Drew University

College of Liberal Arts

Avian richness and population dynamics in the Drew Forest during the 2023 fall migration

A Thesis in Environmental Science

by

Daniel Magda

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Abstract

The area surrounding Drew University, known as the Drew Forest Preserve, which includes Zuck Arboretum and the Hepburn Woods, has been an important habitat for both resident and migratory species of birds. Early accounts of bird populations, however, have been spotty, anecdotal, and in some cases, all but lost to time. This study aims to compare what historical data remains from the last hundred years of accounts and compare them to a more comprehensive study of the present avian species richness and diversity in the Drew Forest. The aim of this study was to determine the richness of the Drew Forest using diversity indices such as Shannon's Diversity Index and to utilize AIC occupancy models to determine and analyze the population dynamics between migratory species and resident species during the 2023 fall migration. Upon the completion of this study, I found 93 species of birds across 13 taxonomic orders. From these data, I was able to find that the Drew Forest had a high level of diversity ($H' = 2.88$) for the totality of the fall 2023 migration in comparison to the calculated moderate-low level of average daily diversity ($H' = 2.16$) over the course of my data collection. The occupancy models for the selected migratory species, the Common Grackle (*Quiscalus quiscula*), found that the sampling covariates of date and temperature had the largest impact on the detection of Common Grackles. In comparison to the migratory species, the detection of the selected resident species, the Downy Woodpecker *(Dryobates pubescens)*, was most significantly affected by the covariate of date. In the models run on the Common Grackle data, the occupancy was only slightly affected by the site covariates, but only with the sampling covariate of date and time. Based on the results of this study, the Drew Forest is an important ecosystem for many resident and migratory species of birds during the annual migrations through the area.

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Introduction

The study of ornithology is an ever growing and shifting field; avian taxonomy is often being changed and new species are discovered fairly frequently. Another area of ornithology that is developing is our understanding of both short and long term avian migration. Avian migration is an interesting facet of ornithology as much of the topic is based on understanding the impressive migrations that many species complete throughout their lives. Whether it is Canada Geese *(Branta canadensis)* doing their yearly migration to and from their breeding grounds in Canada, Dark-eyed Juncos (*Junco hyemalis*) moving to their over-wintering grounds, or the impressive feats accomplished by many species of songbirds who complete migrations over the Gulf of Mexico, in many cases, in less than 23 hrs (Deppe et al. 2015), the overall understanding of the complexity and sensitivity of these migrations is becoming better understood by scientists. This understanding has been contributed to by data compiled through citizen-science websites such as eBird. This, in conjunction with advancing climate change research over the past few decades, has led to some very interesting questions regarding how climate change has led to critical migrations being influenced or changed over time (McCaslin & Heath 2020).

When looking at the history of ornithology at Drew University, we can see that, much like the increased levels of research done into bird migration, there has been more awareness about the different species of birds, both migratory and resident. The Drew Forest is visited by many species of migratory birds that utilize the resources of the forest to rest and refuel before either continuing their migratory paths or remaining in the region. This understanding of bird migration through the Drew Forest has been increased as databases, such as eBird, have made it easier for more people to track the presence of migratory birds and the timing in which they arrive and leave the area.

This study aims to better understand the population dynamics of resident and migrant bird species during the fall migration through the Drew Forest, which comprises Zuck Arboretum, Hepburn Woods, and areas of the Drew University campus, and analyze whether there have been significant changes in the diversity of bird species over the last 100 years.

History of Bird Migration Understanding

For hundreds of years, the seasonal migrations of birds was a topic that was not fully understood or recorded. Possibly the earliest mentions of bird migration can be seen in myths and stories of early cultures around the world. Some of the earliest written theories into the migrations of birds date to around the 4th century BC when Aristotle was completing his works in the *Historia Animalium* (Heisman 2022). Aristotle made many hypotheses, some of which were more accurate than others, but two examples of his hypotheses include his ideas about the overwintering habits of swallows and the change of color on seasonal birds, now understood to be seasonal molting of seasonal and breeding plumages. Similarly, during the Renaissance period, swallows were once again the subject of early zoological work (Hall 1991). In the work, *De Animantibus Subterraneis* written by Gregorius Agricola between 1549 and 1556, the mention of migrational habits of swallows is loosely described as the “withdrawal to nearby places that have more mild climates" (Aldrich et al. 2009).

Over time, the drive to understand the world led to others attempting to pick up where these cultures and individuals left off in their ideas regarding the migration of birds. This being said, in the early days of science and ecology, there were often hypotheses and ideas that were farfetched to downright impossible. One such example of an interesting, yet incorrect, hypothesis was proposed by Charles Morton in the 1680s. One of his ideas was that birds that migrated in the winter, particularly swallows, not only left their observed habitat, but instead left the planet and migrated to the moon (Heisman 2022). Though the overall knowledge and documentation of birds as a whole continued to grow throughout the following centuries, many of these theories of migration persisted. It wasn't until the 1820s that the first recognized evidence of intercontinental bird migration was recorded in Germany when an African Stork that had been impaled by an arrow produced in Africa was found alive in Germany (Kaatz et al. 2023). The tracking of bird migration continued to advance and, in 1899, the banding of birds was introduced in Denmark by Hans Christian Cornelius Mortensen who began banding European Starlings (*Sturnus vulgaris)* to track their movements (Preuss 2001). From that point on, the understanding of bird migration took off as technology began to offer better answers to many of the previously unanswered questions.

It was also around this time that there were many types of legislation passed, such as the Migratory Bird Treaty Act of 1918, that aimed to unify nations to conserve species of birds that migrate across international borders (Heisman 2022). Technology, such as acoustic amplifiers and radar that were used in the First and Second World Wars were quickly found to be very effective at locating and recording migratory birds as much of their intended uses was to find and track flying objects, principally planes. These new technologies were used for recording the night time migrations of birds by angling the receivers towards the sky in the paths through which they believed birds were migrating (Heisman 2022). Previously, in the 1880s and 1890s, the night time migration of birds was only able to be documented by telescopes and moon light to illuminate the migrating birds (Heisman 2022). Around the same time period that radar was found to be a potential locator of migratory birds, another major ornithological tool was beginning to be utilized. This tool was the mist net, which in modern day ornithology is usually a thin nylon net that is suspended in a location where a target species of bird is either occupying or is known to be migrating through. The goal of these nets is to intercept the birds' flight so that they become ensnared in the net and become immobilized until the researcher can come and free the specimen and collect the necessary data. The idea for mist nets was developed by a researcher by the name of Oliver Austin who, while based in post-WW2 Japan, observed locals utilizing thin silk nets, which were hung on poles, to capture birds as food (Genoways 2020). This advancement in ornithology would prove to be integral to the progression of understanding bird migration as it allowed for the effective capture and recording of species and increased the effectiveness of tagging birds as they could be caught live at a higher rate (Sheldon 1960).

Starting in the late 1960s and continuing through the 1970s and 1980s, the advancement of tagging birds once again took a leap into the realm of technology as the development of radio tracking tags became commonplace, albeit mostly on the larger species of birds such as raptors and large waterfowl as most radio transmitters were quite large during that time. Radio transmitters would allow for accuracy in tracking an individual bird at a level that had been rarely seen before in the pursuit of migration understanding. Yet this technology, too, was eventually eclipsed by the development of smaller GPS trackers that could be placed on smaller birds and had increased accuracy compared to their traditional radio transmitter counterparts in tracking longterm migrations of individuals (Heisman 2022). Another recent advancement in the field of bird tracking is that of the Motus tracking system. The Motus system is a series of linked automated radio telemetry stations that can continuously monitor and track tagged individuals as they move and or migrate (Motus 2024). All this advancement in ornithology has led to the modern day, where our understanding of migration in many avian species is better understood, and accurate data can be accessed and even recorded by the average person in real time, whether they are a professional ornithologist or just a backyard birder.

Bird Diversity

When looking at the diversity of classes in the animal kingdom, Aves has very high biodiversity, both worldwide as well as regionally, with global estimates around 11,000 species and in some cases estimated to be upwards of 18,000 species (Barrowclough et al. 2016). Around the world, new information is being found relating to how bird species are classified or as to the documentation of species that are new to science. In fact, as of when this thesis was being written, there were three new species that were described and added to databases such as eBird. These three species were the Principe Scops-Owl (*Otus bikegila*), the Wangi-wangi White-eye (*Zosterops paruhbesar*), and the Iberan Seedeater (*Sporophila iberaensis*) (eBird 2023). Bird diversity is often viewed through the lens of where the researcher is located as there are regions in the world where bird diversity is higher, on average, than in other regions. One example of two species rich, yet distinct, regions can be seen when comparing the East Coast of North America to the Amazon rainforest. Both of these locations are habitats for many species of birds, albeit some are more distinct species that have evolved to be better adapted to their desired niche and or habitats, but it is seen that the level of avian diversity within the Amazon can be significantly higher (Haffer 1990). On the contrary, there are also instances where the diversity of birds within distinct regions overlaps as a result of migration. This can lead to seasonally high and low levels of avian diversity where species that are found in one region can be found in other regions and vice versa. An example of this diversity flux that can be seen during the spring and fall migration is the motion of many species of songbird such as the Baltimore Oriole *(Icterus galbula)*, which can be found along the East Coast of North America in the spring and summer, but will migrate all the way to the top of South America in the winters (Sealy 1985). Another example is the migration of many "fall warbler" species, such as American Redstarts *(Setophaga rutocilla)*, which migrate in similar ways to the Baltimore Oriole, but only during the beginning to middle of the fall migration along the East Coast as they move to and from their breeding locations (Robbins et al. 1989).

This level of diversity not only applies to birds overall worldwide, but can also be seen within a single species or family. A well known example of this type of diversity within a species can once again be seen within Dark-eyed Juncos. The Dark-eyed Junco is a species of sparrow that has long been the topic of debate as it has many morphological variations that are observed within mostly geographically distinct populations (Ferree 2013). In this debate, there are two factions that have differing opinions on how this species should be categorized. These two groups are known as the "lumpers", who believe that the morphologically distinct groups should be grouped into subspecies, and the "splitters", who believe that the morphological groups should be separated into different species and not be grouped (Montgomerie 2018). The lumping and splitting of bird taxonomy is an ongoing debate that has been going on for over 100 years and has caused many species, both non-migratory and migratory, to be renamed or recategorized (Vaidya et al. 2018). For the longest time these geographically defined populations were considered their own species and were identified and recorded as such. It was not until genetic testing and analysis advanced that it was found that these distinct populations were not actually distinct enough genetically to be defined as individual species (Ferree 2013). It was eventually decided that the large number of previously recognized Dark-eyed Junco species were consolidated and categorized into five main sub-species along with the classifications of isolated groups that were distinct enough to remain categorized as separate such as the Guadalupe Junco *(Junco insularis)* (Ferree 2013). This is one of the most well known examples of avian intraspecies diversity in North America as all five of these subspecies are found within North America.

Similar examples of such variation can be found throughout the world across many different types of species. Another example of birds that are known by the classification of their subspecies is the Hawaiian Honeycreepers which also have a very large breadth of subspecies that can look very different from each other morphologically (Lovette et al. 2002). Currently it is believed that there are around 50 species and subspecies of Honeycreepers that currently exist or once existed on the Hawaiian Islands as the result of a massive speciation event that was seemingly unique to the Hawaiian Honeycreepers on the Hawaiian Archipelago as the other groups of bird taxa here never speciated in this way (Lovette et al. 2002). The diversity of birds has also been recognized as an important indicator of environmental health as oftentimes birds are one of the first organisms to evacuate an environment when it is thrown out of equilibrium (Francis 2017). This is due to the fact that birds are sensitive to changes that could affect other levels of an environment such as pollution or loss of habitat. There are several reasons that birds are often used as indicator species while observing the health of an ecosystem both short term and long term. One such reason for this is that most birds are easy to find and observe within an environment so changes to their behaviors are well documented. With this in mind, we can often infer that habitats with increased biodiversity compared to habitats with lower biodiversity are healthier and more likely to sustain that health long term (Francis 2017).

Indicator species are important because it is difficult to monitor whole ecosystems and so, indicator species can act as an early warning system to deteriorating environmental conditions in a habitat and also act as a way to gauge if conservation efforts are having a positive effect in increasing biodiversity (Mekonen 2017). Birds are a good indicator species for a number of reasons. They are more easily affected by environmental changes than many other types of animals and they are present in many places. This ubiquity has the tendency to draw community members in and serves as a way to enlist volunteers to document the indicator species' presence through citizen-science databases. This heightened awareness within the community further fuels support for conservation (Mekonen 2017). Through the course of entering data gathered during this study, Hepburn Woods and the Drew University campus itself are now hotspots on the citizen-science database, eBird. The increased awareness this distinction brings will further highlight the need for conservation of these open spaces and help combat further habitat fragmentation. Government agencies, like the US Department of Agriculture Forest Service, use birds as indicator species to measure ecosystems' responses to urban expansion and habitat fragmentation, in part, by looking at biodiversity and species richness, especially the presence of rare and threatened species (Mekonen 2017).

Migrational Cues

Many species of birds rely on the change of season as a primary cue for events such as migration, seasonal nesting habitats, and even basic access to food. Common Redpolls (*Acanthis flammea*), a species that generally inhabits the subarctic to more northern regions of the world, is a prime example of how variations on seasonal cues can cause some interesting changes in their typical behaviors. In addition to the normal migrations of this species, in many places, Common

Redpolls are known to be explosive migrants where they may not migrate to that location for several years and then migrate to that location all at once (Dale 2021). Dale (2021) found that the habitat preference of breeding Redpolls seemed to be influenced by levels of snow on the ground allowing for individuals to feed on their preferred food.

There have been many hypotheses into changes in the arrival and departure times of species to and from both feeding and breeding grounds in the winter and spring. This topic has been the source of much conjecture over the past decade, as there is no easy way to make an overall conclusion to this question as different species of birds are affected in different ways. For example, some species are not affected at all, while others have major shifts in their behaviors (Møller et al. 2010). Based on the idea that migration in certain species is the result of genetic influence, there are also many hypotheses that have been introduced in recent years regarding why certain species are more influenced than others (Howard et al. 2018). Many of these hypotheses contend that species that rely on genetically controlled migrational cues have the greater potential to be influenced by seasonal changes (Louchart 2008). This is due to the fact that these species are generally long distance migrants that have stricter timelines in which they can successfully complete their migrations, thus lowering their flexibility to change (Louchart 2008). Furthermore, recent studies into how long distance migrants perform their migrations have found that these species are more likely to need more frequent stops along their migratory paths (Howard et al. 2018). This need for additional stops during long term migrations will cause the overall duration that these species travel to increase which could play a role in changing the current way we view these long distance migratory species (Howard et al. 2018).

Birds that migrate a long distance may be more heavily influenced in their migration timing by cues that are more fixed such as photoperiod than are birds that migrate short distances. Long distance migrants rely heavily on these fixed cues as their migrations are more physically taxing and expose them to dangers such as increased predation risk, meaning that correctly timed cues are more important. This makes long-distance bird migratory species slower to respond to environmental changes in their destination than birds that migrate shorter distances (Zaifman et al. 2017).

Still, both long and short distance migratory species are influenced by a variety of migratory cues. In a 30 year long study done in Tatarstan Republic, Russia, it was found that over the past several decades the number and frequency of migrating species observed in this study (Common Redpolls *(Acanthis flammea)*, Bohemian Waxwings *(Bombycilla garrulus)*, Eurasian Siskin *(Spinus spinus)*, and Red Crossbill (*Loxia curvirostra)*) have been affected by variations in temperature and food supply (Askeyev et al. 2023). The primary location of this study was Tatarstan Russia, but the study also mentioned data collected from other areas of Europe such as Finland and Sweden. In this case, they found that there was a correlation between the timing and severity of winter and the arrival of some of the above listed species, meaning if there is a later and less severe winter, the frequency in which these sampled species appear will also change, as warmer and less severe winters allow for increased food abundance and more habitable long term conditions (Askeyev et al. 2023).

Drew University Campus Ornithological History

Drew University may have began its life as a theological school, but it wasn't long before the sciences made their way into the curriculum at the school. The surrounding forest was the ideal spot for nature to flourish and additionally was an ideal location for interested faculty and students to observe wildlife. Even though Drew University is not known for ornithology, there is historical data that exists regarding birds on campus and the Drew Forest. This data ranges from present day all the way back until the early 1930s and oftentimes varies from simple notes in campus newspaper clippings to personal student and faculty accounts, to at least one full bird banding station that was operational in the spring of 1938 with the intent of understanding bird migration. One example of the earliest recorded birds at Drew University in any sort of ornithological sense were taken by Dr. Wyman R. Green as he seems to have handled most of the bird sampling and banding on campus in the 1930s and 1940s. In addition to Dr.Green's banding, there were also several individuals that utilized photography as a method of documenting the bird species found on campus (The Drew Acorn 1938). Unfortunately, if any records of species counts and banding records were taken, along with the photos taken during that period have seemingly been lost to time. This loss of access to the data taken during Dr. Green's surveys means that, with the exception of brief mentions in the school newspaper, the earliest Drew University ornithological records that can still be found are recorded in the book *The Building of Drew University* by Charles Sitterly, published in 1938. This book contains the accounts of Mrs. Olin A. Curtis, the wife of a Drew University professor, which she recorded during her time at Drew University. Even by her own admission, however, her accounts were not methodically recorded as she notes, "doubtless there have come and gone, in migration, many birds which have escaped my notice." (Sitterly 1938 p. 276). These accounts did provide realistic counts and descriptions of species that match with similar accounts from the surrounding areas that seem to indicate that Mrs. Olin had a better than average understanding of bird identification to the point where she could confidently record and publish her accounts. In her accounts she identifies 62 species of birds that she observed on campus and the surrounding forest including several accounts of behavioral and migrational observations.

Since Sitterly's publication, Drew University's biology and sciences department continued to expand and grow and along with this growth, so did the data pertaining to Drew's birds. Unfortunately, many of these records are unable to be found along with the data that was collected in the 1930's, but some accounts of students still live on in Drew University's school newspaper, the Acorn. It wasn't until the late 1990s to the early 2000s that Drew introduced an official ornithology course into the curriculum and this is the point where more consistent data began to become available. During this time, there were many individuals who recorded long term data, such as the accounts of Dan Lane who took records of birds within the Drew Forest from 1991 to 1995.

The primary goal of my honors research was to complete an updated survey of the overall avian richness of the Drew University Forest over the course of the fall migration of 2023. Additionally, I compared the diversity found during this current study to historical records from both Drew University and the immediate surrounding areas to examine how avian diversity has changed over the last 100 years. Finally, I will utilize this study's data to produce occupancy models to better understand the seasonal trends of migrant and resident species through the Drew Forest in relation to both occupancy and detection.

Methods

Data Collection

For my research, I first had to outline my sampling area that I would be using for the duration of my data collection. To begin narrowing down this sampling area I took a similar route to that which was laid out by Dr. Windfelder for her ongoing small mammal research. This route consisted of Zuck Arboretum, Hepburn Woods, President's House Woods and the Main

Campus of Drew University (Figure 1). This set of locations were chosen because they consisted of the greatest variety of habitat types available at Drew; these habitat types include meadows, ponds, ephemeral wetlands, and dense deciduous forest. Data collection for these locations was carried out on Tuesday, Thursday, Saturday, and Sunday mornings starting at 6:30-7:00 am, weather permitting. This schedule allowed for the collection of data during the dawn chorus when most species of birds were at their most active and were vocalizing the most. This activity made audio recordings and identification much simpler as it allowed for cryptic species to be detected more consistently. If there were a case where the weather inhibited the collection of data at these times, a makeup day was used to gain data that was missed. On the aforementioned planned data collections, I implemented two separate sampling methods along my main route. These methods consisted of standard transect sampling where data were collected as I walked along the route (Figure 1) and a point census sampling method in which I stopped at predetermined locations along the route (Figure 2). This point census contained 10 individual sites that were spread out at intervals along the route in order to try to minimize the amount of potential double counting between sites. Out of these ten sites, two were located on the Main Campus, one was in President's House Woods, four were in Hepburn Woods, two were in Zuck Arboretum, and one was in between the Zuck Arboretum and Hepburn Woods. These separate collections on make-up days were marked separately as they were not on the same days as the complete collections. On my field data and my spreadsheets, I used the four letter banding codes to identify different species as opposed to the common name as they took less space (see Table 1 for translation of codes to common names). While taking data, I did not only take the counts of birds I had seen, but I also utilized a variety of tools to document different species and behaviors that were observed. These tools included my Canon mirrorless camera, a Zoom H1n audio recorder paired with a mid range shotgun microphone, the Sennheiser MKE 600, Nikon 7x50 OceanPro binoculars, and Browning trail cameras. The products of using these tools were then used to document arrival and departure times of certain species along with the presences of isolated migrants and rare/cryptic species that may only be seen once during a migration, if at all.

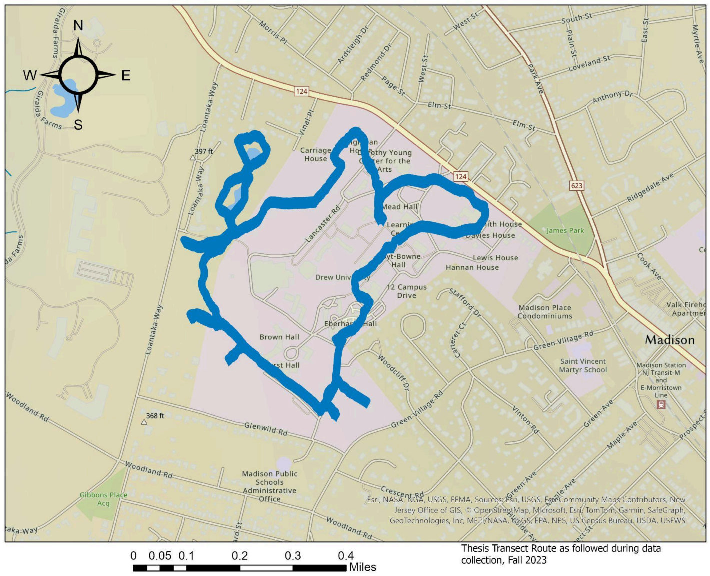

Figure 1. Map of Survey Transect utilized during the 2023 fall season, NAD 1983 2011 State Plane New Jersey FIPS 2900

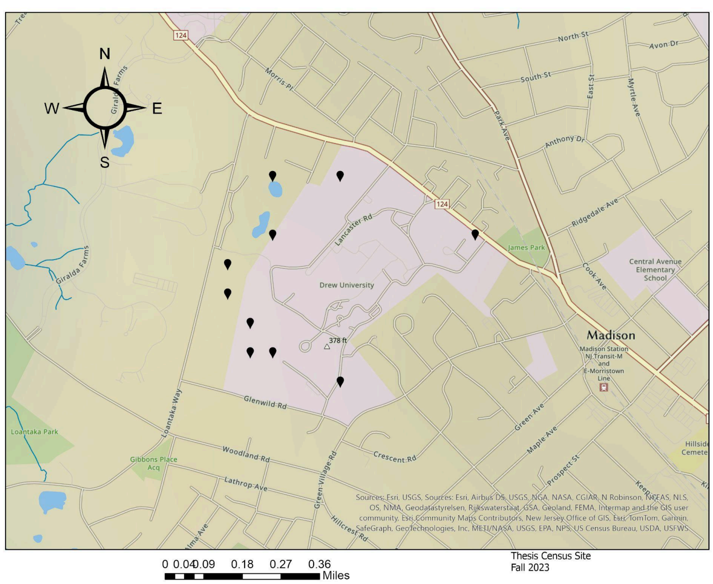

Figure 2. Map of Survey Point Census Sites utilized during the 2023 fall season, NAD 1983 2011 State Plane New Jersey FIPS 2900

Table 1. A list of all species observed during this study includes both the 4-digit banding code used in data collection and comparison and the translation to the common name (The Institute for Bird Populations 2023).

Banding Code	Common Name
AGOL	American Goldfinch
AGWT	American Green-winged Teal
AMCR	American Crow
AMKE	American Kestrel
AMRE	American Redstart
AMRO	American Robin
BADO	Barred Owl
BAWW	Black and White Warbler
BCCH	Black-capped Chickadee
BEKI	Belted Kingfisher
BHCO	Brown-headed Cowbird
BHVI	Blue-headed Vireo
BLJA	Blue Jay
BLVU	Black Vulture
BRCR	Brown Creeper
BTBW	Black-throated Blue Warbler
BWHA	Broadwing Hawk
CANG	Canada Goose
CARW	Carolina Wren

Banding Code	Common Name
CEDW	Cedar Waxwing
CHSP	Chipping Sparrow
CHSW	Chimney Swift
COGR	Common Grackle
COHA	Cooper’s Hawk
CONI	Common Nighthawk
CORA	Common Raven
COYE	Common Yellowthroat
DCCO	Double-crested Cormorant
DEJU	Dark-eyed Junco
DOWO	Downy Woodpecker
EABL	Eastern Bluebird
EAPH	Eastern Phoebe
EASO	Eastern Screech Owl
EATO	Eastern Towhee
EAWP	Eastern Wood Pewee
EUST	European Starling
FICR	Fish Crow
FOSP	Fox Sparrow
FISP	Field Sparrow

Banding Code	Common Name
GBHE	Great Blue Heron
GCKL	Golden-crowned Kinglet
GCTH	Gray-cheeked Thrush

GRCA	Gray Catbird
GRHE	Green Heron
HAWO	Hairy Woodpecker
HETH	Hermit Thrush
HOFI	House Finch
HOSP	House Sparrow
HOWR	House Wren
KILL	Killdeer
LEFL	Least Flycatcher
MALL	Mallard
MAWA	Magnolia Warbler
MERL	Merlin
MODO	Morning Dove
NAWA	Nashville Warbler
NOCA	Northern Cardinal
NOFL	Northern Flicker

Banding Code	**Common Name**
NOMO	Northern Mockingbird
NOPA	Northern Paulara
OVEN	Ovenbird
PAWA	Palm Warbler
PEFA	Peregrine Falcon
PISI	Pine Siskin
PIWA	Pine Warbler
PIWO	Pileated Woodpecker

PUFI	Purple Finch
RBGU	Ring-billed Gull
RBWO	Red-bellied Woodpecker
RCKL	Ruby-crowned Kinglet
REVI	Red-eyed Vireo
ROPI	Rock Pigeon
RSHA	Red-shouldered Hawk
RTHA	Red-tailed Hawk
RTHU	Ruby-throated Hummingbird
RUBL	Rusty Blackbird
RWBL	Red-winged Blackbird

Banding Code	Common Name
SCTA	Scarlet Tanager
SOSP	Song Sparrow
SSHA	Sharp-shinned Hawk
SWSP	Swamp Sparrow
SWTH	Swainson’s Thrush
TUTI	Tufted Titmouse
TUVU	Turkey Vulture
WAVI	Warbling Vireo
WBNU	White-breasted Nuthatch
WIWR	Winter Wren
WOTH	Wood Thrush
WTSP	White-throated Sparrow
YBSA	Yellow-bellied Sapsucker

Banding Code	Common Name
SCTA	Scarlet Tanager
SOSP	Song Sparrow
SSHA	Sharp-shinned Hawk
SWSP	Swamp Sparrow
SWTH	Swainson's Thrush
TUTI	Tufted Titmouse
TUVU	Turkey Vulture
WAVI	Warbling Vireo
WBNU	White-breasted Nuthatch
WIWR	Winter Wren
YEWA	Yellow Warbler
YRWA	Yellow-rumped Warbler
YTVI	Yellow-throated Vireo

Photographic & Videographic Documentation

When tracking migratory birds, it often helps to be able to not only observe the birds as they move through a region, but to also document their presence in photographs and video in situ in their habitat. Gathering of this kind of documentation was done using two separate methods: my personal handheld camera and a combination of school supplied and personal trail cameras. My handheld camera was carried with me during the majority of my data collection in case of the appearance of significant species or arrival of incoming species that would indicate migration. The exception to this use of photographic equipment was the presence of inclement weather such as heavy rain or snow that would damage the equipment. In these cases of inclement weather, my phone digiscoped through my waterproof binoculars was sufficient in producing identifiable photographs. In order to best adapt to the varying conditions present in my study region, I carried a selection of lenses that would work better in different scenarios under certain parameters such as low light or highly skittish, cryptic species that needed increased distance to be detected. In addition to photographs, video, both standard speed (60fps) and hi-speed (120fps), were captured of many species in order to isolate and compare behavior traits that are associated with many species. Some of these traits and behaviors included feeding/hunting, nesting, fly overs, preening, and instances of intraspecies and interspecies encounters.

For areas that were difficult to consistently reach or were suspected of being nesting sights/roosting sites, trail cameras were used to assist in monitoring. One such area where this technique was used was the suspected roosting site of owl species within the abandoned building in Zuck Arboretum. A trail camera was suspended on a tree about 4 to 4.5 meters above the ground and pointed at a broken window where the owls were suspected to be entering and exiting. The trail camera was set to capture video with sound in order to not only show whether my theory of owls occupying this space was supported, but also to try and capture calls that could be associated with mating/nesting. A second trail camera was utilized in an area where it was believed that a population of Winter Wrens (*Troglodytes hiemalis)* was occupying as a foraging and nesting site, but consistent human disturbance would likely have interfered with their prolonged presence in the site.

Audio Recording

In many cases during data collection, there were times when individuals were unable to be captured in photographs, whether it was due to foliage or other obstructions. The remedy to this issue was to record the calls and songs that these individuals made while moving around out of view. This was accomplished initially utilizing my phone to try to capture the vocalizations of these individuals, but it was soon clear that the microphone on my phone was not sensitive enough for recording many species of birds, so a small shotgun mic was then employed to help increase the sensitivity of my phone. This increased the sensitivity and was successful in picking up the calls, but was eventually upgraded to a much longer and more directionally sensitive shotgun microphone and designated recorder. In doing this, I was able to better isolate and amplify the calls of some of the smaller species which included species that inhabit niches that were almost exclusively in areas that binoculars and cameras were unable to see/record. This method of audio recording also allowed me to document species that primarily operate in the early morning or night when light levels restrict the use of cameras, such species include owls, nightjars, and shorebirds such as American Woodcocks *(Scolopax minor)*. As with the previously mentioned photographs and videos, these audio recordings were used to convey both species presence within my chosen study area and to indicate a specific species' behavior.

Statistical Analysis

In order to accurately quantify the data that was collected during this study, several types of statistical analysis were used to isolate trends within the present data. Two diversity indices, Shannon's Diversity Index and Simpson's Diversity Index were calculated to quantify avian diversity. Shannon's Diversity Index was included in this study as it is impacted by the richness and presence of rarer species allowing for the measurement of diversity. Simpson's Diversity Index was included in this study as it not only measured diversity, but has a heavy emphasis on evenness of the reported species. These two tests are the Shannon's Diversity Index and the Simpson's Diversity Index which are described in the table below (Table 2)

Table 2. Description of equations and variables for Shannon's Diversity Index and Simpson's Diversity Index

Shannon's Diversity Index $H' = -\sum_{i=1}^{S} (p_i)(\ln p_i)$	**Simpson's Diversity Index** $D = 1 - ((\Sigma n (n - 1)) / (N (N - 1)))$
H' = Total Shannon's	D = Total Simpson's
p_i = Proportion of species in i species	n = Total number of individuals of a particular species
S = Number of species in the total sample	N = Total number of organisms of all species

Shannon's Diversity Index was calculated for the totals of the entire sampling time frame. This allowed me to make an estimate of the overall diversity of species present in the Drew Forest and campus over the course of the 2023 fall migration season as a whole. Once the total overall Shannon's H′ was found, I took the daily Shannon's value which allowed for the diversity to be plotted against date to show possible changes over my sampling frame (Figure 9). I also calculated the Simpson's Diversity Index, which emphasizes the evenness of the sightings within a data set. Calculating the Simpson's Diversity Index allows for further corroboration to the total calculated Shannon's Diversity Index, but with a higher emphasis on the evenness of the data presented.

The primary analysis that I ran on my data was using a program by the name of PRESENCE to run single season occupancy models of a migratory species Common Grackles (*Quiscalus quiscula*) and a resident species Downy Woodpeckers *(Dryobates pubescens)*. In order to complete the next analysis, I utilized the sampling covariates of temperature, date and time, as well as the site covariances of site name and habitat type to determine if there were any significant models. In the context of occupancy modeling, covariates are representative of the chosen independent variables that are being tested for. In this case, my sampling covariates were selected for testing for detection (p) of my selected species, while my site covariates were selected for testing for the occupancy (psi) of my selected species. These covariates were also selected due to them fitting the assumptions that are set when running occupancy models. In the occupancy models that I ran for in my study, there were several assumptions made, but the primary assumption that was made for testing was that there was no movement between sites that could skew the results. The fitness of each model was determined using the Akaike Information Criterion (AIC) which revolves around the interpretation of ΔAIC value and the AIC value to determine the ranking of which models are the most accurate and best fit (MacKenzie et al. 2018). In these models the closer the calculated ΔAIC value is to 0, along with the stipulation that this value is found to have a value of 2 or lower means that particular model is a better competitor for the best fit model. Additionally, we need to take into account the complexity of the models that are produced, as the more complex a model becomes, the more it will be penalized over lower complexity models meaning greater explanatory power is needed to make higher complexity models more fit. This means that a model that comprises two parameters is more likely to contend with the most fit model than a model with four parameters.

Historical Comparison

Upon the completion of the statistical analysis of my collected data, a comparison was made to better understand if there were any potential changes in richness during the annual migrations of birds through this region over time. This comparison was against historically recorded richness data from the surrounding region of Southern Morris County, New Jersey, along with data that was collected within my designated study area in the Drew Forest. The age of this historical data ranged from the early 20th century (1925) until the present and was found through many means such as internet searches, the Drew University library, previous student records and studies, and official bird counts from other organizations outside of the Drew community. There were seven sources of historical data that I utilized for this study; five of these data sets (1925, 1991-1994) were found on eBird, the sixth data set was sourced from the Drew Library (1938), and the seventh data set (1991-1995) was sourced from my advisor, Dr.Windfelder.

Results

At the conclusion of my sampling period, which had run from September 12 to December 15 of 2023, I was able to detect a total of 93 species of birds with a total of 6,747 individuals over the course of 37 censuses. As a part of these species, I was able to identify two species, the Barred Owl (*Strix viria*) and the American Kestrel (*Falco sparverius*) that sit on the New Jersey Threatened species list, and eight species that reside on the New Jersey Species of Special Environmental Concern list including two breeding species (Br). These eight species were the Peregrine Falcon (*Falco peregrinus*), Red-shouldered Hawk (*Buteo lineatus*), Sharp-shinned Hawk (*Accipiter striatus*), Common Nighthawk (*Chordeiles minor*), Winter Wren (Br) (*Troglodytes hiemalis*), Gray-cheeked Thrush (*Catharus minimus*), Wood Thrush (Br) (*Hylocichla mustelina*), and Cooper's Hawk (Br) (*Accipiter cooperii*) (Table 3). I also was able to detect three species that were listed on the IUCN Red List and hold a conservation level at Near Threatened. These three species were the Chimney Swift (*Chaetura pelagica*), the Common Grackle (*Quiscalus quiscula*), and the Rusty Blackbird (*Euphagus carolinus*) (Table 3).

Table 3. List of birds of outstanding conservation status in New Jersey or on the IUCN Red List with a level of "Near Threatened" or higher found during this study. (VU) = Vulnerable; (NT) = Near Threatened. (Br) = Breeding or believed breeding pair / group present.

NJ Threatened Species Detected	NJ Special Environmental Concern Detected	IUCN Red List Detected (Near Threatened and Above)
Barred Owl (*Strix viria*)	Peregrine Falcon (*Falco peregrinus*)	Chimney Swift (VU) (*Chaetura pelagica*)
American Kestrel (*Falco sparverius*)	Red-shouldered Hawk (*Buteo lineatus*)	Common Grackle (NT) (*Quiscalus quiscula*)
	Wood Thrush (Br) (*Hylocichla mustelina*)	Rusty Blackbird (VU) (*Euphagus carolinus*)
	Sharp-shinned Hawk (*Accipiter striatus*)	
	Common Nighthawk (*Chordeiles minor*)	
	Winter Wren (Br) (*Troglodytes hiemalis*)	
	Cooper's Hawk (Br) (*Accipiter cooperii*)	
	Gray-cheeked Thrush (*Catharus minimus*)	

In Figures 3 and Figure 4, the 93 species I detected are displayed on the basis of taxonomic order to illustrate the overall change in detection over the course of the sampling period. It can be seen that the largest order is Passeriformes (Figure 4) with a total of 18 detected families. The trends present between these 18 families are displayed in Figure 5, Figure 6. The family with the highest detection was Icteridae with the highest level of detection being just over 350 individuals in a day (Figure 5). Conversely, the family with the lowest detection was Certhiidae, with only five overall instances of detection over the study period (Figure 6).

In addition to these 93 species, I was able to observe many cases of genetic anomalies such as leucistic individuals, hyper melanated individuals, and alternate morphs which will be discussed more in the discussion section.

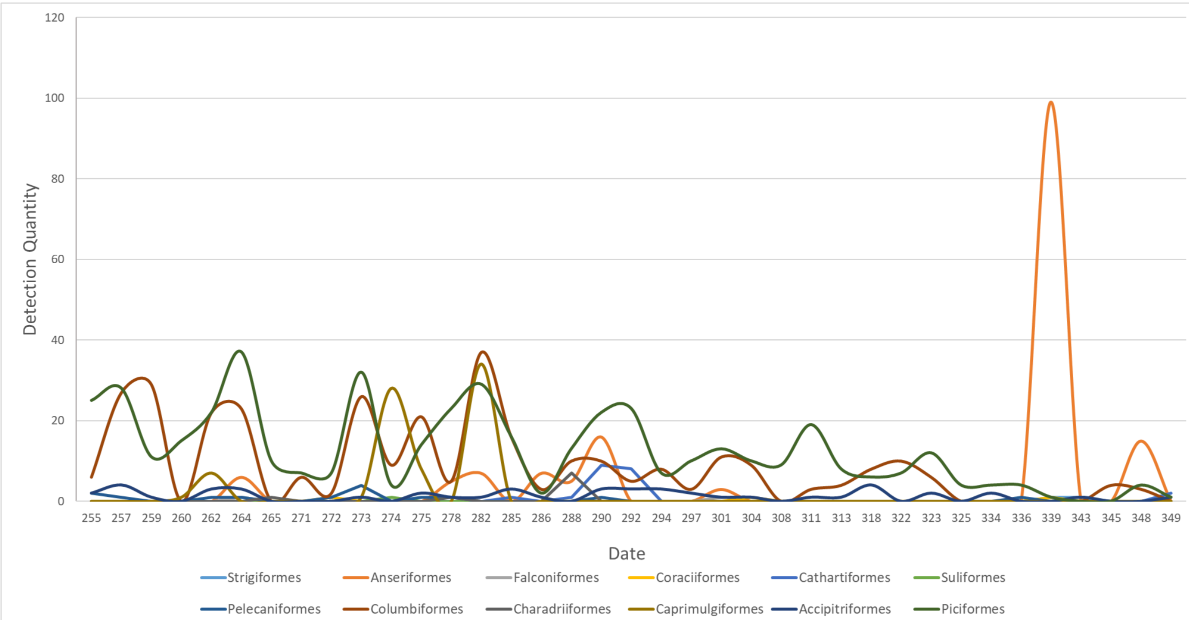

Figure 3. The detection of the 12 taxonomic orders found during the 2023 fall season. This figure excludes the order Passeriformes.

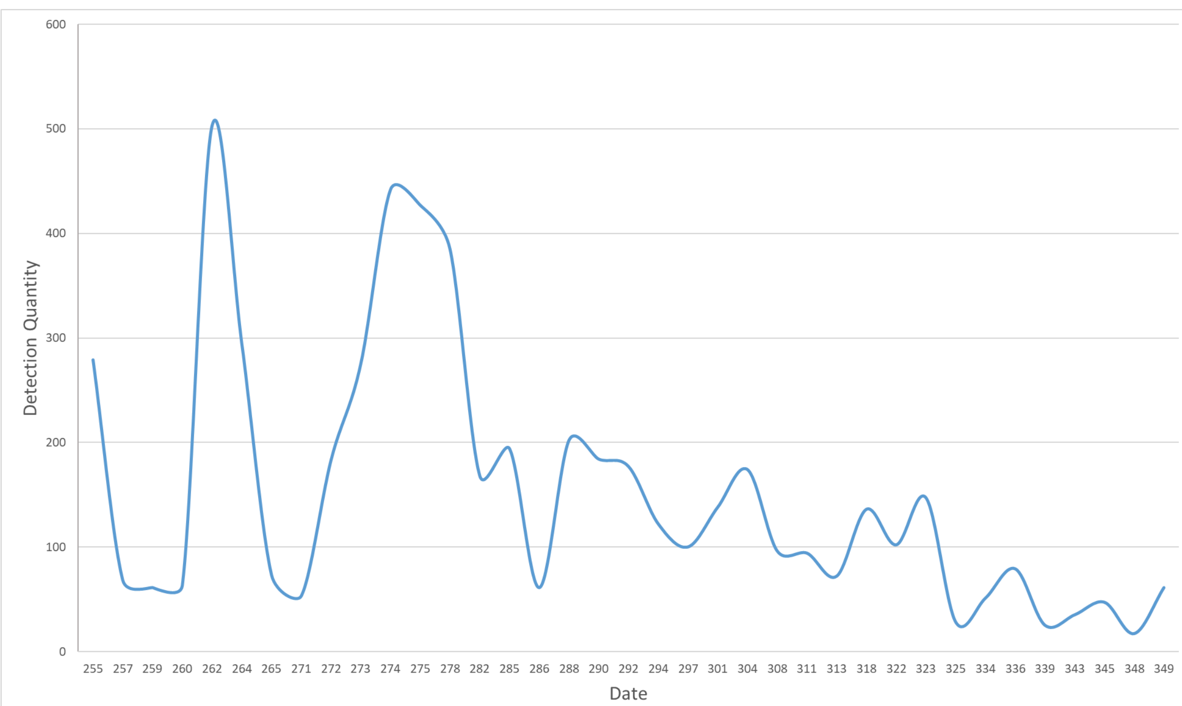

Figure 4. The detection of the order Passeriformes.

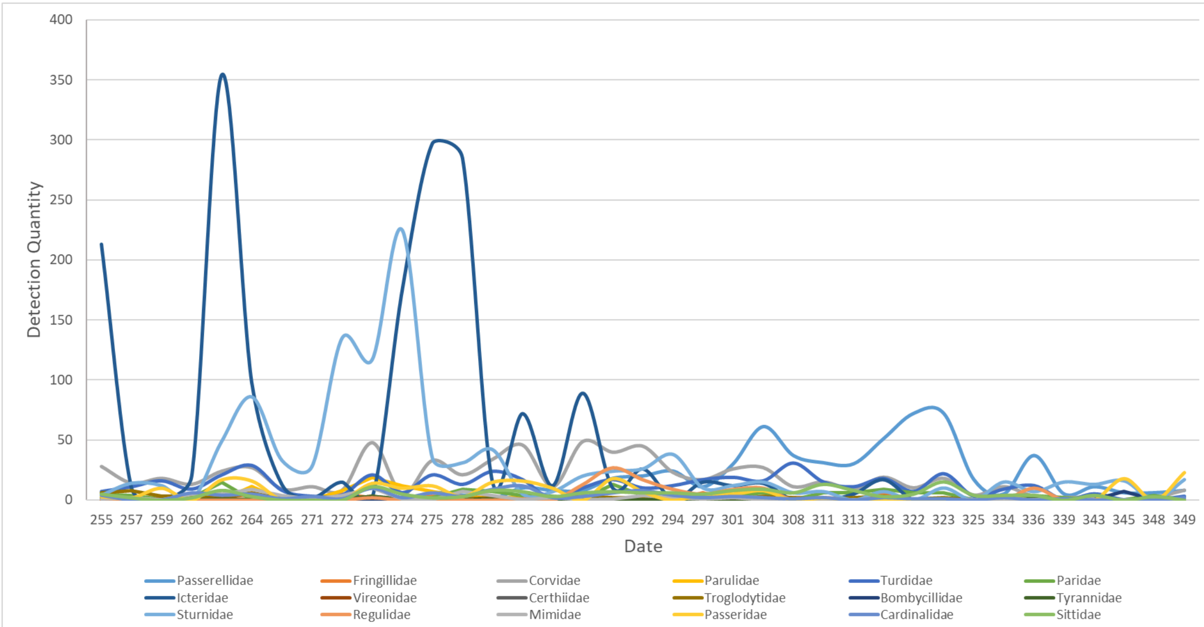

Figure 5. Detection of fall 2023 Passeriformes filtered down to the family level. A total of 18 families within Passeriformes were found during this sampling period.

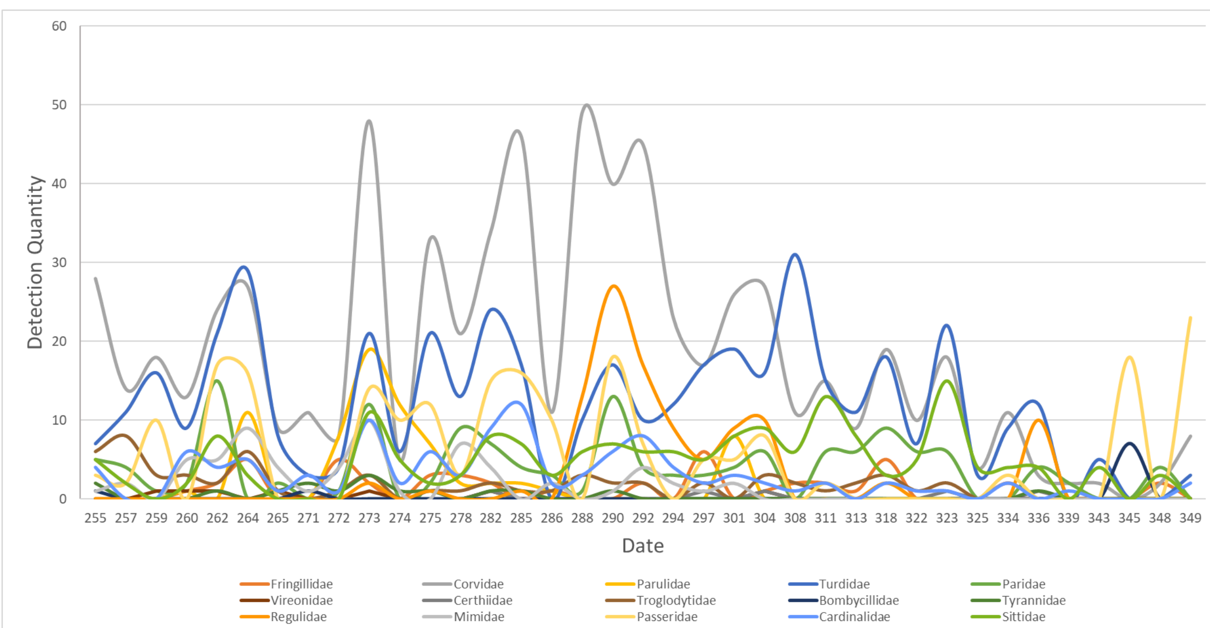

Figure 6. Detection of families within Passeriformes excluding Passerellidae, Icteridae, and Sturnidae.

Next, the temperature data that was taken on each sampling day was compiled and the averages of each month of sampling was calculated (Table 4). For my sampling done in

September, the average temperature was found to be 14.3℃ (57.7℉) with a standard deviation of 2.71, for October it was found to be 10.4℃ (50.8℉) with a standard deviation of 9.47, for November it was found to be 3.1℃ (37.5℉) with a standard deviation of 8.51, and finally for December the average was found to be 5.2°C (41.3℉) with a standard deviation of 5.61. The average daily temperatures that were collected have been displayed along with the selected migratory species, Common Grackle detection over the sampling period (Figure 7). This comparison allowed for further analysis during my population models as now we can visualize that there is an association between daily temperature and changes in Common Grackle detection as the study continued.

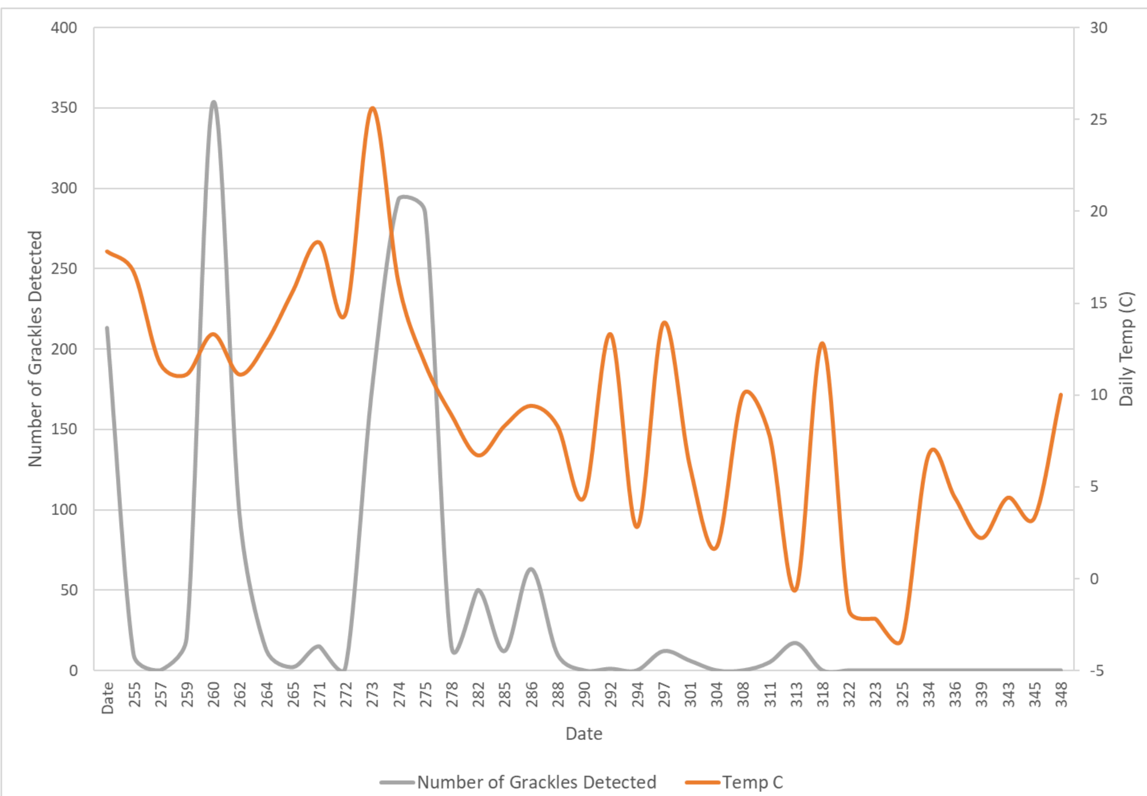

Figure 7. Daily temperature in ℃ in relation to the detection of Common Grackles over the data collection period.

Table 4. Average Monthly Recorded Temperatures and the Monthly Standard Deviations

Month	Average Temperature (℃)	Standard Deviation
September	14.3	2.71
October	10.4	9.47
November	3.1	8.51
December	5.2	5.61

With this data, I was able to calculate Simpson's Diversity Index for all of the gathered data as well as Shannon's Diversity Index for both the daily and combined data. After calculating the Simpson's Index, a value of $D = 0.89$ was found for the total data collected. Next, the cumulative Shannon's Index was calculated, which yielded a value of $H' = 2.88$. In addition to calculating the overall Shannon's Diversity Index for the total individuals recorded during my study and the Simpson's Index, I also calculated the daily Shannon's Diversity Index for each day that data was collected (Figure 8). From these calculations, the average daily Shannon's Diversity Index was 2.16.

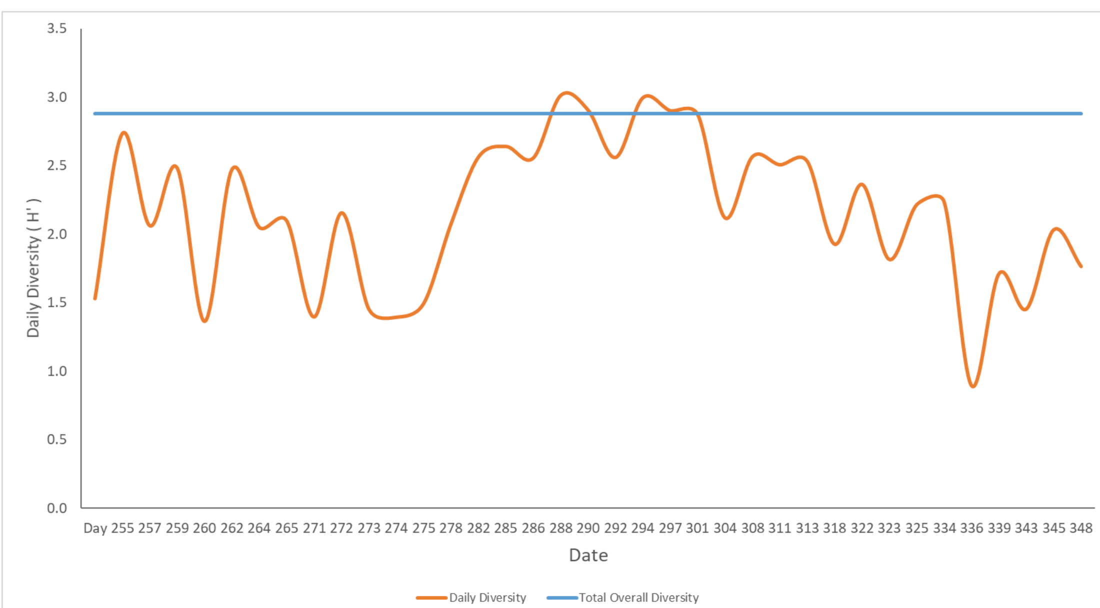

Figure 8. Daily and Total Overall Shannon's H′ value detected over the course of data collection; displayed against date as data collection progressed.

AIC Occupancy Modeling

Once I finished inputting the data for my population models of both my resident species (Downy Woodpeckers, Table 5) and my migratory species (Common Grackles, Table 6), we found that for Downy Woodpeckers, the date played a role in the overall detection of individuals over the course of the study (ΔAIC = 0.00). In addition to this, date when paired with time and temperature affected detection, yet this model was significantly less fit than date alone, ΔAIC (Date,Time) = 1.68 and ΔAIC (Date,Temp) = 1.86. It was also found our second most fit model for the Downy Woodpeckers was our null model which had no covariates entered. In the case of the Common Grackles, the most fit model used the covariates of date and temperature. This indicates that these variables played the most significant role in predicting the detection of this species during my sampling (ΔAIC = 0.00). Additionally, the next most fit models for this species consisted of the same covariates with the addition of the time covariant which significantly lowered the fitness and increased the model parameters from three to four.

Table 5. Population model output for Downy Woodpeckers detected during the fall 2023 point census. Psi is denoting the occupancy covariants and p is denoting the detection covariants.

Model	AIC	deltaAIC	AIC wqt	No. Parameters
psi(.),p(Date)	396.44	0.00	0.2710	2
psi(.),p(.)	397.92	1.48	0.1293	2
psi(.),p(Date,Time)	398.12	1.68	0.1170	3
psi(.),p(.Date,Temp)	398.30	1.86	0.1069	3
psi(Sitename),p(.)	399.92	3.48	0.0476	3
psi(Habitat),p(.)	399.92	3.48	0.0476	3
psi(.),p(Date,Time,Temp)	400.01	3.57	0.0455	4

psi(Habitat),p(Time,Date)	400.12	3.68	0.0430	4
psi(Sitename),p(Time,Date)	400.12	3.68	0.0430	4
psi(Habitat),p(Date,Temp)	400.30	3.86	0.1451	4
psi(Sitename),p(Date,Temp)	400.30	3.86	0.1451	4
psi(.),p(Time)	400.51	4.07	0.0354	2
psi(.),p(Time,Temp)	401.91	5.47	0.0176	3
psi(Habitat,Sitename),p(.)	401.92	5.48	0.0175	4
psi(.),p(Temp)	436.93	40.49	0.0000	2

Table 6. Population model output for Common Grackles detected during the fall 2023 point census. Psi is denoting the occupancy covariants and p is denoting the detection covariants.

Model	AIC	deltaAIC	AIC wqt	No. Parameters
psi(.),p(Date,Temp)	244.15	0.00	0.4708	3
psi(.),p(Date,Time,Temp)	246.05	1.90	0.1821	4
psi(Habitat),p(Date,Temp)	246.15	2.00	0.3679	4
psi(Sitename),p(Date,Temp)	246.15	2.00	0.3679	4
psi(.),p(Date)	257.99	13.84	0.0005	2
psi(.),p(Time,Date)	259.99	15.84	0.0002	3
psi(.),p(Time,Temp)	261.26	17.11	0.0001	3
psi(.),p(.Time)	268.93	24.78	0.0000	2
psi(.),p(.)	269.90	25.75	0.0000	2
psi(Sitename),p(.)	271.90	27.75	0.0000	3
psi(Habitat),p(.)	271.90	27.75	0.0000	3
psi(Sitename,Habitat),p(.)	273.90	29.75	0.0000	4
psi(.),p(Temp)	392.58	148.43	0.0000	2

Historical Findings

Once the study was complete, the 93 species found were compared to other historical accounts that date back to the 1920s (Table 7). This table shows that there has been several shifts in bird species within this area over time, with several species only occurring in specific years. Similarly, other species only occur in more recent years whereas some species solely occur in the more historical records.

Table 7. Species richness over time for Drew University and the immediate surrounding areas as visualized in species common name; coded names provided.

Watson 1925	Curtis 1938	eBird 1991	eBird 1992	eBird 1993	eBird 1994	Dan Lane 91'-95'	Magda 2023
			ABDU	ABDU	ABDU		
AGOL	AGOL		AGOL			AGOL	AGOL
							AGWT
AMCR	AMCR					AMCR	AMCR
			AMCO				
						AMKE	AMKE
						AMPI	
	AMRE					AMRE	AMRE
	AMRO	AMRO				AMRO	AMRO
	ATSP						
					AMWI		
						AMWO	
		BADO					BADO
						BAEA	
	BAOR					BAOR	
	BARS					BARS	
BAWW	BAWW					BAWW	BAWW
BBCU	BBCU						
						BBWA	
BCCH	BCCH		BCCH	BCCH		BCCH	BCCH
						BCNH	
BEKI			BEKI			BEKI	BEKI
						BGGN	

BHCO						BHCO	BHCO
							BHVI
	BLBW					BLBW	
	BLJA			BLJA		BLJA	BLJA
	BLPW					BLPW	
							BLVU
			BOBO			BOBO	
			BRCR			BRCR	BRCR
	BRTH					BRTH	
						BTBW	BTBW
	BTNW					BTNW	
BWHA						BWHA	BWHA
						BWWA	
		CANG	CANG	CANG		CANG	CANG
						CARW	CARW
CAWA							
						CAWR	
	CEDW	CEDW		CEDW		CEDW	CEDW
	CHSP			CHSP		CHSP	CHSP
CHSW	CHSW					CHSW	CHSW
	CMWA					CMWA	
	COGR	COGA		COGR		COGR	COGR
COHA						COHA	COHA
			COME				
	CONI			CONI		CONI	CONI
				CONW		CONW	
							CORA
	CORE			CORE			
COYE	COYE					COYE	COYE
	CSWA					CSWA	
						DCCO	DCCO
	DEJU			DEJU	DEJU	DEJU	DEJU
DOWO	DOWO	DOWO	DOWO	DOWO		DOWO	DOWO
	EABL		EABL			EABL	EABL
	EAKI					EAKI	
	EAME						
	EAPH					EAPH	EAPH
	EASO					EASO	EASO
	EATO				EATO		EATO

EAWP	EAWP					EAWP	EAWP
	EUST		EUST			EUST	EUST
						EVGR	
						FICR	FICR
	FISP				FISP	FISP	FISP
		FOSP		FOSP	FOSP	FOSP	FOSP
						GBBG	
GBHE			GBHE			GBHE	GBHE
				GCBT			
	GCFL					GCFL	
	GCKL					GCKI	GCKI
						GCTH	GCTH
						GHOW	
	GRCA	GRCA				GRCA	GRCA
					GREG	GREG	
GRHE						GRHE	GRHE
						GWWA	
	HAWO					HAWO	HAWO
						HERG	
	HETH					HETH	HETH
				HOFI		HOFI	HOFI
HOSP	HOSP					HOSP	HOSP
	HOWR					HOWR	HOWR
						INBU	
						KEWA	
						KILL	KILL
						LAWA	
	LEFL					LEFL	LEFL
MAKE		MAKE					
		MALL	MALL	MALL		MALL	MALL
	MAWA					MAWA	MAWA
MAWR							
							MERL
MODO				MODO	MODO	MODO	MODO
						MOWA	
			MUSW				
	MYWA					MYWA	
						NAWA	NAWA
				NOCA	NOCA	NOCA	NOCA

NOFL	NOFL			NOFL		NOFL	NOFL
		NOHA				NOHA	
						NOMO	NOMO
						NOPA	NOPA
					NOPI		
						NOWA	
						NRWS	
						OCWA	
	OROR					OROR	
						OSPR	
	OVEN					OVEN	OVEN
						PAWA	PAWA
			PBGR				
							PEFA
						PHVI	
	PISI	PISI				PISI	PISI
						PIWA	PIWA
							PIWO
						PRAW	
						PUFI	PUFI
	RBGR					RBGR	
						RBGU	RBGU
						RBNU	
				RBWO	RBWO	RBWO	RBWO
						RCKI	RCKI
	REVI					REVI	REVI
RHWO	RHWO						
						ROPL	ROPL
RSHA				RSHA		RSHA	RSHA
	RTHA	RTHA	RTHA		RTHA	RTHA	RTHA
	RTHU					RTHU	RTHU
						RUBL	RUBL
			RUDU				
RWBL		RWBL				RWBL	RWBL
						SAVS	
	SCTA					SCTA	SCTA
						SOSA	
	SOSP					SOSP	SOSP
						SOVI	

						SPSA	
						SSHA	SSHA
SWSP				SWSP	SWSP	SWSP	SWSP
						SWTH	SWTH
						TEWA	
						TRES	
			TUTI	TUTI		TUTI	TUTI
			TUVU			TUVU	TUVU
						URST	
	VEER					VEER	
			VIRA				
						WAVI	WAVI
WBNU	WBNU			WBNU		WBNU	WBNU
					WCSP	WCSP	
						WEVI	
						WEWA	
						WITU	
						WIWR	WIWR
					WODU	WODU	
	WOTH					WOTH	WOTH
	WTSP			WTSP	WTSP	WTSP	WTSP
						YBCH	
						YBFL	
						YBSA	YBSA
						YEWA	YEWA
							YRWA
						YTVI	YTVI
						YTWA	

Discussion

Study Overview

The primary goal of my study for the fall migration of 2023 was not only to determine if there have been shifts in avian diversity over time, but also to take a more modern and quantitative sampling of the species richness and diversity over the course of the fall migration.

In addition to this, I also utilized occupancy models on selected migratory species versus selected resident species to gain a better understanding of population dynamics during the fall migration in the Drew Forest.

From past accounts of faculty and students and also from my own records over the last three years, I had been familiar with the birds that inhabited and migrated through the Drew Forest. Unfortunately, in these prior years my record keeping for specific migration timing was informal, yet it was enough to give me a loose impression of what a fully documented migration could yield. This being said, the levels of species richness which were recorded for the fall of 2023 surpassed my expectations by reaching 93 species, including several species that had not previously been documented within the Drew Forest such as Barred Owls and the Peregrine Falcon. The photographs taken of many of these species can be seen in the Appendix to this study. Unfortunately, due to several factors, the trail cameras that were deployed for owl detection and nest monitoring were not used in the final data as they were not continuously monitored during my sampling and in certain cases the sites they were monitoring became compromised due to human interference. Because of this human interference, the trail camera did not reveal any sufficient data for statistical analysis. In future studies, the use of trail cameras could still be beneficial, but more measures would need to be taken to safeguard the study area from potential human interference.

Diversity Evaluation

To begin, I calculated Shannon's Diversity analysis for the whole data set that compared total numbers of these 93 species detected by the total number of individuals overall. Shannon's diversity index is a measure of the number of species within a community that was measured over time as well as distribution of all species across an ecosystem. When interpreting the final result of a Shannon's test, which is reported as H′, the closer to zero this value is, the lower the diversity in that ecosystem. This means that a value of zero indicates that there is only one species within an ecosystem and as the H′ value increases, so can the assumption that the overall diversity within the ecosystem would be higher. Knowing now how the Shannon's diversity is interpreted, my calculated H′ value of 2.88 would seemingly indicate a level of high-moderate richness (Baliton et al. 2020) in the Drew Forest during the 2023 fall migration overall. This finding of a fairly high moderate level of diversity is not completely unexpected based on my previous observations of the migrations that have occurred on Drew's campus over the past few years and the observations of others who wrote historical accounts in a similar manner. Once the total overall value for Shannon's Diversity Index was calculated for the whole sampling period, I went about calculating the average daily Shannon's Diversity Index for my data set. This had resulted in an average Shannon's H′ value of 2.16 per day sampled, which would indicate a relatively moderate to low-moderate level of daily diversity (Baliton et al. 2020). This lower result is to be expected as, on any given day, I was only able to stay out for a handful of hours so the number of daily species were not high in comparison to the total species for the whole sampling period. In addition to the Shannon's Diversity statistics, I also calculated a Simpson's Diversity Index in order to try and corroborate the results of my total Shannon's Diversity test that I conducted first. In a Simpson's test, we are not only analyzing the diversity of an ecosystem, but also the evenness of species across an ecosystem, which is weighted more heavily in Simpson's. For this test, we expect to get a value between 0 to 1, with a score of zero representing no diversity and less even species distribution and a score of 1 representing higher diversity and more even species distribution. Once calculated for my data, I found that the D value for my data set is 0.89 which is relatively consistent with my total Shannon's Index value of high-moderate diversity.

There were some interesting trends in the daily diversity ($H' = 2.16$) seen in the Drew Forest during the 2023 fall migration that seemed to be correlated with the timeframe in which the data was collected. One of the primary trends that was seen was the steady decrease in diversity as the migration progressed over the fall. This result is to be expected as migrant species finished their migrations and subsequently moved out of the Drew Forest. The daily Shannon's values are also higher, on average, during the peak of migration (October 19 through October 24) for my study in comparison to the start and end of data collection. This is likely due to the influx of migratory species moving into the forest, thus adding to the number of resident species that exist here year round.

Historical Analysis

With a more consistent understanding of the richness of the Drew Forest during the fall migration in 2023, I can compare how the richness of species has changed in this region over the past 100 years or so. The data that I ultimately found was divided into three categories that cover three different timeframes: the 1920s, the 1930s, and the 1990s. There is quite a large gap between the 1930s and the 1990s, but my goal is to understand changes in the Drew Forest, so I am limited by the resources that I could find that maintained consistent or verifiable data in this region of Southern Morris County, New Jersey. I only found two sources that were directly linked to Drew University and the Drew Forest: the accounts of Dan Lane, a student at Drew University in the 1990s, and the accounts of Mrs. Olin Curtis, the wife of a Drew University professor in the 1930s. For additional data, I turned to eBird's historical records and checked for records in Southern Morris County, New Jersey. I was able to find a finalized report from 1925 and a good amount of additional data from the 1990s.

Once all of the historical data was gathered, I was able to begin my comparison of the data during the fall 2023 migration. I compared my found richness to that of the historical data from 1925. The 1925 data report was recorded by Frank Watson at the Troy Meadows Nature Area (eBird 2024) and it documented a total of 37 species (Table 7). Of these species recorded by Frank Watson in 1925, I found that there were six species detected that were absent in my data set: Black-billed Cuckoo *(Coccyzus erythropthalmus)*, Canada Warbler *(Cardellina canadensis)*, Marsh Wren *(Cistothorus palustris)*, Barn Swallows *(Hirundo rustica)*, Tree Swallows (*Tachycineta bicolor)*, and Red-headed Woodpeckers *(Melanerpes erythrocephalus)*. While I have detected some of these species at Drew before, such as Barn Swallows and Marsh Wrens, the Black-billed Cuckoo, which I did not detect, was of particular interest. The Black-billed Cuckoo bird is quite a rare species for Morris County, with only a total of 281 individuals logged in eBird for all time (eBird 2024). I was unable to find more data recorded by Mr.Watson, which was unfortunate as it could have been beneficial in a more thorough comparison, as his accounts were well laid out and had notes discussing many of the species or described sightings in more detail when necessary.

Moving forward roughly five to ten years from the accounts of Mr. Watson, I am now able to compare my contemporary data to that of Mrs. Curtis in the 1930s. What sets the data gathered by Mrs. Curtis apart from the data gathered by Mr.Watson in 1925, is that it is more long term data that was taken directly on Drew University's campus. This means that a more direct comparison can be made to my 2023 data, as many of the locations that Mrs. Curtis was observing were the same areas that I was observing in my study. The accounts of Mrs. Curtis lists a total of 62 species of which 17 species differed from my own data with three species, Black-billed Cuckoo, Red-headed Woodpecker, and Barn Swallow, overlapping with the 1925 accounts of Frank Watson (Sitterly 1938). Interestingly enough, much of Mrs. Curtis's data did not contain much information of the quantities of species seen, yet she does note the timings in which many of her reported species, on average, arrive on campus or if a species is a more permanent resident. This is another indication that this data was not the culmination of a single season, but instead was the culmination of several seasons that allowed for her to compare the arrivals of many migratory species, which allows for better analysis of migration patterns overall. One interesting comparison that I was able to make when looking at my data alongside Mrs. Curtis's data was that the Drew Forest and by extension, Drew University's campus, is a site in which many species of migratory warblers visit during the fall migration. In my data set, migratory warblers were one of the most rich groups in numbers of different species, coming in at a total of twelve different species being recorded over my sampling period. Similarly, in the data gathered in the 1930s, we can see that Mrs. Curtis lists a total of ten species of warblers of which four species, the American Redstart, Magnolia Warbler (*Setophaga magnolia)*, Black-and-white Warbler *(Mniotilta varia),* and the "Maryland Yellow-throat" aka the Common Yellowthroat *(Geothlypis trichas)*, overlap with current data (Sitterly 1938). As an interesting side note of Mrs. Curtis's data, there are often birds that are listed as names that have since been changed or are less frequently used such as the "English Sparrow" aka the House Sparrow *(Passer domesticus)* or the "Chewink" that is more commonly known now as the Eastern Towhee *(Pipilo erythrophthalmus)* (Sitterly 1938). This didn't make much of a difference in my comparison, but it is interesting as it shows how much the world of ornithology has changed in just under 100 years and provides a glimpse into how birds were documented on Drew University's campus at the beginning of the 20th century.

Unfortunately, there is about a 53 year long gap, between 1938 and 1991, in which there is limited ornithological data for both the Drew forest and the surrounding region. This meant that the next available, pertinent data, which was given to me by Dr. Windfelder, was collected at Drew University between 1991 and 1995 by Dan Lane. The data collected by Dan Lane in this period was far more organized and consistent than the two previous sources from 1925 and the 1930s and indicated that over those five years a total of 143 species were detected at Drew University, and of these 143 species, 84 species overlapped with my data set (Table 7). Dan Lane's data set was set up differently from my own in that he did not provide the raw data of quantity of birds seen by species, but instead categorized the level of detection by rarity, which in turn was based on the number of sightings. These levels were described as abundant (hard to miss), common (seen daily), uncommon (more than 3 in a season), and rare (less than 3 in a season) (Lane 1995). To further supplement the data gathered by Dan Lane, I also gathered data from eBird that ranged from 1991 to 1994 that was taken in the timespan between September to December to better account for the full extent of the fall migration. The results of my eBird searches yielded very similar results to Dan Lane's data, with the primary exception being that much like my data, Dan Lane's data was fairly continuous while the eBird data was mostly fragmented because it relies on the potentially sporadic reports of various eBird users.

Avian Diversity & Richness Changes

When stepping back and comparing all of these past data to the current data, it became clear that, while there have been some changes to avian diversity and richness of the Drew Forest and the surrounding areas over the past approximately 100 years, it also becomes difficult, based on only the one organized recorded fall migration observed in 2023, to definitively make a claim that there has been significant migratory change. I have tracked and observed other recent spring and fall migrations in the Drew Forest, but these observations were not formalized and so can not be used as part of a comparison between the historical data and the fall 2023 data. In addition, there is also a large gap of time for which the ornithological data for the Drew Forest and Southern Morris County is missing or non-existent. This gap in the data record impeded supporting a conclusion in overall change in richness. This fall 2023 data does, however, allow us to see that while there have been changes to the avian richness, the Drew Forest has maintained a high level of avian richness. Not only is the Drew Forest a diverse and rich ecosystem, but is also home to species with varying levels of conservation interests such as the Barred Owls which currently reside on the New Jersey State Threatened List or Chimney Swifts which reside on the IUCN Red List at the Vulnerable level and are still in a state of decline. It is not only bird species that reside on one of these lists that can show the presence of an important species and one prime example of this is the Common Raven (*Corvus corax*). The Common Raven is a species that is not on any of the state conservation lists and is listed on the IUCN Red List as Least Concern, yet it wasn’t too long ago that this species was all but extirpated from New Jersey entirely by the 1920s (Byers 2021). It wasn’t until the 1990s that Common Raven populations had begun to rebound and were seen again in New Jersey; even though they can now be found, they are still relatively rare. When looked at on the smaller scale of the Drew Forest, we now have seen Common Ravens relatively consistently each fall, which is a good indication that this species is returning to its once natural range. Not only has this species been detected by multiple people on Drew’s campus, but a Common Raven had consistently roosted in one of the bell towers on campus. Additionally, I even observed up to three ravens at once in Hepburn Woods which gives me hope that nesting ravens could be a possibility in the near future, barring any further potential loss of habitat at Drew University. If data is collected formally on a more regular basis going forward, a better understanding of human's impact on the environment surrounding the Drew Forest can be gained.

Temperature & Migration

Another goal of this study was to gain an understanding of how changes in temperature may affect the timing of fall bird migrations through Drew's Forest. The temperature data reviewed included the average temperature for August 1925, which was contemporaneous with Frank Watson's bird data, the average temperatures for September through December for the years 1931 through 1938 which was contemporaneous with Mrs. Curtis's bird data, and the averages temperature taken for September through December taken for the years 1991 through 1995 which is contemporaneous with the data taken from eBird and the bird data collected by Dane Lane. The average temperatures taken during my fall 2023 study, can be seen in Figure 7 and Table 4 of my results section.

Once compiled, the temperature data showed minor fluctuation in monthly temperatures throughout the historical records, yet when compared to the temperatures taken during this fall 2023 study, the historical records actually report higher temperatures than present day. This would seemingly indicate a reverse effect in that it seems that temperatures have gone down, especially in November where I reported an average of 3.1℃ which compared to the historical averages is significantly lower. With this analysis in mind, it is also important to note that the comparison of temperatures made here was based on only one semester's worth of data and the historical data outlined above, which at the best of times, was sparse, so further research would be needed in order to attempt and validate this kind of hypothesis.

Occupancy Modeling Analysis

In contrast, the data that I collected during the fall of 2023 was able to yield other information that allowed for greater understanding of the Drew Forest and the annual cycles that occur within it. One type of analysis that was run were the two occupancy models done on the data collected for the Downy Woodpeckers as the resident species and the Common Grackle as the migratory species. The model utilized in this study allowed for both occupancy and detection to be analyzed both by themselves and in conjunction with each other in order to see if there were correlations in the collected data for a species. When interpreting the results of these models, we are primarily looking at the AIC and ΔAIC values that are found. The ΔAIC value is the representative value of how a specific model compares to the best statistical model completed in specific analysis (MacKenzie et al. 2003), while the AIC value is the score given to a specific model after all models have been completed that indicate which model best fits the data and is likely the most accurate model (MacKenzie et al. 2018).

The date appeared to have an effect on the level of detection of Downy Woodpeckers during my sampling period (Table 5). We can see that the ΔAIC level of the model analyzes detection based on date; (psi(.),p(Date), had a ΔAIC value of 0.00 and an AIC value of 396.44, meaning that this was the best fit model of this dataset indicating during the 2023 fall migration, the date seemed to have an effect on the detection of Downy Woodpeckers at my point census sites. When looking at the raw data, Downy Woodpeckers remained ubiquitous during the sampling period with only 2-3 days out of the sampling frame lacking a sighting at the point census sites, yet the frequency of sightings and number of individuals seen on days with sightings varied as the semester moved forward. This further shows how date appeared to play a role in the detection of this particular resident species that has been confirmed many times to nest and remain at this location year round. One possible explanation for the pattern seen in the best fit model could be that as the migration progressed later into the fall, the available food decreased making the detection of Downy Woodpeckers change. This is a possibility, but this aspect did not fall under the scope of my study and would need further investigation to fully support this hypothesis.

In contrast to the Downy Woodpecker, the Common Grackle, which represented a migratory species in this set of models, allowed for an interesting comparison in the analysis of the data collected in the fall. In this case, the results indicated that the date and temperature played a significant role in the detection of Common Grackles (Table 6). This model; (psi(.), p(Date,Temp), also resulted in a ΔAIC value of 0.00 and an AIC value of 244.15 making it the most accurate model out of the set completed on my Grackle data. This result, much like the Downy Woodpeckers, could be seen when observing the raw data as at a certain point sightings of Common Grackles tapered off until no more individuals were detected, corresponding with the shortening of photoperiod at the end of fall migration and subsequent drops in average temperatures (Figure 7). When looking at the significant models found for Common Grackles, it was seen that both of the site covariants, Sitename and Habitat, influenced the occupancy of the Common Grackles, but only in conjunction with date and temperature (Table 6).

Conclusions

At the conclusion of this study, it can be seen that the Drew Forest and campus not only houses an abundance of different species of birds, but are also an important avian hotspot that attracts high levels of migratory birds during the annual fall migration season. In addition to these migratory birds, it was seen that many species of birds such as American Kestrels or Rusty Blackbirds which have higher conservation statuses, both at the state and international levels, call this area home, whether it be temporary or permanent. The Drew Forest has undergone many changes over the past 100 years, and so has the world around it which has led to some interesting changes to its avian biodiversity.

In summary, the results of this study allowed for a more up to date understanding of the avian richness of the Drew Forest, along with a more definitive understanding of how the fall migration occurs through this region. The population modeling completed in this study also allowed for a deeper understanding of how Drew University's campus and the Drew Forest acts as a hotspot for migratory birds to stop off during their migrations as well as how date and temperature affected the detection of the selected migratory species (Common Grackles). Similarly, the population models run on the data pertaining to the selected resident species (Downy Woodpeckers) indicated that the date played a role in the detection of this species during my sampling period. The results of these models allow us to better understand the dynamics between how different species utilize this important ecosystem, not only during the migration as the Common Grackles do, but also year round as residents such as the Downy Woodpeckers do.

In the end, it can be seen that the Drew Forest is not only a very diverse ecosystem, but also a healthy one. High levels of avian diversity are often correlated with balanced ecosystems and the presence of larger species such as the Barred Owl or the more cryptic migratory species like nesting Winter Wrens are prime examples of this. To continue this positive trend of a diverse and healthy ecosystem, it is essential to avoid future habitat fragmentation in the form of over-development so that these species and many others can continue to thrive in the Drew Forest.

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Appendix

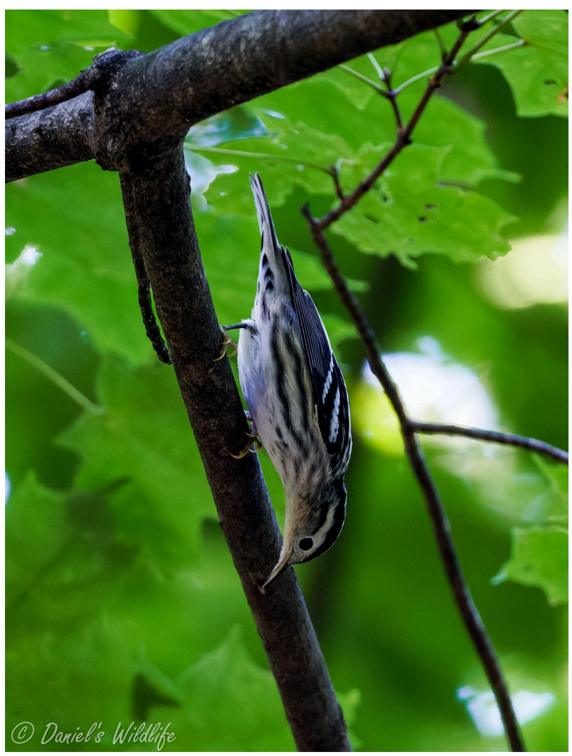
American Goldfinch, *Spinus tristis*

American Kestrel, *Flaco Sparverius*

American Robin, *Turdus migratorius*

Barred Owl, *Strix viria*

Belted Kingfisher, *Megaceryle alcyon*



Black-and-White Warbler, *Mniotilta varia*

Black-capped Chickadee, *Poecile atricapillus*

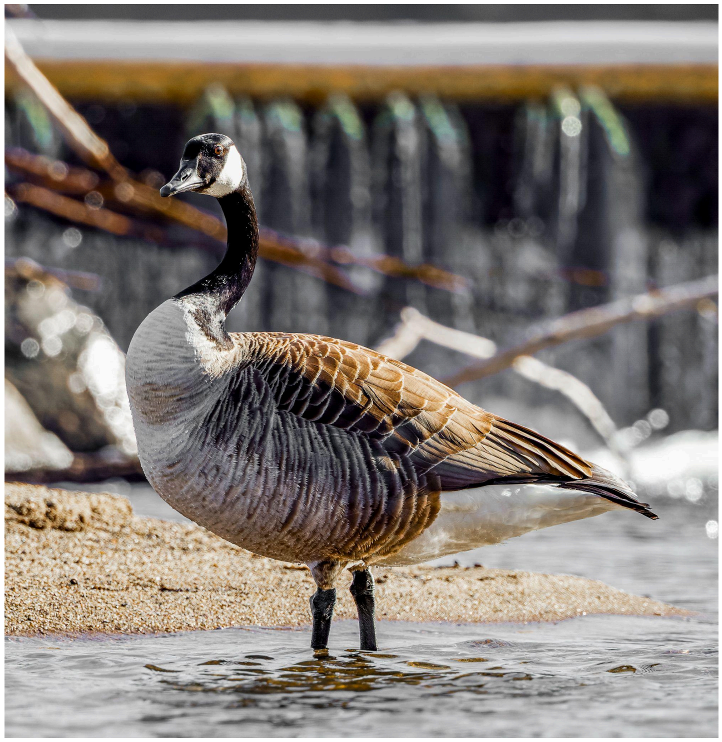
Black-throated Blue Warbler, *Setophaga caerulescens*

Blue Jay, *Cyanocitta cristata*

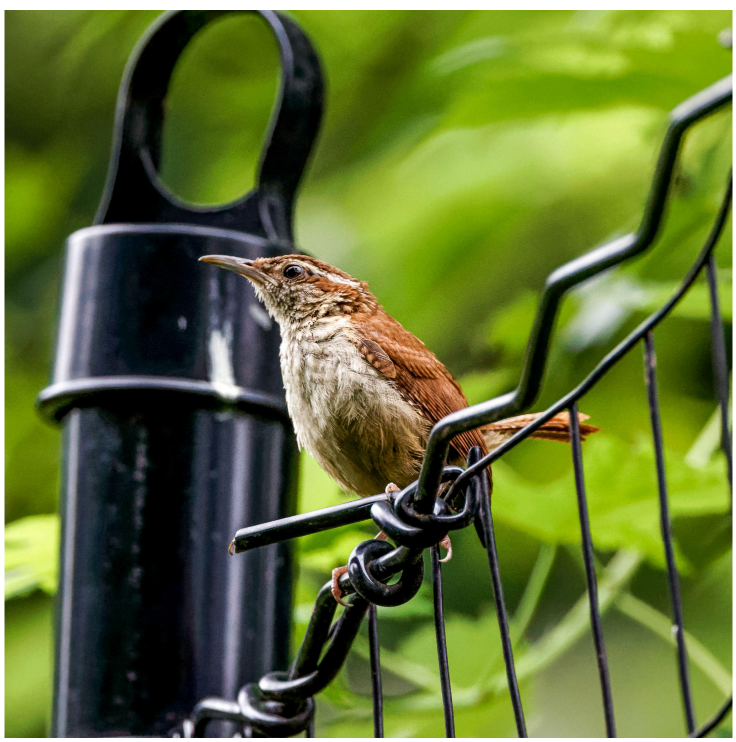
Blue-headed Vireo, *Vireo solitarius*

Broad-winged Hawk, *Buteo platypterus*

Brown Creeper, *Certhia americana*



Canada Goose, *Branta canadensis*



Carolina Wren, *Thryothorus ludovicianus*

Cedar Waxwing, *Bombycilla cerdrorum*

Chimney Swift, *Chaetura pelagica*

Chipping Sparrow, *Spizella passerina*

Common Grackle, *Quiscalus quiscula*

Cooper's Hawk*, Accipiter cooperii*

Dark-eyed Junco, *Junco hyemalis*

Downy Woodpecker, *Dryobates pubescens*

Eastern Bluebird(s), *Sialia sialis*

Eastern Phoebe, *Sayornis phoebe*

European Starling, *Sturnus vulgaris*

Fish Crow, *Corvus ossifragus*

Gray Catbird, *Dumetella carolinensis*

Gray-cheeked Thrush, *Catharus minimus*

Great Blue Heron, *Ardea herodias*

Green Heron, *Butorides virescens*

Hermit Thrush, *Catharus guttatus*

Merlin, *Falco columbarius*

Northern Cardinal, *Cardinalis cardinalis*

Northern Mockingbird, *Mimus polyglottos*

Ovenbird, *Seiurus aurocapilla*

Palm Warbler, *Setophaga palmarum*

Peregrine Falcon, *Falco peregrinus*

Red-eyed Vireo, *Vireo olivaceus*


Red-shouldered Hawk, *Buteo lineatus*

Red-tailed Hawk, *Buteo jamaicensis*

Red-winged Blackbird, *Agelaius phoeniceus*

Ruby-throated Hummingbird, *Archilochus colubris*

Song Sparrow, *Melospiza melodia*

White-throated Sparrow, *Zonotrichia albicollis*

Winter Wren, *Troglodytes hiemalis*

Wood Thrush, *Hylocichla mustalina*

Yellow-bellied Sapsucker, *Sphyrapicus varius*