THE NORTHERN WATERTHRUSH: ANALYZING THE DISTRIBUTION AND ABUNDANCE OF A SECRETIVE SONGBIRD IN PENNSYLVANIA

By

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A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
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to the Office of Graduate and Extended Studies of
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ABSTRACT

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Abstract

The northern waterthrush *(Parkesia noveboracensis)* experienced a drastic decline between the first and second Pennsylvania Breeding Bird Atlases despite higher sampling effort during the second atlas. Atlas data suggested a slight northward range contraction and detectable increase in elevation of occupied blocks, potentially caused by climate change. This study investigates factors that may be responsible for any detected changes in distribution in northeastern Pennsylvania (Pike, Monroe and Northampton counties). In spring of 2017 and 2018, wetland surveys were conducted to detect singing males. At each of 53 sites, point counts were conducted to characterize the avian community. Vegetative, physical, and hydrological characteristics were also recorded. Sites occupied by northern waterthrush were compared to unoccupied sites in apparently suitable habitat. Shrub height and upturned tree roots were found to be significantly different between site types as was the avian community and the herbaceous plant community. It was also found that there was a range contraction at both the northern and southern end of the NOWA range between the two atlases in the study area. These results suggest that changes in vegetation structure due to deer overbrowsing and eastern hemlock decline are contributing to the decline observed between atlases.

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CHAPTER I

Introduction

Study Justification

The northern waterthrush (*Parkesia noveboracensis*, NOWA) is a cryptic species that prefers habitat that is often very difficult to access. Therefore, relatively little is known about its life history, especially regarding nesting, specific habitat preferences and its avian community associates.   NOWA is also an excellent candidate to use to examine how climate change is affecting avian populations because this species is at the southern edge of its range in Pennsylvania and prefers cooler, high elevation peatlands for the most part. Highly vagile species such as birds, especially those with this habitat preference, are expected to be the first to respond to climate change (DCNR 2015). Lastly, this species has already experienced a 40.7% decline between the 1st and 2nd Pennsylvania Breeding Bird Atlas (PBBA) (Wilson et al. 2012). Thus, there are several compelling reasons to conduct in-depth studies of this species in Pennsylvania

Taxonomy

The NOWA is a small, dark colored warbler with dark streaking on a white breast. It belongs to the family Parulidae and is one of the New World's most widely ranging warblers (Bent 1963, Craig 1987, Whitaker and Eaton 2014, NatureServe 2017) (Figure 1). Between 1880 and 1948, this species was divided into four subspecies, based on various studies of color variation and morphometric distinctions, which were ultimately lumped into a single species (Molina et al. 2000). In the early 2000s, phylogenetic evidence supported a separation of the two waterthrush species, northern and Louisiana (*Parkesia motacilla*, LOWA) from the genus (*Seiurus)* because of differences in morphology and phylogeny from the ovenbird (*Seiurus aurocapilla)*. In order to make *Seiurus* a monophyletic group, the two waterthrushes were moved into their current genus, *Parkesia*, as established by Sangster (2008).

Figure 1. NOWA displaying the characteristic marks used to identify it. The widening superciliary strip and buffy yellow color (left) as well as the heavily streaked throat (right) (photo credit Justin Clarke).

Ridgeway described a western subspecies that ranged from northwestern Alaska to western Quebec (Bent 1963, Ridgeway 1880, 1902). *Seiurus noveboracensis notabilis* is distinguishable by a larger bill, whiter ventral coloration, and a more gray and olive dorsal coloration. He also described a subspecies, *S. n. noveboracensis*, that ranged from western Quebec to Newfoundland. McCabe and Miller (1933) proposed another subspecies, *S. n. limnaeus*, which was restricted to northwestern and central British Columbia and showed an intermediate form that was paler than *S. n. noveboracensis* but darker than *S. n. notabilis* (Bent 1963). A fourth subspecies, *S. n. uliginosus*, was described by Burleigh and Peters (1948) and found on the islands of Newfoundland, Saint-Pierre, and Miquelon in Canada. This subspecies was defined by a longer wing and tail than the other populations. There have been many studies done that contradict these findings due to extensive geographic overlap in some of the size differences. It was found however, that western specimens typically had longer tails and shorter wings than eastern specimens and *P.n.notabilis*, *P.n.limnaeus*, and *P.n.uliginosus* were lumped together into *P. noveboracensis* (Molina et al. 2000).

General Natural History

The breeding range of this small warbler (Figure 2) extends from western Alaska through most of southern and central Canada and into the northern portion of the United States. The range extends as far south as northwestern Wyoming in the west and extreme northwestern Virginia, West Virginia, all of Pennsylvania (except the southwest and southeast), and northwestern New Jersey in the east. During winters, it migrates south to northern Mexico, the Caribbean, and as far as Venezuela (Eaton 1957, Bent 1963, NatureServe 2017).

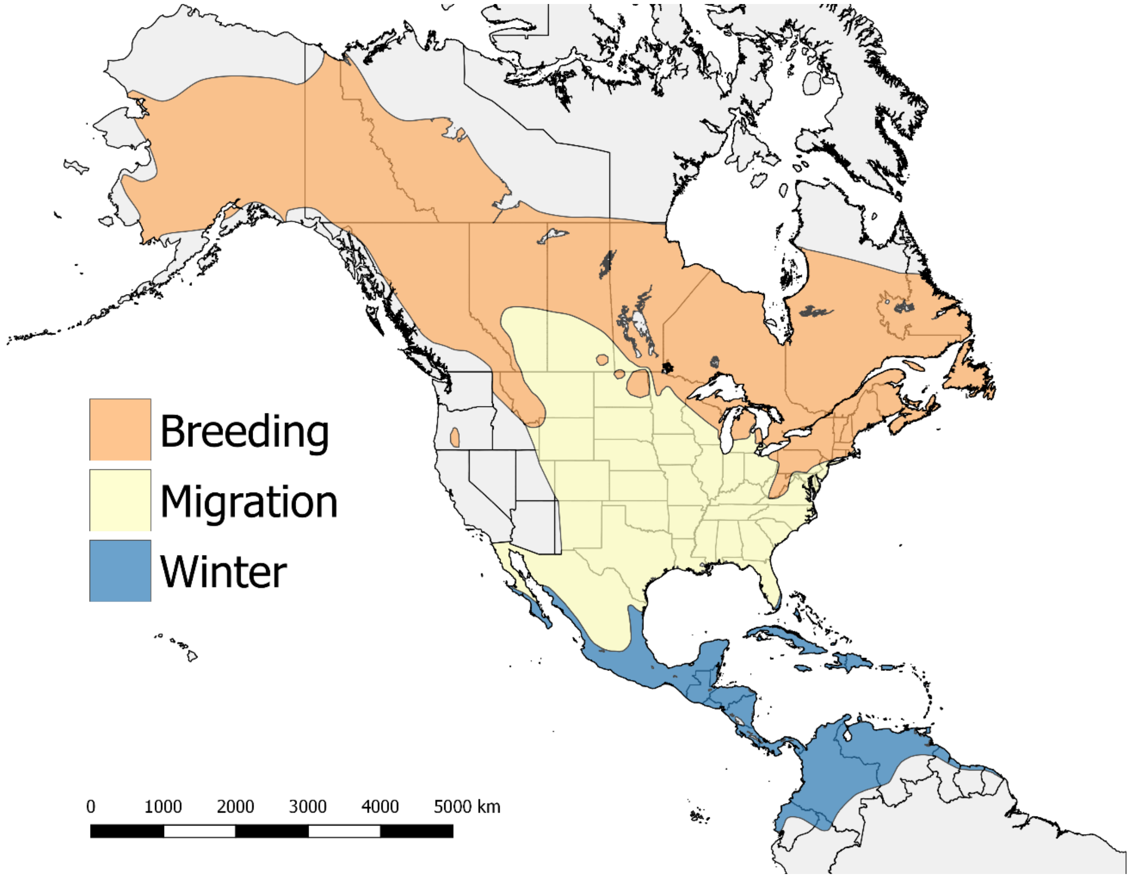


Figure 2. NOWA distribution map (distribution data from BirdLife International).

Throughout its northern breeding range, NOWA favor wooded areas with slow moving or stagnant water such as bogs or swamps with dense cover near ground level (Bent 1963, Craig 1985, Whitaker and Eaton 2014). In Pennsylvania, especially on the Allegheny Plateau, NOWA prefers rhododendron thickets (*Rhododendron ponticum*) with high concentrations of eastern hemlock (*Tsuga canadensis*) in swamps and along slow-moving streams, e.g., hemlock benches (Figure 3). In other parts of the state, as well as in New York, nesting has occurred in swamps with spruce (*Picea*), tamarack (*Larix)*, and balsam fir (*Abies*) (Craig 1985, Wilson et al. 2012, Whitaker and Eaton 2014).The southern wintering range consists of swampy areas, especially the mangroves

(*Rhizophora*, *Avicennia*, and *Laguncularia*) (Whitaker and Eaton 2014). These habitats seem relatively secure throughout most of the breeding range but some of this range was lost in Pennsylvania, New York, and the lower peninsula of Michigan due to deforestation and destruction of wetlands in the past (Whitaker and Eaton 2014, NatureServe 2017).

Figure 3. Bear Swamp field site (left) shows more open NOWA habitat while Cranberry Bog (right) shows the more typical dense understory of NOWA habitat (photo credit Justin Clarke).

NOWA are most easily confused with the Louisiana waterthrush but the two can be confidently distinguished from one another using a combination of physical, auditory, and habitat characteristics (Dunn and Alderfer 2017). LOWA prefer areas that have faster moving water such as streams and rivers whereas NOWA prefer more stagnant swamps and bogs (Bent 1963, Whitaker and Eaton 2014). However, there are areas such as hemlock benches with braided streams where the two species intermingle. They can also be identified based on differences in their songs. LOWA have a song with much more slurred and drawn out notes than NOWA which incorporate relatively short, staccato notes in their song (Bent 1963, Brown 1975, Whitaker and Eaton 2014). They can also be distinguished by plumage characters. Adult NOWA underparts are white but often with a noticeable yellowish wash below while LOWA are always nearly pure white. Streaking on the breast and belly is darker in NOWA and streaks typically extend onto the throat whereas LOWA have lighter streaking on the breast and usually none on the throat. The bill of a LOWA is distinctly larger than a NOWA but this may be difficult to distinguish in the field. The supercilliary stripe in NOWA can be white or buff and narrows behind the eye whereas LOWA have a white supercilliary stripe that either does not narrow or more often broadens behind the eye (Whitaker and Eaton 2014).

NOWA are insectivorous and get most of their prey from the water. They feed mainly by wading and walking along logs or branches at the water's edge picking benthic or swimming organisms out of the water (Figure 4). They forage alone and will typically pick up leaves and toss them aside to uncover the insects beneath (Bent 1963, Whitaker and Eaton 2014). They have also been observed feeding on terrestrial invertebrates and will hawk and glean insects from the air and vegetation, respectively (Craig 1984, Whitaker and Eaton 2014).

Figure 4. NOWA brings insects back to the nest (photo credit Terry Master).

During the breeding season, their diet is composed predominantly of insects, spiders and snails but they can be generalists during migration where they have even been seen feeding on small minnows (Bent 1963, Whitaker and Eaton 2014). Their diet during the breeding season consists of Coleoptera (beetles) larvae, adult Lepidoptera (moths and butterflies), adult Odonata (dragonflies), larval Neuroptera (lacewings), adult Plecoptera (stoneflies), Ephemeroptera (mayflies), and many other insect orders. In wintering habitat, their diet is composed of small snails, clams, Atlantic mangrove fiddler crabs (*Uca thayeri*), small spiders, adult snout beetles, small ants, flies, and other insect larvae (Whitaker and Eaton 2014).

Arrival on the breeding grounds occurs from mid-April to late-May with pairs forming as soon as the females arrive (Whitaker and Eaton 2014). Singing begins in late

April and continues until late June in the more southern parts of their range while more northern individuals will continue singing until mid-July. After establishing territories and selecting mates, NOWA typically start building nests in mid to late May and lay eggs during the first week of June (Craig 1987, Wilson et al. 2012, Whitaker and Eaton 2014, NatureServe 2017). Incubation begins after the third egg is laid and will continue for about 12 days. Brooding then lasts for approximately 5 days. The young hatch in the last week of June and are cared for until approximately the last week of July (Craig 1987, Wilson et al. 2012, Whitaker and Eaton 2014, NatureServe 2017). The earliest departure from the breeding grounds is approximately July 15^{th} with the peak occurring in September. Earliest departure from Pennsylvania is July 24^{th} (Whitaker and Eaton 2014). They arrive on the wintering grounds from early August to early November (Whitaker and Eaton 2014) and are among the earliest fall migrants, along with LOWA.

This neotropical migrant is essentially monogamous although there is evidence of extra-pair mating (Whitaker and Eaton 2014). NOWA are single brooded and it is very rare to see them reuse a nest. This behavior was only seen in 1 of 91 nests in a study done in Ontario, however, they will re-nest and build a new nest following failure caused by depredation (NatureServe 2017). NOWA lay one clutch of four to five eggs once per season (Craig 1987, Wilson et al. 2012, Whitaker and Eaton 2014, NatureServe 2017). Eggs are laid early in the morning on successive days and, while the adults will feed in the area, they will not return to the nest until the female lays the next egg (Whitaker and Eaton 2014). Both parents feed chicks and females are cryptic when leaving the nest. They will land on the ground and slowly walk about 10 meters away before standing up and flying off to feed (Whitaker and Eaton 2014). Both parents remove fecal sacs and during the first few days will eat them, but later take them away from the nest for disposal (Figure 5) (Whitaker and Eaton 2014). They are known to be territorial throughout the year and can be intensely aggressive towards conspecifics (Craig 1984, NatureServe 2017).

Figure 5. Adult NOWA flying from the nest at Bear Swamp in 2017 carrying a fecal sac (photo credit Terry Master).

Nest site selection is up to the female. It will most often be placed on the ground, in a hollow of a bank or among the roots of overturned trees (Bent 1963, Wilson et al. 2012, Whitaker and Eaton 2014) (Figure 6). NOWA nests are cups that are typically hidden from above with an opening on one side, and they sometimes have an entranceway of leaves similar to LOWA nests. The outside of the cup is composed of leaves and lined on the inside with grass stems, twigs, and/or pine needles (Bent 1963, Whitaker and Eaton 2014). Mean dimensions of nests are: diameter 10.7 cm, height 5.6 cm, inside diameter of cup 6.2 cm, depth of cup 3.1 cm (Whitaker and Eaton 2014).

Figure 6. A typical NOWA nest site at Grass Lake (photo credit Justin Clarke).

Eggs are white with brown/gray blotches or spots. Spotting density can vary and all markings are concentrated toward the larger end of the egg. Mean dimensions of the eggs are 19.1 mm long and 14.6 mm in width (Bent 1963, Whitaker and Eaton 2014). Eaton (2014) reports that after egg laying only the female incubates, sometimes for periods of 30 minutes on, 10 minutes off from 09:50 to 19:30, for approximately 12 days.

Young are able to leave the nest at nine days old before they can fly. For 2-3 days they will hide in dense vegetation and are able to fly approximately eight days after leaving the nest. They continue to be cared for by both adults for approximately four weeks after hatching. By 30 days old, they are indistinguishable from adults and can breed during their first spring after fledging (Wilson et al. 2012, Whitaker and Eaton 2014).

Little research has been done on dispersal/site fidelity of hatch-year individuals, but a study conducted in Newfoundland found that 7/103 individuals were re-sighted or recaptured in subsequent years. However, this remains the only study of this type and encounter effort was uneven so it may not accurately reflect dispersal patterns (Whitaker and Eaton 2014). The impression is that site fidelity is relatively high (as is the case with LOWA, especially males), but more studies need to be conducted to determine fidelity accurately.

A study in Newfoundland found that 16.3% of 141 individuals banded returned to their previous breeding territory. This number was biased towards males because song playbacks were used during the surveys and most of the individuals sighted were males. During the last few years of the study, it was found that 75% of 20 individuals banded were observed for 3 years (Whitaker and Eaton 2014). In their wintering range, they appear to have high site fidelity as well. One study in Costa Rica found individuals returning up to five years after they were first banded and individuals in better condition were more likely to return to the same site (Whitaker and Eaton 2014).

The oldest recorded NOWA was 8 years and 11 months old (Klimkiewicz and Futcher 1989). The average annual survival rate on the breeding grounds is very high (64%) but this drops in the northeast where the regional survival rate is 46%. Most of the losses appear to occur on the wintering grounds where the survival rate can be as low as 37% in Panama, Costa Rica, and Mexico (Saracco et al. 2008). Many of these losses are attributed to hurricanes and other storms that are encountered during migration and on wintering grounds. This pattern, where most losses occur during migration and wintering, is typical for neotropical migrants (Saracco et al. 2008, Whitaker and Eaton 2014). The Mayfield estimate for survival rate of nests during incubation is 50.4% but increases during the nesting stage to 90.3% for an overall survival rate of 45.5% (Warkentin et al. 2003, Whitaker and Eaton 2014). It is believed that nesting success is most affected by how well a nest is concealed early in the breeding season before leaf-out when nests are most vulnerable (Warkentin et al. 2003, Whitaker and Eaton 2014). There is very little data on predation of NOWA. However, their ground nesting habit makes this species vulnerable to snakes. In one study, a ribbon snake (*Thamnophis sauritus*) was seen eating a nestling in Washington Co., RI (Whitaker and Eaton 2014).

NOWA can be recognized on their breeding grounds by a very distinct, 3-parted song commonly represented as *sweet sweet sweet swee wee wee chew chew chew chew* (Bent 1963, Brown 1975, Whitaker and Eaton 2014). Brown (1975) examined 139 NOWA individuals and 158 recordings and found that, while there is variation in song type, this song was heard from 76.92% of the individuals examined. Other variations are a 2-parted song (2.31%), 4-parted song (16.15%), and 5-parted song (2.31%) (Brown 1975). One example of these variations can be reproduced as *chWhitt chWhit chWhit whit whit whit tcheew* or *chit chit chit chit chit weeOoo weeOoo weeOoo chblit* where the first two parts have distinct syllables and the final part is shortened (Bent 1963, Brown 1975, Whitaker and Eaton 2014). While establishing territories, males will sing from perches that can vary from 8-15 m in height in more dense areas to canopy height in more open habitats (Brown 1975, Whitaker and Eaton 2014). After establishing territories singing will decline throughout the season. While these songs are most often heard on the breeding ground, they can occur on occasion on the wintering grounds as well as is also the case with LOWA (Whitaker and Eaton 2014, T. Master, pers. comm.).

The flight song of NOWA is a sharp, loud *chip* that can be intermixed with jumbled and truncated song notes. Subdued songs can also be heard from non-territorial males and from territorial males while the female is incubating (Whitaker and Eaton 2014). The call note of a NOWA is a sharp and steely *chick* and is given throughout the year on both the breeding, migratory and wintering grounds (Whitaker and Eaton 2014).

Conservation and Management

Pennsylvania Breeding Bird Atlas (PBBA) surveys were conducted by thousands of volunteers searching nearly 5,000 atlas blocks in Pennsylvania for various levels of breeding evidence for species observed in each block. Fieldwork for the first atlas took place between 1983 and 1989 and for the second atlas from 2004 to 2009, 20 years later. The atlases utilized the "block" as their survey unit which was defined as "one-sixth of a standard U.S. Geological Survey 7.5-minute topographic map" (Wilson et al. 2012). This allowed them to cover the state in a coordinated and organized fashion. Blocks were 24.8 km^2 (9.6 mi^2) in extent. Effort was greater during the second atlas for a variety of reasons, thus, results from the second atlas had to be adjusted to take into account the change in effort between the two atlases (Wilson et al. 2012).

Based on USGS Breeding Bird (BBS) routes, NOWA have shown an increase of 0.9% per year from 1966 to 2011 across their entire range (Sauer et al. 2013, Whitaker and Eaton 2014). In Pennsylvania, a 40.7% decline in block occupancy for NOWA occurred between atlas periods, one of the largest declines of any Pennsylvania breeding species (Brauning 1992, Wilson et al. 2012). Although all blocks were surveyed during the first atlas, effort, as mentioned above, was more extensive during the second atlas, which lends credence to the veracity of the decline. Due to NOWA habitat preference, several potential stressors may be affecting their abundance and distribution including habitat degradation and destruction, vegetative succession, hemlock decline due to woolly adelgid (*Adelges tsugae*) (HWA) infestation, and climate change. The 2nd PBBA reported a range contraction to the north that appeared to be altitudinally driven (Wilson et al. 2012). The southern edge of their overall range moved north 1 km and the northern edge moved south by 21 km (probably from the loss of low elevation sites) between the two atlases (Wilson et al. 2012). The blocks that remain occupied were more northerly and/or higher which implicates climate change as a possible cause. Other biotic and abiotic factors that may affect NOWA conservation status will need to be investigated to assess all possible causes for the decline. Isolating, analyzing and extrapolating these factors across wetlands will provide a basis for understanding the species' range dynamics and predicting future impacts on population abundance and distribution.

The major threats to NOWA, as listed in the Pennsylvania Wildlife Action Plan, are habitat loss due to forest fragmentation and hydrological changes associated with this development and perhaps with climate change as well (PGC-PFBC 2015). Yahner (2003) showed that 97% of wetland and riparian species in Pennsylvania were restricted in their distribution because of scarcity of their habitats. This study determined that habitat loss or degradation in wetland and riparian habitats affected up to 64.5% of species that reside in these habitats (Yahner 2003). Between 1956 and 1979, Pennsylvania averaged a loss of 1,200 acres of vegetated wetlands per year (Tiner 1990).

The main goal of the Pennsylvania Wildlife Action Plan is to increase the population by 10% in at least 250 breeding bird atlas blocks. This will be accomplished by establishing better management practices and acquiring land and water rights and protections for suitable habitat (PGC-PFBC 2015). However, there is a more pressing threat on its wintering grounds where preferred habitat, mangrove swamps, are cut down and drained for fuel, space, and food (NatureServe 2017). Even with these imminent threats, the population seems stable and has even shown a slight increase in certain areas across their entire range (Whitaker and Eaton 2014, NatureServe 2017).

Wetlands

Importance of Wetlands

Wetlands are one of the most productive ecosystems in the world and offer a variety of services that can’t be easily replaced. The productivity of wetlands is tied to a unique set of characteristics that they share including shallow water, high levels of nutrients, and high levels of primary productivity (Flynn 1996). This primary productivity is due to the unusually high efficiency that wetland plants have for converting sunlight, nutrients, and water into biomass (Flynn 1996). Wetlands also provide services such as water quality improvement, flood protection, and shoreline erosion control (Hemond and Benoit 1988, Sheehan and Master 2010, United States Environmental Protection Agency 2018). More than one-third of threatened and endangered species in the U.S. are endemic to wetlands and approximately half use wetlands during at least a part of their life cycle (United States Environmental Protection Agency 2018).

Status of Pennsylvania Wetlands

Wetlands are not easily defined, and the definitions vary greatly. The most widely accepted definition is "areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions" (Cowardin et al. 1979, Pennsylvania Department of Environmental Protection 2014). Wetland classification depends on three environmental components including hydrology, hydric soils, and obligate or facultative hydrophytic vegetation. At least two of these three factors must be present for an area to be legally considered a wetland (Cowardin et al. 1979, Tiner 1990).

Approximately 95% of the 44.6 million ha (110.1 million acres) of wetlands in the conterminous U.S. are freshwater wetlands. This translates to 42.2 million ha of freshwater wetlands (Dahl 2011). Wetlands have been in decline for centuries, but in recent years this decline has slowed from 185,346 ha per year between 1954 and 1970 to 5,590 ha per year between 2004 and 2009 with most of the loss being due to silviculture (124,376 ha lost from 2004-2009) (Dahl 2011). Loss of freshwater vegetation has declined as well by about 50% since the 1950s. There were 256,320 ha of forested wetlands lost between 2004 and 2009. Most of this loss was due to clear-cutting associated with silviculture, converting forested wetlands to other wetland types (Dahl 2011). However, this is a much slower rate of loss than occurred in the 1950-1970s when almost 2,428,113 ha were lost resulting in the greatest loss of forested wetlands in the U.S. (Tiner and Finn 1986, Dahl 2011).

Pennsylvania wetlands have been disappearing since European colonization. It is estimated that Pennsylvania, prior to colonization, had approximately 1,127,000 ha of wetlands of which only 403,924 acres remain, a loss of about 56% of the original wetlands (Tiner 1990, Pennsylvania Department of Environmental Protection 2014). More recently, between 1956 and 1979, Pennsylvania lost 11,331 ha, or six percent of its vegetated wetlands. This loss is attributed to conversion to other wetland types through human-induced changes (Tiner and Finn 1986). Almost 1/3 of this loss took place in the northeastern portion of the state with the heaviest losses occurring in the northern Pocono region (2,144 ha) (Tiner and Finn 1986).

Currently, 1.4% of the state is still covered by wetlands and most of these (~40%) are found in the glaciated northeastern and northwestern corners of the state. Pike and Monroe counties have the highest proportion of wetland area within their boundaries of any Pennsylvania county with the estimates of 6.7% and 6.4% of their total area respectively (Tiner 1990).

Approximately 97% (392,728 acres) are freshwater wetlands. Deciduous forested wetlands compose 36% of the total palustrine wetlands followed by about 15% open water, 13% emergent, and 12% shrub wetlands with the remainder a mix of these groups (Tiner 1990). These wetlands are found at approximately 160,000 sites which indicates that most are small and isolated. Cowardin et al. (1979) defines these as “nontidal wetlands that are dominated by trees, shrubs, persistent emergents, emergent mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5%". These wetlands can be divided into categories such as marshes, swamps, bogs, fens, and prairies depending mainly on hydrology, pH and vegetation structure (Cowardin et al. 1979, Zimmerman et al. 2012) .

The three greatest threats to wetlands in Pennsylvania are loss, fragmentation, and degradation. One of the biggest factors contributing to these problems is urbanization. Degradation can occur in a variety of ways including pollution, improper management by land owners (e.g., mowing and cutting), and invasion by exotic species (Zimmerman et al. 2012, PGC-PFBC 2015). Pennsylvania is ranked as the 2th highest state for total sprawl (the amount of rural land lost to development) estimated at 341 square miles from 2002 to 2010. When the states were ranked based on their sprawl from 1982 to 2010, Pennsylvania jumped to 6th with a total sprawl of 2,529 square miles showing that the rate cities are expanding in Pennsylvania has slowed in recent years compared to other states (Kolankiewicz, Beck, and Manetas 2014).

Climate Change

Global Trend

Scientists have recorded a global change in the mean surface air temperature of 0.9 ºC (1.62 ºF) since the nineteenth century (NASA Jet Propulsion Laboratory 2018). In Pennsylvania, the increase is greater than 1º C in the past 110 years with anthropogenic factors being the major cause (DCNR 2015). The greatest seasonal warming over land has been observed in the northern hemisphere during the winter and spring seasons. The maximum spring temperatures in the northern hemisphere have increased 1.1 degrees ºC between 1954 and 2004 (Hitch and Leberg 2007).

Avian Range Shifts

Hitch and Leberg (2007) showed that the northern range margins of breeding birds in North America have been shifting northward over recent decades. They concluded that some of this movement may be due to other factors, but it is difficult to explain the drastic shift of so many species without invoking some discussion of climate change. In this same study, NOWA had a mean shift north of 9.28 ± 42.67 km/yr. This study is consistent with the results of Thomas and Lennon (1999) who did a similar study in Great Britain on multiple species of birds.

Langham et al. (2015) predicted that there will be drastic changes in the breeding ranges of many birds. Peak areas of loss will be along the U.S. - Canadian border, which is composed mainly of eastern deciduous forests, prairie potholes, and where the high elevations of the Rockies and Cascade ranges occur. This is because this area could gain as many as 80 species and lose up to 69 species due to breeding range shifts as the average global temperature increases (Langham et al. 2015). Plants and animals have already begun a migration to higher elevations at a rate of 36 ft/decade and they have been moving to higher latitudes at a rate of 10.5 mi/decade (Groffman et al. 2017). Pounds et al. (1999) demonstrated an increase in elevation of bird ranges from climate change in Monteverde Cloud Forest in Costa Rica.

The model made by Langham et al. (2015) predicted that climate change will tend to push species toward higher elevations through the end of the century although many species are still projected to move downslope which emphasizes the importance of looking at how individual species respond (Langham et al. 2015). This downslope shift could be caused by a variety of factors. Lenoir et al. (2010) examined multiple studies that showed a downslope shift and found that it could be due to less competition, disturbance, habitat modification or a combination of other environmental factors that have been overlooked.

The Pennsylvania Ornithology Technical Committee (part of the Pennsylvania Biological Survey) climate change survey states that the first species to respond to climate change are wetland species that have a southern range limit in Pennsylvania and prefer high elevation/cooler microclimates (Pennsylvania Biological Survey Technical Committee 2013). Due to NOWA's preference for both northerly breeding grounds and higher elevations, it is a species likely to be affected by climate change, especially in Pennsylvania, which is at the extreme southern limit of its breeding range in the eastern half of the state (Wilson et al. 2012).

NOWA was used as a flagship species by Sneddon and Hammerson (2014) in the climate change vulnerability assessments of selected species in the North Atlantic Landscape Conservation Corporation (LCC) region. They were used to represent species at the southern edge of their range in the region. This plan listed NOWA as moderately vulnerable in the mid-Atlantic states because it is already at the edge of its range and there is a predicted loss in its preferred habitat, both potentially exacerbated by climate change (Sneddon and Hammerson 2014). The Pennsylvania Wildlife Action Plan (2015) states that NOWA are expected to have a drastic suitable habitat reduction of up to 70% within the state (PGC-PFBC 2015).

Project Rationale

The general objectives of this study are: (1) to refine the accuracy of the second PBBA with regard to NOWA distribution in the three-county study area, (2) characterize NOWA habitat with regard to avian community, vegetative and hydrological conditions by comparing occupied and unoccupied but apparently suitable sites, (3) investigate the cause(s) of decline between the first and second PBBA with emphasis on what climate change data can tell us about atlas block occupancy patterns between the 1^{st} and 2^{nd} atlas and between both atlases and this study, and (4) gather natural history information on this understudied species.

These goals translate to the following working hypotheses: (1) atlas block occupancy will be higher than reported in the 2^{nd} PBBA, (2) there will be distinctive and measurable differences in avian community composition, vegetation parameters, and physical characteristics between occupied and unoccupied territories in apparently suitable habitat, and (3) changes in NOWA block occupancy patterns, both between the 1^{st} and 2^{nd} atlas and between both atlases and this study, will reflect the effects of climate change with regard to the elevation and northerly progression of currently occupied blocks.

CHAPTER II

Methods

Study Sites

This study was conducted in Northampton, Monroe, and Pike counties which encompass most of the core breeding range of NOWA in northeastern Pennsylvania. Within these counties, as many sizeable hemlock/rhododendron swamps as possible were located by comparing eBird® hotspots, the 2nd PBBA, topographical maps and digital maps with Quantum GIS® version 2.18.21 with GRASS 7.4.1 (QGIS Development Team, open source). Most wetlands were already named on maps but if not, they were named based on the road nearest to the site.

Mapping

A study site map was made with digital elevation models (DEM) with 1/3 arc-second resolution (United States Geological Survey 2017) for Pike, Monroe, and Northampton counties using the Hillshade tool in QGIS® (QGIS Development Team, open source) to create a 3D layer and overlaying a DEM of each county that was classified based on elevation and color coded accordingly (United States Geological Society 2018). Atlas block coordinates were available from atlas coordinators. A map of

Pennsylvania hydrology (United States Fish and Wildlife Service 2016) was also added after sorting out only the forested swamps, the preferred habitat of NOWA, from the dataset.

Pennsylvania Breeding Bird Atlas

Occupied (territorial) blocks from the 1st PBBA (1984-1989) were compared to those from the 2nd PBBA (2004-2009) (Figure 7) to determine elevation and/or latitudinal shifts over the intervening period between atlas efforts (Wilson et al. 2012). Data from both sets of atlas blocks were also compared in a similar manner to that collected during this project (Wilson et al. 2012).

In the PBBAs, the blocks were classified into one of four breeding code categories. These utilized safe dates and breeding behaviors defined by the atlas (Table 1). The first category, “Observed”, requires the least amount of effort and is when a bird is seen or heard during the safe dates. The second category, “Possible”, is when a species is observed in suitable habitat, within the safe dates but not exhibiting any breeding behaviors. The third category, “Probable”, is the same as Possible except breeding behaviors are observed. The last category, “Confirmed”, is used for birds exhibiting more definitive breeding behaviors (Wilson et al. 2012). Thus, these categories define the level of confidence for breeding within a block in the two atlases. Only Probable and Confirmed blocks were used in all analyses because of their more robust indication of breeding.

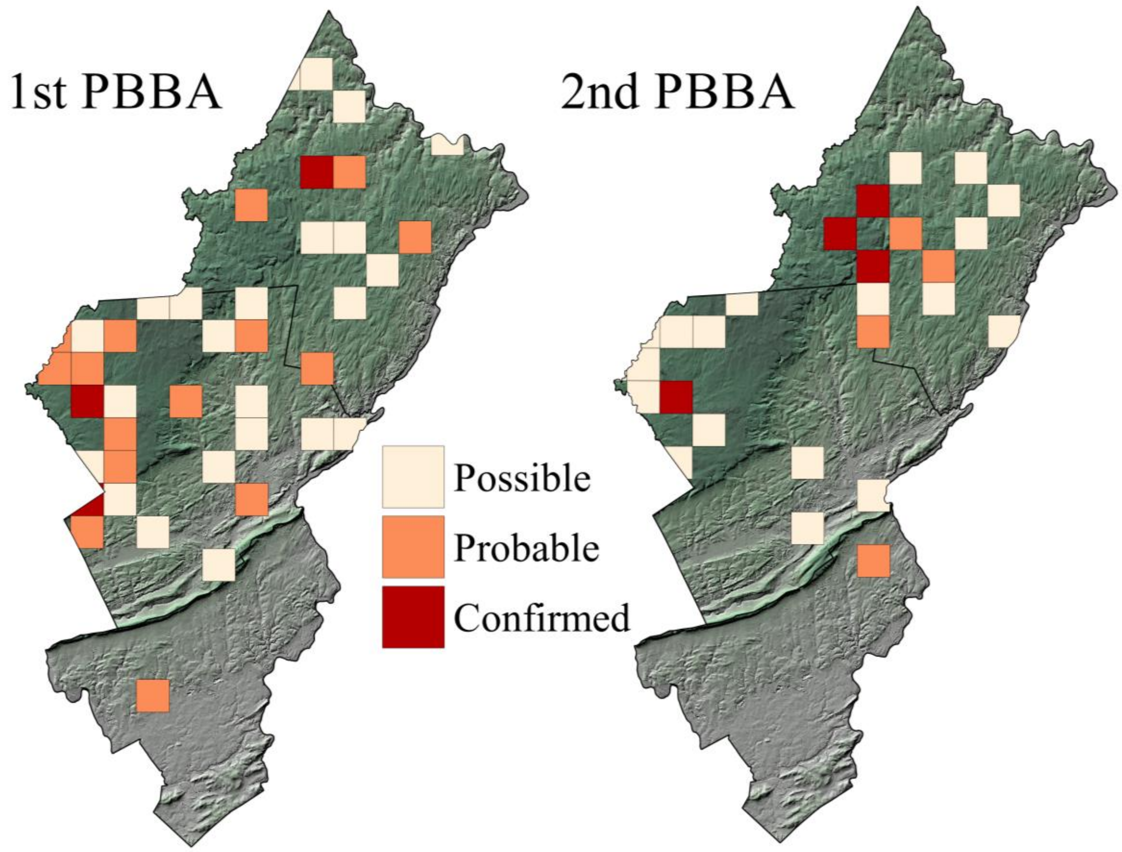


Figure 7. Confirmed and probable blocks for NOWA in 1st and 2nd PBBA.

Table 1. Classification of blocks during the 1st and 2nd PBBA.

Classification	Category	Behavior
Probable	Pair	Pair seen in close proximity and/or interacting non-aggressively
	Territorial Behavior	Counter-singing, aggressive interactions between same sex individuals, singing male in the same location on visits separated by 5 days or more
	Ritualized Courtship	Aerial displays, courtship, etc. or copulation observed
	Used Nest	Only species with unique nests
	Agitated	Anxiety calls or agitated behavior due to observer or predator presence
Confirmed	Carrying Nest Material	Adult carrying nesting materials
	Physical Evidence of Breeding Condition	Observed for birds in hand, specifically brood patch and/or visibly gravid condition
	Nest Building	Adult observed building a nest
	Distraction Display	Especially injury feigning or apparent direct defense of unobserved nest/young
	Recently Fledged Young	Recently fledged young observed with an adult
	Adult Carrying Food or Fecal Sac	Adult carrying food or a fecal sac
	Adult Feeding Fledged Young	Adult seen feeding fledged young
	Nest Containing Eggs	Nest of species was found containing eggs
	Occupied Nest	Occupied nest found but contents are not known because adults are on the nest or the nest placement prevents examination of the nest
	Nest Containing Young	Nest of species found containing young

Vegetation Surveys and Analyses

Vegetative surveys were conducted using a modified BBird Protocol (Martin et al. 1997) from the last week of June to the third week of July in 2017 and 2018 to minimize disturbance during the point count/nesting period (see below). Vegetative parameters measured included canopy coverage measured using a densiometer (%), shrub and herbaceous plant coverage (%) (subjective, estimated from shore due to the difficulty of navigating through the swamps), tree and shrub height measured using a clinometer (m), and the number of tree throws or root overturns within sight from the nest or dominate song perch. Trees were defined as any woody plants that originated from one stem and shrubs as woody plants that arose from multiple stems. Herbaceous plants were defined as herbaceous plants that grew in or near the edge of the water. These include both emergent and submergent plants that are rooted in the substrate (Cowardin et al. 1979, Texas A&M 2018).

During vegetation surveys, the percent coverage (subjective, visual estimate for each group) of all tree, shrub, and herbaceous plants was recorded within a 10 m diameter circle of the point count location. The coverage of categories could total more than 100% because categorical overlap in coverage can occur. A timed meander search procedure, defined as when a meandering path is followed within a designated field unit and every species encountered is recorded, was used to record the species present in each designated plant group. The transect may meander in any way as long as it covers all unique habitats in the area (Goff et al. 1982). An hour was spent at each site recording every plant group present and the percent coverage each species contributed to the overall coverage. This method was selected because of the difficulty associated with moving through swamps. Cynthia (2007) found that it was the most accurate method at representing species present at each site but, due to observer bias, was not necessarily the best measure of abundance.

Canopy cover was measured with a spherical densiometer model-C (Forest Densiometers, Barlesville, OK). A reading was taken at each cardinal direction from as close to the dominant song perch as possible by counting the number of equidistant dots within the etched squares on the densiometer that were not covered by vegetation and multiplying by 1.04 for the percent of sky not occupied by forest canopy. This number was then subtracted from 100 to get canopy coverage (%). The mean of the four measurements was taken to determine the average percent canopy coverage in each swamp.

Tree height was measured with a Suunto® Tandem clinometer. A meter tape was used to measure the distance to the tree from the observer and the clinometer was pointed to the apex of the tree and the angle (%) recorded. Shrub height was measured using a visual estimate. The angle was then multiplied by the distance to the tree and the observer's height in meters added to get the total tree height (m).

Ordinations were used to visualize the differences between occupied and unoccupied sites for the overall plant communities and subsets (all plants, trees, shrubs, herbaceous plants) using non-metric multidimensional scaling (NMDS) in the R package vegan (Oksanen et al. 2018). An ordination is a multivariate analysis where sites are plotted in three dimensions based on a predetermined set of characteristics with the distance between points indicating how similar or dissimilar two sites are. (Goodall 1954, Gotelli and Ellison 2013). A separate NDMS was done with only presence/absence data for each of the four groups (all plants, trees, shrubs, and herbaceous vegetation). NMDS ordinations used Bray-Curtis dissimilarity for abundances and presence/absence analyses. The Bray-Curtis dissimilarity is a measure of distance or dissimilarity that is most often used for continuous numerical data (Gotelli and Ellison 2013).

Differences in plant community composition between the two types of sites were assessed using analysis of similarities (ANOSIM) in the R package vegan (Oksanen et al. 2018) to complement the NMDS visualization. Similarity percentages (SIMPER) in the R package vegan (Clarke 1993, Oksanen et al. 2018) was used to determine which taxa contributed most to overall dissimilarity between the groups. SIMPER is a tool developed by Clarke (1993) that determines what percentage that each species contributes to the overall Bray-Curtis dissimilarity. Warton et al. (2012) found that SIMPER may confound the mean between groups and within group variation and can single out variable species instead of distinctive species. Therefore, I verified the SIMPER results using the multivariate ANOVA technique described in Warton et al. (2012).

Canopy cover, shrub cover, and herbaceous plant cover were compared between occupied and unoccupied sites with an ANOVA. The Shannon-Weaver Index was calculated to describe plant diversity at each site. Shannon-Weaver Index is defined in this case as $H = \sum_i^s p_i \ln(b)\, p_i$, where s is the species richness, p_i is the proportion abundance of species i , and b is the base of the logarithm.

Physical Parameters and Analyses

Physical parameters, including elevation (m) and area (m^2), which were determined using GIS, as well as mean water depth (cm), were compared between occupied and unoccupied blocks. Wetland size data was taken from the National Wetland Inventory (2017). Total wetland area was divided into forested and scrub-shrub wetlands. The area of these two wetland types was compared between occupied and unoccupied sites using an analysis of variance (ANOVA) as was the total wetland area.

PBBA blocks were classified as gained (1st unoccupied, 2nd occupied), lost (1st occupied, 2nd unoccupied), or unchanged (remains occupied or remains unoccupied) from the 1st to the 2nd PBBA. The zonal statistics tool in QGIS® was used to determine the mean elevation for atlas blocks and the elevations among groups were then compared using an ANOVA. Occupied and unoccupied site elevations from this field season were compared using an ANOVA.

Spatial distribution of occupied blocks in this study was compared to the distribution of 2nd PBBA block locations to estimate the degree to which the species was under or over-counted during the atlas effort. Comparison of currently occupied atlas blocks from my field work to those occupied in both the 1st and 2nd PBBA will provide the opportunity to determine if there has been a noticeable northward and/or elevational range shift in block occupancy.

Wetland size and water depth were also compared between occupied and unoccupied field sites. Wetland size was determined using data from the National

Wetland Inventory (2017) and compared using an ANOVA. Water depth was gathered during the field season and analyzed using an ANOVA.

Avian Point Counts and Analyses

A preliminary search of wetlands within the study area was done in the first three weeks of May in both years to determine what swamps were suitable habitat (a forested wetland with an understory of shrubs) for NOWA. Two variable circular plot point counts were conducted at each swamp within suitable habitat during the height of the breeding season within the safe dates (last week of May to the first week of July) for most breeding species as determined from the 2nd PBBA. Point counts were conducted from 6:00 AM to 10:00 AM during the period of most singing activity but sites were visited until 12:00 PM to determine occupancy. All sites were visited once during the first round of point counts before being visited a second time for the second round.

Sites were classified as occupied if a NOWA was seen or heard within the safe dates and a site was classified as unoccupied if there was no evidence of a NOWA within the safe dates. Sites were considered occupied if a NOWA was present in at least two visits. In occupied sites, plot center points were located as close to the dominant male song perch as possible. In unoccupied sites, plot centers were located in an area determined as the most suitable habitat in the swamp. These counts recorded any bird species, using American Ornithology Society (AOS) codes (Matsuoka et al. 2014), heard or seen each minute during a ten-minute count period. Any species heard that were greater than seventy-five meters away were noted as distant observations. Lynch (1995) found that 55 percent and 82 percent of species were detected within the first 5 to 10 min of a point count, respectively, regardless of what time of morning a point count was conducted. Using a slightly longer count of 10 minutes rather than 5 minutes also increases the detectability of more cryptic species such as NOWA (Lynch 1995).

Counts were performed following a 5-minute acclimation period during which environmental data (including sky condition, precipitation and wind speed as determined subjectively by observer), temperature and noise level (using the Beaufort scale) were recorded to characterize survey conditions. To increase the certainty that a site was unoccupied, song playback was used in an attempt to elicit a response by any male in the area when determining occupancy (playback was not used for point counts). This has been shown to substantially increase detectability of species that vocalize infrequently (Lynch 1995).

Species richness was determined by pooling the data from all visits during the field season for a complete list of all species detected at each field site for 2017 and 2018 separately (Sheehan and Master 2010). The Shannon-Weaver Index was used for this calculation because of its emphasis on evenness among species (Shannon 1948). Frequency of occurrence was determined for each species by dividing the number of sites a species was found at by the total number of sites surveyed for 2017 and 2018 separately (Sheehan and Master 2010). All statistical analyses were done using R (R Core Team 2017).

Ordinations were used to visualize any differences in the avian community between occupied and unoccupied sites. NMDS was used to visualize the differences between NOWA-occupied and unoccupied sites in the abundance and presence/absence of bird species. This was repeated for a subset of the data excluding all species heard farther than seventy-five meters away, and for presence/absence rather than abundance data (again excluding the distant species).

An ANOSIM was performed on the two groups to statistically test for differences between occupied and unoccupied sites to complement the NMDS visualization. SIMPER was used to determine which taxa contributed the most to the dissimilarity seen between the two groups (Clarke 1993). The method described by Warton et al. (2012) was used to confirm SIMPER results. Only 2018 data was used to compare occupied and unoccupied sites because all sites in 2017 were visited again in 2018, although locations differed slightly as NOWA territories were not in the exact same location at the swamp.

Nest Searching

Singing males were located by a combination of auditory and visual surveying. Once singing males were located, each individual was observed and audio playback used as needed to determine the territorial boundary of the pair. Pair movements were observed to attempt to determine the location of nests with careful attention paid to any nesting material or food being brought to a specific location. Nest locations, if found, were recorded with a handheld Garmin® 60cxs GPS unit (Garmin, Olathe, KS)., and GPS-mapped using QGIS®.

Climate Change and Analyses

Climate NA v5.21 (Wang et al. 2016) was used to gather average, maximum, and minimum temperatures as well as precipitation data for the decades during which the two PBBAs were conducted (1980-1990 and 2000-2010). Block centroids were used as the location and average elevation for each of the blocks for PBBA comparisons. Field site location and elevations were used for field site comparisons. Only temperature and precipitation data from the breeding months (May – July) were used because they are the months when the arrival and breeding of migratory species such as NOWA would be most affected (Virkkala et al. 2018). Change in maximum, minimum, and average temperature as well as average temperature were calculated between the two atlas periods for both field sites and PBBA block centroids. Occupied and unoccupied field sites were then compared for each of the climate indices using an ANOVA.

PBBA blocks were categorized into three groups: blocks that had no change, blocks that were gained in the second atlas, or blocks that were lost in the second atlas. A gain was classified as moving from observed or possible in the 1st atlas to probable or confirmed in the 2nd atlas. A loss was classified as going from probable or confirmed in the 1st atlas to possible or observed in the 2nd atlas. A change from probable to confirmed or possible to observed and vice versa were both classified as unchanged. These categories were chosen because probable and confirmed represent both the most effort and hence highest probability of being accurate with respect to occupancy. These categories were also more likely to be truly occupied sites in either of the atlases. Changes in climate indices were then compared using an ANOVA for each of these three categories.

Shifts in latitude between the 1st and 2nd PBBA were also calculated. This was done using the same method as Thomas and Lennon (1999). Mean latitudes for the ten northernmost and ten southernmost atlas blocks were calculated for both the first and second atlas. Distances were then calculated between mean latitudes of the centroids of northernmost and southernmost blocks.

CHAPTER III

Results

Study Sites

Fifty-three wetlands identified as having appropriate habitat were surveyed during the current project in Northampton, Monroe and Pike counties in northeastern Pennsylvania. Thirty-five of these were occupied with NOWA and 18 were unoccupied. Thirteen of these sites were identified during the 2017 field season and the other 40 were identified during the 2018 field season (Figure 8). Together, these sites covered all PBBA blocks that were classified as either probable or confirmed (26) in both atlases except five due to inaccessibility or lack of suitable habitat (Appendix I). Of the PBBA blocks surveyed during this study, I found 22 that were occupied (85% of probable and confirmed). Three of these overlapped confirmed (breeding) atlas blocks, 9 overlapped probable atlas blocks, 5 overlapped possible blocks, and 5 were entirely new blocks.

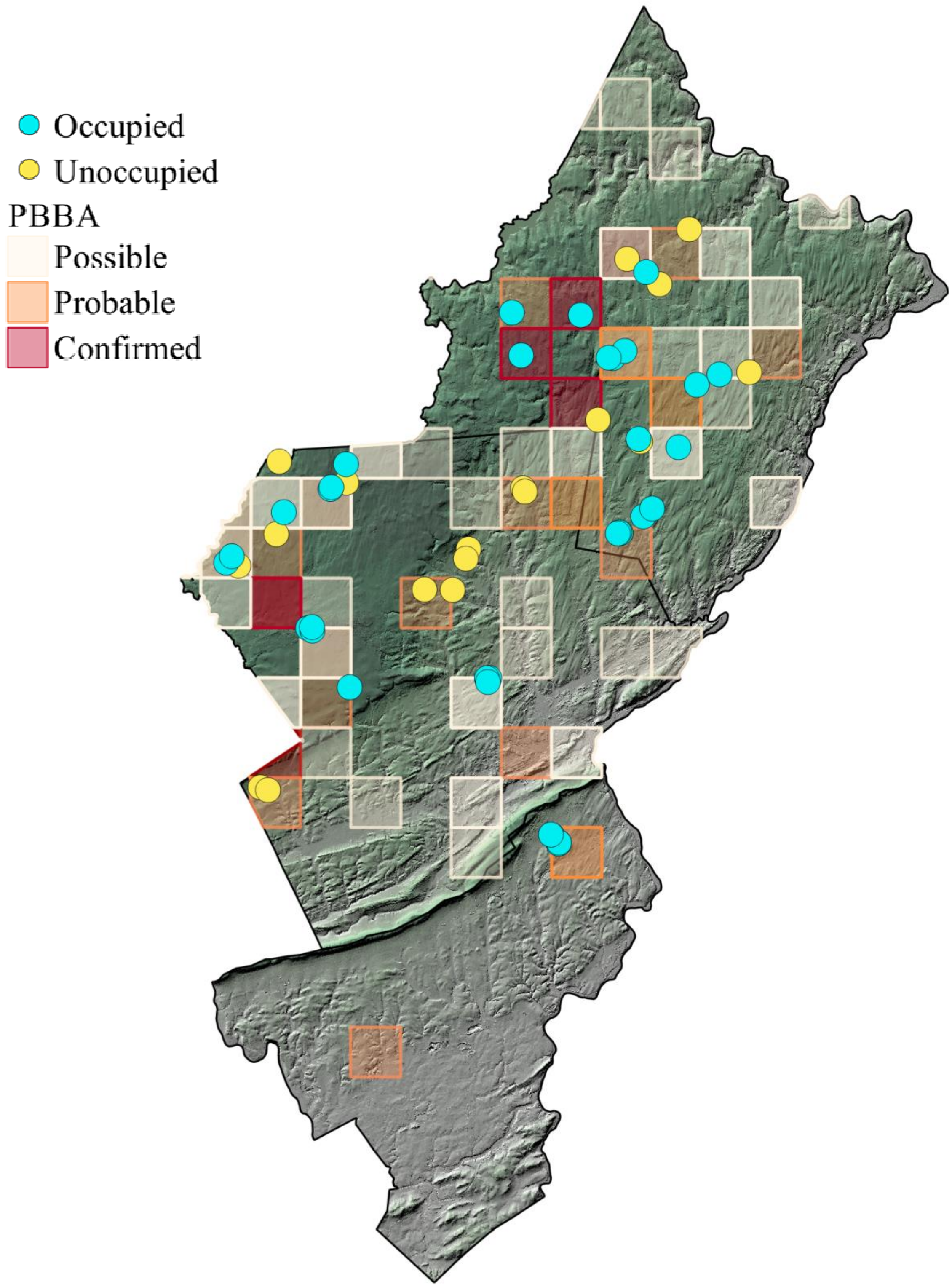


Figure 8. Study sites and PBBA blocks from both atlases covered during the 2017 and 2018 field season.

Vegetation Analysis

Across both field seasons, a total of 93 plant species were counted with 82 species at occupied sites and 61 species at unoccupied sites (Appendix II). Plant species richness in occupied sites was 14.32 ± 0.64 (mean SE), while it was 11.29 ± 0.75 in unoccupied sites (Appendix III). Tree species richness at occupied sites was 3.73 ± 0.25, while it was 3.53 ± 0.34 at unoccupied sites (Appendix III). Shrub species richness was 2.50 ± 0.15 at occupied sites and 1.76 ± 0.26 at unoccupied sites. Herbaceous plant richness was 8.00 ± 0.47 in occupied sites and 6.00 ± 0.46 in unoccupied sites (Appendix III).

The Shannon Diversity Index for the occupied sites ranged from 2.76 (Turner Swamp 2) to 1.78 (Lost Lakes – Lake 1) (Table 2) while the unoccupied sites ranged from 2.59 (Ice Lake) to 1.62 (Plank Road) (Table 3) (Appendix IV). Shannon Diversity between occupied and unoccupied sites was significantly different (ANOVA, df = 1, 49, F = 9.13, $p = 0.004$).

Table 2. Top 10 vegetation Shannon diversity indices for all 2018 field sites (mean of occupied sites = 2.29 ± 0.05)

Site	**Shannon Index**	**County**
Turner Swamp 2	2.76	Pike
Whitaker Farm Road 2	2.72	Pike
Turner Swamp	2.70	Pike
Grass Lake	2.69	Monroe
Bear Swamp 2	2.66	Northampton
Painter Swamp	2.58	Pike
Turner Swamp 3	2.53	Pike
Cranberry Bog – Boardwalk	2.50	Monroe
Cranberry Bog – Parking Lot 2	2.49	Monroe
Brady’s Lake	2.49	Monroe

Table 3. Top 10 vegetation Shannon diversity indices for unoccupied field sites (mean of unoccupied sites = 2.05 ± 0.07).

Site	Shannon Index	County
Ice Lake	2.59	Monroe
Beaver Run	2.35	Pike
Tobyhanna Road	2.31	Monroe
Merry Hill Wet Meadow	2.30	Monroe
Brady's Lake – Parking Lot	2.28	Monroe
Shohola Swamp	2.22	Pike
Grange Road	2.11	Monroe
Hell Hollow 2	2.11	Monroe
Dwarfskill	2.07	Pike
Hemlock Way	2.07	Monroe

The most frequently encountered species at occupied sites were red maple (*Acer rubrum*) (100%), sphagnum moss (*Sphagnum* sp.) (85%), and high-bush blueberry (*Vaccinium corymbosum*) (79%) while 25 different species were tied for least frequent being observed in only 3% of the field sites (Appendix V). The most frequent species encountered at unoccupied sites were red maple (94%), sphagnum moss (76%), and high-bush blueberry (76%), and sedges (*Carex* sp.) (76%). There were 30 species tied for least frequent, found in only 6% of the unoccupied sites (Appendix V).

Mean percent canopy coverage between occupied and unoccupied sites was not significantly different (ANOVA, df = 1, 49, F = 1.21, $p = 0.28$) with occupied sites averaging 88% ± 0.02 and unoccupied sites 83% ± 0.05. Mean percent shrub coverage also was not significantly different (ANOVA, df = 1, 49, F = 0.86, p = 0.36). The mean shrub coverage for occupied sites was 54% ± 0.04 and for unoccupied sites was 46% ± 0.06. Herbaceous plant coverage was also not significantly different (ANOVA, df = 1, 49, F = 1.62, p = 0.21). The mean herbaceous plant coverage for occupied sites was 78% ± 0.03 and 70% ± 0.06 for unoccupied sites. (Table 4).

The mean tree height for occupied sites was 16.56 m ± 1.05 and for unoccupied sites was 16.57 m ± 1.08; there was no significant difference between the two (ANOVA, df = 1, 49, F = 0, p = 1.00). Mean shrub height for occupied sites was 2.72 m ± 0.08 and 2.31 m ± 0.09 for unoccupied sites and it was significantly different between the two (ANOVA, df = 1, 49, F = 10.08, p = 0.0026). The mean number of root overturns for occupied sites was 2.64 ± 0.32 and for unoccupied sites was 1.06 ± 0.35. The ANOVA revealed that there was a significant difference between the two site types (ANOVA, df = 1, 49, F = 9.55, p = 0.0033) (Table 4).

Table 4. Mean vegetative parameters of occupied and unoccupied sites (asterisk indicates significant differences).

Vegetative Structure	**Occupied**	**Unoccupied**
Canopy Coverage (percent)	0.88	0.83
Shrub Coverage (percent)	0.54	0.46
Herbaceous Plant Coverage (percent)	0.78	0.70
Tree Height (m)	16.56	16.57
*Shrub Height (m)	2.72	2.31
*Root Overturns	2.64	1.06

Twenty-six species of trees, 15 species of shrub, and 52 species of herbaceous plants were identified across all field sites for both field seasons (Appendix II). The overall plant community was significantly different between occupied and unoccupied sites. An ANOSIM on the abundance of each species present at occupied and unoccupied sites revealed a significant difference (ANOSIM, R = 0.14, p = 0.02). Presence/absence of species across both site types also revealed a significant difference (ANOSIM, R = 0.14, p = 0.03) (Figure 9).

The ANOSIM on trees revealed no significant difference for either the number of individuals of each species or the presence/absence of each species between the two site types (ANOSIM, R = 0.09, 0.09, p = 0.18, 0.21, respectively) (Figure 10). There was no significant difference in shrub community composition, either based on abundance (ANOSIM, R = 0.07, p = 0.10) or presence/absence (ANOSIM, R = 0.07, p = 0.11). (Figure 11). There were significantly more individuals of each herbaceous plant species (ANOSIM, R = 0.18, p = 0.005) at occupied sites and presence/absence of each species was also significantly different across the two groups (ANOSIM, R = 0.18, p = 0.002) (Figure 12).

Looking at all plants, high-bush blueberry (*Vaccinium corymbosum*), rosebay rhododendron (*Rhododendron maximum*), red maple, sphagnum moss (*Sphagnum* sp.) and sedges (*Carex* sp.) contributed most to the Bray-Curtis dissimilarity seen between occupied and unoccupied sites. In addition, high-bush blueberry (p = 0.02), hay-scented fern (*Dennstaedtia punctilobula*) (p = 0.001), and asters (*Asteraceae*) (p = 0.05) had significant differences in abundance between site types (Appendix VI).

Sphagnum, sedges, cinnamon fern (*Osmundastrum cinnamomeum*), jewelweed (*Impatiens capensis*), and sensitive fern (*Onoclea sensibilis*) contributed most to the Bray-Curtis dissimilarity seen between site types for herbaceous plants. Hay-scented fern (p = 0.001), asters (p = 0.03), and false hellebore (*Veratrum californicum*) (p = 0.02) also had a significant difference in abundance between occupied and unoccupied sites (Appendix VII).

This contrasted with the Warton et al. (2012) multivariate ANOVA method. Using this method, the overall plant communities were still significantly different (p = 0.002) with spicebush (p = 0.04) contributing a significant amount to the difference seen between site types (Appendix VIII). Trees remained non-significant between site types (p = 0.31). Conversely, shrubs differed between site types (p = 0.004), with spicebush contributing significantly to the difference (p = 0.02) and winterberry less so (p = 0.05) (Appendix IX). Herbaceous vegetation remained significant (p = 0.04) but hay-scented fern (p = 0.09) was not (Appendix X).

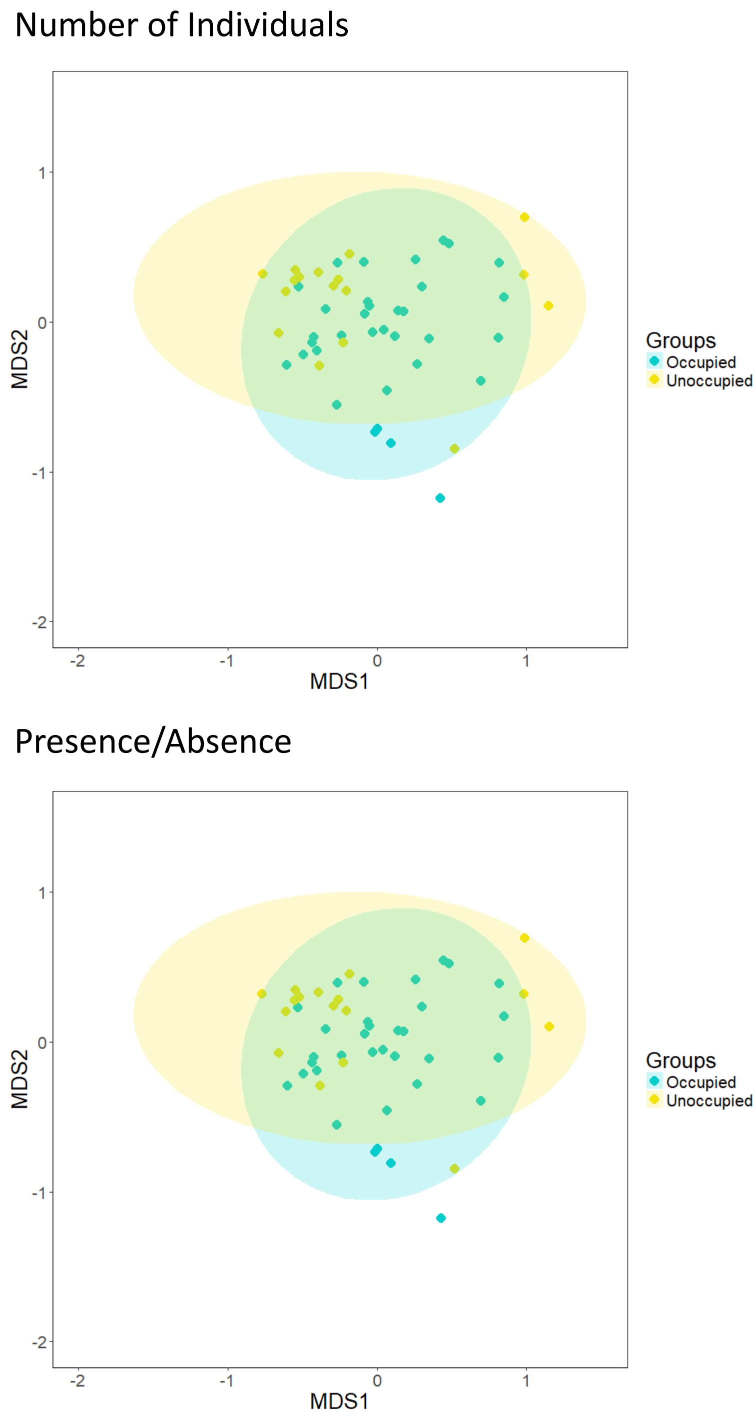
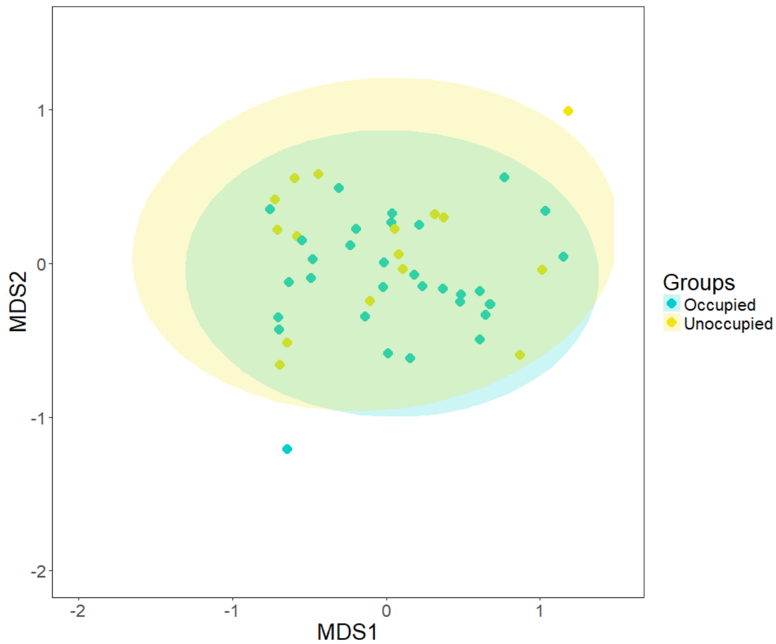


Figure 9. NMDS ordinations of plant communities at each field site with 95% confidence ellipses. The top is the abundance of each species and the bottom is presence/absence (ANOSIM, p = 0.019, 0.028, R = 0.138, 0.138, 3D-stress = 0.13, 0.13, respectively).

Number of Individuals



Presence/Absence

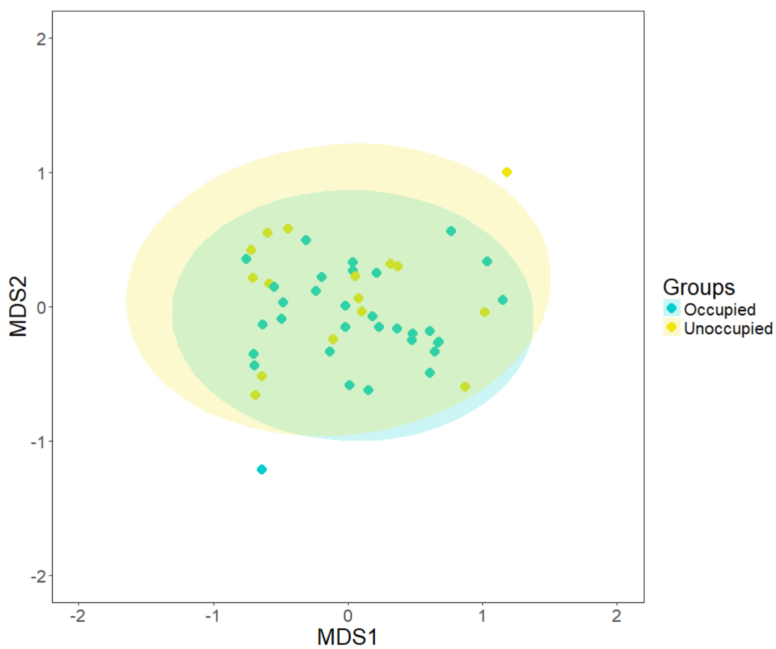


Figure 10. NMDS ordinations of tree communities at each field site with 95% confidence ellipses. The top is the abundance of each species and the bottom is presence/absence (ANOSIM, p = 0.184, 0.21, R = 0.048, 0.048, 3D-stress = 0.09, 0.09, respectively).

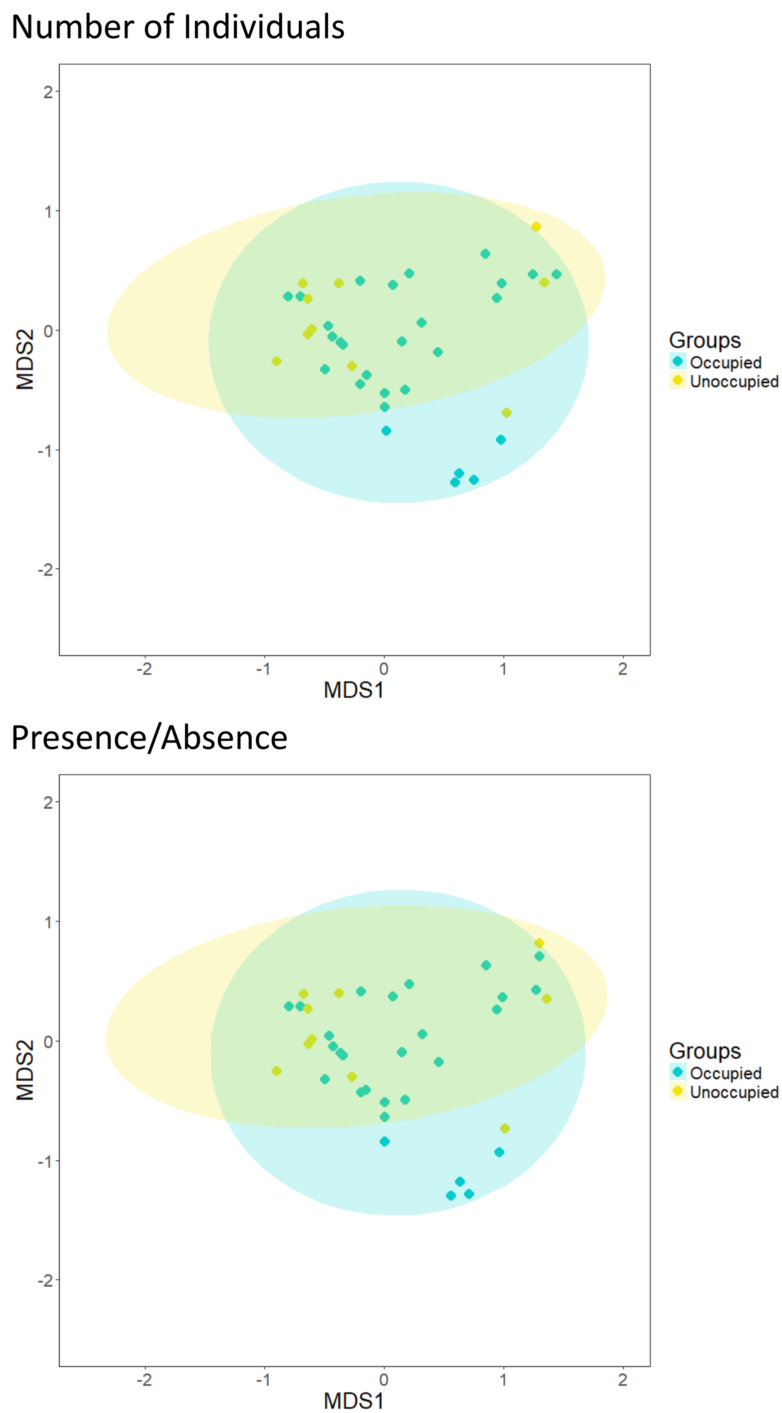


Figure 11. NMDS ordinations of shrub communities at each field site with 95% confidence ellipses. The top is the abundance of each species and the bottom is presence/absence. (ANOSIM, *p* = 0.095, 0.087, R = 0.072, 0.073, 3D-stress = 0.04, 0.04, respectively).

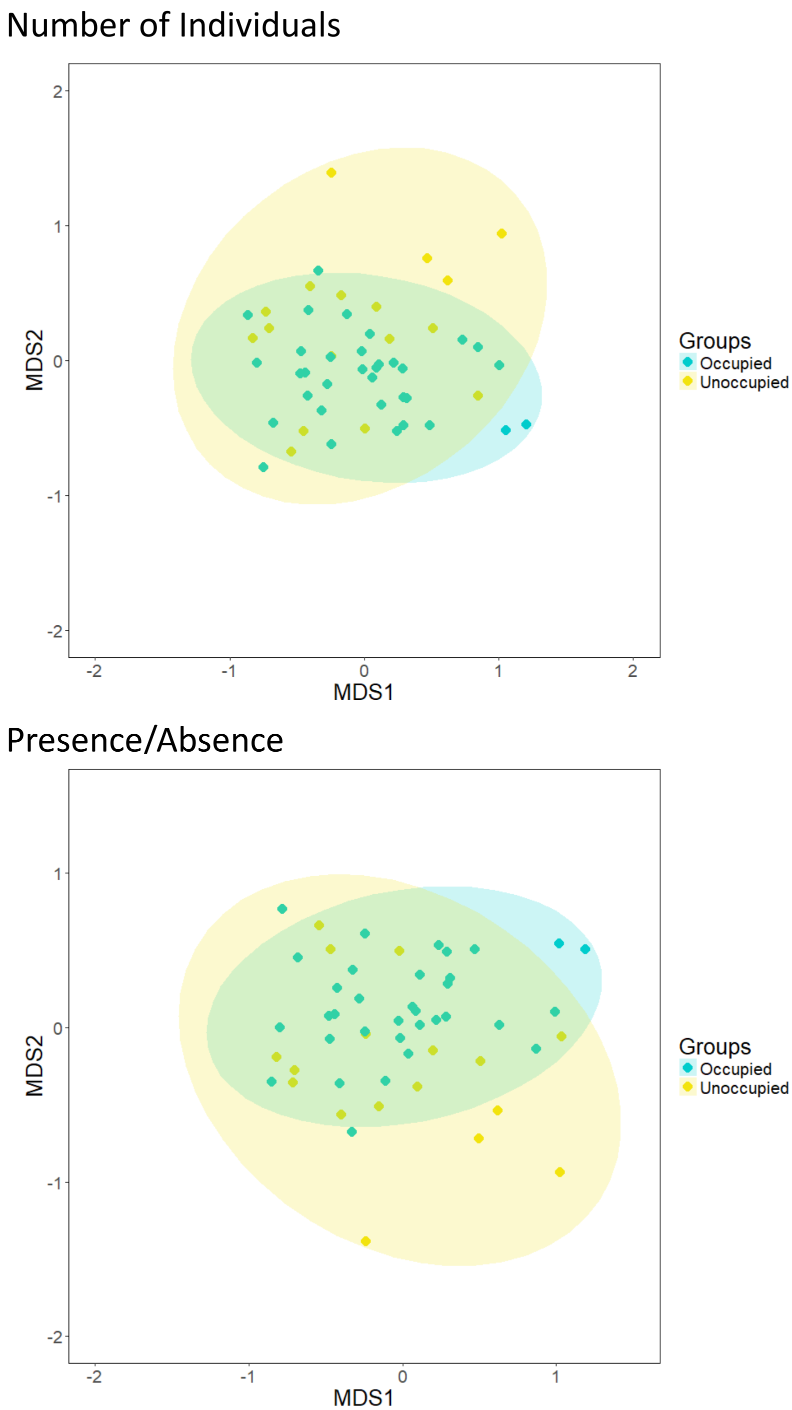


Figure 12. NMDS ordinations of herbaceous plant communities at each field site with 95% confidence ellipses. The top is the abundance of each species and the bottom is presence/absence (ANOSIM, *p* = 0.005, 0.002, R = 0.177, 0.177, 3D-stress = 0.12, 0.12, respectively).

Physical Parameters

The mean wetland area was 63.30 ha ± 19.83 for occupied sites and 19.27 ha ± 7.79 for unoccupied sites (ANOVA, df = 1, 37, F= 2.88, *p* = 0.098). The occupied wetlands were composed of means of 47.91 ha ± 14.88 of forested and 15.39 ha ± 6.41 of scrub-shrub wetlands. In comparison, unoccupied sites had a mean forested wetland area of 15.75 ha ± 6.63 and 3.51 ha ± 1.49 of scrub-shrub wetland (ANOVA: forests df = 1, 37, F= 2.69, *p* = 0.11, scrub-shrub df = 1.37, F= 2.09, *p* = 0.16) (Table 5). There was also no significant difference between occupied and unoccupied sites with respect to water depth. Occupied sites had a mean water depth of 4.82 cm ± 0.68 in comparison to 6.72 cm ± 1.81 for unoccupied sites (ANOVA, df = 1, 49, F= 1.43, *p* = 0.24).

Table 5. Wetland areas of occupied and unoccupied sites (hectares).

Status	**Forested**	**Scrub-shrub**	**Total**
Occupied	47.91	15.39	63.30
Unoccupied	15.75	3.51	19.27

Avian Point Count Analysis

Across both field seasons, a total of 80 species were identified with 49 species in the first year and 70 species in the second year (Appendix XI, Appendix XII). The mean number of species observed across sites was 15.46 ± 1.04 in 2017 (Appendix XIII) and 16.97 ± 0.62 at occupied sites and 16.56 ± 0.71 at unoccupied sites in 2018 (Appendix XIV). There were 64 total species at occupied sites in 2018 and 58 total species at unoccupied sites (Appendix XII). The Shannon Diversity Index for 2017 ranged from

2.26 - 2.99 for occupied sites (Table 6). In 2018, it ranged from 1.98 - 2.99 (Table 7) for occupied sites and 2.16 - 2.95 for unoccupied sites (Table 8) (Appendix XV).

Table 6. Avian Shannon diversity index for all 2017 field sites (mean = 2.54 ± 0.06).

Sites	**Shannon Index**	**County**
Hobday Road	2.99	Pike
Bear Swamp - Nest	2.81	Northampton
Cranberry Bog – Edge	2.64	Monroe
Cranberry Bog - Boardwalk	2.61	Monroe
Lost Lakes- Lake 1	2.57	Monroe
Grass Lake	2.55	Monroe
Whitaker Road	2.54	Pike
Brady's Lake	2.48	Monroe
Bear Swamp - Boardwalk	2.45	Northampton
Cranberry Bog – Parking Lot	2.38	Monroe
Bear Swamp	2.34	Northampton
Lost Lakes – Swamp Alley	2.31	Monroe
Brady's Lake – 7 Mile Road	2.26	Monroe

Table 7. Top 10 avian Shannon diversity index for occupied sites in 2018 (mean = 2.67 ± 0.04).

Sites	**Shannon Index**	**County**
Long Pond Swamp	2.99	Pike
Tarkill Demo	2.95	Pike
Turner Swamp 3	2.94	Pike
Cranberry Bog - Boardwalk	2.92	Monroe
Hobday Road	2.89	Pike
Bear Wallow	2.87	Pike
Valley Road	2.84	Pike
Whitaker Road 2	2.81	Pike
Bear Swamp 2	2.78	Northampton
Cranberry Bog – Parking Lot 2	2.76	Monroe

Table 8. Top 10 avian Shannon indices for unoccupied 2018 field sites (mean = 2.64 ± 0.05).

Sites	Shannon Index	County
Hemlock Way	2.95	Monroe
Plank Road	2.93	Monroe
Lake Greeley	2.80	Pike
Brady's Lake - Parking Lot	2.79	Monroe
Hell Hollow Road 2	2.78	Monroe
Merry Hill Wet Meadow	2.78	Monroe
Lake Road	2.74	Monroe
Shohola Creek	2.73	Pike
Indian Swamp	2.66	Pike
Beaver Run	2.63	Pike

The species detected most often among the 12 sites in 2017 was the veery (*Catharus fuscescens*) (Table 9) while thirteen species were least frequent (Appendix XI). At the 35 occupied sites in 2018, the most frequently detected species was the red-eyed vireo (*Vireo olivaceus*) with the ovenbird (*Seiurus* aurocapilla) and veery close behind while nine species were least frequent (Table 10, Appendix XVI). Several species competed for the most frequent species detected at the 18 unoccupied sites in 2018 including the veery, ovenbird, and red-eyed vireo whereas the red-eyed vireo was clearly the most frequent species at all unoccupied sites (Table 10, Table 11) (Appendix XVI).

Table 9. Top 10 avian species frequencies of 2017.

Species	**2017 Frequency**
Veery	1.00
Gray Catbird	0.92
Red-eyed Vireo	0.92
Ovenbird	0.85
Black-and-white Warbler	0.77
Blue Jay	0.77
Wood Thrush	0.77
Common Yellowthroat	0.69
Northern Waterthrush	0.69
American Crow	0.54

Table 10. Top 10 avian species frequencies of 2018 at occupied sites (not including NOWA).

Species	**2018 Frequency**
Veery	1.00
Ovenbird	0.97
Red-eyed Vireo	0.93
Black-and-white Warbler	0.90
Gray Catbird	0.80
Blue Jay	0.77
Canada Warbler	0.63
Common Yellowthroat	0.60
Black-capped Chickadee	0.57
Eastern Towhee	0.57

Table 11. Top 10 avian species frequencies of 2018 at unoccupied sites.

Species	**2018 Frequency**
Red-eyed Vireo	1.00
Gray Catbird	0.83
Ovenbird	0.83
Blue Jay	0.72
Common Yellowthroat	0.72
Veery	0.72
Black-capped Chickadee	0.67
Eastern Towhee	0.67
Tufted Titmouse	0.61
American Crow	0.55

The NMDS ordination and ANOSIM among the avian communities at occupied and unoccupied sites in 2018 showed a significant difference in species composition between the two site types for abundance and presence/absence (ANOSIM, R = 0.24, 0.14, p = 0.001, 0.009, respectively) (Figure 13). The ovenbird, common yellowthroat, veery, red-eyed vireo, and Canada warbler contributed the most to the Bray-Curtis dissimilarity seen. In addition, ovenbird (p = 0.02), common yellowthroat (p = 0.04), veery (p = 0.002), black-and-white warbler (p = 0.01), swamp sparrow (*Melospiza georgiana* (p = 0.02), tufted titmouse (p = 0.02), red-winged blackbird (*Agelaius phoeniceus*) (p = 0.04), and eastern phoebe (*Sayornis phoebe*) (p = 0.03) showed significant differences in abundance between the two site types (Appendix XVII).

The species composition for both site types was significantly different when species heard > 75 m away were eliminated for abundance and presence/absence (ANOSIM, R = 0.13, 13, p = 0.008, 0.015, respectively) (Figure 14). ovenbird, veery, blue jay (*Cyanocitta cristata*), red-eyed vireo, and common yellowthroat contributed most to the Bray-Curtis dissimiliarity seen between groups. The SIMPER test revealed that tufted titmouse (p = 0.03), black-throated blue warbler (*Setophaga caerulescens*) (p = 0.03), and hermit thrush (*Catharus guttatus*) (p = 0.05) exhibited significant differences in abundance between site types (Appendix XVIII).

Conversely, following the Warton et al. (2012) method, the avian community between occupied and unoccupied sites was significantly different (p = 0.004) with the Canada warbler (p = 0.001) contributing most to the difference seen between the groups (Appendix XIX). When the species further than seventy-five meters were removed, groups were no longer significantly different (p = 1.0) (Appendix XX). Canada warblers were seen at 21 of the 35 (60%) of the sites that were occupied by NOWA.

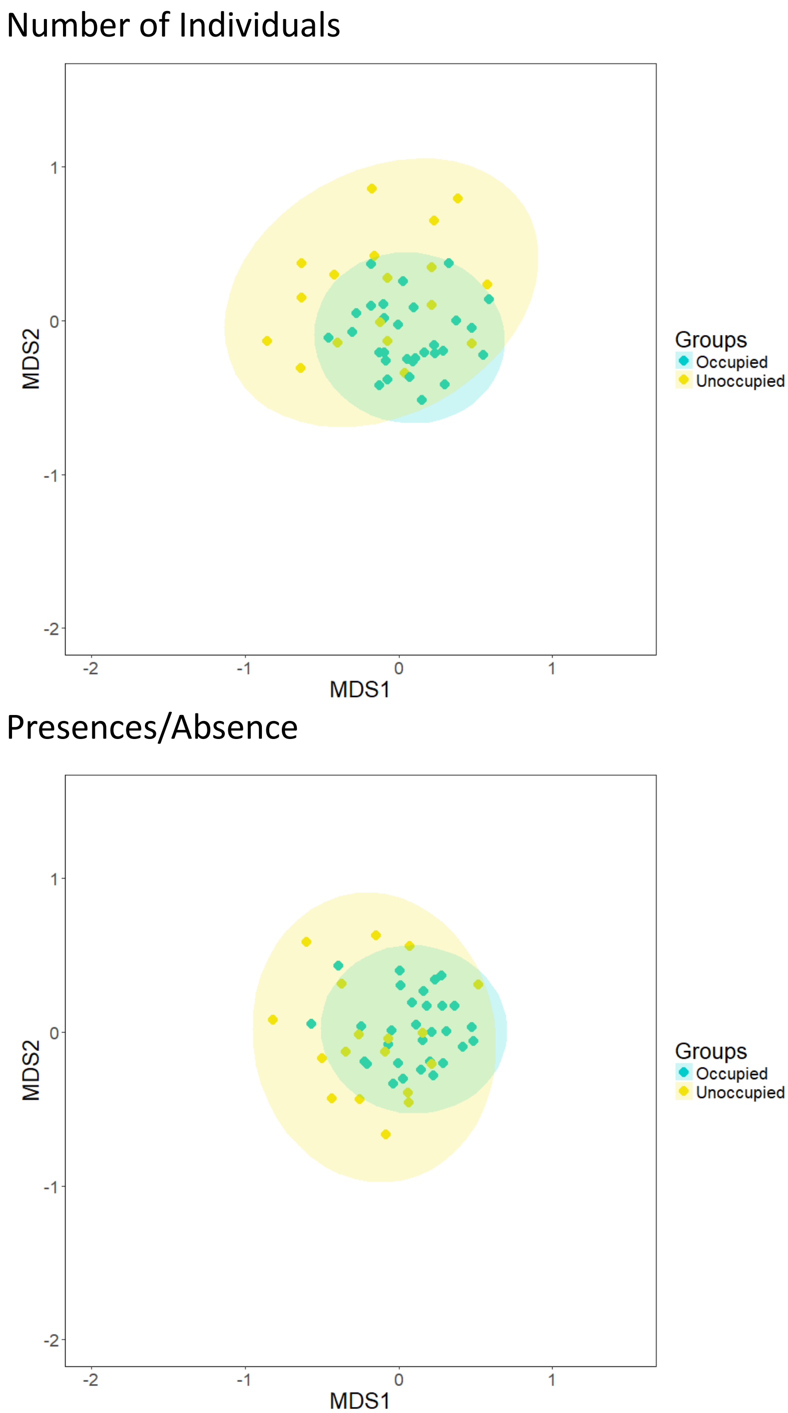


Figure 13. NMDS ordinations of avian communities at each field site with 95% confidence ellipses. The top is the abundance of each species and bottom is presence/absence. (ANOSIM, p = 0.001, 0.009, R = 0.238, 0.139, 3D-stress = 0.17, 0.19, respectively).

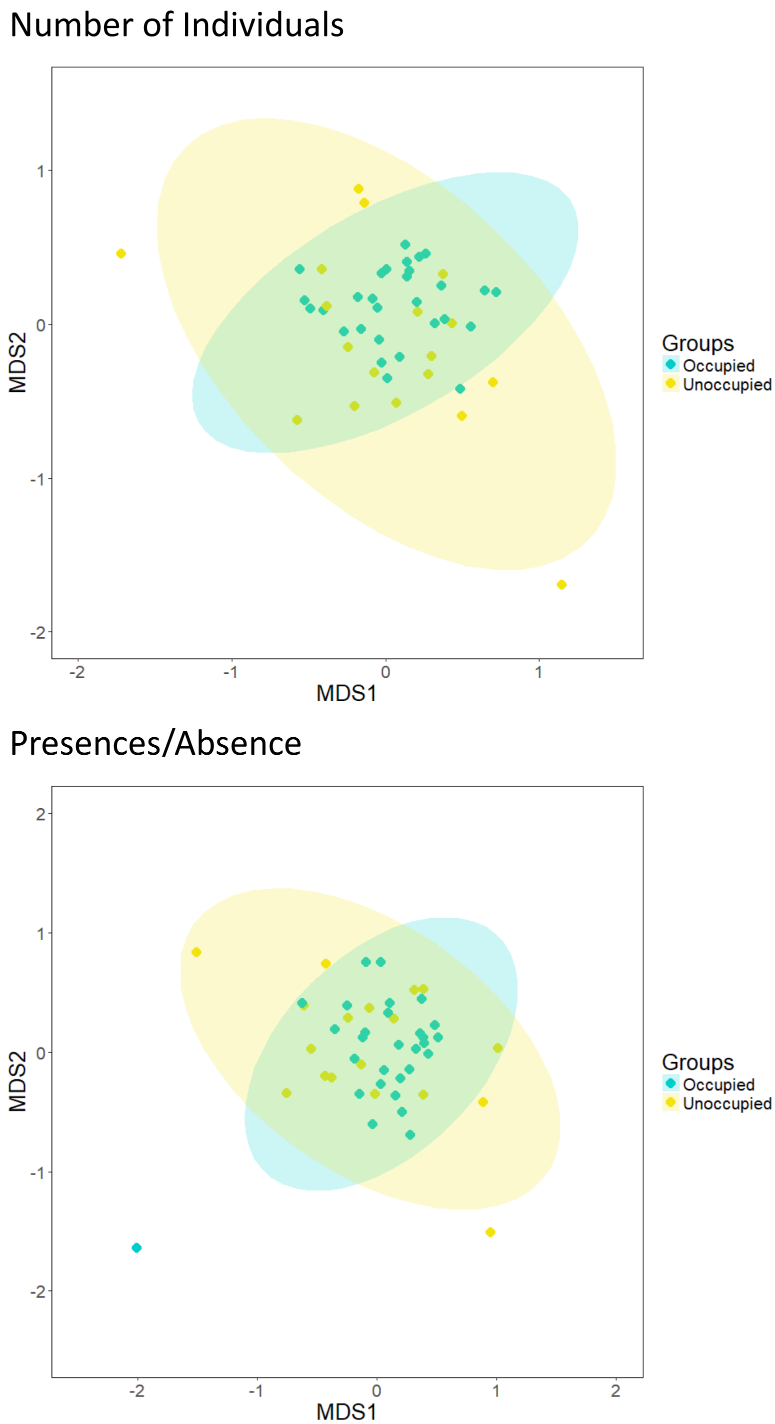


Figure 14. NMDS ordinations of avian communities at each field site with distant species removed and 95% confidence ellipses. The top is the abundance of each species and the bottom is presence/absence (ANOSIM, *p* = 0.008, 0.013, R = 0.133, 0.125, 3D-stress = 0.14, 0.14, respectively).

Nests

Two nests were found, one each in 2017 and one in 2018. The 2017 nest was found at Bear Swamp. The nest was located about 0.6 m above water level in the roots of an overturned green ash (*Fraxinus pennsylvanica*) with another green ash facing the opposite way to form two walls with the two overturned root systems. This nest was found on 13 June 2017 and contained five chicks that appeared to be about 7 days old (T. Master, pers. comm.). The nest was empty on 15 June 2017 (Figure 15). There was no sign of disturbance and the chicks did not appear ready to fledge so the cause of nest failure is unknown.

Figure 15. NOWA nest with chicks at Bear Swamp in 2017 (photo credit Justin Clarke).

The second nest was found on 7 May 2018 in the roots of an overturned red maple at Grass Lake (Figure 16). This nest was located about 0.30 m above the water level and the red maple was slanted slightly so the top hung over the bottom. The parent was seen going to and from the nest when it was first discovered and was later seen sitting on the nest but there was no sign of eggs or chicks at the nest. The nest was checked once per week for two weeks after which the parents were no longer visiting. There was no indication of predation or disturbance to the nest so perhaps this was a false or decoy nest but whether NOWA have been known to do this or not is unknown.

Figure 16. NOWA in nest at Grass Lake in 2018 (photo credit Justin Clarke).

On 25 June 2018, as we were leaving Maple Run after a point count, we noticed two juvenile NOWA with an adult in the brush, likely evidence of another nest that was not found. The two juveniles were chipping in the underbrush and looked like the adult but the superciliary stripe was slightly buffier and the underparts were less defined (personal observation).

Climate Analysis

The average elevation of the occupied sites was 420.91 m ± 21.90 while the average elevation of the unoccupied sites was 429.35 m ± 24.56 (Table 12). There was no significant difference in the elevation between occupied and unoccupied field sites from both field seasons (ANOVA, df = 1, 50, F= 0.059, p = 0.81). Comparisons between the two atlases also revealed no significant difference (ANOVA, df = 2, 55, F= 0.76, p = 0.47), the mean elevation for blocks gained during the 2^{nd} PBBA was 420.46 m ± 37.09, the mean for blocks lost was 422.35 m ± 30.75, and mean elevation for blocks that were unchanged was 381.45 m ± 21.75 (Table 13).

Table 12. Average elevation of occupied and unoccupied sites.

Status	**Average of Elevation (m)**
Occupied	420.91
Unoccupied	429.35

Table 13. Average elevation of PBBA blocks gained, lost, and with no change between the 1st and 2nd PBBA.

Status	**Average of Elevation (m)**
Gain	420.46
Loss	422.35
None	381.45

At occupied sites, the mean temperature change from the first (1980-1990) to the second atlas (2000-2010) was -0.11° C ± 0.01 and the mean unoccupied site temperate change was -0.13° C ± 0.01. An ANOVA showed that there was no significant difference in temperature change between the occupied and unoccupied sites (df = 2, 50, F= 0.22, *p* = 0.80). Maximum and minimum temperature changes were also not significant across site types (ANOVA, df = 2, 50, 2, 50, F = 2.68, 0.06, *p* = 0.08, 0.94, respectively). The maximum temperature change for occupied sites was -0.43° C ± 0.01 while the minimum temperature change was 0.20° C ± 0.01. Unoccupied sites had a maximum temperature change of -0.45° C ± 0.01 and a minimum of 0.19° C ± 0.02. The mean precipitation change between those two periods was 13.54 mm ± 0.34 for occupied sites and 14.32 mm ± 0.28 for unoccupied sites (ANOVA, df = 2, 50, F= 1.93, p = 0.16) (Table 14).

Table 14. Mean temperatures and precipitation amount for occupied and unoccupied sites over the intervening period between the two atlas time periods.

Climate Indices	**Occupied**	**Unoccupied**
Average Temperature Change (°C)	-0.11	-0.13
Max Temperature change (°C)	-0.43	-0.45
Min Temperature Change (°C)	0.20	0.19
Average Precipitation Change (mm)	13.54	14.32

The PBBA blocks did not exhibit any significant differences in the climate variables examined. The average temperature change for blocks gained between the two atlases was -0.13° C ± 0.02, blocks lost had an average temperature change of -0.10° C ± 0.01, and blocks that remained unchanged had an average temperature of -0.12° C ± 0.01. There was no significant difference in the temperature change between these three block groups (ANOVA, df = 2, 55, F = 0.50, p = 0.61). Maximum temperature change only varied slightly (-0.43° C ± 0.03, -0.42° C ± 0.01, and -0.42° C ± 0.01, respectively) and was not significantly different among the three block groups (ANOVA, df = 2, 55, F = 0.25, p = 0.78). Minimum temperature change was 0.19° C ± 0.02 for blocks gained, 0.21° C ± 0.02 for blocks lost, and 0.18° C ± 0.01 for blocks that were unchanged between the two atlases. Maximum and minimum temperatures were not significantly different from one another for the three block groups (ANOVA, df = 2, 55, F = 0.15, p = 0.47). Precipitation change was not significantly different between the three block groups either (ANOVA, df = 2, 55, F = 0.59, p = 0.87). The average precipitation change was 13.88 mm ± 0.67 for blocks gained, 13.68 mm for blocks lost ± 0.47 , and 14.00 mm ± 0.35 for blocks that were unchanged between the two atlases (Table 15).

Table 15. Mean temperatures and precipitation amount for the two atlas time periods for blocks gained, lost, and those with no change between the first and second PBBA.

Climate Index	**Gain**	**Loss**	**None**
Average Temperature Change (°C)	-0.13	-0.10	-0.12
Max Temperature Change (°C)	-0.43	-0.42	-0.42
Min Temperature Change (°C)	0.19	0.21	0.18
Average Precipitation Change (mm)	13.88	13.68	14.00

Between the first and second PBBA, 24 blocks changed in occupancy status. Seven blocks were gained (newly occupied) in the second atlas and 17 were lost (no longer occupied) from the first to the second atlas (Figure 17). This resulted in a noticeable contraction in NOWA range between the first and second PBBA. The northern margin of the NOWA range moved about ten km south and the southern margin moved about nine km north.

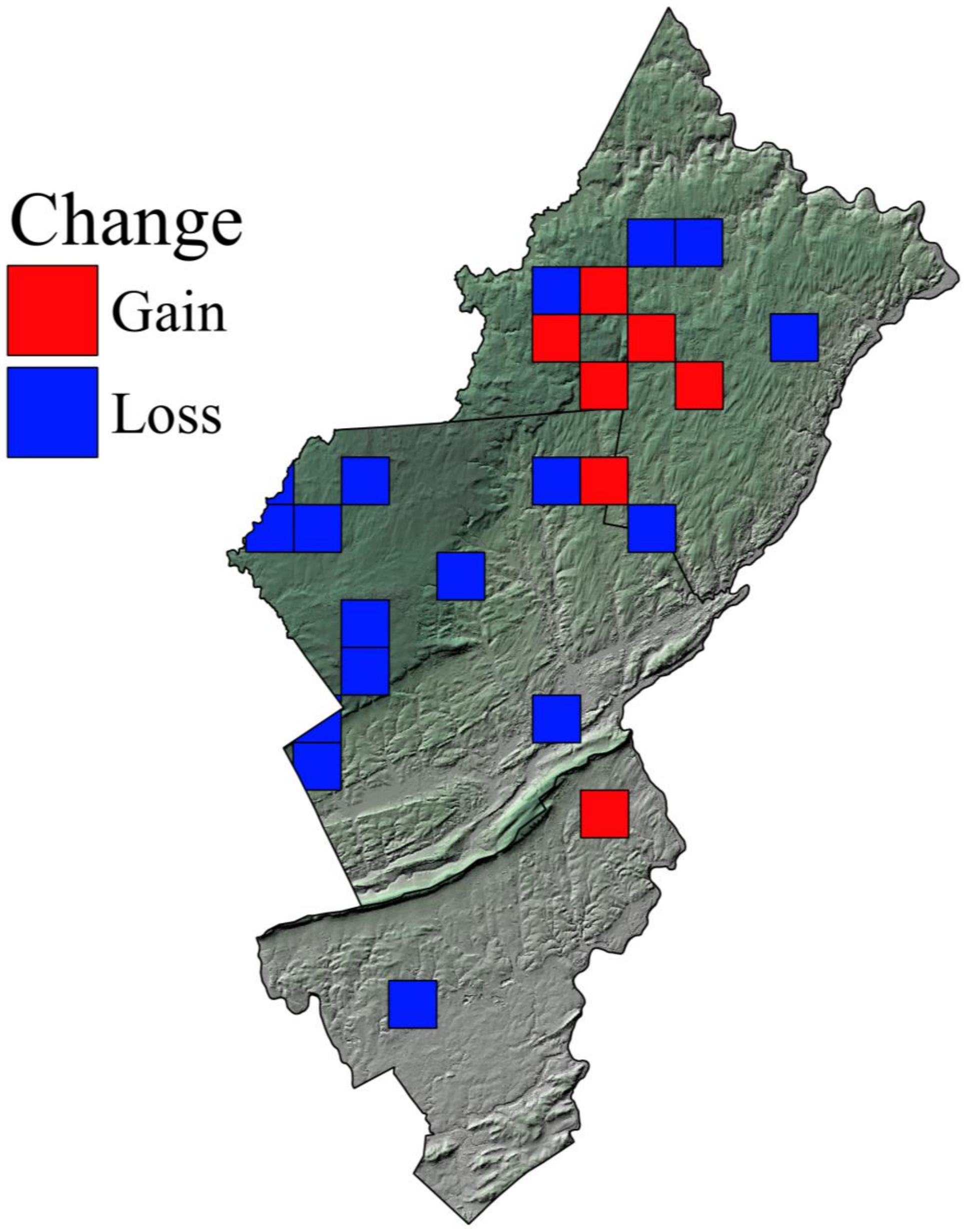


Figure 17. PBBA blocks that were gained or lost from the 1st to the 2nd PBBA.

CHAPTER IV

Discussion

The goal of this study was to investigate NOWA distribution and decline indicated by block occupancy patterns between the 1st and 2nd PBBA (Wilson et al. 2012) and investigate potential causes for the decline. I was only able to cover 53 of the hundreds of wetlands in the study area, mainly because many of the potential wetlands I found, were located on private land. However, by focusing on PBBA blocks rather than each individual wetland, I was able to cover much of the study area and confirm almost every block that was considered probable or confirmed in both PBBAs in addition to finding new swamps inhabited by NOWA.

During the 2017 and 2018 field season, NOWA were found in 35/53 swamps surveyed (Figure 8). There were 73 total detections of individual NOWA throughout the two field seasons. Since individuals were not banded and point counts were taken from the same point at each site, it is possible that individuals could have been counted multiple times but not likely given the distance between point counts.

Throughout the breeding season, I was able to confirm three blocks as breeding blocks while the others were defined as probable based on the territorial and agitated behavior categories defined in the 2nd PBBA (Wilson et al. 2012). Confirming breeding behavior based on 2nd PBBA categories was extremely difficult for two reasons: (1) many of the sites found had very dense understory that impeded sight and made it difficult to keep track of NOWA individuals, and; (2) because of the dense understory and the thick layer of mud beneath the water, it was very difficult to move about without disturbing birds.

The three confirmed blocks were all open areas where I was able to observe NOWA movements more easily. Visibility is one explanation for the lack of confirmed blocks seen in both the 1st (3 blocks) and 2nd PBBA (4 blocks) (Wilson et al. 2012). However, it fails to explain the drastic decline in probable blocks between the two atlases (15 and 4 blocks, respectively), especially considering that effort was more extensive during the 2nd PBBA. Another explanation for the observed decline is detectability of this species. NOWA singing ends in mid to late -June so it is difficult to accurately sample many different locations within their relatively abbreviated singing period. I tried to mitigate this issue by visiting every site once before revisiting sites but it still limited the amount of time I had to survey as many wetlands within the three-county study area as I could. This issue was also noted by Stephen Eaton during the first New York Atlas of Breeding Birds (Eaton 1988, McGowan and Corwin 2008).

However, even with difficulty detecting and observing this species, I was able to confirm occupancy in twenty-two of the original atlas blocks (Figure 8) in the study area. This was more than both the 1st (8 blocks) and 2nd PBBA (18 blocks) (Figure 7) which suggests that the species may have been underrepresented, especially in the 2nd PBBA in spite of the increased effort. Eaton (1988) mentioned the difficulty associated with detecting this species may have resulted in underrepresentation in the New York atlas as well. The actual population decline is difficult to estimate though because the density of NOWA within each block was not measured in the first atlas and was not able to be measured in the second atlas because detections during point counts were too few. I had several blocks with multiple sites and many NOWA within them and so if there is a decline in blocks, it likely translates to an even larger decline in population size within the state.

I observed a contraction in NOWA range from the first to the second atlas with the northern margin moving south approximately 10 km and the southern margin moving north about 9 km from the 1st to the 2nd atlas (Figure 17). This supports the range contraction observed in the atlas. However, I was unable to find evidence that this range shift was driven by climate change or that the range contraction was due to a shift to higher elevations (Table 13). My results show that the 1st PBBA occupied blocks were about 20 m lower in elevation than the blocks occupied in the 2nd PBBA (Table 13) (406m and 430m, respectively).

Although not statistically significant, the observed difference in elevation could very well be meaningful with regard to the influence of climate change and suggestive of the initial stages of a shift to higher elevation that is ongoing. A larger sample size might aid in determining significance, but it must be recognized that vertical relief in this region, while greater than in some parts of Pennsylvania, may not be sufficient for birds to move high enough to reflect a statistically significant change in elevation. Without coordinates for exact sites used in the first PBBA, I was forced to use mean elevations for the blocks in that atlas which likely does not reflect the actual elevation at the detection sites and consequently does not reflect more precise measures of elevational change between atlases.

This is in contrast to other studies that have found breeding birds moving north due to climate change (Thomas and Lennon 1999, Hitch and Leberg 2007, Sneddon and Hammerson 2014, Langham et al. 2015). However, these studies were modeling changes that will be seen in the future. Pounds et al. (1999) did find that species were moving higher based on climate change. This study was conducted in cloud forest at Monteverde, Costa Rica and the change in elevation was highly correlated with dry-season-mist frequency and cloud deck elevation. Again, significant changes in elevation may be more difficult to detect at lower elevations with generally less relief in the Appalachians of Pennsylvania.

Water depth was also not significantly different between occupied and unoccupied sites and thus the difference between relatively shallow and deeper sites was not sufficient to provide more protection from predators (Table 4). Hoover (2006) found a link between larger differences in water depth and predation on nests. Over 75% of the nests studied in shallow water (0-30 cm) were depredated as opposed to 24% in deep water (greater than 60 cm). While the predators varied, raccoons were responsible for 73% of all of nest predation in the study (Hoover 2006).

Changes in wetland size could also play a role in population decline but it is not likely there has been any significant change in the area of individual wetlands between the two atlas periods. However, there was a large wetland size difference between occupied and unoccupied sites and so area could be important with respect to NOWA habitat selection. Occupied sites were over 40 ha larger than unoccupied sites on average although this large difference was not significant (Table 5). Occupied sites had a standard deviation of 19.83 ha while unoccupied sites had a standard deviation of just 7.79 ha. This suggests that there is a lot more variation in the occupied sites and a larger sample size may help to create a more robust analysis of occupied and unoccupied wetland sizes.

Wilcove (1985) found a linear trend between forest size and predation rate with larger forest tracts having less predation than smaller tracts (Wilcove 1985). Another factor affecting predation rates is fragment shape. One of the larger sites (283 ha) in Wilcove's (1985) study had a 48% nest predation rate which may have been because it was a very long and narrow corridor that could easily be penetrated by predators. Winter et al. (2000) found that meso-predators were more active near the edge of grasslands than interiors. Since smaller wetlands have proportionally more edge than interior, predation pressure would be increased. Many studies consider these smaller forest fragments to be population "sinks" where the mortality rates are higher than the reproduction rates (Donovan et al. 1995, Robinson et al. 1995).

The Biological Dynamics of Forest Fragments Project (BDFFP),the largest and longest-running experimental study of habitat fragmentation, found that edges can change a lot in smaller, more fragmented forests (Laurance et al. 2011). Fragmentation affects patchily distributed species such as NOWA more than other species because of sampling effects. The sampling effect states that species that were not present when the fragment was isolated would not be present in the fragment after isolation (Laurance 1991, 2004, Laurance et al. 2011). These effects can change not just NOWA distribution directly by removing habitat or access to habitat, but they can have indirect effects by changing the characteristics of preferred NOWA habitat.

Edge effects also include increased desiccation stress that can be especially stressful to species dependent on wetlands like NOWA. The effects on the microclimate of the forest understory can extend at least 40 m into the interior and, in some cases, as much as 200 m into the forest interior from edges (Betts et al. 2006, Kopos 1989, Laurance 1991, 2004, Laurance et al. 2011). Such desiccation could affect the availability of the macroinvertebrates that NOWA feed on and increase predation on NOWA nests by increasing accessibility to the nest (Hoover 2006).

Unlike forest fragments that are usually surrounded by suburbia and agriculture, as in the examples above, wetlands inhabited by NOWA are embedded within a larger forested landscape and so population dynamics and predation threat imposed by size are likely different than those at work in typical forest fragments. For example, do predators take advantage of the increased access provided by the proportionally greater edge of smaller wetlands given the difficulty of moving around once inside the wetland? Is the relative habitat quality of a smaller wetland embedded within a large forest fragment different from a small or a large wetland found within a smaller forest fragment? Additional considerations like these, cloud the effects and dynamics of wetland size on NOWA populations.

Size could directly affect the amount/availability of nesting substrate; thus, this is a much more likely and discernable effect of wetland size on NOWA distribution and abundance. I found that occupied sites had significantly more root overturns than the smaller unoccupied sites on an absolute basis. The typically larger occupied wetlands would therefore more likely provide tree root overturns at the right stage of decay for nesting (stages of decay affect the number of suitable nesting sites in an overturn) than would the smaller unoccupied wetlands (Mattingly 2016) The number of root overturns was 2.5 times greater on occupied vs. unoccupied sites. However, this was not relativized for wetland size since I only recorded overturns inside or close to each territory and not through the entire wetland. Finally, perhaps size is important simply because NOWA have an intrinsic minimum required area to breed successfully as is the case with many grassland birds (Kobal et al. 1999, Douglas and Lawrence 2001) .

Although many studies attribute declines in songbird distribution and abundance to climate change and fragmentation (Wilcove 1985, Thomas and Lennon 1999, Hitch and Leberg 2007, Laurance et al. 2011, Sneddon and Hammerson 2014, Langham et al. 2015), our results suggest that changes in vegetation structure, and, to a lesser extent, vegetation composition, may be driving the decline of NOWA most visibly. Two, perhaps interacting factors are at play, over browsing by the White-tailed Deer (*Odocoileus virginianus*) (deCalesta 1994a, Allombert et al. 2005a, Baiser et al. 2008) and the devastating effect of Hemlock Woolly Adelgid infestations on the Eastern Hemlock.

White-tailed deer were historically controlled by harsh winters, hunting by natives, and predation by mountain lions (*Felis concolor*) and gray wolves (*Canis lupus*) (McCabe and McCabe 1984, Witmer and deCalesta 1991, and deCalesta 1997).

Historically, white-tailed deer population density was estimated to be approximately 3-4 deer/km^2 in Wisconsin prior to European arrival (McCabe and McCabe 1984). After Europeans arrived, the deer population was almost brought to extinction by overhunting by the early 1900s (McCabe and McCabe 1984, Witmer and deCalesta 1991, deCalesta 1997). With careful management and hunting regulations the deer population has rebounded with current population densities of approximately 12 deer/km^2 throughout Pennsylvania (Julian and Smith 2001) .

The Pennsylvania Game Commission divides the state into wildlife management units (WMU) for monitoring and managing the white-tailed deer population. The WMU that this study takes place in covers 5,441 km^2. During our 2017 and 2018 field season this WMU had an average of 32,014 and 30,727 deer, respectively. This equals 5.88 and 5.65 deer/km, respectively, both above the historical estimate. In the annual deer population report (Pennsylvania Game Commission 2018) the deer population was considered stable with an average population density estimate of 6 deer/ km^2 for the WMU that overlaps the study area.

Vegetation changes are accompanied by deer over browsing and these changes, especially with regard to structure, will affect avian communities (Casey and Hein 1983, deCalesta 1994a, McShea and Rappole 2000, Allombert et al. 2005). Over browsing can affect species in a variety of ways from increasing the efficiency of nest predators by reducing vegetation available for nest concealment (Martin and Roper 2007) to reducing abundance of invertebrates that birds feed on (Allombert et al. 2005b). These studies suggest that such changes affect avian species that depend in particular on understory vegetation, either for nesting or foraging, compared to those inhabiting the canopy (Casey and Hein 1983, deCalesta 1994a, Allombert et al. 2005a). Allombert et al. (2005a) found a 70% reduction of breeding pair density, and a 92% decline in species that depend on understory vegetation due to over browsing in the Haida Gwaii Archipelago off the coast of British Columbia, Canada.

In the SIMPER analysis, many of the differences in plants that were most obvious between occupied and unoccupied sites involved high-bush blueberry, rosebay rhododendron and red maple (Appendix VI, Appendix VII), two of which are understory plants and all of which are typically associated with the swamps that NOWA prefer (Craig 1985, Whitaker and Eaton 2014). One of the species that stood out in the SIMPER analysis that is associated with deer over browsing is hay-scented fern (Appendix VI, Appendix VII). This species was found, on average, in higher abundance at unoccupied sites than occupied sites (less than 1% coverage at occupied sites, 7% coverage at unoccupied sites).

This fern colonizes areas that deer over browse because they will heavily graze plants they find palatable, opening the understory allowing the fern to dominate the ground cover, since they are largely unpalatable to deer (Horsley and Marquis 1983), along with graminoids such as grasses and sedges (DeGraaf et al. 1991, Horsley et al. 2003, Rooney 2009). While grasses (3% coverage at occupied sites and 5% coverage at unoccupied sites) and sedges (13% coverage at occupied and 21% coverage at unoccupied sites) weren’t found to be significantly different between occupied and unoccupied sites, they were found to occur, on average, in higher densities at unoccupied sites in our study (Appendix II, Appendix V).

Rooney (2009) found that deer over browsing can result in a change in the composition and structure of the avian community at a site without affecting species richness or diversity. DeGraaf et al. (1991) found an increase in intermediate canopy birds in contrast to McShea and Rappole (2000) who found an increase in both intermediate canopy and ground dwelling birds. McShea and Rappole (2000) suggest this may be due to both different sampling methods (mist netting vs point counts) and different study areas. DeGraaf et al. (1991) conducted studies in a combination of forest management types whereas McShea and Rappole (2000) conducted their study well within protected forests.

DeGraaf et al. (1991) also found that over browsing by white-tailed deer did not affect the richness or diversity of avian species in forested areas. McShea and Rappole (2000) suggest that the reason there is no change in diversity is because avian species will replace each other as the habitat changes. However, DeGraaf et al. (1991) did find that three species in particular appeared to be very sensitive to vegetation changes associated with over browsing. These species were the Canada warbler, chestnut-sided warbler, and black-throated blue warbler (DeGraaf et al. 1991). This could explain why we did not see a significant difference in avian richness or diversity but did find that both CAWA and NOWA were absent from unoccupied sites.

Spicebush was the only plant that the Warton et al. (2010) method identified as significantly different between site types (Appendix VIII, Appendix IX). This species composed 12% of total shrub coverage at occupied sites and wasn't seen at unoccupied sites at all (Appendix II). It is known to be unpalatable to deer and typically only undergoes moderate browsing if any (Randle and Wenzel 2014, Jenkins et al. 2015). Horsley et al. (2003) found that over- browsed sites resulted in shorter trees and more ground cover, especially grass, forbs, and ferns, than less browsed sites. This supports my findings where there were less tall, woody, understory stems and more grasses, forbs, and ferns at unoccupied sites indicating that NOWA may not utilize these sites because of the effects of deer over browsing.

A study conducted by Baiser et al. (2008) found that white-tailed deer can alter the composition of a site so it is no longer suitable habitat for understory birds. They also determined that over browsing can open gaps that make it easier for invasive, or in this case, native plants that are unpalatable to deer, to further transform the understory into a matrix that is completely different from what these species deem suitable habitat. Baiser et al. (2008) suggest that these two factors can transform even large tracts of habitat that seem appropriate into unsuitable areas for understory birds.

White-tailed deer could be one explanation for why shrub height was higher at occupied compared to unoccupied sites (Horsley et al. 2003) (Table 4). McShea et al. (1995) showed that Kentucky warblers (*Geothlypis formosa*) were found at lower densities in areas that were under high browsing pressure because deer were changing the understory. However, they note that the lower densities observed at some sites may have also been due to the decline of Kentucky warblers within the state in general. These results agree with deCalesta et al. (1994b) who also found that avian species richness was reduced in areas that were heavily browsed by deer.

Allombert et al. (2005b) observed that understory invertebrates were found in lower densities in areas that were heavily browsed by deer, specifically edge habitats. They suggest that a cascade effect could be occurring through the food web that is manifested in the decline of many songbirds in North America.

Another potential explanation for the change in vegetation structure and certainly a cause of concern for this species is eastern hemlock decline. This species was more frequently encountered at occupied sites (62% of total at occupied sites) compared to 42% at unoccupied sites) (Appendix V). Most of the literature suggests that NOWA are often associated with swamps containing eastern hemlock (Craig 1985, Wilson et al. 2012, Whitaker and Eaton 2014). Thus, loss of eastern hemlock could negatively affect the NOWA population by changing vegetation structure and the microclimate within these swamps in combination with the changes caused by deer over browsing (Becker et al. 2008, Allen et al. 2009, Shelton et al. 2014).

Orwig et al. (2002) determined that within 15 years of entering the state of Connecticut, HWA had infected hemlocks in every town as it travelled north through the state. They found that The loss of hemlock results in a more homogenous environment and the disappearance of important cooler microclimates that are created with the deep shade cast by stands of this tree (Orwig et al. 2002, Brantley et al. 2013). Declines have already been documented in some bird species that are closely associated with eastern hemlock such as Acadian Flycatchers (Allen et al. 2009, Becker et al. 2008).

The mortality of HWA appears to vary greatly. McClure (1991) found that hemlocks die rapidly (within 1 to 4 years) after infestation, but other studies have shown that trees can live substantially longer and that mortality rates may be less than expected (Orwig 2002, Eschtruth et al. 2013). Eschtruth et al. (2013) conducted the most complete and long-term study on hemlock mortality in the Delaware Water Gap National Recreate Area, PA. They calculated that survivorship of eastern hemlock average 73% after HWA infestation.

Deer over browsing could also result in a loss of eastern hemlock in these swamps. Hough (1965) found that deer can drastically alter the composition of the understory in hemlock-mixed hardwood forests. He found that white-tailed deer will heavily browse young hemlocks which will kill many and, if they manage to survive, greatly reduce the vigor of remaining individuals. Rogers (1977) also found that deer will readily eat eastern hemlock and can be one of the most important factors in preventing reestablishment of this tree species. It is well documented that white-tailed deer will readily eat hemlock and consume all seedlings and saplings in yarding areas during the winter months (Hosley and Ziebarth 1935, Rogers 1977).

The loss of eastern hemlock will open gaps in wetlands that NOWA occupy and over browsing by deer will prevent regeneration of trees. This will reduce the rate that succession can progress at which will extend the life of these gaps. As has already been explained, these gaps will cause changes in the microclimate of NOWA habitat and this warming, along with the warming associated with climate change, may have an effect on their food availability and abundance (Orwig et al. 2002, Baiser et al. 2008, Brantley et al. 2013). Kamler (1965) found that species richness, specifically of the insect orders Ephemeroptera and Plecoptera, was higher in cooler, more thermally stable environments that are often associated with hemlock-dominated streams (Snyder et al. 2002). This is especially important because Plecoptera and Ephemeroptera are two main food resources of both LOWA and NOWA (Whitaker and Eaton 2014).

A study conducted by Adkins and Rieske (2015) compared the composition of insects known as shredders in headwaters with hemlock dominated overstory to headwaters dominated by deciduous species, the likely replacements following the loss of eastern hemlock. They found that shredders, with Plecopterans being the dominant order, were significantly more abundant during the summer in headwaters streams that were near hemlock forests, possibly due to the constant litter output that these shredders feed upon (Adkins and Rieske 2015). Eastern hemlock is a less nutritious but more constant food source whereas deciduous trees are more nutritious but highly seasonal (Adkins and Rieske 2015).

Confirming and understanding the possible reasons for NOWA decline is important for continued existence of this species in Pennsylvania. NOWA can also be considered an umbrella species for peatland habitats and other species found in this habitat type. (Pennsylvania Biological Survey Technical Committee 2013, Sneddon and Hammerson 2014). The most important "other" species is probably the Canada Warbler (CAWA). CAWA and NOWA were seen together at 60% of the field sites and it was the only species that was significantly different in both the SIMPER analysis (Appendix XVII) and the Warton et al. (2012) method (Appendix XIX).

CAWA occupies higher elevation wetlands at the southern edge of its range, which is in Pennsylvania, as is the case with NOWA (Reitsma et al. 2009). Based on the 2nd PBBA, CAWA appear to be stable within the state (Wilson et al. 2012) despite their general, overall long-term decline due to fragmentation, loss of wetlands, and forest maturation) (NatureServe 2017). In New York, CAWA experienced a 23% decline between the first and second atlas there (McGowan and Corwin 2008). NOWA, on the other hand, were found in low numbers throughout New York State but the population appeared to be relatively stable between the two atlases (McGowan and Corwin 2008). However, the decline of CAWA in the New York State Atlas appears to be a more general decline.

<u>Future Studies and Issues of Concern Highlighted by This Study</u>

Previous research has documented changes in avian populations due to climate change (Thomas and Lennon 1999, Hitch and Leberg 2007). NOWA and CAWA are two species that are likely to be severely impacted by climate change because they are at the southern edge of their range in an area that will lose a lot of potential habitat as temperatures warm (Thomas and Lennon 1999, Reitsma et al. 2009, Whitaker and Eaton 2014). Our study did not support this finding, perhaps because the magnitude of topographical relief in Pennsylvania is simply not great enough for detection of significant elevationally driven range shifts. At the same time, this also makes such species considerably more susceptible to climate change because the higher elevations with cooler temperatures they will eventually require are quite limited in Pennsylvania where the highest point, Mt. Davis, is only 3,200 ft above sea level. Further research needs to be conducted at a broader scale, e.g. including more surrounding states, for this species, and other peatland species, in order to truly determine whether climate change is affecting their range, distribution and abundance.

Fragmentation effects on NOWA have proven difficult to establish but nevertheless are another factor potentially affecting the decline of this species. The influence of wetland size and shape on NOWA populations is probably not similar to the dynamics associated with typical woodland fragments and bird populations. This is because the habitat of concern, wetland, is embedded within larger forest fragments, making it difficult to separate the effects of wetland size and shape from the size and shape of the forest fragments that surround them. Thus, it is difficult to tease apart all of the habitat size and shape influences acting on NOWA populations. One additional area that could be investigated further with regard to fragmentation is the extent to which second home development is having an impact on NOWA in areas where there was a decline in block occupancy.

There has been a lot of research conducted on how deer over browsing affects vegetation, but only recently have the effects on the avian community been examined in detail using modern field methods (Hosley and Ziebarth 1935, Allombert et al. 2005a, Baiser et al. 2008). An overabundance of deer throughout their range (McCabe and McCabe 1984, deCalesta 1997) could be a major factor contributing to the decline of NOWA. Specific factors that could be examined in further detail are increased predation due to lack of concealing vegetation with regard to nests and how changes in the vegetation structure affect the foraging behavior and reproductive success of NOWA.

Examination of the loss of hemlocks and how this is currently affecting NOWA populations should be examined in more detail. Obvious factors related to hemlock loss that could be investigated are how the microclimate of wetlands that no longer have eastern hemlock is changing and how this loss affecting the macroinvertebrates that NOWA feed on. Less obvious, but potentially very interesting to investigate in the future, is the interplay, with regard to changes in vegetation structure and composition, between deer over browsing and hemlock decline. Deer over browsing removes mostly woody understory shrubs and some ground cover (e.g., native wildflowers) which opens space typically usurped by invasive species such as hayscented fern and Japanese barberry (*Berberis thunbergii*). Hemlock decline affects both the canopy and the understory, the latter not by freeing up space but by allowing light penetration to the forest floor which then stimulates understory growth, probably more often composed of native species, due to acidic soil conditions, than invasive species. Thus, the two impacts may tend to counteract one another with regard to understory structure.

Conclusion

NOWA are potentially under pressure from many different negative impacts from fragmentation to deer over browsing, changes in forest composition, hydrological changes and climate change. However, the most pressing of these concerns currently appears to be changes in vegetation structure. These changes appear to be influenced by several factors and may be largely responsible for the current decline in NOWA populations detected by the 2nd PBBA. Climate change, on the other hand, is likely the most important future impact affecting this species in Pennsylvania (Sneddon and Hammerson 2014, Langham et al. 2015).

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APPENDICES

Appendix I. Field Site Locations.

Name	Status	Latitude	Longitude	County
Bear Swamp	Occupied	40.90325	-75.17834	Northampton
Bear Swamp - Boardwalk	Occupied	40.91027	-75.18654	Northampton
Bear Swamp - Boardwalk 2	Occupied	40.91085	-75.18800	Northampton
Bear Swamp - Nest	Occupied	40.90428	-75.17796	Northampton
Bear Swamp 2	Occupied	40.90415	-75.17802	Northampton
Bear Wallow	Occupied	41.34683	-75.23599	Pike
Beaver Run 2	Occupied	41.24111	-75.07771	Pike
Brady's Lake	Occupied	41.17997	-75.52119	Monroe
Brady's Lake - 7 Mile Road	Occupied	41.19946	-75.46296	Monroe
Brady's Lake - 7 Mile Road 2	Occupied	41.20090	-75.46190	Monroe
Caughbaugh Road	Occupied	41.13772	-75.59298	Monroe
Caughbaugh Road 2	Occupied	41.14313	-75.58611	Monroe
Cranberry Bog - Boardwalk	Occupied	41.03838	-75.26625	Monroe
Cranberry Bog - Edge	Occupied	41.04008	-75.26655	Monroe
Cranberry Bog - Parking Lot	Occupied	41.04173	-75.26471	Monroe
Cranberry Bog - Parking Lot 2	Occupied	41.04149	-75.26749	Monroe
Dingmans Turnpike	Occupied	41.29476	-74.97618	Pike
Fivemile Meadow	Occupied	41.28616	-75.00475	Pike
Grass Lake	Occupied	41.03388	-75.43866	Monroe
Hobday Road	Occupied	41.30896	-75.11485	Pike
Long Pond Swamp	Occupied	41.34460	-75.14977	Pike
Lost Lakes - Lake 1	Occupied	41.08410	-75.48576	Monroe
Lost Lakes - Lake 3	Occupied	41.08319	-75.49067	Monroe
Lost Lakes - Swamp Alley	Occupied	41.08126	-75.48526	Monroe
Lower Lake	Occupied	41.31104	-75.22452	Pike
Maple Run	Occupied	41.31462	-75.09493	Pike
Painter Swamp	Occupied	41.23410	-75.02780	Pike
Tarkill Demo	Occupied	41.30865	-75.10969	Pike
Tobyhanna Road 2	Occupied	41.22018	-75.44351	Monroe
Turner Swamp Road	Occupied	41.16269	-75.10042	Pike
Turner Swamp Road 2	Occupied	41.16321	-75.10198	Pike
Turner Swamp Road 3	Occupied	41.16229	-75.10381	Pike
Valley Road	Occupied	41.38041	-75.06758	Pike
Whitaker Road	Occupied	41.18290	-75.06086	Pike
Whitaker Road 2	Occupied	41.17639	-75.07210	Pike
Beaver Lake	Unoccupied	41.39140	-75.09140	Pike

Beaver Run	Unoccupied	41.23896	-75.07557	Pike
Brady's Lake - Parking	Unoccupied	41.16169	-75.53054	Monroe
Dwarfs Kill	Unoccupied	41.29649	-74.93886	Pike
Grange Road	Unoccupied	41.11560	-75.34540	Monroe
Hell Hollow Road	Unoccupied	40.95023	-75.54957	Monroe
Hell Hollow Road 2	Unoccupied	40.94794	-75.54018	Monroe
Hemlock Way	Unoccupied	41.20008	-75.22235	Monroe
Ice Lake	Unoccupied	41.14940	-75.29030	Monroe
Indian Swamp	Unoccupied	41.25710	-75.12830	Pike
Lake Greeley	Unoccupied	41.41600	-75.01350	Pike
Lake Road	Unoccupied	41.19732	-75.21992	Monroe
Merry Hill Trail Wet Meadow	Unoccupied	41.11525	-75.31028	Monroe
Plank Road	Unoccupied	41.22235	-75.52712	Monroe
Seven Pines	Unoccupied	41.14141	-75.29370	Monroe
Shohola Creek	Unoccupied	41.37022	-75.05106	Pike
Tobyhanna Road	Unoccupied	41.20481	-75.44308	Monroe
Two Mile Run	Unoccupied	41.13525	-75.57781	Monroe

Appendix II. Average percent of plant species found at occupied and unoccupied sites.

Common Name	Latin Name	Group	Occupied	Unoccupied
American Elm	*Ulmus americana*	Tree	0.01	0.00
Beech	*Fagus grandifolia*	Tree	0.04	0.07
Black Birch	*Betula lenta*	Tree	0.01	0.04
Black Cherry	*Prunus serotina*	Tree	0.00	0.01
Black Spruce	*Picea mariana*	Tree	0.04	0.01
Black Walnut	*Juglans nigra*	Tree	0.00	0.00
Black Willow	*Salix nigra*	Tree	0.00	0.01
Blue Spruce	*Picea pungens*	Tree	0.00	0.00
Eastern Hemlock	*Tsuga canadensis*	Tree	0.19	0.11
Gray Birch	*Betula populifolia*	Tree	0.00	0.00
Green Ash	*Fraxinus pennsylvanica*	Tree	0.04	0.01
Musclewood	*Carpinus caroliniana*	Tree	0.00	0.00
Red Maple	*Acer rubrum*	Tree	0.39	0.46
Red Oak	*Quercus rubra*	Tree	0.00	0.00
Shagbark Hickory	*Carya ovata*	Tree	0.00	0.01
Slippery Elm	*Ulmus rubra*	Tree	0.00	0.00
Smooth Alder	*Alnus serrulata*	Tree	0.06	0.05
Sycamore	*Platanus occidentalis*	Tree	0.00	0.00
Tamarack	*Larix larcinia*	Tree	0.01	0.00
Tulip	*Lirodendron tulipifera*	Tree	0.00	0.01
Tupelo	*Nyssa sylvatica*	Tree	0.02	0.06
White Ash	*Fraxinus americana*	Tree	0.01	0.00
White Birch	*Betula papyrifera*	Tree	0.00	0.01
White Oak	*Quercus alba*	Tree	0.00	0.01
White Pine	*Pinus strobus*	Tree	0.02	0.06
Yellow Birch	*Betula alleghaniensis*	Tree	0.14	0.07
Buttonbush	*Cephalanthus occidentalis*	Shrub	0.00	0.01
European Elderberry	*Sambucus nigra*	Shrub	0.00	0.01
Fox Grape	*Vitis labrusca*	Shrub	0.01	0.00
High-bush Blueberry	*Vaccinium corymbosum*	Shrub	0.43	0.63
Japanese Barberry	*Berberis thunbergii*	Shrub	0.00	0.05

Mountain Holly	*Ilex mucronate*	Shrub	0.02	0.01
Multiflora Rose	*Rosa multiflora*	Shrub	0.00	0.01
Rhododendron	*Rhododendron maximum*	Shrub	0.20	0.17
Serviceberry	*Amelanchier arborea*	Shrub	0.00	0.02
Sheep Laurel	*Kalmia angustifolia*	Shrub	0.00	0.00
Southern Arrowwood	*Viburnum dentatum*	Shrub	0.00	0.00
Spicebush	*Lindera benzoin*	Shrub	0.12	0.00
Swamp Azalea	*Rhododendron viscosum*	Shrub	0.00	0.03
Winterberry	*Ilex verticillata*	Shrub	0.18	0.04
Witch Hazel	*Hamamelis virginiana*	Shrub	0.02	0.00
Arroweed	*Pluchea sericea*	Herbaceous	0.03	0.00
Aster	*Asteraceae*	Herbaceous	0.00	0.03
Bedstraw	*Gallium* sp.	Herbaceous	0.01	0.00
Bittercress	*Cardamine hirsuta*	Herbaceous	0.01	0.00
Broadleaf Cattail	*Typha latifolia*	Herbaceous	0.00	0.00
Bugleweed	*Lycopus americanus*	Herbaceous	0.04	0.01
Calla Lily	*Zantedeschia aethiopica*	Herbaceous	0.01	0.00
Canada Maylily	*Maianthemum canadense*	Herbaceous	0.01	0.00
Canadian Bunchberry	*Cornus canadensis*	Herbaceous	0.00	0.00
Cinnamon Fern	*Osmundastrum cinnamomeum*	Herbaceous	0.11	0.05
Common Blue Violet	*Viola sororia*	Herbaceous	0.00	0.00
Common Boneset	*Eupatorium perfoliatum*	Herbaceous	0.00	0.00
Dewberry	*Rubus pubescens*	Herbaceous	0.00	0.01
Enchanter’s Nightshade	*Circaea lutetiana*	Herbaceous	0.00	0.01
False Hellebore	*Veratrum californicum*	Herbaceous	0.00	0.01
Field Horsetail	*Equisetum arvense*	Herbaceous	0.00	0.00
Golden Club	*Orontium aquaticum*	Herbaceous	0.00	0.00

Golden Saxifrage	*Chrysosplenium americanum*	Herbaceous	0.00	0.00
Grass	*Poaceae* sp.	Herbaceous	0.03	0.05
Hay-scented Fern	*Dennstaedtia punctilobula*	Herbaceous	0.01	0.07
Jack-in-the-Pulpit	*Arisaema triphyllum*	Herbaceous	0.01	0.00
Japanese Stiltgrass	*Microstegium vimineum*	Herbaceous	0.02	0.03
Jewelweed	*Impatiens capensis*	Herbaceous	0.05	0.07
Marginal Wood Fern	*Dryopteris marginalis*	Herbaceous	0.00	0.00
Marsh Fern	*Thelypteris palustris*	Herbaceous	0.02	0.00
Marsh Marigold	*Caltha palustris*	Herbaceous	0.01	0.00
New York Fern	*Thelypteris noveboracensis*	Herbaceous	0.01	0.00
Northern Blue Flag	*Iris versicolor*	Herbaceous	0.01	0.01
Poison Ivy	*Toxicodendron radicans*	Herbaceous	0.01	0.01
Purple Pitcher Plant	*Sarracenia purpurea*	Herbaceous	0.00	0.00
Ragweed	*Ambrosia artemisiifolia*	Herbaceous	0.00	0.01
Royal Fern	*Osmunda regalis*	Herbaceous	0.00	0.01
Sedge	*Carex* sp.	Herbaceous	0.13	0.21
Sensitive Fern	*Onoclea sensibilis*	Herbaceous	0.08	0.04
Sideflowering Skullcap	*Scutellaria lateriflora*	Herbaceous	0.00	0.00
Skunk Cabbage	*Symplocarpus foetidus*	Herbaceous	0.01	0.01
Sphagnum	*Sphagnum* sp.	Herbaceous	0.24	0.22
St. John's Marshwort	*Hypericum perforatum*	Herbaceous	0.01	0.00
Starflower	*Trientalis borealis*	Herbaceous	0.01	0.01
Swamp Candle	*Lysimachia terrestris*	Herbaceous	0.01	0.03
Tall Meadow Rue	*Thalictrum dasycarpum*	Herbaceous	0.00	0.00
Threeleaf Goldenthread	*Coptis trifolia*	Herbaceous	0.02	0.00
Threeway Sedge	*Dulichium arundinaceum*	Herbaceous	0.01	0.00

Virginia Chainfern	*Woodwardia virginica*	Herbaceous	0.00	0.02
Virginia Creeper	*Parthenocissus quinquefolia*	Herbaceous	0.01	0.01
Virginia Strawberry	*Fragaria virginiana*	Herbaceous	0.00	0.00
Water Pennywort	*Hydrocotyle ranunculoides*	Herbaceous	0.00	0.00
White Meadowsweet	*Spiraea alba*	Herbaceous	0.01	0.04
Wineberry	*Rubus phoenicolasius*	Herbaceous	0.01	0.02
Wood Nettle	*Laportea candensis*	Herbaceous	0.00	0.00
Wood Sorrel	*Oxalis stricta*	Herbaceous	0.00	0.00
Other		Herbaceous	0.02	0.03

Appendix III. Species richness at occupied and unoccupied sites during the 2017 and 2018 field season.

Name	Status	Species Richness
Bear Swamp 2	Occupied	23
Whitaker Farm Road 2	Occupied	21
Grass Lake	Occupied	19
Cranberry Bog - Boardwalk	Occupied	19
Painter Swamp	Occupied	19
Turner Swamp	Occupied	19
Turner Swamp 2	Occupied	19
Brady's Lake	Occupied	17
Turner Swamp 3	Occupied	16
Cranberry Bog - Parking Lot 2	Occupied	16
Hobday Swamp	Occupied	16
Caughbaugh Road	Occupied	15
Bear Swamp - Boardwalk 2	Occupied	15
Caughbaugh Road 2	Occupied	15
Fivemile Meadow	Occupied	15
Tarkill Demo	Occupied	15
Valley Road	Occupied	14
Lower Lake	Occupied	14
Beaver Run 2	Occupied	14
Brady's Lake - 7 Mile Road 2	Occupied	14
Cranberry Bog - Parking Lot	Occupied	13
Cranberry Bog - Edge	Occupied	13
Bear Swamp - Boardwalk	Occupied	12
Bear Wallow	Occupied	12
Long Pond	Occupied	12
Tobyhanna Road 2	Occupied	11
Dingman's Turnpike	Occupied	11
Lost Lakes - Lake 3	Occupied	11
Brady's Lake - 7 Mile Road	Occupied	11
Maple Run	Occupied	11
Whitaker Farm Road	Occupied	10
Bear Swamp - Nest	Occupied	10
Lost Lakes - Swamp Alley	Occupied	8
Lost Lakes - Lake 1	Occupied	7
Ice Lake	Unoccupied	18
Beaver Run	Unoccupied	14
Shohola Swamp	Unoccupied	14

Merry Hill Wet Meadow	Unoccupied	14
Dwarfskill	Unoccupied	13
Brady's Lake - Parking Lot	Unoccupied	13
Grange Road	Unoccupied	13
Tobyhanna Road	Unoccupied	12
Hemlock Way	Unoccupied	11
Hell Hollow 2	Unoccupied	11
Two Mile Run	Unoccupied	10
Lake Road	Unoccupied	10
Hell Hollow	Unoccupied	9
Lake Greeley	Unoccupied	9
Seven Pines	Unoccupied	9
Indian Swamp	Unoccupied	6
Plank Road	Unoccupied	6

Appendix IV. Shannon diversity Index of plant communities for all field sites.

Site Name	Status	Shannon Index
Turner Swamp 2	Occupied	2.76
Whitaker Farm Road 2	Occupied	2.72
Turner Swamp	Occupied	2.70
Grass Lake	Occupied	2.69
Bear Swamp 2	Occupied	2.66
Ice Lake	Unoccupied	2.59
Painter Swamp	Occupied	2.58
Turner Swamp 3	Occupied	2.53
Cranberry Bog - Boardwalk	Occupied	2.50
Cranberry Bog - Parking Lot 2	Occupied	2.49
Brady's Lake	Occupied	2.49
Caughbaugh Road 2	Occupied	2.39
Bear Swamp - Boardwalk 2	Occupied	2.39
Caughbaugh Road	Occupied	2.38
Tarkill Demo	Occupied	2.38
Lower Lake	Occupied	2.35
Beaver Run	Unoccupied	2.35
Cranberry Bog - Edge	Occupied	2.34
Fivemile Meadow	Occupied	2.34
Tobyhanna Road	Unoccupied	2.31
Merry Hill Wet Meadow	Unoccupied	2.30
Beaver Run 2	Occupied	2.29
Brady's Lake - Parking Lot	Unoccupied	2.28
Tobyhanna Road 2	Occupied	2.24
Cranberry Bog - Parking Lot	Occupied	2.22
Shohola Swamp	Unoccupied	2.22
Hobday Swamp	Occupied	2.21
Bear Swamp - Boardwalk	Occupied	2.20
Bear Wallow	Occupied	2.16
Valley Road	Occupied	2.15
Brady's Lake - 7 Mile Road 2	Occupied	2.13
Grange Road	Unoccupied	2.11
Bear Swamp - Nest	Occupied	2.11
Hell Hollow 2	Unoccupied	2.11
Dwarfs Kill	Unoccupied	2.07
Hemlock Way	Unoccupied	2.07
Lost Lakes - Lake 3	Occupied	2.07
Brady's Lake - 7 Mile Road	Occupied	2.05

Whitaker Farm Road	Occupied	2.00
Lake Road	Unoccupied	1.99
Dingman's Turnpike	Occupied	1.99
Hell Hollow	Unoccupied	1.94
Long Pond	Occupied	1.93
Maple Run	Occupied	1.91
Lost Lakes - Swamp Alley	Occupied	1.87
Lake Greeley	Unoccupied	1.81
Two Mile Run	Unoccupied	1.79
Lost Lakes - Lake 1	Occupied	1.78
Seven Pines	Unoccupied	1.69
Indian Swamp	Unoccupied	1.67
Plank Road	Unoccupied	1.62

Appendix V. Frequency of plant species found at occupied and unoccupied sites.

Common Name	Latin Name	Occupied Frequency	Unoccupied Frequency
American Elm	*Ulmus americana*	0.06	NA
Arroweed	*Pluchea sericea*	0.26	NA
Aster	*Asteraceae*	0.06	0.18
Bedstraw	*Gallium* sp.	0.09	NA
Beech	*Fagus grandifolia*	0.21	0.24
Bittercress	*Cardamine hirsuta*	0.09	NA
Black Birch	*Betula lenta*	0.06	0.12
Black Cherry	*Prunus serotina*	NA	0.06
Black Spruce	*Picea mariana*	0.21	0.06
Black Walnut	*Juglans nigra*	0.03	NA
Black Willow	*Salix nigra*	NA	0.06
Blue Spruce	*Picea pungens*	0.03	NA
Broadleaf Cattail	*Typha latifolia*	0.03	NA
Bugleweed	*Lycopus americanus*	0.62	0.12
Buttonbush	*Cephalanthus occidentalis*	NA	0.06
Calla Lily	*Zantedeschia aethiopica*	0.09	NA
Canada Maylily	*Maianthemum canadense*	0.21	NA
Canadian Bunchberry	*Cornus canadensis*	0.03	NA
Cinnamon Fern	*Osmundastrum cinnamomeum*	0.76	0.41
Common Blue Violet	*Viola sororia*	0.06	0.06
Common Boneset	*Eupatorium perfoliatum*	NA	0.06
Dewberry	*Rubus pubescens*	0.03	0.06
Eastern Hemlock	*Tsuga canadensis*	0.62	0.47
Enchanter’s Nightshade	*Circaea lutetiana*	0.03	0.06
European Elderberry	*Sambucus nigra*	0.03	0.06
False Hellebore	*Veratrum californicum*	NA	0.12
Field Horsetail	*Equisetum arvense*	0.06	NA
Fox Grape	*Vitis labrusca*	0.06	NA
Golden Club	*Orontium aquaticum*	0.03	NA
Golden Saxifrage	*Chrysosplenium americanum*	0.03	NA
Grass	*Poaceae* sp.	0.18	0.24
Gray Birch	*Betula populifolia*	0.06	NA
Green Ash	*Fraxinus pennsylvanica*	0.15	0.12
Hay-scented Fern	*Dennstaedtia punctilobula*	0.09	0.53
High-bush Blueberry	*Vaccinium corymbosum*	0.79	0.76
Jack-in-the-Pulpit	*Arisaema triphyllum*	0.15	0.06

Japanese Barberry	*Berberis thunbergii*	0.03	0.12
Japanese Stiltgrass	*Microstegium vimineum*	0.03	0.18
Jewelweed	*Impatiens capensis*	0.50	0.47
Marginal Wood Fern	*Dryopteris marginalis*	0.03	NA
Marsh Fern	*Thelypteris palustris*	0.35	0.06
Marsh Marigold	*Caltha palustris*	0.09	0.06
Mountain Holly	*Ilex mucronate*	0.06	0.06
Multiflora Rose	*Rosa multiflora*	NA	0.12
Musclewood	*Carpinus caroliniana*	0.06	0.06
New York Fern	*Thelypteris noveboracensis*	0.03	NA
Northern Blue flag	*Iris versicolor*	0.21	0.06
Poison Ivy	*Toxicodendron radicans*	0.09	0.06
Purple Pitcher Plant	*Sarracenia purpurea*	0.06	NA
Ragweed	*Ambrosia artemisiifolia*	NA	0.06
Red Maple	*Acer rubrum*	1.00	0.94
Red Oak	*Quercus rubra*	0.03	NA
Rhododendron	*Rhododendron maximum*	0.41	0.24
Royal Fern	*Osmunda regalis*	0.06	0.06
Sedge	*Carex* sp.	0.68	0.76
Sensitive Fern	*Onoclea sensibilis*	0.59	0.35
Serviceberry	*Amelanchier arborea*	NA	0.06
Shagbark Hickory	*Carya ovata*	0.03	0.12
Sheep Laurel	*Kalmia angustifolia*	0.06	NA
Sideflowering Skullcap	*Scutellaria lateriflora*	0.03	NA
Skunk Cabbage	*Symplocarpus foetidus*	0.15	0.06
Slippery Elm	*Ulmus rubra*	0.03	NA
Smooth Alder	*Alnus serrulata*	0.18	0.12
Southern Arrowwood	*Viburnum dentatum*	0.03	NA
Sphagnum	*Sphagnum* sp.	0.85	0.76
Spicebush	*Lindera benzoin*	0.26	NA
St. John’s Marshwort	*Hypericum perforatum*	0.12	NA
Starflower	*Trientalis borealis*	0.12	0.12
Swamp Azalea	*Rhododendron viscosum*	0.03	0.06
Swamp Candle	*Lysimachia terrestris*	0.24	0.06
Sycamore	*Platanus occidentalis*	0.03	NA
Tall Meadow Rue	*Thalictrum dasycarpum*	NA	0.06
Tamarack	*Larix larcinia*	0.03	NA
Threeleaf Goldenthread	*Coptis trifolia*	0.32	NA
Threeway Sedge	*Dulichium arundinaceum*	0.06	NA
Tulip	*Lirodendron tulipifera*	0.09	0.12
Tupelo	*Nyssa sylvatica*	0.15	0.29

Virginia Chainfern	*Woodwardia virginica*	NA	0.06
Virginia Creeper	*Parthenocissus quinquefolia*	0.15	0.06
Virginia Strawberry	*Fragaria virginiana*	0.03	0.06
Water Pennywort	*Hydrocotyle ranunculoides*	0.03	NA
White Ash	*Fraxinus americana*	0.06	NA
White Birch	*Betula papyrifera*	NA	0.06
White Meadowsweet	*Spiraea alba*	0.06	0.18
White Oak	*Quercus alba*	0.06	0.06
White Pine	*Pinus strobus*	0.12	0.29
Wineberry	*Rubus phoenicolasius*	0.15	0.18
Winterberry	*Ilex verticillata*	0.62	0.18
Witch Hazel	*Hamamelis virginiana*	0.12	0.06
Wood Nettle	*Laportea candensis*	0.03	NA
Wood Sorrel	*Oxalis stricta*	0.03	0.06
Yellow Birch	*Betula alleghaniensis*	0.47	0.35
Other		0.15	0.35

Appendix VI. SIMPER results showing the contribution of each species to the overall Bray-Curtis dissimilarity between occupied and unoccupied sites with all plants included (asterisk indicates significance).

Species	**Latin Name**	**Cumulative Contribution**	***p*-value**
High-bush Blueberry	*Vaccinium corymbosum*	0.11	0.02*
Rhododendron	*Rhododendron maximum*	0.19	0.43
Red Maple	*Acer rubrum*	0.26	0.08
Sphagnum	*Sphagnum* sp.	0.31	0.28
Sedge	*Carex* sp.	0.36	0.06
Eastern Hemlock	*Tsuga canadensis*	0.41	0.76
Winterberry	*Ilex verticillata*	0.46	0.14
Yellow Birch	*Betula alleghaniensis*	0.50	0.79
Spicebush	*Lindera benzoin*	0.53	1.00
Smooth Alder	*Alnus serrulata*	0.56	0.62
Beech	*Fagus grandifolia*	0.58	0.24
Cinnamon Fern	*Osmundastrum cinnamomeum*	0.61	0.30
Jewelweed	*Impatiens capensis*	0.63	0.12
Sensitive Fern	*Onoclea sensibilis*	0.65	0.78
Hay-scented Fern	*Dennstaedtia punctilobula*	0.67	0.001*
White Pine	*Pinus strobus*	0.69	0.08
Grass	*Poaceae* sp.	0.70	0.19
Tupelo	*Nyssa sylvatica*	0.72	0.06
Green Ash	*Fraxinus pennsylvanica*	0.73	0.83
Black Birch	*Betula lenta*	0.75	0.19
Japanese Barberry	*Berberis thunbergii*	0.76	0.10
Bugleweed	*Lycopus americanus*	0.77	0.31
Japanese Stiltgrass	*Microstegium vimineum*	0.78	0.36
Black Spruce	*Picea mariana*	0.80	0.82
White Meadowsweet	*Spiraea alba*	0.81	0.13
Other		0.82	0.21
Swamp Candle	*Lysimachia terrestris*	0.83	0.31
Swamp Azalea	*Rhododendron viscosum*	0.83	0.33
Aster	*Asteraceae*	0.84	0.05*
Arroweed	*Pluchea sericea*	0.85	1.00
Wineberry	*Rubus phoenicolasius*	0.86	0.35
Mountain Holly	*Ilex mucronate*	0.86	0.71
Serviceberry	*Amelanchier arborea*	0.87	0.34

Virginia Chainfern	*Woodwardia virginica*	0.87	0.34
Marsh Fern	*Thelypteris palustris*	0.88	0.94
Virginia Creeper	*Parthenocissus quinquefolia*	0.89	0.69
Witch Hazel	*Hamamelis virginiana*	0.89	0.89
Threeleaf Goldenthread	*Coptis trifolia*	0.90	0.89
Poison Ivy	*Toxicodendron radicans*	0.90	0.35
Skunk Cabbage	*Symplocarpus foetidus*	0.91	0.71
Shagbark Hickory	*Carya ovata*	0.91	0.10
Royal Fern	*Osmunda regalis*	0.91	0.33
Northern Blue Flag	*Iris versicolor*	0.92	0.67
Tulip	*Lirodendron tulipifera*	0.92	0.13
St. John's Marshwart	*Hypericum perforatum*	0.92	1.00
Threeway Sedge	*Dulichium arundinaceum*	0.93	1.00
Fox Grape	*Vitis labrusca*	0.93	1.00
Canada Maylily	*Maianthemum canadense*	0.94	1.00
European Elderberry	*Sambucus nigra*	0.94	0.58
Dewberry	*Rubus pubescens*	0.94	0.57
Tamarack	*Larix larcinia*	0.95	1.00
Multiflora Rose	*Rosa multiflora*	0.95	0.12
Starflower	*Trientalis borealis*	0.95	0.56
Jack-in-the-Pulpit	*Arisaema triphyllum*	0.95	0.92
Calla Lily	*Zantedeschia aethiopica*	0.96	1.00
White Ash	*Fraxinus americana*	0.96	1.00
False Hellebore	*Veratrum californicum*	0.96	0.10
Bittercress	*Cardamine hirsuta*	0.96	1.00
White Oak	*Quercus alba*	0.97	0.41
Marsh Marigold	*Caltha palustris*	0.97	0.80
American Elm	*Ulmus americana*	0.97	1.00
Enchanter's Nightshade	*Circaea lutetiana*	0.97	0.34
White Birch	*Betula papyrifera*	0.97	0.35
Black Cherry	*Prunus serotina*	0.97	0.35
Black Willow	*Salix nigra*	0.98	0.35
Buttonbush	*Cephalanthus occidentalis*	0.98	0.34
Bedstraw	*Gallium* sp.	0.98	1.00
Ragweed	*Ambrosia artemisiifolia*	0.98	0.31
New York Fern	*Thelypteris noveboracensis*	0.98	1.00
Common Blue Violet	*Viola sororia*	0.98	0.72
Gray Birch	*Betula populifolia*	0.98	1.00

Slippery Elm	*Ulmus rubra*	0.99	1.00
Marginal Wood Fern	*Dryopteris marginalis*	0.99	1.00
Virginia Strawberry	*Fragaria virginiana*	0.99	0.58
Wood Sorrel	*Oxalis stricta*	0.99	0.58
Musclewood	*Carpinus caroliniana*	0.99	0.73
Sheep Laurel	*Kalmia angustifolia*	0.99	1.00
Field Horsetail	*Equisetum arvense*	0.99	1.00
Southern Arrowwood	*Viburnum dentatum*	0.99	1.00
Purple Pitcher Plant	*Sarracenia purpurea*	0.99	1.00
Golden Club	*Orontium aquaticum*	0.99	1.00
Water Pennywort	*Hydrocotyle ranunculoides*	0.99	1.00
Golden Saxifrage	*Chrysosplenium americanum*	1.00	1.00
Common Boneset	*Eupatorium perfoliatum*	1.00	0.34
Tall Meadow Rue	*Thalictrum dasycarpum*	1.00	0.33
Sideflowering Skullcap	*Scutellaria lateriflora*	1.00	1.00
Blue Spruce	*Picea pungens*	1.00	1.00
Sycamore	*Platanus occidentalis*	1.00	1.00
Black Walnut	*Juglans nigra*	1.00	1.00
Red Oak	*Quercus rubra*	1.00	1.00
Canadian Bunchberry	*Cornus canadensis*	1.00	1.00
Broadleaf Cattail	*Typha latifolia*	1.00	1.00
Wood Nettle	*Laportea candensis*	1.00	1.00

Appendix VII. SIMPER results showing the contribution of each species to the overall Bray-Curtis dissimilarity between occupied and unoccupied sites including only herbaceous vegetation (asterisk indicates significance).

Species	**Latin Name**	**Cumulative Contribution**	***p*-value**
Sphagnum	*Sphagnum* sp.	0.15	0.24
Sedge	*Carex* sp.	0.28	0.08
Cinnamon Fern	*Osmundastrum cinnamomeum*	0.35	0.33
Jewelweed	*Impatiens capensis*	0.40	0.13
Sensitive Fern	*Onoclea sensibilis*	0.46	0.82
Hay-scented Fern	*Dennstaedtia punctilobula*	0.51	0.001*
Grass	*Poaceae* sp.	0.56	0.15
Bugleweed	*Lycopus americanus*	0.59	0.34
Japanese Stiltgrass	*Microstegium vimineum*	0.63	0.34
Other		0.65	0.19
Swamp Candle	*Lysimachia terrestris*	0.68	0.32
White Meadowsweet	*Spiraea alba*	0.70	0.11
Aster	*Asteraceae*	0.73	0.03*
Arroweed	*Pluchea sericea*	0.75	1.00
Wineberry	*Rubus phoenicolasius*	0.76	0.39
Virginia Chainfern	*Woodwardia virginica*	0.78	0.06
Marsh Fern	*Thelypteris palustris*	0.80	0.96
Virginia Creeper	*Parthenocissus quinquefolia*	0.81	0.65
Threeleaf Goldenthread	*Coptis trifolia*	0.83	0.92
Poison Ivy	*Toxicodendron radicans*	0.84	0.34
Skunk Cabbage	*Symplocarpus foetidus*	0.85	0.71
Royal Fern	*Osmunda regalis*	0.86	0.21
Northern Blue Flag	*Iris versicolor*	0.87	0.65
St. John's Marshwart	*Hypericum perforatum*	0.88	0.97
Threeway Sedge	*Dulichium arundinaceum*	0.89	0.94
Canada Maylily	*Maianthemum canadense*	0.90	1.00
Dewberry	*Rubus pubescens*	0.91	0.21
Starflower	*Trientalis borealis*	0.92	0.55
Jack-in-the-Pulpit	*Arisaema triphyllum*	0.93	0.90
Calla Lily	*Zantedeschia aethiopica*	0.93	0.96
False Hellebore	*Veratrum californicum*	0.94	0.02*
Bittercress	*Cardamine hirsuta*	0.94	0.97
Marsh Marigold	*Caltha palustris*	0.95	0.80

Enchanter's Nightshade	*Circaea lutetiana*	0.96	0.16
Ragweed	*Ambrosia artemisiifolia*	0.96	0.06
Bedstraw	*Gallium* sp.	0.96	0.95
New York Fern	*Thelypteris noveboracensis*	0.97	0.92
Common Blue Violet	*Viola sororia*	0.97	0.64
Virginia Strawberry	*Fragaria virginiana*	0.97	0.56
Wood Sorrel	*Oxalis stricta*	0.98	0.57
Marginal Wood Fern	*Dryopteris marginalis*	0.98	1.00
Field Horsetail	*Equisetum arvense*	0.98	0.94
Common Boneset	*Eupatorium perfoliatum*	0.98	0.06
Tall Meadow Rue	*Thalictrum dasycarpum*	0.99	0.07
Purple Pitcher Plant	*Sarracenia purpurea*	0.99	0.94
Golden Club	*Orontium aquaticum*	0.99	0.92
Water Pennywort	*Hydrocotyle ranunculoides*	0.99	0.91
Golden Saxifrage	*Chrysosplenium americanum*	1.00	0.92
Sideflowering Skullcap	*Scutellaria lateriflora*	1.00	1.00
Canadian Bunchberry	*Cornus canadensis*	1.00	0.92
Broadleaf Cattail	*Typha latifolia*	1.00	0.93
Wood Nettle	*Laportea candensis*	1.00	0.92

Appendix VIII. Warton et al. (2012) results for all plant species (asterisk indicates significance).

Species	Scientific Name	Group	*p*-value
American Elm	*Ulmus americana*	Tree	1
Beech	*Fagus grandifolia*	Tree	1
Black Birch	*Betula lenta*	Tree	1
Black Cherry	*Prunus serotina*	Tree	1
Black Spruce	*Picea mariana*	Tree	1
Black Walnut	*Juglans nigra*	Tree	1
Black Willow	*Salix nigra*	Tree	1
Blue Spruce	*Picea pungens*	Tree	1
Eastern Hemlock	*Tsuga canadensis*	Tree	1
Gray Birch	*Betula populifolia*	Tree	1
Green Ash	*Fraxinus pennsylvanica*	Tree	1
Musclewood	*Carpinus caroliniana*	Tree	1
Red Maple	*Acer rubrum*	Tree	1
Red Oak	*Quercus rubra*	Tree	1
Shagbark Hickory	*Carya ovata*	Tree	1
Slippery Elm	*Ulmus rubra*	Tree	1
Smooth Alder	*Alnus serrulata*	Tree	1
Sycamore	*Platanus occidentalis*	Tree	1
Tamarack	*Larix larcinia*	Tree	1
Tulip	*Lirodendron tulipifera*	Tree	1
Tupelo	*Nyssa sylvatica*	Tree	0.99
White Ash	*Fraxinus americana*	Tree	1
White Birch	*Betula papyrifera*	Tree	1
White Oak	*Quercus alba*	Tree	1
White Pine	*Pinus strobus*	Tree	0.99
Yellow Birch	*Betula alleghaniensis*	Tree	1
Buttonbush	*Cephalanthus occidentalis*	Shrub	1
European Elderberry	*Sambucus nigra*	Shrub	1
Fox Grape	*Vitis labrusca*	Shrub	1
High-bush Blueberry	*Vaccinium corymbosum*	Shrub	0.95
Japanese Barberry	*Berberis thunbergii*	Shrub	0.57
Mountain Holly	*Ilex mucronate*	Shrub	1
Multiflora Rose	*Rosa multiflora*	Shrub	1
Rhododendron	*Rhododendron maximum*	Shrub	1
Serviceberry	*Amelanchier arborea*	Shrub	0.95

Sheep Laurel	*Kalmia angustifolia*	Shrub	1
Southern Arrowwood	*Viburnum dentatum*	Shrub	1
Spicebush	*Lindera benzoin*	Shrub	0.04*
Swamp Azalea	*Rhododendron viscosum*	Shrub	0.99
Winterberry	*Ilex verticillata*	Shrub	0.17
Witch Hazel	*Hamamelis virginiana*	Shrub	1
Arrowweed	*Pluchea sericea*	Herbaceous	0.95
Aster	*Asteraceae*	Herbaceous	0.99
Bedstraw	*Gallium* sp.	Herbaceous	1
Bittercress	*Cardamine hirsuta*	Herbaceous	1
Broadleaf Cattail	*Typha latifolia*	Herbaceous	1
Bugleweed	*Lycopus americanus*	Herbaceous	1
Calla Lily	*Zantedeschia aethiopica*	Herbaceous	1
Canada Maylily	*Maianthemum canadense*	Herbaceous	1
Canadian Bunchberry	*Cornus canadensis*	Herbaceous	1
Cinnamon Fern	*Osmundastrum cinnamomeum*	Herbaceous	1
Common Blue Violet	*Viola sororia*	Herbaceous	1
Common Boneset	*Eupatorium perfoliatum*	Herbaceous	1
Dewberry	*Rubus pubescens*	Herbaceous	1
Enchanter s Nightshade	*Circaea lutetiana*	Herbaceous	1
False Hellebore	*Veratrum californicum*	Herbaceous	1
Field Horsetail	*Equisetum arvense*	Herbaceous	1
Golden Club	*Orontium aquaticum*	Herbaceous	1
Golden Saxifrage	*Chrysosplenium americanum*	Herbaceous	1
Grass	*Poaceae* sp.	Herbaceous	1
Hay-scented Fern	*Dennstaedtia punctilobula*	Herbaceous	0.39
Jack-in-the-Pulpit	*Arisaema triphyllum*	Herbaceous	1
Japanese Stiltgrass	*Microstegium vimineum*	Herbaceous	1
Jewelweed	*Impatiens capensis*	Herbaceous	1
Marginal Wood Fern	*Dryopteris marginalis*	Herbaceous	1
Marsh Fern	*Thelypteris palustris*	Herbaceous	1
Marsh Marigold	*Caltha palustris*	Herbaceous	1
New York Fern	*Thelypteris noveboracensis*	Herbaceous	1
Northern Blue Flag	*Iris versicolor*	Herbaceous	1
Poison Ivy	*Toxicodendron radicans*	Herbaceous	1
Purple Pitcher Plant	*Sarracenia purpurea*	Herbaceous	1
Ragweed	*Ambrosia artemisiifolia*	Herbaceous	1
Royal Fern	*Osmunda regalis*	Herbaceous	1

Sedge	*Carex* sp.	Herbaceous	1
Sensitive Fern	*Onoclea sensibilis*	Herbaceous	1
Sideflowering Skullcap	*Scutellaria lateriflora*	Herbaceous	1
Skunk Cabbage	*Symplocarpus foetidus*	Herbaceous	1
Sphagnum	*Sphagnum* sp.	Herbaceous	1
St. John's Marshwart	*Hypericum perforatum*	Herbaceous	1
Starflower	*Trientalis borealis*	Herbaceous	1
Swamp Candle	*Lysimachia terrestris*	Herbaceous	1
Tall Meadow Rue	*Thalictrum dasycarpum*	Herbaceous	1
Threeleaf Goldenthread	*Coptis trifolia*	Herbaceous	0.99
Threeway Sedge	*Dulichium arundinaceum*	Herbaceous	1
Virginia Chainfern	*Woodwardia virginica*	Herbaceous	0.90
Virginia Creeper	*Parthenocissus quinquefolia*	Herbaceous	1
Virginia Strawberry	*Fragaria virginiana*	Herbaceous	1
Water Pennywort	*Hydrocotyle ranunculoides*	Herbaceous	1
White Meadowsweet	*Spiraea alba*	Herbaceous	1
Wineberry	*Rubus phoenicolasius*	Herbaceous	1
Wood Nettle	*Laportea candensis*	Herbaceous	1
Wood Sorrel	*Oxalis stricta*	Herbaceous	1
Other		Herbaceous	1

Appendix IX. Warton et al. (2012) results with only shrub species (asterisk indicates significance).

Species	Scientific Name	*p*-value
Buttonbush	*Cephalanthus occidentalis*	0.98
European Elderberry	*Sambucus nigra*	0.98
Fox Grape	*Vitis labrusca*	0.85
High-bush Blueberry	*Vaccinium corymbosum*	0.51
Japanese Barberry	*Berberis thunbergii*	0.34
Mountain Holly	*Ilex mucronate*	0.98
Multiflora Rose	*Rosa multiflora*	0.79
Rhododendron	*Rhododendron maximum*	0.98
Serviceberry	*Amelanchier arborea*	0.51
Sheep Laurel	*Kalmia angustifolia*	0.98
Southern Arrowwood	*Viburnum dentatum*	0.98
Spicebush	*Lindera benzoin*	0.02*
Swamp Azalea	*Rhododendron viscosum*	0.67
Winterberry	*Ilex verticillata*	0.05
Witch Hazel	*Hamamelis virginiana*	0.85

Appendix X. Warton et al. (2012) results with only herbaceous species (asterisk indicates significance).

Species	Scientific Name	***p*-value**
Arrowweed	*Pluchea sericea*	0.65
Aster	*Asteraceae*	0.73
Bedstraw	*Gallium* sp.	1
Bittercress	*Cardamine hirsuta*	1
Broadleaf Cattail	*Typha latifolia*	1
Bugleweed	*Lycopus americanus*	0.90
Calla Lily	*Zantedeschia aethiopica*	0.99
Canada Maylily	*Maianthemum canadense*	0.95
Canadian Bunchberry	*Cornus canadensis*	1
Cinnamon Fern	*Osmundastrum cinnamomeum*	0.84
Common Blue Violet	*Viola sororia*	1
Common Boneset	*Eupatorium perfoliatum*	1
Dewberry	*Rubus pubescens*	1
Enchanter s Nightshade	*Circaea lutetiana*	1
False Hellebore	*Veratrum californicum*	0.97
Field Horsetail	*Equisetum arvense*	1
Golden Club	*Orontium aquaticum*	1
Golden Saxifrage	*Chrysosplenium americanum*	1
Grass	*Poaceae* sp.	1
Hay-scented Fern	*Dennstaedtia punctilobula*	0.09
Jack-in-the-Pulpit	*Arisaema triphyllum*	1
Japanese Stiltgrass	*Microstegium vimineum*	1
Jewelweed	*Impatiens capensis*	1
Marginal Wood Fern	*Dryopteris marginalis*	1
Marsh Fern	*Thelypteris palustris*	0.95
Marsh Marigold	*Caltha palustris*	1
New York Fern	*Thelypteris noveboracensis*	1
Northern Blue Flag	*Iris versicolor*	1
Poison Ivy	*Toxicodendron radicans*	1
Purple Pitcher Plant	*Sarracenia purpurea*	1
Ragweed	*Ambrosia artemisiifolia*	1
Royal Fern	*Osmunda regalis*	1
Sedge	*Carex* sp.	0.90
Sensitive Fern	*Onoclea sensibilis*	0.98

Sideflowering Skullcap	*Scutellaria lateriflora*	1
Skunk Cabbage	*Symplocarpus foetidus*	1
Sphagnum	*Sphagnum* sp.	1
St. John's Marshwart	*Hypericum perforatum*	0.94
Starflower	*Trientalis borealis*	1
Swamp Candle	*Lysimachia terrestris*	0.99
Tall Meadow Rue	*Thalictrum dasycarpum*	1
Threeleaf Goldenthread	*Coptis trifolia*	0.76
Threeway Sedge	*Dulichium arundinaceum*	0.94
Virginia Chainfern	*Woodwardia virginica*	0.65
Virginia Creeper	*Parthenocissus quinquefolia*	1
Virginia Strawberry	*Fragaria virginiana*	1
Water Pennywort	*Hydrocotyle ranunculoides*	1
White Meadowsweet	*Spiraea alba*	0.84
Wineberry	*Rubus phoenicolasius*	1
Wood Nettle	*Laportea candensis*	1
Wood Sorrel	*Oxalis stricta*	1
Other		1

Appendix XI. Avian species abundance and frequency found across all sites in 2017 (only occupied).

Common Name	Latin Name	Total	Frequency
American Crow	*Corvus brachyrhynchos*	8	0.54
American Redstart	*Setophaga ruticilla*	6	0.15
American Robin	*Turdus migratorius*	2	0.15
Black-and-white Warbler	*Mniotilta varia*	16	0.77
Black-billed Cuckoo	*Coccyzus erythropthalmus*	1	0.08
Black-capped Chickadee	*Poecile atricapillus*	11	0.31
Black-throated Green Warbler	*Setophaga virens*	2	0.15
Blue Jay	*Cyanocitta cristata*	35	0.77
Blue-headed Vireo	*Vireo solitarius*	9	0.46
Canada Warbler	*Cardellina canadensis*	7	0.38
Carolina Wren	*Thryothorus ludovicianus*	1	0.08
Cedar Waxwing	*Bombycilla cedrorum*	5	0.08
Chestnut-sided Warbler	*Setophaga pensylvanica*	6	0.23
Chipping Sparrow	*Spizella passerina*	2	0.15
Common Yellowthroat	*Geothlypis trichas*	20	0.69
Downy Woodpecker	*Dryobates pubescens*	6	0.46
Eastern Phoebe	*Sayornis phoebe*	5	0.23
Eastern Towhee	*Pipilo erythrophthalmus*	8	0.31
Eastern Wood-Pewee	*Contopus virens*	1	0.08
Gray Catbird	*Dumetella carolinensis*	28	0.92
Great-crested Flycatcher	*Myiarchus crinitus*	2	0.15
Louisiana Waterthrush	*Parkesia motacilla*	1	0.08
Marsh Wren	*Cistothorus palustris*	1	0.08
Mourning Dove	*Zenaida macroura*	2	0.15
Nashville Warbler	*Oreothlypis ruficapilla*	6	0.31
Northern Cardinal	*Cardinalis cardinalis*	5	0.23
Northern Flicker	*Colaptes auratus*	6	0.31
Northern Harrier	*Circus cyaneus*	1	0.08
Northern Parula	*Setophaga americana*	6	0.31
Northern Waterthrush	*Parkesia noveboracensis*	20	0.69
Ovenbird	*Seiurus aurocapilla*	39	0.85
Pileated Woodpecker	*Dryocopus pileatus*	2	0.15
Prothonotary Warbler	*Protonotaria citrea*	1	0.08
Red-bellied Woodpecker	*Melanerpes carolinus*	2	0.08
Red-eyed Vireo	*Vireo olivaceus*	23	0.92
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	2	0.15
Ruffed Grouse	*Bonasa umbellus*	1	0.08

Scarlet Tanager	*Piranga olivacea*	3	0.23
Song Sparrow	*Melospiza melodia*	2	0.15
Tufted Titmouse	*Baeolophus bicolor*	10	0.46
Veery	*Catharus fuscescens*	50	1.00
White-breasted Nuthatch	*Sitta carolinensis*	1	0.08
Winter Wren	*Troglodytes hiemalis*	2	0.08
Wood Thrush	*Hylocichla mustelina*	30	0.77
Worm-eating Warbler	*Helmitheros vermivorum*	6	0.23
Yellow-bellied Sapsucker	*Sphyrapicus varius*	7	0.31
Yellow-billed Cuckoo	*Coccyzus americanus*	1	0.08
Yellow-rumped Warbler	*Setophaga coronata*	4	0.23
Yellow-throated Vireo	*Vireo flavifrons*	2	0.15

Appendix XII. 2018 Avian species found across occupied and unoccupied sites.

Common Name	Latin Name	Occupied	Unoccupied
Acadian Flycatcher	*Empidonax virescens*	3	0
Alder Flycatcher	*Empidonax alnorum*	10	8
American Crow	*Corvus brachyrhynchos*	15	14
American Redstart	*Setophaga ruticilla*	22	21
American Robin	*Turdus migratorius*	10	9
Baltimore Oriole	*Icterus galbula*	0	1
Black-and-white Warbler	*Mniotilta varia*	54	18
Blackburnian Warbler	*Dendroica fusca*	24	6
Black-capped Chickadee	*Poecile atricapillus*	40	21
Black-throated Blue Warbler	*Setophaga caerulescens*	10	5
Black-throated Green Warbler	*Setophaga virens*	11	9
Blue Jay	*Cyanocitta cristata*	44	17
Blue-gray Gnatcatcher	*Polioptila caerulea*	3	2
Blue-winged Warbler	*Vermivora cyanoptera*	1	0
Broad-winged Hawk	*Buteo platypterus*	1	2
Brown-headed Cowbird	*Molothrus ater*	3	4
Canada Warbler	*Cardellina canadensis*	46	6
Cedar Waxwing	*Bombycilla cedrorum*	9	13
Chestnut-sided Warbler	*Setophaga pensylvanica*	24	16
Chipping Sparrow	*Spizella passerina*	0	2
Common Grackle	*Quiscalus quiscula*	3	0
Common Raven	*Corvus corax*	1	0
Common Yellowthroat	*Geothlypis trichas*	39	39
Dark-eyed Junco	*Junco hyemalis*	1	2
Downy Woodpecker	*Dryobates pubescens*	1	1
Eastern Kingbird	*Tyrannus tyrannus*	0	2
Eastern Phoebe	*Sayornis phoebe*	0	3
Eastern Towhee	*Pipilo erythrophthalmus*	27	16
Eastern Wood-Pewee	*Contopus virens*	11	2
Fish Crow	*Corbus ossifragus*	1	1
Golden-winged Warbler	*Vermivora chrysoptera*	1	3
Gray Catbird	*Dumetella carolinensis*	48	33
Great Crested Flycatcher	*Myiarchus crinitus*	5	7

Hairy Woodpecker	*Leuconotopicus villosus*	4	1
Hermit Thrush	*Catharus guttatus*	2	4
Hooded Warbler	*Setophaga citrina*	2	2
Least Flycatcher	*Empidonax minimus*	3	0
Louisiana Waterthrush	*Parkesia motacilla*	2	3
Magnolia Warbler	*Setophaga magnolia*	1	1
Mourning Dove	*Zenaida macroura*	6	7
Nashville Warbler	*Oreothlypis ruficapilla*	4	1
Northern Cardinal	*Cardinalis cardinalis*	8	4
Northern Flicker	*Colaptes auratus*	4	4
Northern Parula	*Setophaga americana*	0	1
Northern Waterthrush	*Parkesia noveboracensis*	51	2
Ovenbird	*Seiurus aurocapilla*	105	62
Pileated Woodpecker	*Dryocopus pileatus*	7	3
Red-bellied Woodpecker	*Melanerpes carolinus*	5	3
Red-eyed Vireo	*Vireo olivaceus*	68	56
Red-shouldered Hawk	*Buteo lineatus*	2	0
Red-winged Blackbird	*Agelaius phoeniceus*	5	13
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	5	3
Ruby-throated Hummingbird	*Archilochus colubris*	1	0
Scarlet Tanager	*Piranga olivacea*	20	15
Song Sparrow	*Melospiza melodia*	6	10
Swamp Sparrow	*Melospiza georgiana*	13	23
Tree Swallow	*Tachycineta bicolor*	1	1
Tufted Titmouse	*Baeolophus bicolor*	11	17
Turkey Vulture	*Cathartes aura*	2	0
Veery	*Catharus fuscescens*	83	33
White-breasted Nuthatch	*Sitta carolinensis*	12	6
Wild Turkey	*Meleagris gallopavo*	2	2
Wood Duck	*Aix sponsa*	2	2
Wood Thrush	*Hylocichla mustelina*	16	13
Worm-eating Warbler	*Helmitheros vermivorum*	0	1
Yellow Warbler	*Setophaga petechia*	7	12
Yellow-bellied Sapsucker	*Sphyrapicus varius*	15	5
Yellow-billed Cuckoo	*Coccyzus americanus*	1	0
Yellow-rumped Warbler	*Setophaga coronate*	7	2
Yellow-throated Vireo	*Vireo flavifrons*	6	0

Appendix XIII. Species richness of the 2017 field sites.

Site	Species Richness
Bear Swamp - Nest	23
Hobday Road	23
Cranberry Bog - Boardwalk	16
Cranberry Bog - Edge	16
Lost Lakes - Lake 1	16
Whitaker Road	16
Bear Swamp - Boardwalk	15
Brady's Lake	14
Grass Lake	14
Lost Lakes - Swamp Alley	13
Brady's Lake - 7 Mile Road	12
Cranberry Bog - Parking Lot	12
Bear Swamp	11

Appendix XIV. Species richness for occupied and unoccupied sites in 2018.

Site.Name	Status	Species Richness
Long Pond Swamp	Occupied	23
Cranberry Bog - Boardwalk	Occupied	22
Tarkill Demo	Occupied	22
Turner Swamp 3	Occupied	22
Bear Wallow	Occupied	20
Hobday Road	Occupied	20
Valley Road	Occupied	20
Whitaker Road 2	Occupied	19
Bear Swamp 2	Occupied	18
Brady's Lake	Occupied	18
Cranberry Bog - Parking Lot 2	Occupied	18
Turner Swamp 2	Occupied	18
Bear Swamp - Boardwalk 2	Occupied	17
Brady's Lake - 7 Mile Road 2	Occupied	17
Caughbaugh Road 2	Occupied	17
Fivemile Meadow Road	Occupied	17
Grass Lake	Occupied	17
Painter Swamp	Occupied	17
Lost Lakes - Lake 1	Occupied	16
Lost Lakes - Swamp Alley	Occupied	16
Tobyhanna Road 2	Occupied	16
Turner Swamp	Occupied	16
Caughbaugh Road	Occupied	15
Whitaker Road	Occupied	15
Dingman's Turnpike	Occupied	14
Lower Lake	Occupied	14
Maple Run	Occupied	14
Beaver Run 2	Occupied	13
Lost Lakes - Lake 3	Occupied	10
Brady's Lake - 7 Mile Road	Occupied	8
Hemlock Way	Unoccupied	21
Plank Road	Unoccupied	21
Hell Hollow Road 2	Unoccupied	20
Brady's Lake - Parking Lot	Unoccupied	19
Lake Greeley	Unoccupied	19
Merry Hill Wet Meadow	Unoccupied	19
Shohola Creek	Unoccupied	19
Lake Road	Unoccupied	17

Beaver Run	Unoccupied	16
Hell Hollow Road	Unoccupied	16
Indian Swamp	Unoccupied	16
Beaver Lake	Unoccupied	15
Dwarfskill	Unoccupied	15
Tobyhanna Road	Unoccupied	15
Seven Pines	Unoccupied	14
Ice Lake	Unoccupied	13
Grange Road	Unoccupied	12
Two Mile Run	Unoccupied	11

Appendix XV. Shannon diversity Index of avian communities for 2018 field sites.

Sites	Status	Shannon Index
Long Pond Swamp	Occupied	2.99
Tarkill Demo	Occupied	2.95
Hemlock Way	Unoccupied	2.95
Turner Swamp 3	Occupied	2.94
Plank Road	Unoccupied	2.93
Cranberry Bog - Boardwalk	Occupied	2.92
Hobday Road	Occupied	2.89
Bear Wallow	Occupied	2.87
Valley Road	Occupied	2.84
Whitaker Road 2	Occupied	2.81
Lake Greeley	Unoccupied	2.80
Brady's Lake - Parking Lot	Unoccupied	2.79
Hell Hollow Road 2	Unoccupied	2.78
Bear Swamp 2	Occupied	2.78
Merry Hill Wet Meadow	Unoccupied	2.78
Cranberry Bog - Parking Lot 2	Occupied	2.76
Bear Swamp - Boardwalk 2	Occupied	2.75
Brady's Lake - 7 Mile Road 2	Occupied	2.73
Shohola Creek	Unoccupied	2.73
Caughbaugh Road 2	Occupied	2.72
Grass Lake	Occupied	2.72
Turner Swamp 2	Occupied	2.70
Painter Swamp	Occupied	2.70
Lake Road	Unoccupied	2.69
Brady's Lake	Occupied	2.68
Fivemile Meadow Road	Occupied	2.68
Tobyhanna Road 2	Occupied	2.66
Indian Swamp	Unoccupied	2.66
Lost Lakes - Swamp Alley	Occupied	2.65
Beaver Run	Unoccupied	2.63
Beaver Lake	Unoccupied	2.62
Hell Hollow Road	Unoccupied	2.62
Turner Swamp	Occupied	2.61
Lost Lakes - Lake 1	Occupied	2.59
Tobyhanna Road	Unoccupied	2.55
Caughbaugh Road	Occupied	2.53
Lower Lake	Occupied	2.52
Dwarfskill	Unoccupied	2.50

Dingman's Turnpike	Occupied	2.50
Whitaker Road	Occupied	2.49
Maple Run	Occupied	2.47
Seven Pines	Unoccupied	2.45
Ice Lake	Unoccupied	2.43
Beaver Run 2	Occupied	2.43
Grange Road	Unoccupied	2.37
Lost Lakes - Lake 3	Occupied	2.18
Two Mile Run	Unoccupied	2.16
Brady's Lake - 7 Mile Road	Occupied	1.98

Appendix XVI. Frequency of avian species at occupied and unoccupied sites in 2018.

Common Name	Latin Name	Occupied Frequency	Unoccupied Frequency
Acadian Flycatcher	*Empidonax virescens*	0.07	0.00
Alder Flycatcher	*Empidonax alnorum*	0.23	0.28
American Crow	*Corvus brachyrhynchos*	0.33	0.56
American Redstart	*Setophaga ruticilla*	0.40	0.56
American Robin	*Turdus migratorius*	0.17	0.22
Baltimore Oriole	*Icterus galbula*	0.00	0.06
Black-and-white Warbler	*Mniotilta varia*	0.90	0.56
Blackburnian Warbler	*Dendroica fusca*	0.47	0.17
Black-capped Chickadee	*Poecile atricapillus*	0.57	0.67
Black-throated Blue Warbler	*Setophaga caerulescens*	0.17	0.17
Black-throated Green Warbler	*Setophaga virens*	0.27	0.17
Blue Jay	*Cyanocitta cristata*	0.77	0.72
Blue-gray Gnatcatcher	*Polioptila caerulea*	0.10	0.11
Blue-winged Warbler	*Vermivora cyanoptera*	0.03	0.00
Broad-winged Hawk	*Buteo platypterus*	0.03	0.11
Brown-headed Cowbird	*Molothrus ater*	0.13	0.17
Canada Warbler	*Cardellina canadensis*	0.63	0.17
Cedar Waxwing	*Bombycilla cedrorum*	0.23	0.39
Chestnut-sided Warbler	*Setophaga pensylvanica*	0.43	0.50
Chipping Sparrow	*Spizella passerina*	0.00	0.06
Common Grackle	*Quiscalus quiscula*	0.07	0.00
Common Raven	*Corvus corax*	0.03	0.00
Common Yellowthroat	*Geothlypis trichas*	0.60	0.72
Dark-eyed Junco	*Junco hyemalis*	0.03	0.06
Downy Woodpecker	*Dryobates pubescens*	0.03	0.06
Eastern Kingbird	*Tyrannus tyrannus*	0.00	0.11
Eastern Phoebe	*Sayornis phoebe*	0.00	0.17
Eastern Towhee	*Pipilo erythrophthalmus*	0.57	0.67
Eastern Wood-Pewee	*Contopus virens*	0.23	0.11
Fish Crow	*Corbus ossifragus*	0.03	0.06
Golden-winged Warbler	*Vermivora chrysoptera*	0.03	0.11
Gray Catbird	*Dumetella carolinensis*	0.80	0.83
Great Crested Flycatcher	*Myiarchus crinitus*	0.13	0.22
Hairy Woodpecker	*Leuconotopicus villosus*	0.13	0.06
Hermit Thrush	*Catharus guttatus*	0.10	0.11
Hooded Warbler	*Setophaga citrina*	0.03	0.11
Least Flycatcher	*Empidonax minimus*	0.03	0.00

Louisiana Waterthrush	*Parkesia motacilla*	0.07	0.11
Magnolia Warbler	*Setophaga magnolia*	0.07	0.00
Mourning Dove	*Zenaida macroura*	0.17	0.33
Nashville Warbler	*Oreothlypis ruficapilla*	0.10	0.06
Northern Cardinal	*Cardinalis cardinalis*	0.20	0.22
Northern Flicker	*Colaptes auratus*	0.13	0.17
Northern Parula	*Setophaga americana*	0.00	0.06
Ovenbird	*Seiurus aurocapilla*	0.97	0.83
Pileated Woodpecker	*Dryocopus pileatus*	0.23	0.17
Red-bellied Woodpecker	*Melanerpes carolinus*	0.13	0.17
Red-eyed Vireo	*Vireo olivaceus*	0.93	1.00
Red-shouldered Hawk	*Buteo lineatus*	0.07	0.00
Red-winged Blackbird	*Agelaius phoeniceus*	0.10	0.28
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	0.10	0.17
Ruby-throated Hummingbird	*Archilochus colubris*	0.03	0.00
Scarlet Tanager	*Piranga olivacea*	0.53	0.33
Song Sparrow	*Melospiza melodia*	0.13	0.28
Swamp Sparrow	*Melospiza georgiana*	0.33	0.50
Tree Swallow	*Tachycineta bicolor*	0.03	0.06
Tufted Titmouse	*Baeolophus bicolor*	0.23	0.61
Turkey Vulture	*Cathartes aura*	0.07	0.00
Veery	*Catharus fuscescens*	1.00	0.72
White-breasted Nuthatch	*Sitta carolinensis*	0.27	0.22
Wild Turkey	*Meleagris gallopavo*	0.03	0.11
Wood Duck	*Aix sponsa*	0.03	0.06
Wood Thrush	*Hylocichla mustelina*	0.53	0.44
Worm-eating Warbler	*Helmitheros vermivorum*	0.00	0.06
Yellow Warbler	*Setophaga petechia*	0.20	0.33
Yellow-bellied Sapsucker	*Sphyrapicus varius*	0.27	0.22
Yellow-billed Cuckoo	*Coccyzus americanus*	0.03	0.00
Yellow-rumped Warbler	*Setophaga coronate*	0.20	0.11
Yellow-throated Vireo	*Vireo flavifrons*	0.17	0.00

Appendix XVII. Avian SIMPER results showing the contribution of each species to the overall Bray-Curtis dissimilarity between occupied and unoccupied (asterisk indicates significance).

Species	Latin Name	Cumulative Contribution	*p*-value
Ovenbird	*Seiurus aurocapilla*	0.06	0.02*
Common Yellowthroat	*Geothlypis trichas*	0.11	0.04*
Veery	*Catharus fuscescens*	0.16	0.002*
Red-eyed Vireo	*Vireo olivaceus*	0.20	0.16
Canada Warbler	*Cardellina canadensis*	0.25	0.06
Gray Catbird	*Dumetella carolinensis*	0.28	0.70
Black-capped Chickadee	*Poecile atricapillus*	0.32	0.81
Black-and-white Warbler	*Mniotilta varia*	0.36	0.01*
Swamp Sparrow	*Melospiza georgiana*	0.39	0.02*
American Redstart	*Setophaga ruticilla*	0.42	0.37
Blue Jay	*Cyanocitta cristata*	0.45	0.41
Chestnut-sided Warbler	*Setophaga pensylvanica*	0.48	0.52
Scarlet Tanager	*Piranga olivacea*	0.51	0.19
Tufted Titmouse	*Baeolophus bicolor*	0.54	0.02*
Eastern Towhee	*Pipilo erythrophthalmus*	0.56	0.93
Blackburnian Warbler	*Dendroica fusca*	0.58	0.78
American Crow	*Corvus brachyrhynchos*	0.61	0.16
Red-winged Blackbird	*Agelaius phoeniceus*	0.63	0.04*
Wood Thrush	*Hylocichla mustelina*	0.65	0.10
Cedar Waxwing	*Bombycilla cedrorum*	0.67	0.13
American Robin	*Turdus migratorius*	0.69	0.23
Yellow Warbler	*Setophaga petechia*	0.71	0.05
Black-throated Green Warbler	*Setophaga virens*	0.73	0.37
Song Sparrow	*Melospiza melodia*	0.75	0.07
Yellow-bellied Sapsucker	*Sphyrapicus varius*	0.76	0.92
Alder Flycatcher	*Empidonax alnorum*	0.78	0.31
White-breasted Nuthatch	*Sitta carolinensis*	0.79	0.64

Black-throated Blue Warbler	*Setophaga caerulescens*	0.81	0.52
Great Crested Flycatcher	*Myiarchus crinitus*	0.82	0.16
Mourning Dove	*Zenaida macroura*	0.83	0.16
Eastern Wood-Pewee	*Contopus virens*	0.84	0.94
Northern Cardinal	*Cardinalis cardinalis*	0.86	0.52
Pileated Woodpecker	*Dryocopus pileatus*	0.86	0.68
Northern Flicker	*Colaptes auratus*	0.87	0.23
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	0.88	0.42
Yellow-rumped Warbler	*Setophaga coronata*	0.89	0.80
Red-bellied Woodpecker	*Melanerpes carolinus*	0.90	0.58
Brown-headed Cowbird	*Molothrus ater*	0.90	0.41
Hermit Thrush	*Catharus guttatus*	0.91	0.27
Louisiana Waterthrush	*Parkesia motacilla*	0.92	0.12
Golden-winged Warbler	*Vermivora chrysoptera*	0.92	0.09
Yellow-throated Vireo	*Vireo flavifrons*	0.93	0.97
Blue-gray Gnatcatcher	*Polioptila caerulea*	0.93	0.46
Nashville Warbler	*Oreothlypis ruficapilla*	0.94	0.63
Hooded Warbler	*Setophaga citrina*	0.94	0.25
Wild Turkey	*Meleagris gallopavo*	0.95	0.27
Hairy Woodpecker	*Leuconotopicus villosus*	0.95	0.78
Eastern Phoebe	*Sayornis phoebe*	0.95	0.03*
Wood Duck	*Aix sponsa*	0.96	0.29
Dark-eyed Junco	*Junco hyemalis*	0.96	0.25
Broad-winged Hawk	*Buteo platypterus*	0.97	0.16
Eastern Kingbird	*Tyrannus tyrannus*	0.97	0.07
Chipping Sparrow	*Spizella passerina*	0.97	0.24
Common Grackle	*Quiscalus quiscula*	0.97	0.80
Least Flycatcher	*Empidonax minimus*	0.98	0.68
Acadian Flycatcher	*Empidonax virescens*	0.98	0.80
Fish Crow	*Corbus ossifragus*	0.98	0.25
Downy Woodpecker	*Dryobates pubescens*	0.98	0.48
Tree Swallow	*Tachycineta bicolor*	0.99	0.47

Baltimore Oriole	*Icterus galbula*	0.99	0.16
Magnolia Warbler	*Setophaga magnolia*	0.99	0.78
Turkey Vulture	*Cathartes aura*	0.99	0.80
Red-shouldered Hawk	*Buteo lineatus*	0.99	0.81
Worm-eating Warbler	*Helmitheros vermivorum*	1.00	0.19
Northern Parula	*Setophaga americana*	1.00	0.25
Common Raven	*Corvus corax*	1.00	0.64
Blue-winged Warbler	*Vermivora cyanoptera*	1.00	0.66
Yellow-billed Cuckoo	*Coccyzus americanus*	1.00	0.68
Ruby-throated Hummingbird	*Archilochus colubris*	1.00	0.67

Appendix XVIII. Avian SIMPER results showing the contribution of each species to the overall Bray-Curtis dissimilarity between occupied and unoccupied excluding distant species (asterisk indicates significance).

Species	Latin Name	Cumulative Contribution	*p*-value
Ovenbird	*Seiurus aurocapilla*	0.11	0.13
Veery	*Catharus fuscescens*	0.21	0.44
Blue Jay	*Cyanocitta cristata*	0.27	0.94
Red-eyed Vireo	*Vireo olivaceus*	0.32	0.39
Common Yellowthroat	*Geothlypis trichas*	0.37	0.07
Eastern Towhee	*Pipilo erythrophthalmus*	0.42	0.91
Wood Thrush	*Hylcichla mustelina*	0.47	0.67
American Crow	*Corbus brachyrhynchos*	0.52	0.09
Red-winged Blackbird	*Agelaius phoeniceus*	0.56	0.10
Mourning Dove	*Zenaida macroura*	0.59	0.08
Black-capped Chickadee	*Poecile atricapillus*	0.62	0.87
Tufted Titmouse	*Baeolophus bicolor*	0.65	0.03*
Black-throated Blue Warbler	*Setophaga caerulescens*	0.67	0.03*
Song Sparrow	*Melospiza melodia*	0.70	0.08
Chestnut-sided Warbler	*Setophaga pensylvanica*	0.72	0.65
Scarlet Tanager	*Piranga olivacea*	0.75	0.25
Swamp Sparrow	*Melospiza georgiana*	0.77	0.40
Eastern Wood-Pewee	*Contopus virens*	0.79	0.80
Black-throated Green Warbler	*Setophaga virens*	0.81	0.81
Hermit Thrush	*Catharus guttatus*	0.82	0.05*
Gray Catbird	*Dumetella carolinensis*	0.84	0.52
Canada Warbler	*Cardellina canadensis*	0.85	0.75
American Redstart	*Setophaga ruticilla*	0.86	0.27
Pileated Woodpecker	*Dryocopus pileatus*	0.87	0.36
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	0.88	0.20
Alder Flycatcher	*Empidonax alnorum*	0.89	0.97
Hooded Warbler	*Setophaga citrina*	0.90	0.58
Red-bellied Woodpecker	*Melanerpes carolinus*	0.91	0.15
Yellow Warbler	*Setophaga petechia*	0.92	0.63
Turkey Vulture	*Cathartes aura*	0.93	0.92
American Robin	*Turdus migratorius*	0.94	0.05
Wood Duck	*Aix sponsa*	0.94	0.07
Wild Turkey	*Meleagris gallopavo*	0.95	0.05
Yellow-bellied Sapsucker	*Sphyrapicus varius*	0.96	0.99

Broad-winged Hawk	*Buteo platypterus*	0.96	0.05
Northern Flicker	*Colaptes auratus*	0.97	0.05
Northern Cardinal	*Cardinalis cardinalis*	0.98	0.97
Black-and-white Warbler	*Mniotilta varia*	0.98	0.98
Yellow-billed Cuckoo	*Coccyzus americanus*	0.98	0.90
Red-shouldered Hawk	*Buteo lineatus*	0.99	0.90
Blackburnian Warbler	*Dendroica fusca*	0.99	0.07
Great Crested Flycatcher	*Myiarchus crinitus*	1.00	0.07
Least Flycatcher	*Empidonax minimus*	1.00	0.94
Nashville Warbler	*Oreothlypis ruficapilla*	1.00	0.96

Appendix XIX. Warton et al. (2012) results for the 2018 occupied and unoccupied sites (asterisk indicates significance).

Species	Latin Name	*p*-value
Acadian Flycatcher	*Empidonax virescens*	1
Alder Flycatcher	*Empidonax alnorum*	1
American Crow	*Corvus brachyrhynchos*	1
American Redstart	*Setophaga ruticilla*	1
American Robin	*Turdus migratorius*	1
Baltimore Oriole	*Icterus galbula*	1
Black-and-white Warbler	*Mniotilta varia*	0.25
Blackburnian Warbler	*Dendroica fusca*	0.60
Black-capped Chickadee	*Poecile atricapillus*	1
Black-throated Blue Warbler	*Setophaga caerulescens*	1
Black-throated Green Warbler	*Setophaga virens*	1
Blue Jay	*Cyanocitta cristata*	0.80
Blue-gray Gnatcatcher	*Polioptila caerulea*	1
Blue-winged Warbler	*Vermivora cyanoptera*	1
Broad-winged Hawk	*Buteo platypterus*	1
Brown-headed Cowbird	*Molothrus ater*	1
Canada Warbler	*Cardellina canadensis*	0.004*
Cedar Waxwing	*Bombycilla cedrorum*	1
Chestnut-sided Warbler	*Setophaga pensylvanica*	1
Chipping Sparrow	*Spizella passerina*	1
Common Grackle	*Quiscalus quiscula*	1
Common Raven	*Corvus corax*	1
Common Yellowthroat	*Geothlypis trichas*	1
Dark-eyed Junco	*Junco hyemalis*	1
Downy Woodpecker	*Dryobates pubescens*	1
Eastern Kingbird	*Tyrannus tyrannus*	0.97
Eastern Phoebe	*Sayornis phoebe*	0.57
Eastern Towhee	*Pipilo erythrophthalmus*	1
Eastern Wood-Pewee	*Contopus virens*	1
Fish Crow	*Corbus ossifragus*	1
Golden-winged Warbler	*Vermivora chrysoptera*	1
Gray Catbird	*Dumetella carolinensis*	1

Great Crested Flycatcher	*Myiarchus crinitus*	1
Hairy Woodpecker	*Leuconotopicus villosus*	1
Hermit Thrush	*Catharus guttatus*	1
Hooded Warbler	*Setophaga citrina*	1
Least Flycatcher	*Empidonax minimus*	1
Louisiana Waterthrush	*Parkesia motacilla*	1
Magnolia Warbler	*Setophaga magnolia*	1
Mourning Dove	*Zenaida macroura*	1
Nashville Warbler	*Oreothlypis ruficapilla*	1
Northern Cardinal	*Cardinalis cardinalis*	1
Northern Flicker	*Colaptes auratus*	1
Northern Parula	*Setophaga americana*	1
Ovenbird	*Seiurus aurocapilla*	1
Pileated Woodpecker	*Dryocopus pileatus*	1
Red-bellied Woodpecker	*Melanerpes carolinus*	1
Red-eyed Vireo	*Vireo olivaceus*	1
Red-shouldered Hawk	*Buteo lineatus*	1
Red-winged Blackbird	*Agelaius phoeniceus*	1
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	1
Ruby-throated Hummingbird	*Archilochus colubris*	1
Scarlet Tanager	*Piranga olivacea*	1
Song Sparrow	*Melospiza melodia*	1
Swamp Sparrow	*Melospiza georgiana*	0.84
Tree Swallow	*Tachycineta bicolor*	1
Tufted Titmouse	*Baeolophus bicolor*	0.71
Turkey Vulture	*Cathartes aura*	1
Veery	*Catharus fuscescens*	0.35
White-breasted Nuthatch	*Sitta carolinensis*	1
Wild Turkey	*Meleagris gallopavo*	1
Wood Duck	*Aix sponsa*	1
Wood Thrush	*Hylocichla mustelina*	1
Worm-eating Warbler	*Helmitheros vermivorum*	1
Yellow Warbler	*Setophaga petechia*	1
Yellow-bellied Sapsucker	*Sphyrapicus varius*	1
Yellow-billed Cuckoo	*Coccyzus americanus*	1
Yellow-rumped Warbler	*Setophaga coronata*	1
Yellow-throated Vireo	*Vireo flavifrons*	0.66

Appendix XX. Warton et al. (2012) results for the 2018 occupied and unoccupied sites excluding distant species (asterisk indicates significance).

Species	Latin Name	*p*-value
Alder Flycatcher	*Empidonax alnorum*	0.99
American Crow	*Corbus brachyrhynchos*	1
American Redstart	*Setophaga ruticilla*	1
American Robin	*Turdus migratorius*	1
Black-and-white Warbler	*Mniotilta varia*	1
Blackburnian Warbler	*Dendroica fusca*	1
Black-capped Chickadee	*Poecile atricapillus*	1
Black-throated Blue Warbler	*Setophaga caerulescens*	1
Black-throated Green Warbler	*Setophaga virens*	1
Blue Jay	*Cyanocitta cristata*	1
Broad-winged Hawk	*Buteo platypterus*	1
Canada Warbler	*Cardellina canadensis*	1
Chestnut-sided Warbler	*Setophaga pensylvanica*	1
Common Yellowthroat	*Geothlypis trichas*	1
Eastern Towhee	*Pipilo erythrophthalmus*	1
Eastern Wood-Pewee	*Contopus virens*	1
Gray Catbird	*Dumetella carolinensis*	1
Great Crested Flycatcher	*Myiarchus crinitus*	1
Hermit Thrush	*Catharus guttatus*	1
Hooded Warbler	*Setophaga citrina*	1
Least Flycatcher	*Empidonax minimus*	1
Mourning Dove	*Zenaida macroura*	0.96
Nashville Warbler	*Oreothlypis ruficapilla*	1
Northern Cardinal	*Cardinalis cardinalis*	1
Northern Flicker	*Colaptes auratus*	1
Ovenbird	*Seiurus aurocapilla*	1
Pileated Woodpecker	*Dryocopus pileatus*	1
Red-bellied Woodpecker	*Melanerpes carolinus*	1
Red-eyed Vireo	*Vireo olivaceus*	1
Red-shouldered Hawk	*Buteo lineatus*	1
Red-winged Blackbird	*Agelaius phoeniceus*	1
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	1
Scarlet Tanager	*Piranga olivacea*	1
Song Sparrow	*Melospiza melodia*	1
Swamp Sparrow	*Melospiza georgiana*	1

Tufted Titmouse	*Baeolophus bicolor*	0.93
Turkey Vulture	*Cathartes aura*	1
Veery	*Catharus fuscescens*	1
Wild Turkey	*Meleagris gallopavo*	1
Wood Duck	*Aix sponsa*	1
Wood Thrush	*Hylcichla mustelina*	1
Yellow Warbler	*Setophaga petechia*	1
Yellow-bellied Sapsucker	*Sphyrapicus varius*	0.99
Yellow-billed Cuckoo	*Coccyzus americanus*	1