Climate Change Impacts on Pennsylvania Forest Songbirds against the Backdrop of Gas Development and Historical Deer Browsing

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INTRODUCTION

Pennsylvania's forests have been subjected to a constantly evolving set of anthropogenic drivers that changed their composition, structure, and dynamics over the last several centuries. These drivers include timber harvesting, fire management, herbivore pressure (e.g., by near extirpation followed by overabundance of white-tailed deer), introduced insects and pathogens, and climate change. Effects of some of these drivers are relatively immediately apparent, such as when introduced pathogens cause die-offs of host tree species; others may take decades or centuries to emerge. In response to anthropogenic climate change, forests are expected to change much more gradually over time as changes in precipitation and temperature affect their regeneration, growth, and subsequent composition. However, the rate of regeneration and successional mosaic of the landscape will depend heavily on the intensity and frequency of disturbance related to these other drivers. Some of these disturbance factors are likely to increase as a direct result of climate change.

After decades of rampant deforestation during the 18^{th} and early 19^{th} century, Penn's woods have recovered substantially and are beginning to mature across the state. Today, approximately 58% of the state of Pennsylvania is forested (only half that of pre-European settlement times). The distribution of roughly 16.6 million forested acres is fairly even across the state, although the most extensive contiguous forest cover resides on the Allegheny Plateau in northwest Pennsylvania. Pennsylvania's extensive forests are usually simplified into two major types: Northern hardwoods (beech-maple-birch, 38%) and central hardwoods (oak-hickory, 47%). A subtype of Northern hardwoods that predominates in the Allegheny Plateau is Allegheny hardwoods, which consists of mostly black cherry (*Prunus serotina*) and red maple (*Acer rubrum*) anthropogenically produced from large-scale clear-cutting and high deer densities during regeneration approximately 100 years ago (Majumdar et al. 2010). Other components include sugar maple (*A. saccharum*), pin cherry (*P. pennsylvanica*), birch species (*Betula* spp.), white ash (*Fraxinus americana*), northern red oak (*Quercus rubra*), tulip poplar (*Liriodendron tulipifera*), and eastern hemlock (*Tsuga canadensis*), and others (Redding 1995). Boreal conifer-dominated forests are rare in the state and primarily aggregate along the Appalachian Mountains (Pocono area), where early clear-cutters could not reach them. Despite being a heavily forested state, the majority of Pennsylvania forests (~75%) are privately owned, with just 2.1 million acres owned by the state and 0.5-million federally-owned acres on the Allegheny National Forest (NRS 2007). As such, many of the forests are not subject to state or federal management practices and regulations, leaving their health and suitability as habitat for songbirds up to individual land owners.

The current study reports on how three anthropogenic drivers are likely to affect avian populations and communities in forests of Pennsylvania. The Pennsylvania Department of Conservation and Natural Resources identified effects of climate change and effects of energy development on the state's biota as funding priorities for its WRCP grants program in 2011. Additionally, there is a long-standing interest in effects of overabundance of white-tailed deer on other members of the biological community, both in the broader scientific community and in Pennsylvania specifically (see e.g., Tilghman 1989). Therefore, we proposed to address the effects of these three stressors—climate, energy development, and deer overabundance—on forest birds in Pennsylvania, specifically in the Allegheny hardwoods region. This report presents the findings of our study.

METHODS

Our study consists of a combination of empirical field research on forest composition and bird communities, climate change vulnerability modeling, and literature review. We used empirical field studies to evaluate the effects of differences in forest stand composition on bird communities. We used climate change vulnerability modeling to evaluate the vulnerability of focal bird species (identified during our field studies) to climate change. Finally, we used literature reviews and results of our own concurrent research studies to understand likely effects of energy development and its interactions with climate change and deer overabundance.

Effects of forest stand composition on bird communities

We collected data on songbird and tree communities in the Allegheny National Forest (ANF) located on the Allegheny Plateau in northwestern Pennsylvania. The ANF provides the most extensive contiguous forest cover within the state, covering approximately 520,000 acres. As Pennsylvania's only National Forest, it is managed by the United States Forest Service for multiple uses including timber harvesting, oil and gas resource extraction, and recreational activities.

We collected data on bird and tree community composition from May through August, 2012. We used ArcGIS to locate and establish 84 point-count stations stratified throughout the ANF by different vegetation compositions that related to effects of controlled deer densities on forest regeneration (Nuttle et al. 2011). Specifically, we selected sites with varying tree species diversity and dominance of 7 focal tree species (American beech, black cherry, pin cherry, red maple, sweet birch [*Betula lenta*], sugar maple, and yellow birch [*B. allegheniensis*]) and in two age classes (15-30 yr and >60 yr post-harvest). Once established, we visited each point-count station three times from May 18 to July 5, 2012, during the hours of 0600 and 1000 for 5 minutes each (Ralph et al. 1995, Thompson and Schwalback 1995). We aurally and visually located and identified each bird and tallied individuals under one of three distance categories: ≤50-m, 50-m to <100-m, ≥100-m. We used the maximum number of individuals per species detected within 50 m of the point count as our measure of abundance of each species in the stand. Individual birds species were too sparsely distributed across sample stands to be able to analyze them separately. Therefore, we focused on analyzing response of bird community structure, bird diversity, and total bird abundance to tree community structure.

We conducted tree community surveys at 9 sub-points surrounding the point count station using a 10-factor prism to obtain a measure of basal area of each species. We used only basal area of the aforementioned 7 focal tree species in analyses, which accounted for 55-100% of total basal area at all sites. We calculated tree diversity (Shannon diversity, $e^{H'}$; Jost 2006) using the basal area of each species as the abundance measure.

All analyses were performed in R 3.0.1. We analyzed young (15-30 yr old) and older (>60 yr old) stands separately. Bird and tree community data were converted to relative abundance using a Hellinger transformation (decostand function in the vegan R package). To determine relationships between forest tree community structure and bird community structure, we performed canonical correspondence analysis (CCA, cca function of the vegan R package) and Mantel tests (mantel function of the vegan R package), as well as linear regressions (lm function in R) of total bird abundance and bird species diversity ($e^{H'}$) on vegetation statistics (tree diversity, total basal area, leaf area index, and relative dominance of each tree species).

Climate Change Vulnerability Assessment

The Climate Change Vulnerability Index (CCVI) is an Excel-based tool developed by researchers at NatureServe to evaluate species vulnerability to climate change on a state-by-state basis. The overall vulnerability score is based on a combination of factors gleaned from extensive literature review that gauge exposure to climate change within assessment area, species-specific factors, and documented response to climate change. Exposure was determined for Pennsylvania using Climate Wizard, an online tool that utilizes downscaled climate models from Maurer et al. (2007) to examine the magnitude of predicted temperature and moisture change. For a more detailed explanation of the CCVI tool, see Young et al. (2010).

The assessment area of this report encompasses the state of Pennsylvania with emphasis on forested regions within the state. Prior to assessing each species through the CCVI tool, we conducted a thorough review of the literature to collect information on species' life history (see Appendix B) and range within the state as well as GIS data detailing predicted climate change in Pennsylvania by 2050 (Figures 1 and 2). Once the appropriate information was gathered for a species, the CCVI spreadsheet was completed to obtain the vulnerability rank (definitions of ranks are provided in Appendix A). Summaries of data and assumptions that were applied to the CCVI tool are provided in Appendices B – E. Additionally, each species report contains an overview of habitat associations and current conservation threats faced (independent of climate change) within the state. Finally, we include written justification for how important factors pertaining to the vulnerability score were evaluated.

Species Selection

Our report is unique from other CCVI assessments published thus far in that we focus on 20 species of a single taxonomic class (Aves) that inhabit a common biome (temperate forests). Using our own data on species assemblages in the Allegheny National Forest in northwestern Pennsylvania as an initial guideline, we have carefully selected species with unique life histories and statuses within the state. A complete list of species selected and their scientific names is provided in the Results section. We chose some species, such as the Blue-headed Vireo, Canada Warbler, Blackburnian Warbler, Blackpoll Warbler, and Black-throated Green Warbler, because they were suggested (but not evaluated) by PA Natural Heritage Program in their recent CCVI assessment report. We also selected species that have been evaluated or suggested for evaluation using the CCVI tool by neighboring states such as New York and West Virginia (black-throated blue warbler, Canada warbler, and Eastern wood-peewee). Evaluating bird species in multiple neighboring states may assist managers making regional as well as local decisions. Still other species chosen showed significant downward population trends over the long-term (60 years, black-and-white warbler, eastern wood-peewee), short-term (10 years, black-throated green warbler), or both (black-billed cuckoo and indigo bunting) according to Breeding Bird Survey (BBS) data (Sauer et al. 2011). All other species evaluated were detected during May – July of 2012 in the Allegheny National Forest (ANF) while investigating the effects of historic deer overabundance on current songbird communities and are thus species of interest in this report. We evaluate species that occur at a range of different frequencies (i.e.: rare, common, and ubiquitous) within the ANF. Many of the species evaluated in this report are not currently considered state conservation priorities in Pennsylvania; however, they are species representative of a variety of different forest types and age classes in the state and will therefore serve as representation of how overall forest songbird communities may change in response to climate change.

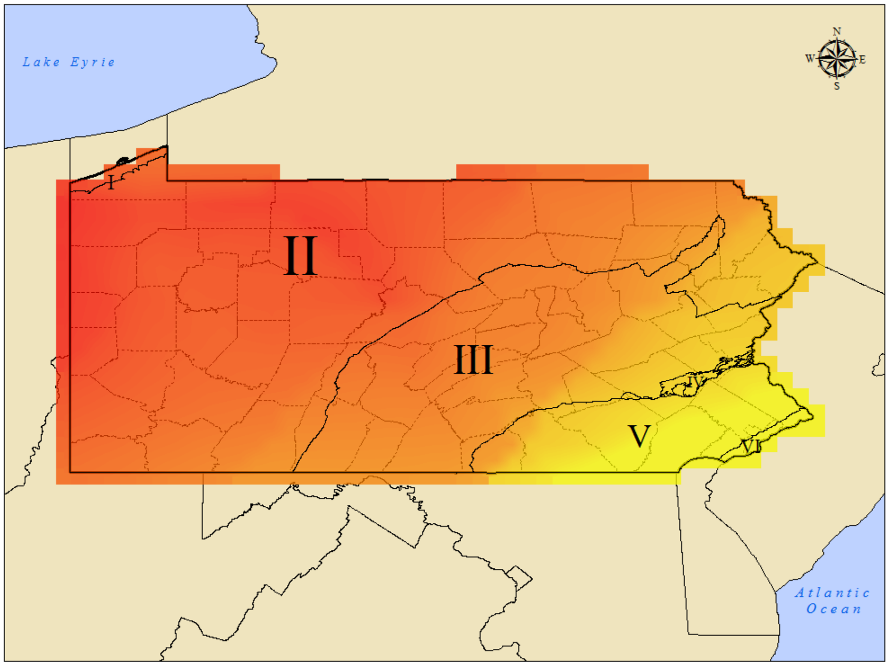


Figure 1. Projected changes in average annual temperature in Pennsylvania by 2050 according to MediumA1B emission scenario. The scenario estimates annual temperature changes will range from +4.75°F (yellow) to +5.26 °F (red).

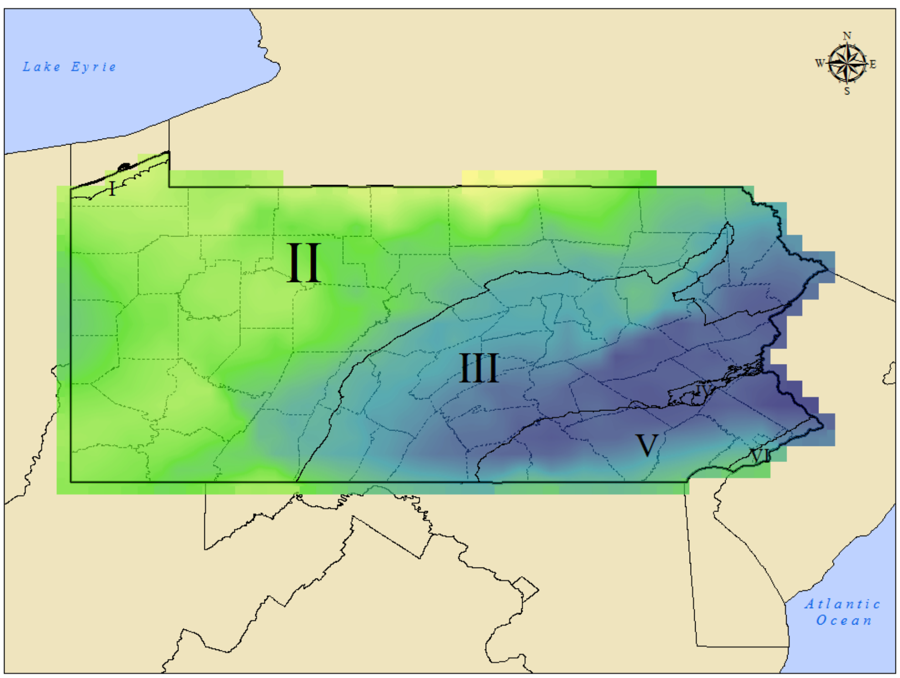


Figure 2. Projected changes in average annual precipitation in Pennsylvania by 2050 according to MediumA1B emission scenario. Areas with darker, cooler colors (e.g.: dark blue) are expected to experience the least amount of change (drying) while areas characterized with warmer colors (e.g.: pale yellow) are expected to experience the most change (drying).

RESULTS AND DISCUSSION

Effects of forest stand composition on bird communities

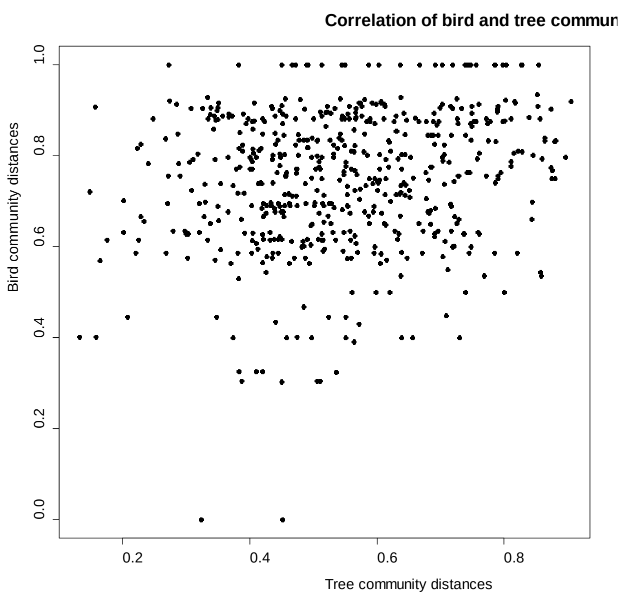
For both young and old stands, the vegetation significantly ($P < 0.05$) influenced bird communities as measured by Mantel tests and community ordination (Canonical Correspondence Analysis, CCA). However, for each age class, different vegetation variables were important; therefore, we discuss patterns in each age class separately.

Young stands:

Bird community structure in young stands was significantly correlated with tree community structure, as measured by the Mantel test with 9999 iterations ($r = 0.1988$, $P = 0.024$; Figure 3). From the CCA, bird community structure was significantly influenced by relative abundance of American beech, black cherry, pin cherry, and sweet birch and by overall tree diversity (Figure 4, Table 1). In the CCA biplot (Figure 4) forest birds are scattered throughout all but the bottom right quadrant, which is populated by more open-habitat birds like dark-eyed junco, eastern towhee, common yellowthroat, and American redstart; note that all the forest vegetation explanatory vectors point away from this quadrant, indicating non-forest conditions. Bird diversity was significantly negatively affected only by relative abundance of sweet birch; however, note that coefficients were negative for each tree species analyzed. Though trees species diversity or maximum dominance of any one tree species (Max relative dominance) was not a significant predictor of bird diversity, examination of scatter plots (Figure 5) suggests that high relative dominance of any one tree species is negatively related to bird diversity. There was also a particular strong negative correlation between relative dominance of black cherry and tree diversity (Pearson $r = -0.81$) for young stands (Figure 6). Though not significant, note that black cherry dominance had a strongly negative standardized coefficient for its relationship to bird diversity (Table 1, Figure 5). Black cherry and sweet birch are on opposite sides of the CCA biplot. None of the vegetation variables investigated was a significant predictor of bird total abundance.

Old stands:

Bird community structure in old stands was significantly correlated with tree community structure, as measured by the Mantel test with 9999 iterations ($r = 0.1572$, $P = 0.0162$; Figure 3). From the CCA, bird community structure was significantly influenced only by relative abundance of red maple (Table 1); note that most bird species cluster away from high relative dominance by red maple (Figure 4). Bird diversity and total abundance were significantly negatively influenced by higher relative abundance of every species except pin cherry and yellow birch, which were both uncommon elements of these forests. In addition to those variables, total bird abundance was also marginally negatively related to higher tree diversity, maximum relative dominance of any one tree species, and total basal area (Figure 4, Table 1). Taken together, these results suggest that high dominance by any particular tree species is bad for bird diversity and abundance, but very high diversity of trees is also not helpful in increasing bird diversity or abundance. Tree diversity was strongly negatively correlated with relative dominance of red maple (Pearson r = -0.51) and somewhat negatively correlated with relative dominance of black cherry (Pearson r = -0.17); dominances of all the other tree species were positively correlated with tree diversity. This pattern emerges because only red maple and black cherry have high values of relative dominance on what is overall a hump-shaped relationship between relative dominance and overall diversity (Figure 6). Again, the pattern suggests that bird abundance and diversity are negatively affected by high dominance by any particular tree species (Figure 5).



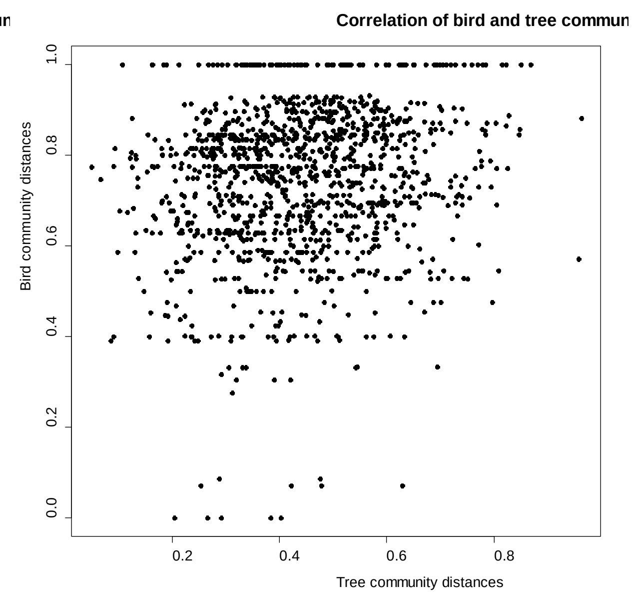


Figure 3. Correlation between bird community distances and tree community distances (Canberra distance metric). Young stands, r = 0.1988 and P = 0.024; Old stands, r = 0.1572 and P = 0.0162. Note that when tree communities are similar (low values of tree community distance), there is much more variation in bird community distance than when tree communities are dissimilar (high values of tree community distance). This means that when tree communities differ between two stands, so do bird communities but when tree communities are similar, bird communities may or may not be similar.

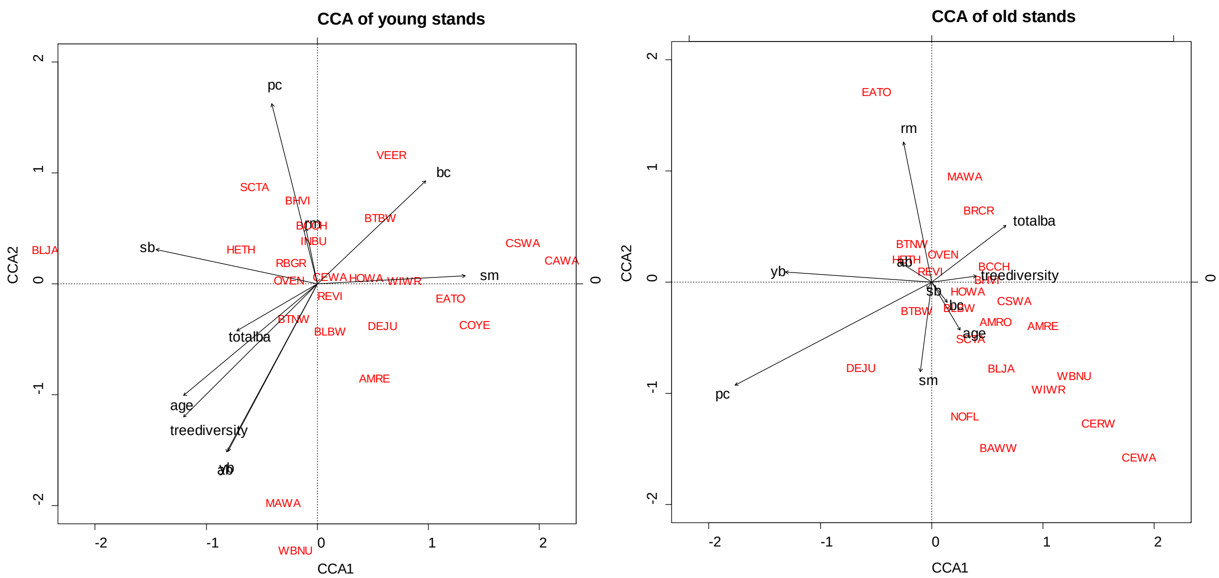


Figure 4. Results of canonical correspondence analysis (CCA) for young (left) and old (right) stands at Allegheny National Forest in 2012. See Table 1 for tree species (vector) abbreviations (yb and ab overlap in left panel). Bird species (centroids of distributions labeled with codes in red) that cluster together tend to co-occur; environmental variables (codes in black) increase in the direction of their vectors (black arrows).

Table 1. Results of statistical tests for effects of vegetation on bird communities and bird community metrics.

	Young Stands					Old Stands				
	CCA	Total abundance		Bird diversity		CCA	Total abundance		Bird diversity	
	P	Coef-ficient	P	Coef-ficient	P	P	Coef-ficient	P	Coef-ficient	P
American beech (ab)	**0.062** ^	-1.4	0.220	-1.0	0.252	0.155	-1.1	**<0.001** ***	-0.7	**0.023** *
Black cherry (bc)	**0.046** *	-2.2	0.144	-1.5	0.196	0.150	-1.3	**0.004** **	-1.0	**0.065** ^
Pin cherry (pc)	**0.028** *	-0.7	0.467	-0.3	0.663	0.200	0.1	0.657	0.3	0.370
Red maple (rm)	0.160	-0.7	0.218	-0.6	0.163	**0.032** *	-2.2	**0.001** **	-1.6	**0.028** *
Sweet birch (sb)	**0.060** ^	-1.0	0.167	-1.1	**0.047** *	0.200	-0.8	**0.003** **	-0.7	**0.022** *
Sugar maple (sm)	0.190	-0.8	0.352	-0.1	0.869	0.088	-1.5	**0.006** **	-1.1	**0.068** ^
Yellow birch (yb)	0.700	-0.9	0.186	-0.3	0.607	0.450	-0.4	0.265	-0.4	0.298
Tree diversity	**0.020** *	-	-	-	-	0.570	-1.1	**0.040** *	-0.3	0.592
Max relative dominance	-	-	-	-	-	-	-1.0	**0.080** ^	-0.4	0.524
Total basal area	0.240	-	-	-	-	0.550	-0.4	**0.083** ^	-0.3	0.281
Stand age	0.630	-	-	-	-	0.650	-	-	-	-

Note: levels of significance are P < 0.10^; P < 0.05*; P < 0.01**; P<0.001*; - indicates the variable was dropped from the model because it was nonsignificant and reduced significance of the overall model.

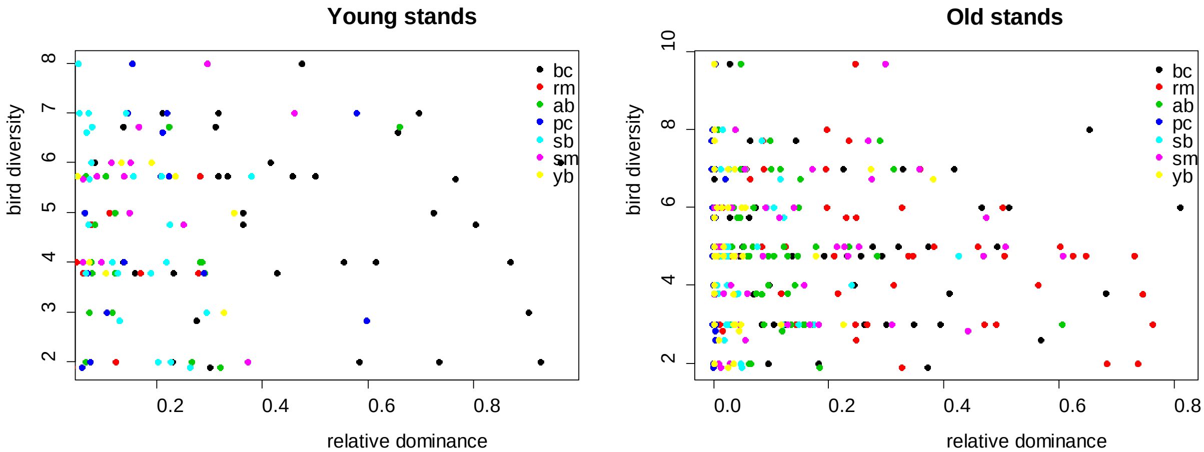


Figure 5. Effect of relative dominance of each tree species on total bird diversity of young and old stands. Note that there are few points in the top right of each graph, suggesting that high relative dominance of any one tree species is bad for bird diversity (even though their effects were nonsignificant for young stands).

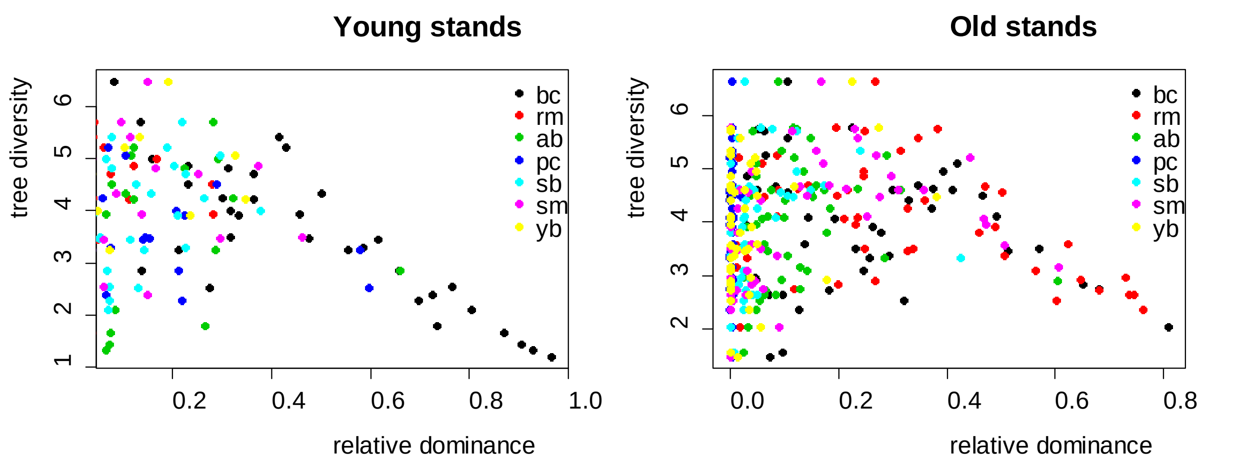


Figure 6. Effect of relative dominance of each tree species on total tree diversity of young and old stands. Low values of relative dominance for a given species may correspond to any value of overall tree diversity (depending on relative dominance of other tree species), whereas high values of relative dominance of any one tree species must result in low overall tree diversity; middle values of relative dominance are associated with middle values of tree diversity. Most tree species have low to middle values of relative dominance and therefore are on the portion of the curve that trends upward (positive relationship with tree diversity). Black cherry in young stands and black cherry and red maple in old stands sometimes approach monodominance; therefore, they are overall negatively correlated with tree diversity.

Impacts of deer overabundance on forest bird populations and communities:

Overbrowsing by high densities of white-tailed deer in Allegheny hardwood forests is associated with an increase in relative dominance of black cherry and a decrease in relative dominance of pin cherry and birches (Horsely et al. 2003, Nuttle et al. 2011). Nuttle et al. (2011) reported that higher densities of white-tailed deer during stand initiation caused stands to have depressed total bird abundance for at least 20 years. Results from the present study scale those limited, experimentally supported results to stands across the Allegheny National Forest that have experienced a range of deer density effects (depending on a variety of uncontrolled factors) and exhibit a range of forest tree compositions.

Our analysis with Mantel tests and community ordination (Canonical Correspondence Analysis, CCA) demonstrates that forest stand composition significantly influences bird community composition in Allegheny hardwoods. In that deer browsing pressure has documented effects on forest stand composition, it is logical that these effects should scale up to bird communities. Our data provide some support for this hypothesis. First, high density of black cherry (an indicator of high deer-density effects) was one of the strongest predictors of bird community structure, as measured with CCA for young stands (Table 1). High density of black cherry was also strongly negatively correlated with total bird abundance and diversity, but this effect was only significant for old stands (Table 1). For older stands, density of red maple was a stronger predictor of bird community composition (from CCA) and was strongly negatively associated with total bird abundance and bird diversity (Table 1). Red maple density was highest at intermediate levels of deer density (Horsley et al. 20003, Nuttle et al. 2011). It may be possible to view changes on forest stand composition on a deer density continuum, such that stands at low deer density are diverse and more dominated by birches and (when young) pin cherry. As deer density increases, birches and pin cherry succumb to browsing and red maple and black cherry dominate. As deer density increases further, deer take an increasing toll on red maple, resulting in stands overwhelmingly (>90%) dominated by black cherry. Red maple is also a longer-lived, shade-tolerant tree species. Hence, over the long term, moderate deer browsing may create stands dominated by red maple once black cherry senesce from the stand. This is cause for conservation concern, due to red maple's strong negative effects on bird community composition, abundance, and diversity in older stands. Furthermore, high dominance by black cherry or red maple results in lower diversity of caterpillars at the stand scale (Wheatall et al. 2013), which could negatively impact birds via reduced availability of prey. Similar concerns about increasing deer density have been raised for oak forests as well (Rodewald and Abrams 2002).

Impacts of gas development on forest bird populations and communities

The northeastern U.S., specifically the Allegheny Plateau in Pennsylvania, West Virginia, Ohio, and Kentucky, is experiencing rapid exploration for shale gas, as well as a continued long-term exploitation of shallow gas and oil plays. How this energy development affects forest bird populations remains virtually unknown. Current estimates suggest up to 54% of the Marcellus shale pads currently being constructed occur within forest, often in previously unfragmented areas (Johnson 2010; Drohan et al. 2012a). At the same time, more than 14,000 conventional oil/gas wells occur on the Allegheny National Forest, with > 5000 of those built since 2007. The current rate of development is expected to continue into the future.

Potential effects of gas and oil development on avian species and communities include (1) destruction (or potentially creation) of habitat resulting from the building of well pads and associated infrastructure; (2) impacts to behavior and distribution due to increases in traffic, people, anthropogenic noise and lighting; and (3) direct mortality from toxic effects of gas, brine or fracking fluids on birds. Most of the rather sparse research published on the effects of oil and gas development on birds has been conducted in very different, primarily non-forested habitats in the western states and provinces (see Naugle 2010); all of the potential effects listed above have been documented in those habitats.

Habitat Destruction. – Development of gas and oil fields necessitates the creation of well pads, plus associated access roads and pipelines. The area converted to non-forest by this development varies considerably with well type (deep shale vs. conventional) and well density. In Pennsylvania, Marcellus well pads typically cover 1.5 – 2.0 ha (Drohan et al. 2012b), while shallow conventional well pads require < 0.3 ha (Thomas et al. in press). However, this difference in pad size does not reflect actual impacts to forest cover associated with the two well types, because Marcellus shale wells utilize horizontal drilling and multiple wells per pad, allowing access to resources covering very large areas (> 1 km^2) from a single pad. In contrast, conventional wells use only a single vertical well per pad, resulting in high densities of wells to extract gas resources from a large area; for example, recent conventional developments on the Allegheny National Forest were constructed with grids of wells spaced approximately 150 m apart (Allegheny National Forest 2007), equivalent to 60 wells / km^2.

Further, most of the habitat conversion resulting from gas development comes not from the well pads themselves but from associated access roads and pipelines. The network of roads and pipelines built through forests increases forest fragmentation; indeed, road density has been suggested as a useful metric for assessing degree of fragmentation (Heilman et al 2002). The negative effects of forest fragmentation on forest birds have been thoroughly studied (e.g., Askins 1994, Robinson et al. 1995, Burke and Nol 2000, King and DeGraaf 2002, Brittingham and Goodrich 2011). Removal of forest decreases the amount of available habitat for forest birds, resulting in reduced populations and greater competition for territories. In addition to actual areas where habitat has been destroyed by conversion to well pads and roads, some birds (especially forest species) avoid areas adjacent to non-forest areas (edge avoidance), effectively magnifying the area impacted by development. Such avoidance of oil and gas infrastructure has been reported in mule deer as well (*Odocoileus hemionus*; Sawyer et al. 2006). For those individuals that do breed in fragmented forest, reproductive success can be drastically reduced due to predation and brood parasitism. Edge habitat created by fragmentation is the preferred hunting habitat for most predators of birds, and nest predation rates tend to increase with proximity to edge and with smaller patch sizes (Burjke and Nol 2000, Batary and Baldi 2004). Brown-headed cowbirds (*Moluthrus ater*) are brood parasites that lay their eggs in nests of other passerines, thereby usurping the parental care of the host species. Cowbirds are open-country birds and avoid intact forest, but will search for host nests near forest edges. The rate of brood parasitism on forest birds increases as patch size decreases (Robinson et al. 1995). Thus, with increasing fragmentation, fewer forest birds breed and their nest success declines.

The sole study to date of the effects of conventional well development on deciduous forest birds (Thomas 2011, Thomas et al. in press) found increasing well densities were associated with *increased* abundance and diversity of birds. However, those increases were due to a strong positive response by synanthropic species (those associated with human development, such as jays, grackles, cowbirds, and Chestnut-sided Warbler) overwhelming a significant decline in forest-interior specialists (like Blackburnian Warbler, Black Throated Green Warbler, and Ovenbird; Appendix E contains relevant life history information for each species). Table 3 presents effects of well density at local and landscape scales on bird species selected for the present CCVI analysis. Further, significant differences in avian assemblages between oak and northern hardwood forests disappeared at high well densities, indicating biotic homogenization due to the loss of habitat specialists. In the present study, not surprisingly we found that younger stands with low tree density were associated with prevalence of bird species that prefer more open and shrubby conditions, such as dark-eyed junco, eastern towhee, and common yellowthroat, chestnut-sided warbler, and winter wren (Figure 4). As gas well density increases, edges associated with well pads would tend to create more of these shrubby conditions, also favoring these species at the expense of forest-dwelling species such as warblers and vireos (Figure 4, Table 3).

An experimental application of gas well brine onto the forest floor in Pennsylvania resulted in the reduction or elimination of most understory vegetation (DeWalle and Galeone 1990). Such impacts on forest understories would likely have severe effects on forest birds dependent on this stratum, as has been demonstrated in studies of the effects of herbicides on forest birds (e.g., Stoleson et al. 2011). A similar, longer-term study conducted in West Virginia produced similar results; in addition, significant overstory mortality occurred and soil salinity increased 50-fold (Adams 2011). How these impacts might affect birds is unknown.

Noise . – Anthropogenic noise may reduce habitat quality for many species, particularly those that rely on acoustic signals for communication, such as forest songbirds (Slabbekoorn and Halfwerk 2009). In boreal forests of Alberta, forest birds were 1.5 times more abundant in areas without well compressor noise than areas with such noise (Bayne et al. 2008). In sagebrush habitats, occupancy by two representative bird species was reduced by 5% in areas with gas compressors; however, this was offset in one species by an increase in nest success (Francis et al. 2011a). Birds have been shown to alter the frequency and structure of their songs in response to chronic noise from gas development (Francis et al. 2011b, McLaughlin and Kunc 2013); how such changes may affect reproductive success or fitness remain unexplored.

Direct Mortality. – Very little research has examined the incidence of direct mortality of oil and gas development on birds. One study by the U.S. Fish and Wildlife Service documented extensive mortality from open pits containing waste fluids (i.e., brine, fracking fluids), affecting an estimated 500,000 to 1,000,000 birds per year (Trail 2006). That mortality level is likely to have risen significantly given the large increase in domestic gas development since 2006. In the western states, significant mortality of water birds has been documented in water holding ponds, primarily due to toxic effects of oil, salt, and surfactants in the water (Ramirez 2010). Such effects are likely to be true in eastern forests as well, but have not yet been documented.

Clearly, much remains to be learned concerning the effects of oil and gas development on forest birds and other taxa. The few published studies indicate considerable potential for habitat loss and degradation, as well as direct mortality. It seems imperative that future research should be conducted in collaboration with energy companies to develop methods and guidelines to minimize those risks.

Climate Change Vulnerability Analysis

According to the North American Bird Conservation Initiative (NABCI 2010), temperate forest ecosystems contain the lowest percentage of bird species vulnerable to climate change compared to other habitat types in the United States. However, the majority of bird species we assessed ranked Very High or Moderate in their vulnerability to climate change within Pennsylvania (Table 2). These eleven species are expected to shift their ranges out of Pennsylvania in the coming decades while only three species are expected to increase within the state; the rest are predicted to remain stable in the state. Those forest songbird species most likely to be affected by predicted changes in Pennsylvania are those already vulnerable (ranked S1, Figure 7), those at the southern edge of their range in the state (Figure 8), or are those species considered Northern hardwood specialists within the state (Figure 9).

During the course of research and evaluation, we found several general patterns of vulnerability across the 20 bird species represented in this report. These patterns were associated with both habitat preferences (e.g., northern hardwood species versus forest generalists; Appendix B) and tritrophic interaction as well as migration phenology (long versus short distance migrants).

There is no evidence that climate change will substantially change overall land cover within Pennsylvania. What it likely will change is the overall composition, dynamics, and possibly diversity of Pennsylvania's forests. Birds that are forest generalists across the state, such as red-eyed vireo, eastern wood-pewee, and ovenbird, are likely to remain stable within the state. However, a majority of species evaluated in this report are northern hardwood specialists, many of which require or strongly prefer a conifer element in their habitats (e.g.: blue-headed vireo, blackpoll warbler, winter wren, and others). While many of these species may be found in areas without hemlock or some other conifer, they usually persist at lower densities (e.g., blackburnian warbler; see Wilson et al. 2012 and Gross 2010 for details). These are the forest birds whose fate within Pennsylvania is relatively uncertain and whose conservation should be prioritized.

Managers should consider the health and extent of the state's most northern forests, particularly those with high conifer components. They are currently few in number and so preventing further degradation of these habitats through resource extraction, over-browsing by deer, and other anthropogenic influences is vital to their survival through the stress of climate change.

While the amount of forested area in Pennsylvania is not expected to change directly due to climate change, forest composition and function as habitat for numerous songbirds is expected to change as certain species recede northwards (eastern hemlock) or decline altogether (sugar maple) while others do better under changing precipitation, temperature, and soil conditions (i.e., oaks, hickories, etc.); and of course, there are other species that may remain within their current distributions. Changes in individual species distributions have been predicted in numerous models in the northeastern United States (Iverson and Prasad 2001, Matthews et al. 2004, McKenney et al. 2007). Additionally, Woodall et al. (2009) found empirical evidence of tree migration in forests of the eastern United States by comparing tree seedling distribution with adult tree biomass for both northern and southern tree species. Such distributional shifts are likely to produce novel interspecific interactions. So, in addition to adapting to the effect of climate change directly, species will be forced to adapt to the presence of potentially different suites of competitors, predators, and prey. Since songbirds have superior dispersal abilities, forest composition changes that result in habitat loss because of species or structural-specific preferences (e.g.: conifer affiliated species such as blackpoll warbler, *Setophaga striata*) will also result in the loss of those bird species.

Forests are dynamic ecosystems that support a variety of organisms, leading to complex interactions among trophic levels. Most efforts to model expected changes in species distributions due to climate change operate under the assumption that organisms show equal sensitivity to climate change across trophic levels. However, a number of researchers have pointed out that this is not the case in many ecosystems (Voigt et al. 2003, Parmesan 2006). More specifically, there have been several studies that indicate caterpillar phenology may shift with changing climate more quickly than bird breeding phenology, at least in some species (Visser et al. 2004, Both et al. 2009, Visser et al. 2001). This phenomenon of unequal response to climate change across trophic levels is referred to as the trophic mismatch hypothesis. Elements influencing one level within the system can have significant impacts on the system as a whole. Climate change has the potential to directly or indirectly affect each member of the food chain individually or in combination, and thus it has the potential to change the dynamics of the system as a whole. We emphasize how climate change will impact the tritrophic interactions among trees, Lepidoptera larvae (caterpillars), and insectivorous songbirds such as New World warblers, vireos, tanagers, and a few other parapatric species.

Due to the prodigious food requirements of their young, many bird species have adapted egg laying dates so that hatching coincides with peak caterpillar abundance (Visser et al. 2001). However, while caterpillars have managed to stay in sync with tree budburst through changes in climate (Bale et al. 2002) there is evidence that their avian predators have not caught up phenologically. This reproductive or phenological mismatch could occur through a number of mechanisms. Firstly, caterpillars go through many generations within a single breeding season as opposed to birds which only produce one. Thus, caterpillars may be able to evolve more quickly to changes in their shared environment than can birds. Additionally, for migrating birds, climactic changes in the breeding ground may not mirror changes at the wintering ground due to uneven climate change across latitudes (Strode 2003, Jones and Cresswell 2010). In this case, the environment of decision making is separated both physically and evolutionarily from the environment of selection. This phenomenon is suspected to have the greatest impact on songbirds that travel long distances from the tropics to temperate or sub-arctic breeding grounds (Both et al. 2009).

Seventy-five percent of the bird species evaluated in this report are Neotropical-Nearctic migrant species (see Appendix B) that travel long distances – at times using trans-oceanic flight paths – from wintering grounds in Central and South America to breed here in Pennsylvania and other temperate or Nearctic destinations (Greenburg and Marra 2005). Such a journey is a physiologically demanding process, requiring many behavioral and physiological adaptions to be successful (Greenburg and Marra 2005). Departure, arrival, and stop-over schedules must be well-timed in order for migratory species to be able to take advantage of food resources along the way. Climate change may directly affect departure, arrival, and stop-over times for migratory songbirds through an increase in powerful storms or hurricanes (Butler 2000) and/or changes in the North Atlantic Oscillation (NAO) or El Niño Southern Oscillation (ENSO). Not only could these factors delay migration, they may also cause higher mortality among migrants at a time when most mortality occurs in these species already (Sillett and Holmes 2002).

The direct and indirect effects of climate change on migration phenology in songbirds have been widely discussed in the literature (Both et al. 2006, Moller et al. 2008, Moller et al.

2010, and others). There is no definitive consensus on how migrants are responding to recent climate change nor how they will continue to respond. This is largely due to a variety of methods being employed to measure the timing of migration (e.g.: first arrival dates versus mean arrival date, etc.) as well as the different scales of climate variables used in quantitative analyses (e.g., NAO or ENSO versus regional temperature data) that make studies difficult to compare (Miller-Rushing et al. 2008). Additionally, while there are more long-term data sets available for migratory birds than perhaps other taxa, they often come from many different observers of varying experience (citizen scientists or hobbyist birders) rather than sampled using a standardized protocol. Many studies agree that phenological response to climate change is both species- and season-specific (Vegvari et al. 2010, van Buskirk et al. 2009). Limited research suggests that migration phenology within a species is tightly programmed. In a unique study, Stanley et al. (2012) tracked 45 individual wood thrushes (*Hylocichla mustelina*) for three years along migration routes between Pennsylvania and Costa Rica using light-level geolocators. Researchers found that while there was a high amount of within-individual variation in migratory route, timing of migration was extremely repeatable with a mean difference between years of only three days. These results suggest that birds may not be able to adjust their migration phenology to keep up with the changing climate. Furthermore, climate change is likely to occur unevenly across latitudes; more northern areas are expected to experience more extreme changes than their southern counterparts (Easterling et al. 1997). Asymmetrical climate change could increase the likelihood of long-distance migrants becoming uncoupled from vital breeding food sources (Strode 2003).

Phenological response to climate change is species-specific, one which may be correlated to other life history traits (Vegvari et al. 2010). Many avian ecologists have independently predicted that short distance migrants will respond more rapidly to climate change than their long-distance counterparts, specifically by displaying earlier spring arrival time (Both et al. 2006, Moller et al. 2008). Studies from all around the United States including Pennsylvania (van Buskirk et al. 2009); Buffalo, New York (DeLeon et al. 2011) and South Dakota and Minnesota (Swanson and Palmer 2009) support this hypothesis. Although the evidence is certainly not conclusive, we utilized this common rule when evaluating the 20 species in this report and rated long distance-migrants as more vulnerable than short-distance migrants or resident birds under the Phenological Response to Climate Change category unless we found species-specific evidence to the contrary.

Future Considerations & Management Recommendations

One major setback when using the CCVI tool to evaluate migratory species that travel great distances and utilize multiple habitats in geographic locations separated by sometimes thousands of miles is that it over-simplifies the threats that are compounding against such species. Many of the birds evaluated within this report have extremely complex life histories that bring them to Pennsylvania for only 3 or 4 months out of the year (NatureServe 2013, Wilson et al. 2012). Webster et al. (2002) aptly pointed out that researchers and managers alike must take migratory connectivity into consideration when considering the future conservation of these species because processes on the wintering grounds can indirectly affect reproductive success on the breeding grounds. For example, one potential constraint for birds migrating to and breeding in Pennsylvania is the food supply found on their wintering grounds. Obtaining enough resources over the wintering months in the tropics is essential for being able to make the journey back to the state and breed successfully the following summer (Greenburg and Marra 2005). These cross-seasonal interactions (Greenburg and Marra 2005) are not properly accounted for within the CCVI tool. More research efforts are needed to establish winter ground connectivity specific to Pennsylvania's breeding bird populations in order for such issues to be addressed.

Table 2. Summary of climate change vulnerability index (CCVI) of 20 forest songbird species that nest within Pennsylvania May – July. See Appendices for individual species accounts and other data sources used to derive these ratings.

Common Name	Scientific Name	CCVI	Confidence
American redstart	*Setophaga rutilla*	Increase Likely	Moderate
Black-billed cuckoo	*Coccyzus erthropthalmus*	Presumed Stable	Very High
Blackburnian warbler	*Setophaga fusca*	Moderately Vulnerable	Very High
Black-capped chickadee	*Poecile atricapillus*	Moderately Vulnerable	Very High
Blackpoll warbler	*Setophaga striata*	Extremely Vulnerable	Low
Black-throated blue warbler	*Setophaga caerulescens*	Moderately Vulnerable	Moderate
Black-throated green warbler	*Setophaga virens*	Presumed Stable	Moderate
Blue-headed vireo	*Vireo solitarius*	Moderately Vulnerable	Very High
Canada warbler	*Cardellina canadensis*	Presumed Stable	Very High
Chestnut-sided warbler	*Setophaga pennsylvatica*	Presumed Stable	Moderate
Eastern wood-pewee	*Contopus virens*	Increase Likely	Very High
Golden-crowned kinglet	*Regulus satrapa*	Moderately Vulnerable	Moderate
Hooded warbler	*Geothlypis nelsoni*	Increase Likely	Moderate
Magnolia warbler	*Setophaga magnolia*	Moderately Vulnerable	Very High
Mourning warbler	*Geothlypis philadelphia*	Moderately Vulnerable	Very High
Ovenbird	*Seiurus aurocapilla*	Presumed Stable	Moderate
Red-eyed vireo	*Vireo olivaceus*	Increase Likely	Moderate
Winter wren	*Troglodytes hiemalis*	Moderately Vulnerable	Very High
Yellow-bellied flycatcher	*Empidonax flaviventris*	Moderately Vulnerable	Moderate
Yellow-bellied sapsucker	*Sphyrapicus varius*	Moderately Vulnerable	Very High

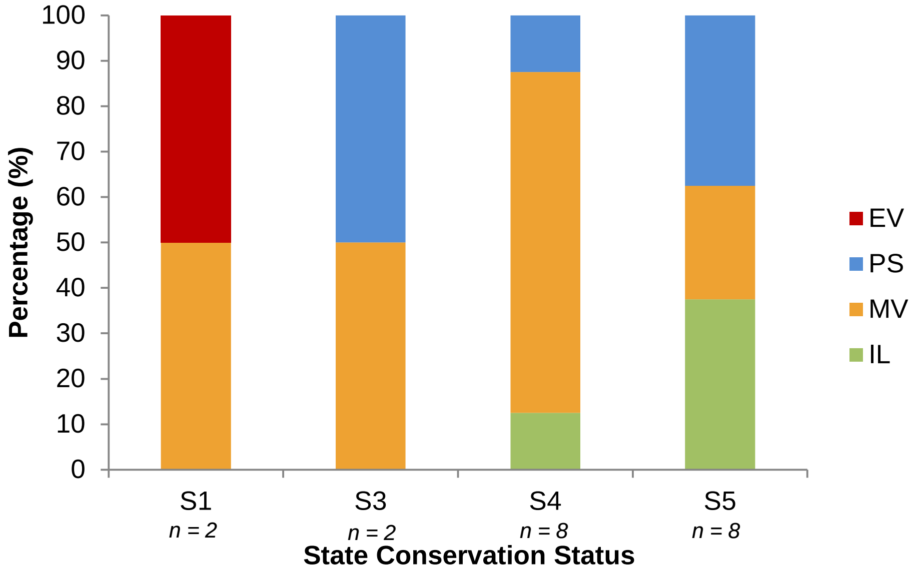


Figure 7: Percentage of bird species within each vulnerability category according to state conservation status in Pennsylvania. S1, Critically Imperiled; S3, Vulnerable; S4, Apparently Secure; S5, Secure. PS = Presumed stable, MV = moderately vulnerable, IL = increase likely, EV = Extremely Vulnerable.

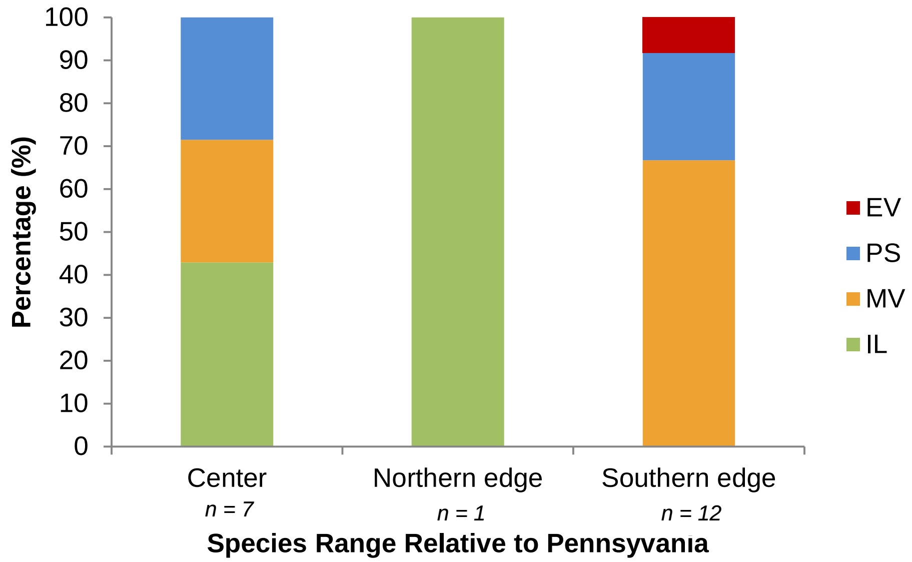


Figure 8: Percentage of bird species within each vulnerability category according its range location relative to Pennsylvania's borders. PS = Presumed stable, MV = moderately vulnerable, IL = increase likely, EV = Extremely Vulnerable. Due to the warming climate, bird species that are northern hardwoods specialists (which tend to be at the southern edge of their ranges) will move northward out of the state and be replaced by central hardwoods specialists (which tend to be at the northern edge of their ranges) and habitat generalists (center) moving up from the south.

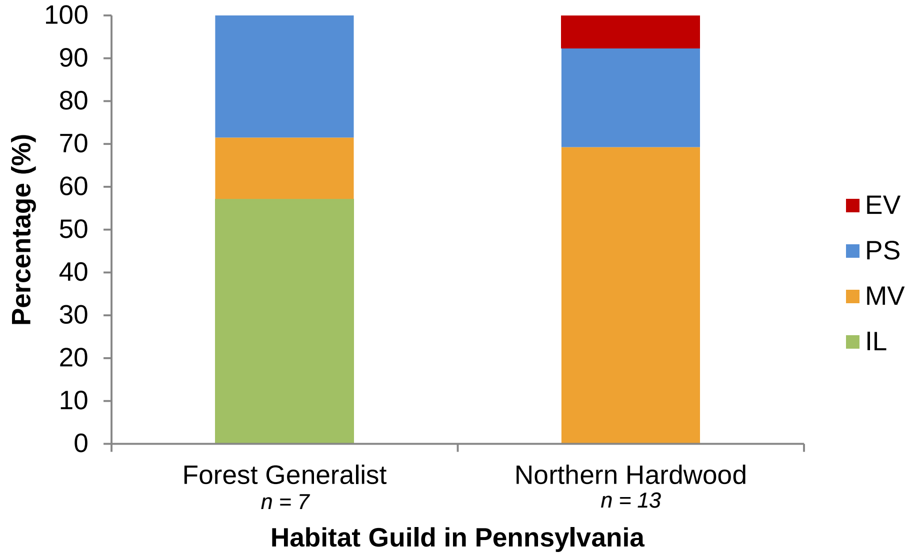


Figure 9: Percentage of bird species within each vulnerability category according to forest habitat guild (see also Appendix B; adapted from Wilson et al. 2012). PS = Presumed stable, MV = moderately vulnerable, IL = increase likely, EV = Extremely Vulnerable.

Interactions of deer density, gas development, and climate change on bird communities

According to models produced by Iverson et al. (1999), all of the focal tree species of the present study, and thus the entire Northern hardwoods/Allegheny hardwoods forest type will decline under climate change scenarios. As these tree species decline in the region, they will likely be replaced by trees of the central hardwoods forest type, namely oaks and hickories. We did not investigate bird community response to differences in stand composition involving these tree species so cannot directly address this question with our data. However, some insights from the broader scientific literature are possible.

White-tailed deer are widespread across eastern North America and may therefore be considered climate generalists. However, climate change has the potential to directly impact deer populations and distributions by decreasing the intensity or frequency of harsh, cold winters that otherwise limit ungulate populations either through starvation or increased vulnerability to predators and hunters (McShea 2012). Additionally, higher levels of snow pack can act as refugia for saplings during this time (Auer and Martin 2013); a warming climate would reduce availability of such refugia, and therefore magnify deer impacts on browse-sensitive species.

An example where such a scenario has occurred is in a high elevation community in Arizona (Auer and Martin 2013). There, climate change and deer density interacted to affect interspecific competition among three warbler species: orange-crowned (*Vermivora celata*), red-faced (*Cardellina rubrifrons*), and Virginia warblers (*Oreothlypis virginiae*). These three ecologically similar species partition resources through different tree species preferences for nesting sites (e.g., the orange-crowned warbler showed a preference for sites dominated by maple whereas Virginia and red-faced warbler preferred those dominated by locust and/or fir). However, in recent years, this system has experienced climate-driven modifications in plant-herbivore interactions: decreases in snowfall have allowed elk (*Cervis canadensis*) access to higher elevations during winter months than previously available. This has resulted in increase in browse pressure and subsequent declines in recruitment for browse-sensitive tree species such as maple, locust, and firs. Declines in prefer tree species abundance has increased overlap among the three species' nest site composition, which was further associated with increases in daily nest predation rates for all three species. Thus, changes in climate can interact with deer browse to modify songbird environments in ways that are detrimental to reproductive success (Auer and Martin 2013).

As noted above, across the Allegheny Plateau, prevalence of central hardwoods, dominated by oaks and hickories, is expected to increase under climate change scenarios (Iverson et al. 1999). However, oaks are also preferred browse for deer and tend to decrease at higher deer densities (Nuttle et al. 2013). With increasing browse pressure on oaks, hickories would tend to increase, which are considered starvation foods for deer (http://extension.missouri.edu/p/g9479). Oaks are also extremely productive hosts for caterpillars, a primary and essential food source for forest birds, but hickories support less than half the richness of caterpillars as oaks (Tallamy and Shropshire 2009). Hence, the combination of climate change and high deer density is likely to negatively impact bird populations if hickories become the dominant tree species in the forest.

In the absence of other anthropogenic factors, effects of climate change on tree communities would take decades or even centuries to manifest because trees generally have a long lifespan. However, as mentioned, continuous disturbances due to timber management, well pad construction, or severe weather events to current forest canopy communities will accelerate this process by resetting the successional clock at more frequent intervals. Regenerating tree species will then not only be subjected to selection pressure from climate change but also from ungulate browsing as well. Browse pressure from high densities of white-tailed deer has been shown to have decades-long impacts that fundamentally change the composition of the forest canopy when compared with lower densities (Nuttle et al. 2011). Thus, resource extraction will act as a major but temporary disturbance to Pennsylvania forests that will accelerate successional processes and allow for climate change and ungulate browsing (among other factors) to determine new forest trajectories that are likely to produce forests very different from those we see maturing within the state today. This will fundamentally change habitat and food availability for breeding insectivorous forest songbirds (Wheatall et al. 2013). Some can be expected to adapt while others will no longer breed in Pennsylvania and this is highly dependent on the plasticity and specialization of the species. It also depends on novel interspecific interactions among trees and birds, leading to changes in competition dynamics among avifauna. Londré and Schnitzer (2006) reported that increasing liana (woody vine) abundance observed over the last 45 yr in Wisconsin was associated with increasing forest fragmentation not by climate change. However, under climate change, vegetation is likely to experience increasing evapotranspiration demands, which has been shown to increase liana prevalence in tropical forests (Schnitzer and Bongers 2006). Therefore, it remains possible that under the combination of increased well density and climate change, forests will become increasingly dominated by open, shrubby conditions that favor synanthropic species (e.g., juncos, chicadees, jays) that prefer these conditions.

Conclusion

The combination of deer overabundance, increased gas development, and climate change will change the nature of bird communities in the state. Due to the warming climate, bird species that are northern hardwoods specialists will move northward out of the state and be replaced by central hardwoods specialists and habitat generalists moving up from the south. When combined with likely effects of deer overbrowsing and increasing land disturbance due to gas development, habitat generalists that prefer open, edge, or shrubby habitats, which are already ubiquitous, will become more common and forest specialists will decline further. Because three-quarters of Pennsylvania forest is privately owned, attention should focus on how private landowners can mitigate the negative effects of these prevalent drivers on Pennsylvania birds.

Table 3. Mean abundance ± standard deviation (individuals/point count) of 18 of the 20 focal songbird species evaluated in this report in response to gas well densities at local and landscape (= 25 ha) scales. Table is an excerpt from Thomas 2011 and data specifically pertains to the Allegheny National Forest located in the northwestern corner of Pennsylvania. * *indicates significance P<0.05.*

	Local Scale		Estimated		Landscape Scale				
Species	Control	Well	Median	*P*	Control	Low	High	*t*	*P*
American Redstart	0.43±0.12	0.58±0.12	0	0.4120	1.63±0.41	1.75±0.42	1.96±0.46	0.94	0.351
Black-billed Cuckoo	0.00±0.00	0.00±0.00			0.04±0.04	0.04±0.04	0.00±0.00		
Blackburnian Warbler	0.95±0.13	0.63±0.11	0.5	0.094*	2.21±0.39	1.54±0.26	1.21±0.31	-1.6	0.114
Black-capped chickadee	0.08±0.04	0.18±0.07			0.58±0.18	0.29±0.09	0.29±0.11		
Black-throated Blue Warbler	0.85±0.12	0.80±0.10	0	0.7370	1.96±0.32	2.42±0.32	1.83±0.31	1.24	0.220
Black-throated Green Warbler	0.80±0.11	0.50±0.09	0	0.049*	2.67±0.29	2.13±0.27	2.38±0.29	-0.36	0.720
Blue-headed Vireo	0.65±0.11	0.45±0.10	0	0.2200	1.83±0.32	1.04±0.20	1.79±0.26	0.48	0.634
Canada Warbler	0.03±0.03	0.03±0.03			0.00±0.00	0.13±0.09	0.08±0.06		
Chestnut-sided warbler	0.40±0.11	0.90±0.14	-0.5	0.011*	0.54±0.17	0.92±0.23	1.04±0.34		
Eastern Wood-Pewee	0.35±0.08	0.28±0.07	0	0.5140	0.67±0.19	0.96±0.22	0.38±0.17		
Hooded Warbler	0.63±0.10	0.45±0.09	0	0.1650	1.67±0.32	1.96±0.46	1.46±0.29	-0.39	0.699
Magnolia Warbler	0.38±0.10	0.33±0.10			0.71±0.30	0.83±0.29	1.00±0.26		
Mourning Warbler	0.00±0.00	0.08±0.04			0.00±0.00	0.21±0.10	0.42±0.13		
Ovenbird	0.73±0.13	0.33±0.08	0.5	0.003*	2.13±0.54	2.46±0.58	1.92±0.49	-0.74	0.464
Red-eyed Vireo	1.75±0.12	1.60±0.12	0	0.3820	5.38±0.29	5.29±0.30	4.54±0.23	-2.12	0.038*
Winter Wren	0.13±0.05	0.08±0.04			0.08±0.06	0.21±0.10	0.50±0.14		
Yellow-bellied Sapsucker	1.13±0.10	1.00±0.08	0	0.3600	2.21±0.22	2.83±0.19	3.04±0.25	2.3	0.025*

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APPENDIX A: CLIMATE CHANGE VULNERABILITY INDEX CODES AND DEFINITIONS

Vulnerability Index Scores

EV	Extremely vulnerable	Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050.
HV	Highly Vulnerable	Abundance and/or range extent within geographical area assessed likely to decrease significantly by 2050.
MV	Moderately Vulnerable	Abundance and/or range extent within geographical area assessed likely to decrease by 2050.
PS	Not Vulnerable/Presumed Stable	Available evidence does not suggest that abundance and/or range extent within the geographical area assessed will change (increase/decrease) substantially by 2050. Actual range boundaries may change.
IL	Not Vulnerable/Increase Likely	Available evidence suggests that abundance and/or range extent within geographical area assessed is likely to increase by 2050.
IE	Insufficient Evidence	Available information about a species' vulnerability is inadequate to calculate an Index score.

Individual Risk Factor Scores

GI	Greatly increase vulnerability
Inc	Increase vulnerability
SI	Somewhat increase vulnerability
N	Neutral
SD	Somewhat decrease vulnerability
Dec	Decrease vulnerability
U	Unknown

APPENDIX B:
BIRD LIFE HISTORY INFORMATION

Pennsylvania specific life history information used to assess vulnerability of 20 forest bird species to climate change and other factors in this report.

Species Code	Common Name	Family	Migratory Guild†	Nesting Guild‡	Forage Guild	Forage Height¶	Diet	Habitat Guild§
AMRE	American redstart	Parulidae	long	canopy	foliage	LC	insect	forest generalist
BBCU	black-billed cuckoo	Cuculidae	long	understory	foliage	C	insect	forest generalist
BCCH	black-capped chickadee	Paridae	res	cavity	foliage	LC	insect	forest generalist
BHVI	blue-headed vireo	Vireonidae	long	canopy	foliage	LC	insect	northern hardwood
BLBW	blackburnian warbler	Parulidae	long	canopy	foliage	C	insect	northern hardwood
BLPW	blackpoll warbler	Parulidae	long	canopy	foliage	C	insect	northern hardwood
BTBW	black-throated blue warbler	Parulidae	long	understory	foliage	LC	insect	northern hardwood
BTNW	black-throated green warbler	Parulidae	long	canopy	foliage	C	insect	northern hardwood
CAWA	Canada warbler	Parulidae	long		foliage	LC	insect	northern hardwood
CSWA	chestnut-sided warbler	Parulidae	long	understory	foliage	LC	insect	northern hardwood
EAWP	eastern wood-pewee	Tyrannidae	long	canopy	aerial	C	insect	forest generalist
GCKI	golden-crowned kinglet	Regulidae	res	canopy	foliage	C	insect	northern hardwood
HOWA	hooded warbler	Parulidae	long	understory	foliage	LC	insect	forest generalist
MAWA	magnolia warbler	Parulidae	long	canopy	foliage	LC	insect	northern hardwood
MOWA	mourning warbler	Parulidae	long		foliage	G/LC	insect	northern hardwood
OVEN	Ovenbird	Parulidae	long	ground	ground	G	mollusc/insect	forest generalist
REVI	red-eyed vireo	Vireonidae	long	canopy	foliage	C	insect	forest generalist
WIWR	winter wren	Troglodytidae	short	cavity	ground	G	insect	northern hardwood
YBFL	yellow-bellied flycatcher	Tyrannidae	long	ground	aerial	C	insect	northern hardwood
YBSA	yellow-bellied sapsucker	Picidae	short	cavity	bark	C	insect, sap	northern hardwood

† long = Neotropical migrant; res = year-round resident of PA; short = temperate migrant; adapted from NatureServe 2013.

‡ Specific to Allegheny National Forest but likely widely applicable to all of Pennsylvania; Thomas 2011.

¶ LC = lower-canopy, C = canopy, G = ground, A = aerial; adapted from Cornell Lab of Ornithology website.

§ According to Wilson et al. 2012.

APPENDIX C:
EXPOSURE AND GEOGRAPHY RISK FACTOR SCORES

Species are scored on how a factor affects it vulnerability (GI- greatly increase, Inc-increase, SI-somewhat increase, N-neutral, SD-somewhat decrease, D-decrease, U-unknown). Factors contributing the most to species vulnerability are highlighted in red; yellow indicates a moderate contribution to vulnerability; and green indicates species resiliency (or decreased vulnerability) to climate change attributable to that factor. Headings defined in detail in Young et al. 2010.

English Name	PA Range Relative to Global Range	Temp 5.1° F	Temp 4.5° F	Most Drying	Moderate Drying	Sea level	Natural barriers	Anthro barriers	CC mitigation
American redstart	Center of range	66	34	46	54	N	N	N	SI-N
Black-billed cuckoo	Center of range	66	34	46	54	N	N	N	SI-N
Blackburnian warbler	Southern edge of range	66	34	46	54	N	N	N	SI-N
Black-capped chickadee	Southern edge of range	66	34	46	54	N	N	N	SI-N
Blackpoll warbler	Southern edge of range	66	34	46	54	N	N	N	Inc-SI
Black-throated blue warbler	Southern edge of range	66	34	46	54	N	N	N	SI-N
Black-throated green warbler	Southern edge of range	66	34	46	54	N	N	N	SI-N
Blue-headed vireo	Southern edge of range	66	34	46	54	N	N	N	SI-N
Canada warbler	Southern edge of range	66	34	46	54	N	N	N	SI-N
Chestnut-sided warbler	Southern edge of range	66	34	46	54	N	N	N	SI-N
Eastern wood-pewee	Center of range	66	34	46	54	N	N	N	SI-N
Golden-crowned kinglet	Southern edge of range	66	34	46	54	N	N	N	SI-N
Hooded warbler	Northern edge of range	66	34	46	54	N	N	N	SI-N
Magnolia warbler	Southern edge of range	66	34	46	54	N	N	N	SI-N
Mourning warbler	Southern edge of range	66	34	46	54	N	N	N	SI-N
Ovenbird	Center of range	66	34	46	54	N	N	N	SI-N
Red-eyed vireo	Center of range	66	34	46	54	N	N	N	SI-N
Winter wren	Center of range	66	34	46	54	N	N	N	SI-N
Yellow-bellied flycatcher	Southern edge of range	66	34	46	54	N	N	N	SI-N
Yellow-bellied sapsucker	Southern edge of range	66	34	46	54	N	N	N	SI-N

APPENDIX D:
INTRINSIC AND MODELED RISK FACTOR SCORES

Species are scored on how a factor affects it vulnerability (GI- greatly increase, Inc-increase, SI-somewhat increase, N-neutral, SD-somewhat decrease, D-decrease, U-unknown). Factors contributing the most to species vulnerability are highlighted in red; yellow indicates a moderate contribution to vulnerability; and green indicates species resiliency (or decreased vulnerability) to climate change attributable to that factor. Headings defined in detail in Young et al. 2010.

Species	Dispersal/ Movement	historical thermal niche	physiological thermal niche	historical hydrological niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Dependence on other spp for habitat	Diet	Pollinators	Other spp. habitat	Other spp interaction	Genetic variation	Genetic bottleneck	Phenological response to CC	Documented response	Modeled change	Modeled overlap	Protected Areas
Setophaga ruticilla	Dec	N	N	N	N	N	N	SD	N	N-SD	N/A	N	N	U	U	SI	U	SI	N	U
Coccyzus erythropthalmus	Dec	N	N	N	N	N-SD	N	SD	N	SD	N/A	N	N	N	N/A	SI	Inc	Inc	SI	U
Setophaga fusca	Dec	N	SI	N	SI	N	N	SD	SI	N-SD	N/A	N	N	U	U	SI	U	GI	U	U
Poecile atricapillus	Dec	N	N	N	N	N	N	SD	SI	N	N/A	N	Inc	U	U	N	U	SI	SI	U
Setophaga striata	Dec	U	GI	N	Inc	N	N	SD	GI	N-SD	N/A	N	N	N	N/A	Inc-SI	U	U	U	U
Setophaga caerulescens	Dec	N	SI	N	N	N	N	SD	N	N-SD	N/A	N	N	U	U	SI	U	GI	N	U
Setophaga virens	Dec	N	SI	N	N	N	N	SD	N	N-SD	N/A	N	N	U	U	SI	U	SI	N	U
Vireo solitarius	Dec	U	SI	U	N	N	N	SD	SI	N-SD	N/A	N	N	U	U	SI-N	U	Inc	SI-N	U
Cardellina canadensis	Dec	U	SI	U	SI	N	N	SD	SI	N-SD	N/A	U	N	U	U	SI	U	SI	N	U
Setophaga pensylvanica	Dec	N	SI	N	N	N	N	SD	N	N-SD	N/A	N	N	U	U	SI	U	U	U	U
Contopus virens	Dec	U	N	U	N	N	N	SD	N	SI-N	N/A	U	N	U	U	SI-N-SD	SD	SD	N	U
Regulus satrapa	Dec	N	Inc	N	GI	N	N	SD	Inc-SI	N-SD	N/A	N	N	U	U	SI-N	U	U	U	U
Wilsonia citrina	Dec	N	N	N	N	N	N	SD	N	N-SD	N/A	N	N	U	U	SI	U	SI	N	U
Setophaga magnolia	Dec	U	Inc-SI	U	Inc-SI	N	N	SD	N	N-SD	N/A	U	N	U	U	SI	SD	GI	U	U
Geothlypis philadelphia	Dec	U	SI	U	SI	N	N	SD	N	N-SD	N/A	U	N	U	U	SI-N	U	GI	U	U
Seiurus aurocapillus	Dec	N	N	N	N	N	N	SD	N	SI-N	N/A	N	N	U	U	SI	U	SI	N	U
Vireo olivaceus	Dec	N	N	N	N	N	N	SD	N	N-SD	N/A	N	N	U	U	SI	U	N	N	U
Troglodytes troglodytes	Dec	N	Inc	N	SI	N	N	SD	SI-N	N-SD	N/A	N	N	U	U	N	U	GI	U	U
Empidonax flaviventris	Dec	U	GI-Inc	U	GI-Inc	N	N	SD	GI	SI-N	N/A	U	N	U	U	SI	U	N-SD	U	U
Sphyrapicus varius	Dec	N	SI	N	SI	N	N	SD	N	N	N/A	N	N	U	U	SI	U	GI	N	U

APPENDIX E:
CCVI SPECIES ACCOUNTS

American redstart (*Setophaga ruticilla*)

Global Rank: 5
State Rank: 5
Migratory Status: Long-distance
Climate Change Vulnerability Index: Increase Likely
Confidence: Moderate
Migratory Status: Neotropical migrant

Life History & Habitat: Widely abundant and dispersed across nearly the entire state, the American redstart is considered a forest habitat generalist. It is often found in second growth deciduous woods near openings or edges, as well as mid-successional, moist forests. This species is common at all elevations within Pennsylvania, although less common in the southeastern corner of the state where urbanization is high.

Current Threats: The American redstart has slightly increased within Pennsylvania over the last 50 years (Sauer et al. 2011); the second breeding bird atlas also reveals a 16 percent increase since the first atlas (Wilson et al. 2012, Brauning 1992). Unlike many other forest songbirds, this species remains vigorous in the face forest fragmentation; however, minor concern is warranted as Pennsylvania's largely second-growth forests continue to mature. Such successional processes have been implicated in the decline of neighboring state populations (Wilson et al. 2012; see also Sherry and Holmes 1993).

Factors Contributing to Vulnerability: This species has been indexed as Presumed Stable largely due to its versatile use of forests and widespread occurrence within Pennsylvania.

Black-billed cuckoo (*Coccyzus erythropthalmus*)

Global Rank: 5
State Rank: 5
Climate Change Vulnerability Index: Presumed Stable
Confidence: Very High
Migratory Status: Neotropical migrant

Life History & Habitat: The black-billed cuckoo is classified as a forest generalist in Pennsylvania (Wilson et al. 2012) although according to Brauning (1992) it is generally restricted to deeper woods in the northern and high elevation (>1,000 feet) areas of the state. Alternatively, the black-billed cuckoo's pattern of occurrence in Pennsylvania may also be described by less forest at these lower elevations (Brauning 1992). This cuckoo is commonly found in mid-successional or second growth mixed forests with edges and tickets that provide cover for its understory nest (PA Wildlife Action Plan). Some evidence indicates that black-billed cuckoos (as well as the sympatric yellow-billed cuckoo) migrate to sites of insect outbreaks, particularly cicadas and gypsy moth caterpillars, which act as food subsidies for these species.

Current Threats: Although Wilson et al. (2012) reports a slight increase in black-billed cuckoo populations since the first Pennsylvania Breeding Bird Atlas (see Brauning 1992), long term trends show a 2.3 % annual decline (Sauer et al. 2011). Causes for decline are not well documented. Nevertheless, this species is listed as one of Maintenance Concern within the state due to its general decline across the northeast region (PA Wildlife Action Plan); it is also considered a species of High Regional Concern within the Allegheny Plateau (NY and PA; PIF 2012). Some sources have documented increased brood parasitism frequency of the black-billed cuckoo by the yellow-billed cuckoo, particularly during cicada outbreaks (Nolan and Thompson 1975). However, interspecific parasitism goes both ways between these species and relative effects of each species on the other's reproductive success have not been quantified in Pennsylvania or elsewhere; nor have studies quantified the effects of cuckoo brood parasitism on the reproductive success of the 10 or 11 other songbird species in which it occurs. Nevertheless, Brauning (1992) suggested the yellow-billed may be slowly displacing the black-billed in Pennsylvania as the latter is more restricted to deeper woods in the northern and high elevation areas of the state; this observation was made using Breeding Bird Survey (BBS) data trends at the time which show similar patterns today (Sauer et al. 2011).

Factors Contributing to Vulnerability: Given the potential for insect outbreak frequency dynamics to change (probably increase) due to climate change (particularly for gypsy moth caterpillars, a primary food source for black-billed cuckoos whose spring abundance is believed to be positively related to mean winter temperature (Barber et al 2008)), it is reasonable to assume that interspecific nest-parasitism dynamics may also be affected. Whether this will ultimately benefit or hurt black-billed cuckoo populations within the state is difficult to say. Of additional interest is the black-billed cuckoo's current status are multiple independent reports of a northward shift in species distribution by Pennsylvania, New York, and Maryland (Wilson et al. 2012). These observations are consistent with Matthews et al. (2004; see also Hitch and Leberg 2007 and Rodenhouse et al. 2009) predicted northward contraction for this species.

Black-capped chickadee (*Poecile atricapillus*)

Global Rank: 5
State Rank: 5
Climate Change Vulnerability Index: Moderately Vulnerable
Confidence: Very High
Migratory Status: Resident

Life History & Habitat: The black-capped chickadee is one of Pennsylvania's few resident songbirds and can often be seen in backyards, particularly if there is a feeder to visit (Brauning 1992). A forest generalist, this chickadee's breeding range in Pennsylvania covers the states many forest types at a number of successional stages (Wilson et al. 2012). Even suburban dominated landscapes with adequate forest cover support breeding and certainly wintering populations of black-capped chickadees (Wilson et al. 2012). The black-capped chickadee builds its nests in cavities excavated by the pair or woodpeckers or in nest boxes, if available (NatureServe 2013). In the cold of winter, they usually roost communally in similar cavities, which minimizes heat loss.

Current Threats: Brauning (1992) found that the distribution map in PA for the black-capped chickadee is inversely related to that of the Carolina Chickadee, and it has long been noted that while they do hybridize where their ranges meet, competitive exclusion dynamics probably exist between the two species (Reudink et al. 2007). Furthermore, in the second atlas released 20 years later, Wilson et al. (2012) noted a contraction of the southern range limit within the state, which supports the hypothesis that black-capped chickadees may be pushed northward by Carolina chickadees as the planet's climate changes. In Ohio and many other parts of their range, the barrier between the two species matches that of air temperature isotherms, suggesting that metabolic performance may be the key (although evidence is certainly not conclusive; see Olson et al 2010).

Factors Contributing to Vulnerability: Increasing encroachment of the Carolina chickadee and subsequent northward shift of the hybrid zone (which is predicted northward at about 1.3km per year due to climate change) between these sympatric species puts the Black-capped chickadee at an increased vulnerability for competitive exclusion from parts of its current range within the state.

Blackburnian warbler (*Setophaga fusca*)

Global Rank: 5
State Rank: 4
Climate Change Vulnerability Index: Moderately Vulnerable
Confidence: Very High
Migratory Status: Neotropical migrant

Life History & Habitat: Blackburnian warblers are associated with the northern hardwood forests in the state at elevations >1,300 feet. They reach their highest densities in mature, old-growth hemlock stands (Wilson et al. 2012). While it cannot be classified as a conifer obligate (this species can be found in deciduous forests in the southwest region of the state and commonly in deciduous forests in the northwest), conifers, particularly hemlock, likely play some important role in this bird's breeding habitat given its strong association throughout most of its occupied area in the state. Current populations follow a modest annual increase of 1.4 percent since 1966 (Sauer et al. 2011), possibly due to maturation of forests.

Current Threats: As an area sensitive species, the blackburnian is particularly vulnerable to loss or fragmentation of habitat. In Pennsylvania, areas with high gas well densities (Table 3 of this report and Thomas 2011) and certain types of timber harvests (Wilson et al. 2012) are a threat to this species as it is less likely to be found or nests at lower densities. Additionally, the potential spread of an invasive insect killing hemlock trees, hemlock woolly adelgid, poses a threat to areas of high blackburnian densities.

Factors Contributing to Vulnerability: The most severe model scenarios from Matthews et al. (2004) predict complete extirpation of this warbler form the northeastern U.S.; both models show a complete loss of abundance in Pennsylvania. July temperatures accounted for most of the explanatory power of the model. Caution must be taken when interpreting such regional models at the state level as it is based on broad scale habitat associations and thus may underrepresent local adaptability. Nevertheless, hemlock and many other conifer species are expected to contract northward in their range, possibly leaving Pennsylvania (Iverson and Prasad 2001). This is likely to affect breeding densities for the northern populations of blackburnian warblers in PA, particularly at high elevation hemlock ravines.

Blackpoll warbler (*Setophaga striata*)

Global Rank: 5
State Rank: 1
Climate Change Vulnerability Index: Extremely Vulnerable
Confidence: Moderate

Life History & Habitat: The blackpoll warbler is particularly rare in Pennsylvania due to the severe rarity of its obligate habitat – moist, boreal spruce and coniferous forests. These relict northern forests were nearly extirpated from the state during Pennsylvania's timber era of the late 1800s and early 1900s. Although historically a member of Pennsylvania's breed bird community, the blackpoll warbler was not seen breeding in the state again until 1993, just after the first Breeding Bird Atlas of Pennsylvania was published (Gross 2010). The species was recently reconfirmed to be nesting in the Wyoming County in very limited areas and numbers (Wilson et al. 2012) – mostly in the north at higher elevations where spruce-dominated forest communities have reestablished (Gross 2010). Blackpoll warblers generally nest in coniferous trees and are particularly fond of spruce although in the southern areas of its range, hemlock is also favored (Wilson et al. 2012). Unfortunately, such forest types are expected to decrease dramatically in area as their range contracts northward due to climate change (Iverson and Prasad 1998, 2001); these forests are likely to disappear from not just Pennsylvania but the United States altogether, leaving the presence of the blackpoll warbler in Pennsylvania as anything except a migrant very unlikely.

Current Threats: The blackpoll warbler is currently listed as a state endangered species in Pennsylvania due to its confinement to boreal coniferous swamps and forests. Loss and degradation of its preferred and rare habitat within the state is of primary concern (Gross 2010). According to Pennsylvania Game Commission, most breeding populations both in Canada and Pennsylvania tend to be in places without road access, making them difficult to monitor (Gross 2010). This observation may also be an indication of area-sensitivity in this species, although no recent studies have inspected this directly.

Factors Contributing to Vulnerability: Limited numbers, confinement to boreal coniferous forests, and the fact that Pennsylvania falls in the very southern extent of this species' range are the main factors contributing to the high vulnerability of the blackpoll warbler.
Another aspect to note is that the blackpoll warbler participates in the longest migration of any of the New World warblers (Gross 2010, Baird 1999, others); it faces prolonged movement through North America in the spring, making it one of the later arrivals at the breeding grounds (Butler 2003). Late arrival as well as a trans-Atlantic migration during the fall would make it much more susceptible to (1) phonological decoupling from its primary food sources during the breeding season and (2) major changes in weather extremity throughout its migration route (Butler 2000). The silver-lining in the unfavorable forecast for this bird's future in Pennsylvania is that a study recently found that the southern populations of blackpoll warblers contain an insignificant number of unique alleles (<11%) and thus do not represent genetically isolated, independently evolving populations (Ralston and Kirchman 2012). So while the blackpoll warbler's range may well move out of Pennsylvania, we do not expect the genetic structure of the continental population to decline due to this factor.

Black-throated blue warbler (*Setophaga caerulescens*)

Global Rank: 5
State Rank: 4
Climate Change Vulnerability Index: Moderately Vulnerable
Confidence: Moderate
Migratory Status: Neotropical migrant

Life History & Habitat: According to the PA Wildlife Action Plan, black-throated blue warblers require unfragmented, mature mixed-coniferous forests with a high level of structural diversity (many canopy levels) as they tend to forage in the mid to low canopy and nest in the understory (Wilson et al. 2012, Brauning 1992). They are generally found within the higher elevations of the state (>1,600 feet).

Current Threats: As a species of Maintenance Concern in the state (PA Wildlife Action Plan), the black-throated blue warbler acts as an indicator species for the health and quality of Pennsylvania's northern hardwood forests. They are particularly sensitive to factors affecting structural diversity (especially the understory), such as deer browse at high densities DeGraaf et al. 1991). Since this species prefers contiguous tracts of forest, fragmentation or development of forested landscapes could negatively impact populations (Wilson et al. 2012). Currently, black-throated blue warblers are increasing within the state at a rate of 2.8 percent annually (Sauer et al. 2011), nearly doubling between atlas periods (Wilson et al. 2012, Brauning 1992).

Factors Contributing to Vulnerability: Given its presence at higher elevations and in cooler forests, the black-throated blue warbler may be sensitive to changes in mean summer temperatures that are expected to occur in Pennsylvania. Additionally, models predicting future suitable habitat within the northeast predict a northward contraction of this warbler's range; in the best case scenario, remnant populations will only persist on the Allegheny Plateau region of PA (Matthews et al. 2004).

Black-throated green warbler (*Setophaga virens*)

Global Rank: 5
State Rank: 5
Climate Change Vulnerability Index: Presumed Stable
Confidence: Moderate
Migratory Status: Neotropical migrant

Life History & Habitat: The black-throated green warbler is most commonly found in mixed-coniferous forests. Although it will nest in purely deciduous forests, this warbler's distribution closely matches that of Eastern hemlock within the state. Additionally, it is rarely found nesting below 1,300 feet. As a forest interior species that prefers to nest under a closed canopy, the black-throated green warbler has done well within the state as Pennsylvania's forests have reached maturity in recent decades; Sauer et al. (2011) reports a 3.1 % increase annually since 1966.

Current Threats: Given the possibility of the black-throated green warbler to be a hemlock within much of the state, it may be a species adversely affected by the introduction of the hemlock woolly adelgid, an invasive insect killing hemlock trees (Wilson et al. 2012, Gross 2010). Additionally, forest fragmentation by traditional gas wells and other factors are associated with decreased breeding densities of this species and others requiring a closed canopy (Table 3 of this report, Thomas 2011).

Factors Contributing to Vulnerability: While climate change is expected to exacerbate current threats for the black-throated green warbler (such as hemlock woolly adelgid) and add new ones (mismatched migration phenology), this species was scored as Presumed Stable. This is likely due to its willingness to nest in forests that lack a conifer component, albeit at lower densities. Additionally, its current high breeding densities (> 8 singing males/km^2 across at least ¼ of the state, see Wilson et al. 2012) and relatively large population (approx. 3% of the North American population at ~300,000 individuals) likely provide a robust buffer against extirpation from the state.

Blue-headed vireo (*Vireo solitarius*)

Global Rank: 5
State Rank: 5
Climate Change Vulnerability Index: Moderately Vulnerable
Confidence: Very High
Migratory Status: Neotropical migrant

Life History & Habitat: Unlike other vireos that share its range, the blue-headed makes notable use of coniferous tree species, particularly hemlock in Pennsylvania. It can be found nesting in homogenous coniferous stands or deciduous forests with very little conifer component at cooler, higher elevations within the state (>1,000 feet). This species is considered a part of the Northern hardwood forest guild for its preference of cool forests, although it will nest in oak dominated areas on north-facing slopes at >1,000 feet. It should be noted, however, that population densities are up to 10 times higher in hemlock dominated stands than in deciduous (Wilson et al. 2012). According to Brauning et al. (1992), its biggest limitation is probably the amount of forest cover; there is some evidence that this species is edge or area sensitive. The blue-headed typically builds its nest lower than the red-eyed vireo, no more than 20 feet from the ground in a small tree or shrub.

Current Threats: The blue-headed vireo population in Pennsylvania (which represents under 3% of its range) is currently increasing, possibly due to the maturation of the states' forests after massive clear cutting that took place in the late 19th and early 20th centuries (Wilson et al. 2012, Sauer et al. 2011). Due to its affinity for hemlock within the state, there is some uncertainty on the effects invasive hemlock wooly adelgids may have on this species' resurrection.

Factors Contributing to Vulnerability: Estimates using both conservative and liberal climate models in Matthews et al. (2004) predict a substantial decrease in incidence rate throughout the assessment area, although it will not leave the state entirely. Additionally, Rodenhouse et al. (2009) predicts a 6 to 8 % decline in occupancy across its range within the next 50 years. These predictions are based on the blue-headed vireo's close association with conifer species; its persistence in the state is projected to be mostly along the Appalachian Plateau.

Canada warbler (*Cardellina canadensis*)

Global Rank: 5
State Rank: 4
Climate Change Vulnerability Index: Presumed Stable
Confidence: Very High
Migratory Status: Neotropical migrant

Life History & Habitat: The Canada warbler breeds in the Northern hardwood forests of Pennsylvania (see Appenix B); as such, it is most commonly found in the northern third of the state as well as along the Appalachian Plateau. Rarely is this bird seen nesting at elevations below 1,000 feet within PA (Brauning 1992). This warbler is associated with cool and moist boreal-zone, mixed-coniferous forests, usually with a partially open canopy and necessarily with an adequate shrub layer for nesting. In the Second Atlas of Breeding Birds of Pennsylvania, this species was one of 27 species to be strongly associated with hemlock; nearly 50% of its records come from forests containing a significant (>50%) hemlock component .

Current Threats: According to both Breeding Bird Survey and the Second Atlas of Breeding Birds of Pennsylvania, Canada warbler populations and occupancy are currently stable in Pennsylvania (Sauer et al. 2011, Wilson et al. 2012). Nevertheless, this species is deemed one of Maintenance Concern due to its status as a Partners in Flight I, II and Northeast Region priority species (PIF 2012). Canada warblers are sensitive to edge effects and require forests with dense understory structure; thus, they are considered indicators of the health and abundance of such forest characteristics. One cautionary note from Wilson et al. (2012) is that the Canada warbler's reliance on earlier successional, shrubby forests may hint that its existence is only ephemeral in the state should Pennsylvania's forests continue to mature. Unmanaged deer-browse may also pose a threat to this warbler, as it does to many understory nesting species (Rooney 2001, DeGraaf et al. 1991), should deer densities become and remain too high.

Factors Contributing to Vulnerability: Although not considered a conifer-obligate, strong state-wide association with northern hardwood and coniferous species make the Canada warbler more vulnerable than some. Additionally, Matthews et al. (2004) and Rodenhouse et al. (2009) predict losses in range and abundance across the remaining range. Although the Canada warbler is not likely to be extirpated from the state, it may only remain at higher elevations at lower densities.

Chestnut-sided warbler (*Setophaga pensylvanica*)

Global Rank: 5
State Rank: 5
Climate Change Vulnerability Index: Presumed Stable
Confidence: Moderate
Migratory Status: Neotropical migrant

Life History & Habitat: Forest clearings and canopy disturbances create the second growth habitat where you are likely to find this understory nesting and foraging warbler. Chestnut-sided warblers build their nests in young thickets of mountain laurel, *Rubus*, and tree seedlings no higher than 2 meters (NatureServe 2013). These warblers are more commonly found in areas above 1,000 feet within the state, although not uniformly. Additionally, chestnut-sided warblers seem to steer away from coniferous forests in favor of more deciduous areas (NatureServe 2011).

Current Threats: The chestnut-sided warbler is currently experiencing a 2.4% increase annually in Pennsylvania despite the fact that forests have reached maturity in recent decades. According to the 2nd PA Breeding Bird Atlas, it is the 5th most common wood warbler in terms of block occupancy and population size within the state (Wilson et al. 2012). A number of studies note that traditional gas wells and other small forest roads that create gaps in a largely forested landscapes may increase the relative abundance of this gap specialist species (e.g., Thomas 2011, Ortega and Capen 2002; see also Table 3 of this report); preliminary data at Marcellus shale wells show no difference in abundance for early successional species (Barton and Brittingham 2013, unpublished data). Thus, the chestnut-sided warbler may actually be benefiting from resource extraction as opposed to the mature forest interior species assessed in this report. Only fragmentation due to heavy human land use such as urban development appears to deter these warblers (Wilson et al. 2012).

Factors Contributing to Vulnerability: Chestnut-sided warblers were ranked as Presumed Stable likely due to their versatile habitat use and overall increasing numbers within Pennsylvania. The only suspected threats from climate change come from general concerns about migration phenology and increasing numbers of wind farms in Pennsylvania. However, these threats are uncertain and not well studied for this specific species.

Eastern wood-pewee (*Contopus virens*)

Global Rank: 5
State Rank: 5
Climate Change Vulnerability Index: Increase Likely
Confidence: Very High

Life History & Habitat: The eastern wood-pewee is another common and extensively distributed breeding species in Pennsylvania. Considered a forest generalist, it will nest in mature deciduous or mixed forests or even in urban areas that contain adequate numbers of trees. Structurally speaking this species prefers areas with larger trees, where it nests up to 60 feet from the ground in a horizontal limb from late May to late August. Unlike most long-distance seasonal migrants, the eastern wood-pewee generally produces two broods. As an aerial insectivore, this wood-pewee also requires some canopy gaps or edges for foraging opportunities (Wilson et al. 2012, Brauning 1992).

Current Threats: While the 2nd breeding bird atlas of Pennsylvania reported no change in the species' range throughout the state (Wilson et al. 2012), BBS data tells a story of moderate decline (mean of 1.7 % per year in the last 50 years; Sauer et al. 2011). The ecological reasons behind this decline can only be speculated: increasing forest cover, indirect impacts of high white-tailed deer densities (see deCalesta 1994), or perhaps habitat loss on the breeding grounds (Wilson et al. 2012). Whatever the case and given that Pennsylvania hosts a disproportionate percentage of the North American breeding population (approx. 3.5%, Rich et al. 2004), managers should be sure to keep a close eye on the status of this species as forests in PA mature.

Factors Contributing to Vulnerability: Several factors contributed to the eastern wood-pewee's optimistic score of Increase Likely. Firstly, it is a generalist forest species not particularly tied or associated with specific tree species. Secondly, Matthews et al. 2004 predict that the wood-pewee will increase in abundance across its range – including Pennsylvania - in response to climate change (precipitation changes in particular). Finally, analysis of first arrival dates (FAD) of eastern wood-pewees in both New York and Massachusetts indicate this species is responding to climate change by arriving earlier during spring migration. Although analyses of FAD are often criticized as being too dependent on overall population size of a species to indicate earlier spring arrival, a declining population (such as that of the eastern wood-pewee across North America, Sauer et al. 2011) would bias analyses towards producing a false *later* (not earlier) arrival time. One final word of caution in interpreting the wood-pewee's vulnerability is its dependence on aerial insects. Some evidence suggests that flycatchers and other primarily aerial insectivores may face food shortages in the wake of climate change (Nebel et al. 2010).

Golden-crowned kinglet (*Regulus satrapa*)

Global Rank: 5
State Rank: 3
Climate Change Vulnerability Index: Moderately Vulnerable
Confidence: Moderate
Migratory Status: Resident/Non-migrant

Life History & Habitat: In Pennsylvania, the golden-crowned kinglet is a part of the Northern hardwood species guild and is considered a conifer-obligate (Wilson et al. 2012, Brauning 1992). Its distribution within the state is rather scattered and localized – much like that of the spruce species it favors for building its nests. Although historically found in red spruce (*Picea rubens*) forests and bogs, this resident bird has proven to be very adaptable to local opportunities and readily nests in ornamental conifers such as Norway spruce (*Picea abies*) as well as pines and hemlocks (Wilson et al. 2012, Gross 2010). Structurally, this kinglet prefers to nest in older coniferous forests (>35 years old) with some tall trees present (Brauning 1992).

Current Threats: Given its use of hemlock within the state, the golden-crowned kinglet could be adversely affected by the recent introduction of hemlock woolly adelgid; however, the magnitude of this pest's effect on golden-crowned kinglet populations in Pennsylvania remains unexamined in the literature (Gross 2010).

Factors Contributing to Vulnerability: The golden-crowned kinglet is ranked as Moderately Vulnerable mostly due to its high affinity for conifers and associated cool, moist forested habitats within the state. Iverson and Prasad (2001) expect drastic reductions of coniferous forests according to several climate models; additionally, other independent species-specific models largely predict that many of Pennsylvania's spruce species will be extirpated or only remain in small, localized areas of few individuals at higher elevations in northern areas (McKenney et al. 2007). Nevertheless, if some conifer components are able to persist within the state, we may expect this flexible kinglet to do the same.

Hooded warbler (*Setophaga citrina*)

Global Rank: 5
State Rank: 4
Climate Change Vulnerability Index: Increase Likely
Confidence: Moderate

Life History & Habitat: Results from the 2nd PA Breeding Bird Atlas show a skewed distribution for hooded warblers within the state with the most densely populated areas located in the northwest corner, just west of the Allegheny Plateau. These areas have high forest cover and are at higher elevations (Wilson et al. 2012, Brauning et al. 1992). Although hooded warblers will nest in both young and mature forests, they are most abundant in more mature landscapes so long as undergrowth is adequate and ground cover is scarce (NatureServe 2013). As a forest interior species, the hooded warbler requires landscapes with extensive forest cover, which is one possible reason for its lesser numbers in eastern Pennsylvania.

Current Threats: BBS data shows a significant trend of 3.8% increase per year in Pennsylvania's hooded warbler populations during the past five decades. This coincides with a suspected northward range expansion noted by Wilson et al. (2012) and others. However, as a gap-specialist forest interior species, the hooded warbler is surprisingly sensitive to fragmentation and brown-headed cowbird nest parasitism, which will surely increase if new gas and oil wells increase throughout core forest area within the state. Consequently, this expansion may be short-lived if land use changes continue the current trend towards increased resource extraction within the state.

Factors Contributing to Vulnerability: Hooded warblers are expected to increase in Pennsylvania due to climate change. This score is most attributable to the fact that Pennsylvania lies on the northern edge of this warbler's range. As aforementioned, there have been reports in multiple surrounding states of range expansion (Wilson et al. 2012) although it has not been directly linked to climate change. It should be noted that one study found significantly higher abundances of hooded warblers in oak rather than northern hardwood forests at the landscape scale within the state (Thomas 2011); given the expectation for oak-hickory forest type to expand northward and replace much of the northern hardwood system in the northern portion of the state due to climate change (Iverson and Prasad 2001), it may not be surprising for the hooded warbler to follow suit.

Magnolia warbler (*Setophaga magnolia*)

Global Rank: 5
State Rank: 4
Climate Change Vulnerability Index: Moderately Vulnerable
Confidence: Very High

Life History & Habitat: The magnolia warbler is another characteristic songbird of Pennsylvania's northern hardwood forests. This warbler seems particularly fond of hemlock ravines at the highest elevations (1,600-1,900 feet) within the state, particularly along the Allegheny Plateau region (Brauning 1992). These moist, cool areas support the greatest densities (>8 singing males per km^2) of this species (Wilson et al. 2012). The magnolia warbler can probably be considered a conifer obligate, as it does not breed without conifers present.

Current Threats: Given its association with hemlock within the state, the magnolia warbler remains vulnerable to indirect effects of Hemlock woolly adelgid. Historically, magnolia warblers were probably abundant within the state, but loss of coniferous habitat due to extensive logging practices (white pine, Eastern hemlock) has reduced its numbers. Despite these setbacks, the magnolia warbler has produced a significant annual increase of 3.6% over the past fifty years and so may have a robust buffer against trials to come.

Factors Contributing to Vulnerability: A score of Moderately Vulnerable with very high confidence is fitting for this boreal warbler given the poor outlook for Eastern hemlock and other coniferous tree species within Pennsylvania in the face of climate change. Its affinity for cool, moist northern forests at higher elevations within the state makes it vulnerable to potential decreases in annual precipitation and increasing annual temperatures – both of which are expected to disproportionately take effect during June and July, the tail end of the breeding season. This is a critical time for young warblers to fledge and begin gaining fat stores in preparation for the long autumn migration back to wintering grounds. In spite of this grim outlook, there is some hope coming from breeding bird atlases throughout the region (PA and NY) that have reported southern range expansions. Whether this is in response to climate change or other factors remains open to speculation (Wilson et al. 2012).

Mourning warbler (*Geothlypis philadelphia*)

Global Rank: 5
State Rank: 4
Climate Change Vulnerability Index: Moderately Vulnerable
Confidence: Very High

Life History & Habitat: Early second-growth boreal forest clearings are a prime place to find this secretive northern breeding bird. The mourning warbler's nest is generally found on the ground where it often forages (in addition to lower canopy leaves). As an early-successional forest species, this warbler requires some type of disturbance which it will colonize within 2 years (Brauning 1992). Unfortunately, it quickly disappears as the forest ages (by around year 10). Thus, a relatively constant disturbance regime is necessary for this migrant, and regular silvicultural harvests will encourage its growth within the maturely forested Pennsylvania.

Current Threats: The mourning warbler's relative scarcity within the state could be due to loss of habitat, as is the case with many earlier successional forest and agricultural dependent songbird species. On the other hand, BBS data shows a modest 1.7 percent annual increase for Pennsylvania populations. Because of its dependence on thickets, chronic high deer densities may negatively affect this species.

Factors Contributing to Vulnerability: Climate change may actually benefit the mourning warbler in providing more suitable habitat if more severe storms or other disturbance factors increase the number of early successional patches within the state. On the other hand, Matthews et al. (2004)'s model predicted a complete extirpation of this warbler from Pennsylvania under the presumptive loss of white cedar.

Ovenbird (*Seiurus aurocapilla*)

Global Rank: 5
State Rank: 5
Climate Change Vulnerability Index: Presumed Stable
Confidence: Moderate

Life History & Habitat: The ovenbird is the most abundant warbler within the state with an estimated population size of 1.6 million males occupying territories throughout nearly every county (Wilson et al. 2012). Considered a forest generalist, this ground gleaning wood warbler will nest in nearly any forest type found throughout the state so long as it provides closed canopy and somewhat open understory (NatureServe 2013).

Current Threats: The ovenbird is considered an area sensitive species and while it will reproduce in smaller forest fragments, it does so at lower densities with much less success (Porneluzi et al. 1993) probably due to lower prey biomass (Burke and Nol 1998) or increased predation risk (Flaspohler et al. 2008). In Penssylvania, areas with high gas well densities (Table 3 of this report, Thomas 2011) are a threat to this species as it is less likely to be found or nests at lower densities. Loss in core forest habitat due to continued expansion of Marcellus shale gas wells and shallow wells poses a conservation concern for this abundant species (Barton and Brittingham 2013, Fronk and Brittingham 2013). Acid rain is also considered a risk factor for these birds as it can affect invertebrate prey resources (Pabian and Brittingham 2007).

Factors Contributing to Vulnerability: The ovenbird ranks as Presumed Stable under the CCVI index given its ubiquity throughout Pennsylvania and its versatile use of forest types. Pennsylvania is located in the center of its particularly large range from Alabama and Georgia up to central Canada. However, as a primary molluscivore and secondary consumer of other ground invertebrates, the ovenbird may be more directly vulnerable to climate change in ways that foliage-gleaning insectivorous birds are not: through changes in soil moisture regime. Although this avenue is not well investigated in the literature, many studies have shown that forest productivity and microhabitat components such as soil moisture affect food resources for these birds (Seagle and Sturtevant 2005, Pabian and Brittingham 2007) and that without proper food availability, nesting success can be adversely effected (Burke and Nol 1998).

Red-eyed vireo (*Vireo olivaceus*)

Global Rank: 5
State Rank: 5
Climate Change Vulnerability Index: Increase Likely
Confidence: Moderate

Life History & Habitat: Red-eyed vireos are one of Pennsylvania's most common and geographically extensive nesting species, particularly among Neotropical migrants. A forest generalist, its density throughout the state closely mirrors maps of forest cover; it is even known to inhabit relatively small tracks of forest within the state and so appears even in counties dominated by agriculture or urbanization (Wilson et al. 2012). This vireo can be found nesting in the sub or high canopy and so nests are often difficult to come upon despite its incessantly vocal nature (Wilson et al. 2012, Brauning 1992).

Current Threats: Existing at an average density of 40 males per square kilometer, the red-eyed vireo is not considered threatened within the borders of Pennsylvania. However, areas of high gas well density had lower numbers of observed Red-eyed Vireos compared to areas of low gas-well density (Table 3 of this report, Thomas 2011).

Factors Contributing to Vulnerability: As one of Pennsylvania's most adaptable and ubiquitous forest bird species, it is no surprise that the red-eyed vireo is Presumed Stable in the face of climate change. Pennsylvania is located at the center of the red-eyed vireo's current range, which extends from the gulf coast up to Newfoundland. The sole indication of uncertainty for this species is whether, as a long-distant migrant, it will be able to adapt its migratory timing in order to take advantage of the earlier arrival of spring and subsequent change in the peak abundance of Lepidoptera larvae, the primary food resource for young red-eyes (Marshall et al. 2002). So far, there has been no evidence to suggest advances in arrival or overall breeding phenology (Wilson et al. 2012).

Winter wren (*Troglodytes hiemalis*)

Global Rank: 5
State Rank: 4
Climate Change Vulnerability Index: Moderately Vulnerable
Confidence: Very High

<u>Life History & Habitat:</u> Winter wrens almost always occur above 1,000 feet and more frequently above 2,000 feet (Brauning 1992) in Pennsylvania. They are usually found close to water such as streams, bogs, etc. especially when dense vegetation is present. Shaded hemlock stands on ravines provide the most favored habitat for this resident species. It feeds on invertebrates located in moist areas at ground level and nests in cavities (NatureServe 2013).

<u>Current Threats:</u> The winter wren's dependence on mature coniferous northern forests, often dominated by hemlock, has earned it a classification of Maintenance Concern. Hemlock and other coniferous species have been in recovery across the state for the past few centuries, having been used extensively in early Pennsylvanian history for the tanning industry (Rhodes and Block 2005).

<u>Factors Contributing to Vulnerability:</u> This species has been suggested by Brauning et al. (1992) to be a good indicator of the health of the northern forests in the state. Declines in this forest type (Iverson and Prasad 2001) and its inhabitants (Matthews et al. 2004, Rodenhouse et al. 2009) have been projected and this is reflected in the winter wrens increased vulnerability under physiological thermal and moisture niche, as well as its propensity to associate with hemlock (Wilson et al. 2012)

Yellow-bellied flycatcher (*Empidonax flaviventris*)

Global Rank: 5
State Rank: 1
Climate Change Vulnerability Index: Moderately Vulnerable
Confidence: Moderate
Migratory Status: Neotropical

Life History & Habitat: Known as a boreal forest species throughout its range, the yellow-bellied flycatcher's preferred habitat of high-elevation conifer-forested wetlands remains scattered across the state (Wilson et al. 2012, Gross 2010). Its small population of approximately 10-20 individuals (PIF 2012) is localized in just a few areas along the Appalachian Plateau, although there is suspected to be some use of the Allegheny National Forest as well (see Wilson et al. 2012). The yellow-bellied flycatcher nests at or near ground-level, hiding its clutch well beneath mossy, ferns, and other dense shrubby vegetation that is characteristic of its habitat. Red spruce (*Picea rubens*) and hemlock commonly dominate forests where this bird breeds in Pennsylvania.

Current Threats: Currently State Endangered (Wildlife Action Plan), the yellow-bellied flycatcher is believed to have always been a rare breeder (Wilson et al. 2012) but has been lost in more southern regions of the state since the turn of the 20th century (Gross 2010). Habitat loss and/or fragmentation and lack of regeneration red spruce bogs and other similar coniferous wetlands are considered the source of scarcity.

Factors Contributing to Vulnerability: The yellow-bellied flycatcher's rating as Moderately Vulnerable stems from the fact that boreal forests on which it depends are expected to retreat northward and possibly even leave the state completely aside from some relic habitat at higher elevations. This is particularly true of red spruce (see McKenney et al. 2007). Climate change is therefore expected to exacerbate the problems this state endangered bird already faces, making it unlikely for the yellow-bellied flycatcher to continue to breed within the state in the future. The breeding populations in Pennsylvania are separated from the closest regularly breeding populations in the northern Adirondacks, and therefore are particularly vulnerable to local extirpation.

Yellow-bellied sapsucker (*Sphyrapicus varius*)

Global Rank: 5
State Rank: 4
Climate Change Vulnerability Index: Moderately Vulnerable
Confidence: Very High
Migratory Status: Temperate migrant

Life History & Habitat: Yellow-bellied sapsucker is a northern hardwood specialist, breeding in Pennsylvania's moist northern forests above 1,500 feet. As its name implies, this unusual woodpecker is known for eating the sap of many soft species such as birches (*Betula* spp.), maples (*Acer* spp.), yellow poplar (*Liriodendron tulipifera*), cherries (*Prunus* spp.), pines (*Pinus* spp.), and aspens (*Populus tremuloides, P. grandidentata*) when available (Brauning 1992). They also feed on many invertebrate species they find along the way. Yellow-bellied sapsuckers can often be found near the edges of mixed, coniferous, and deciduous woodlands, particularly near water (Brauning 1992).

Current Threats: The yellow-bellied sapsucker is one of two woodpeckers currently recognized as part of a priority species pool in the Partners in Flight Bird Conservation Plan for the Allegheny Plateau (PIF Allegheny Plateau, PIF 2012). Over the past several decades, the sapsucker has becoming increasingly common within the state (9.8% annual increase, Sauer et al. 2011). Wilson et al. (2012) found some indication that this species may be area sensitive as it was found at higher densities in areas of Pennsylvania with vast (>70%) forest cover; however, Thomas (2011) found that its abundances increased with increasing gas well densities at the landscape scale. Thus, while overall forest cover within the landscape is important, yellow-bellied sapsuckers probably benefit to a certain extent from fragmentation (and perhaps tree mortality) that creates canopy gaps.

Factors Contributing to Vulnerability: Northern hardwood forests--this species' primary habitat within the state--are expected to recede north and be replaced by central or bottomland hardwoods (oak-hickory) in many different climate scenarios investigated by Iverson and Prasad (2001). Maple and birch species are particularly expected to decline. This species is also found fairly commonly in oak forests as well, however temperature may be limiting as they are almost absent in the southern two-thirds of the state even at high elevations.

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