edu
Assistant Professor of Biological Sciences
Marshall University

John Edwards, PhD
jedwards@wvu.edu; (304) 293-3796
Professor of Wildlife and Fisheries Resources
Division of Forestry and Natural Resources
West Virginia University
PO Box 6125, Morgantown, WV 26506

Amy Welsh, PhD
Amy.Welsh@wvu.edu, (304) 293-0718
Undergraduate Advisor, Assistant Professor of Wildlife and Fisheries Resources
Division of Forestry and Natural Resources
West Virginia University
PO Box 6125, Morgantown, WV 26506

Professional
Jessika Thomas, PhD, JD
Jessika.thomas@mail.wvu.edu, (304) 293-8851

Executive Director for Business Relationships and Customer Support
Information Technology Services
West Virginia University
One Waterfront Place
Morgantown, WV 26506

Susan Weinstein
weistei@marshall.edu
Lab Coordinator
Biological Sciences
Marshall University

David Hockenberry
d.hockenberry@windstream.net, (724) 833-0012, (724) 966-7310
Business Owner
Tri-County Insurance Agency
Carmichaels, PA 15320

Field

Joseph Stefko
jstefko@pa.gov, bearcop1@comcast.net, (724) 331-5280
Wildlife Education Supervisor (retired)
Pennsylvania Game Commission