

Impacts of Migrating Waterfowl on *Escherichia coli* Levels in Water Bodies within the Erie
National Wildlife Refuge.



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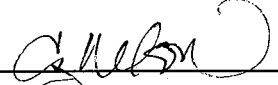
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**Submitted in fulfillment of the senior thesis requirements of the
Department of Environmental Science at Allegheny College
and approved by the senior thesis committee.**



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Pledge

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Abstract

Birds of the United States have been studied for many reasons, however, one category of birds have long been overlooked as one of the most important in biological diversity: waterfowl. Historically, waterfowl have suffered population declines within the United States, but thanks to conservation techniques, specifically the National Wildlife Refuge System, populations are again healthy. With a population of waterfowl once again at high numbers, during their migration, they leave behind bacteria (i.e. *E. coli*) that can be found on land and in water. This study aimed to determine how migrating waterfowl impact *E. coli* levels specifically within impoundments located in the Erie National Wildlife Refuge located in Guys Mills, Pennsylvania during the peak of the fall 2015 migration season. Waterfowl Surveys were conducted once a week from mid-August to mid-December. *Escherichia coli* levels were measured at three separate times during fall migration. Data was analyzed and reviewed using graphs and figures. Canada Geese were found to be most populous. Migration itself was delayed due to altered weather conditions resulting in a later migration season. Overall, waterfowl abundance was highest post-migration while *E. coli* levels were generally not impacted by waterfowl abundance. A longer, smaller scale, project with more sampling in specific impoundments would offer additional information.

Introduction

Waterfowl History & Management

Birds of the United States are studied and researched for many reasons, however, one category of birds have long been overlooked as one of the most important in biological diversity: waterfowl. Waterfowl can be described as birds from the order *Anseriformes*, in particular the family Anatidae, which includes ducks, geese, and swans. Other definitions of waterfowl include shorebirds, waders, gulls, pelicans, and herons. Almost all waterfowl are strong swimmers with webbed feet and a flat rounded bill. Some species dive for fishes or mollusks, such as Hooded Merganser (*Lophodytes cucullatus*) and others feed near the surface (e.g. Mallard Duck (*Anas platyrhynchos*)). Waterfowl live in a broad geographic range on almost every continent of the earth (Checkett & Young, 2015). They thrive in areas from the arctic tundra, to the tropics, and to deserts and oceans (Checkett & Young, 2015). Though waterfowl populations are at a healthy level today, they have had a rough past in regards to population abundance.

Waterfowl have been an interesting topic among conservationists and biological scientists for many years and are prevalent in today's world. Waterfowl not only provide information and research on population control but also climate change and migration seasons, however, they have not always been a topic of research or conservation. Historically in the United States, in the late 19th and early 20th century, population was growing rapidly, with economic success and industrial expansion increasing (Foner, 2008). Waterfowl populations along with many other wildlife species were impacted greatly and waterfowl in particular saw a drastic decline in population abundance. In the 1800s, a new form of hunting known as market gunners began, which were primarily interested in hunting on a commercial scale by using large guns known as punt guns in order to harvest upwards of 100 birds with a single shot (Hampton, 2006; Credland, 2006). This hunting was easy, economical, and became a viable food source for a country that was growing at a rapid rate. Over harvesting included species such as Mallard ducks (*Anas platyrhynchos*) and Canada Geese (*Branta canadensis*), and continued throughout the 1800s until the early 1900s. Overharvesting, however, was not the only cause for population decline. In the early 1900s agricultural production increased rapidly as a source of economic growth and food production. Large scale agriculture practices were detrimental to waterfowl populations due to the degradation and in some cases eradication of wetland and marsh habitat (Yaich, 2009). It was

not until the Bird Act of 1918 when the government prohibited, unless permitted, to pursue, hunt, kill, or possess any listed waterfowl species (Bird Act of 1918).

Today, waterfowl populations are in no immediate threat due to these acts and conservation techniques practiced throughout the 20th century. Throughout the nation, waterfowl conservation is still a very important management technique. The combination of proper hunting regulations, wetland mitigation systems, and national wildlife refuge systems, waterfowl populations have been increasing. This combination of management techniques would not be possible without the revenue of the Federal Duck Stamp. The Federal Duck Stamp is a conservation revenue stamp that originated in 1934 when Congress passed Franklin D. Roosevelt's Migratory Bird Hunting Stamp Act (FWS, 2015). Today, 98% of the purchase price from these stamps goes directly to the protection of wetland habitats for the National Wildlife Refuge System. More than 6.5 million acres have been acquired using Federal Duck Stamp income and over 300 national wildlife refuges have been created using Federal Duck Stamp income (FWS, 2015). Total, there are over 150 million acres across the United States and over 418 million acres of marine monuments owned and preserved by the National Wildlife Refuge System (FWS, 2015).

In this study, one refuge in particular, the Erie National Wildlife Refuge (ENWR) located in Guys Mills, Pennsylvania was selected in order to research and monitor waterfowl populations. ENWR was established in 1959 and was one of the many refuges purchased with funds provided from the sale of the stamps discussed previously (FWS, 2014). Currently the refuge manages to apply many different conservation techniques. Some of these specific to waterfowl management include the manipulation of water levels in impoundments to encourage the growth of wetland plants as food, cover, and shelter for waterfowl and other wildlife, monitoring and surveying wildlife populations, and maintaining naturally occurring habitats such as streams ponds and wetlands (ENWR, 2011). Research and monitoring is also done throughout the refuge including waterfowl surveys, vegetation surveys, and migration patterns.

Not only at ENWR, but across the United States, waterfowl research is being conducted in order to continuously advance knowledge in conservation and management techniques. One of the most interesting aspects of waterfowl is their migration patterns. Specifically in Northwestern Pennsylvania, there is a major hotspot for waterfowl diversity seeing that it is one of the four

major pathways of migration (Crissey, 1985). This pathway, or flyway, is known as the Atlantic Flyway (Figure 1). Though migration patterns seem to be categorized into four major pathways, not all species of birds and individuals will migrate at the same time (Lehikoinen & Jaatinen, 2012). Birds migrate for two major reasons; survival during winter and reproduction. This in return causes different species to migrate at different times. Many birds also will migrate simply to avoid intolerable conditions brought on by colder weather, less daylight, and a lack of available food sources (Kaminski, 2003). Whether a species migrates in early fall or late fall, they all fall subject to and cause environmental degradation throughout the migration route.



Figure 1. Four major waterfowl flyways of migration. Pacific Flyway (Green), Central Flyway (Orange), Mississippi Flyway (Red), Atlantic Flyway (Blue). www.nwf.org

Impacts on Water Quality

With a population of waterfowl once again at high numbers, during their migration, they leave behind bacteria that can be found on land and in water. This impacts vegetation, food sources, and water quality (Fleming et al., 2001). Not only do waterfowl leave behind pollutants but they also feed on local plants as well as animals such as fish in order to maintain the energy that is needed for long flight hours (Fleming et al., 2001). On average, a study showed that a female Wood Duck needs to ingest 75 grams of invertebrates to produce one egg (Checkett & Young, 2015). This can cause serious problems to an ecosystem if you have a larger population of waterfowl within a small area. This study indicated that the research of the pollutants and

impacts of waterfowl from the deposition of fecal coliforms. Migratory birds, depositing fecal matter within any given impoundment can alter the nutrient makeup and change water qualities for an extended period of time via nitrogen and phosphorous and other bacterium (Dobrowolski et al., 1976). Fecal coliforms are anaerobic bacteria that originate in the intestines of warm blooded animals (Louwanda and English). They can enter waterways by waste from mammals and birds, from agricultural and storm runoff, and from human sewage. Within water bodies they have long been studied in respect to water quality for drinking but have more recently been considered in determining overall health of streams and water impoundments (Cohen and Shuval, 1973; U.S. Environmental Protection Agency, 1976). Fecal coliforms within water do not necessarily present a huge problem; however, they can indicate a presence of other waterborne pathogens. Waterborne pathogens that are commonly found and impact humans can cause dysentery, typhoid fever, and hepatitis A (Vogt, 2005). Fecal coliforms and other pathogens can also cause a decrease in oxygen levels within the water (Louwanda and English). This can cause a decrease in fish populations and other aquatic life including macroinvertebrates and some amphibians.

Escherichia coli (*E. coli*) is a type of fecal coliform targeted in this research. *Escherichia coli* like most fecal coliforms are prominently harmless to humans, though like other pathogens, different strains can cause diarrhea, while others cause urinary tract infections, respiratory illness and pneumonia (CDC, 2015).

Importance of Study

With waterfowl populations once again at a healthy level, refuges across the nation see huge flocks of different species inhabiting the protected and managed waterways and water body impoundments during the duration of the fall migration. With large numbers of birds inhabiting these impoundments, specifically those within the ENWR during their resting periods of migration, the above research and information seems to imply that the water quality and the abundance of *E. coli* and other fecal coliforms would be impacted. This study is important not only for a general knowledge of how waterfowl impact water quality, but also for how the National Wildlife Refuge System plans to manage waterfowl populations and water impoundments in the future. ENWR in particular is home to the headwaters of a few of the most important tributary streams in the French Creek Watershed. The French Creek Watershed is

home to 27 species of mussels, 15 species of darters, and holds more biodiversity than any other watershed in Pennsylvania. Fishing and other recreational activities are a big part of both the French Creek watershed and the ENWR. These activities as well as the biodiversity of the area depend on clean water throughout all of its tributaries. If water qualities and *E. coli* levels are being drastically impacted by the abundance of waterfowl during migration season, the watershed could potentially see a loss of biodiversity as well as an increase in waterborne pathogens flowing through the watershed. Overall this could lead to different management techniques of waterfowl on a large scale when discussing federal management or small scale when discussing techniques used at individual refuges such as the ENWR (French Creek Conservancy).

Problem Statement and Hypothesis

This study aimed to determine how migrating waterfowl impact *E. coli* levels specifically within impoundments located in the Erie National Wildlife Refuge during the peak of the fall 2015 migration season. This information will help understand how increased waterfowl populations are impacting water quality during times of high usage and provide insight on whether or not current management techniques of both waterfowl populations and water impoundments are sufficient in maintaining clean water and healthy populations of biotic and abiotic species within the watershed. The hypothesis is that more waterfowl activity will lead to higher *E. coli* levels at each respective impoundment.

Methods

Site Selection

The study took place in Northwestern Pennsylvania in Crawford County at the Erie National Wildlife Refuge. Data was collected at 12 water impoundments located throughout the refuge. Impoundments chosen were controlled by dams and at some times were considered flowing at high water levels. These impoundments were preselected as waterfowl conservation habitats by the refuge and its respective biologists and were chosen based on sufficient water levels for sampling (greater than 25cm in depth). The refuge is composed of two divisions; Seneca Division (Site code PA-003, Figure 2) and Sugar Lake Division (Site code PA-002, Figure 3). Samples were taken from one impoundment within the Seneca Division; TR (Figure

2). Eleven impoundments from the Sugar Lake Division were sampled and previously named by the refuge as; PA, PE, PK, PL, RP, PH, MP, CM, PF, PN, and PP (Figure 3& Table 1). Other impoundments were lacking water during the study due to a dry summer season.

Table 1. Full names; cite codes, and acreage of each sampled impoundment

Unit Abbreviation	Unit Name	Unit Code	Acres
CM	Cooper's Marsh	PA-002-CM	22
PN	Pool N	PA-002-PN	8
PA	Pool 4	PA-002-PA	21
PE	Pool 7N	PA-002-PE	6
PF	Pool 7S	PA-002-PF	10
PH	Pool H	PA-002-PH	4
PK	Pool K	PA-002-PK	16
RP	Reitz Pond	PA-002-RP	29
MP	Meyers Pond	PA-002-MP	19
PL	Pool 9	PA-002-PL	175
PP	Peterson's Pond	PA-002-PP	1
TR	Teepleville Road Marsh	PA-003-TR	2

Field Collections

Waterfowl migration season was roughly September through December and 2015 waterfowl surveys were conducted once a week starting on August 29th, 2015 and ending on December 11th, 2015. Within the waterfowl surveys, data was collected on date, wind speed on Beaufort scale, air temperature in Celsius, start and end times of survey, ice cover, and percent visibility of impoundment (i.e. fog, rain). Wind speed and air temperatures were recorded using a kestrel anemometer Model #0825. Data at each site was also taken on water depth and habitat cover. Water depth was measured by eye and perception in order to imitate bird's eye view in flight using 6 different categories totaling 100%. These categories are dry, mud/saturated, 0-5 centimeters, 5-15 centimeters, 15-25 centimeters, and greater than 25 centimeters. Habitat cover was also measured using 5 different categories totaling 100%; water, scrub/shrub, forest,

emergent, and bare ground. At each site, waterfowl abundance and species were also surveyed. This was done by carefully monitoring waterfowl either entering, leaving, or wading in any given impoundment. Each species were identified and counted. Water birds or shore birds, such as Sandpipers (*Scolopacidae*) and Killdeer (*Charadrius vociferous*), were also classified as waterfowl within the survey.

Water sampling was conducted at 3 different times during the study; once before migration on August 27th, 2015, once during migration on November 4th, 2015, and once after peak migration on December 11th, 2015. These dates and time parameters were selected based on knowledge from former waterfowl surveyor, Michael Vargo, who has done surveys at the refuge for ten years (Vargo, 2015). Water samples were taken using sterile bottles bought from the Coliscan Water Monitoring Kit. At each site, duplicate samples were taken and where collected by inserting the sample bottle into the water, opening the lid, and closing the lid while remaining in the water (Myers & Sylvestor, 1997) to ensure no contamination would occur within the bottle. Each sample bottle was put on ice for the duration of the survey and brought to the lab within 6 hours of sampling. They then were plated for the growth of *Escherichia coli* (*E. coli*).

Escherichia coli Processing and Incubation

Coliscan Water Monitoring Kits were used for the growth and colonization of *E. coli*. Coliscan Easygel, manufactured by Micrology Laboratories LLC, was the agar used in this kit. Easygel was kept in a freezer until use and then thawed out on each respective day of sampling. Following the company's directions, five mL of sampled water was mixed with one bottle of Easygel and then placed in a petri dish provided within the kit that was designed for testing coliform abundance, including *E. coli*.

Once the sampled water and Easygel are mixed and placed within the treated petri dish, *E. coli* and coliforms were able to grow without spreading due to the hardness of the gel. These dishes were incubated for 48 hours on a lab bench at room temperature or roughly 23 degrees Celsius. Once incubation was complete, colony forming units, or CFU's were counted for *E. coli*, other coliforms, and disregarded colonies. Following directions of the kit, different color CFUs represented different coliforms or *E. coli*. Colonies were measured in CFU per one mL (CFU/mL) of water.

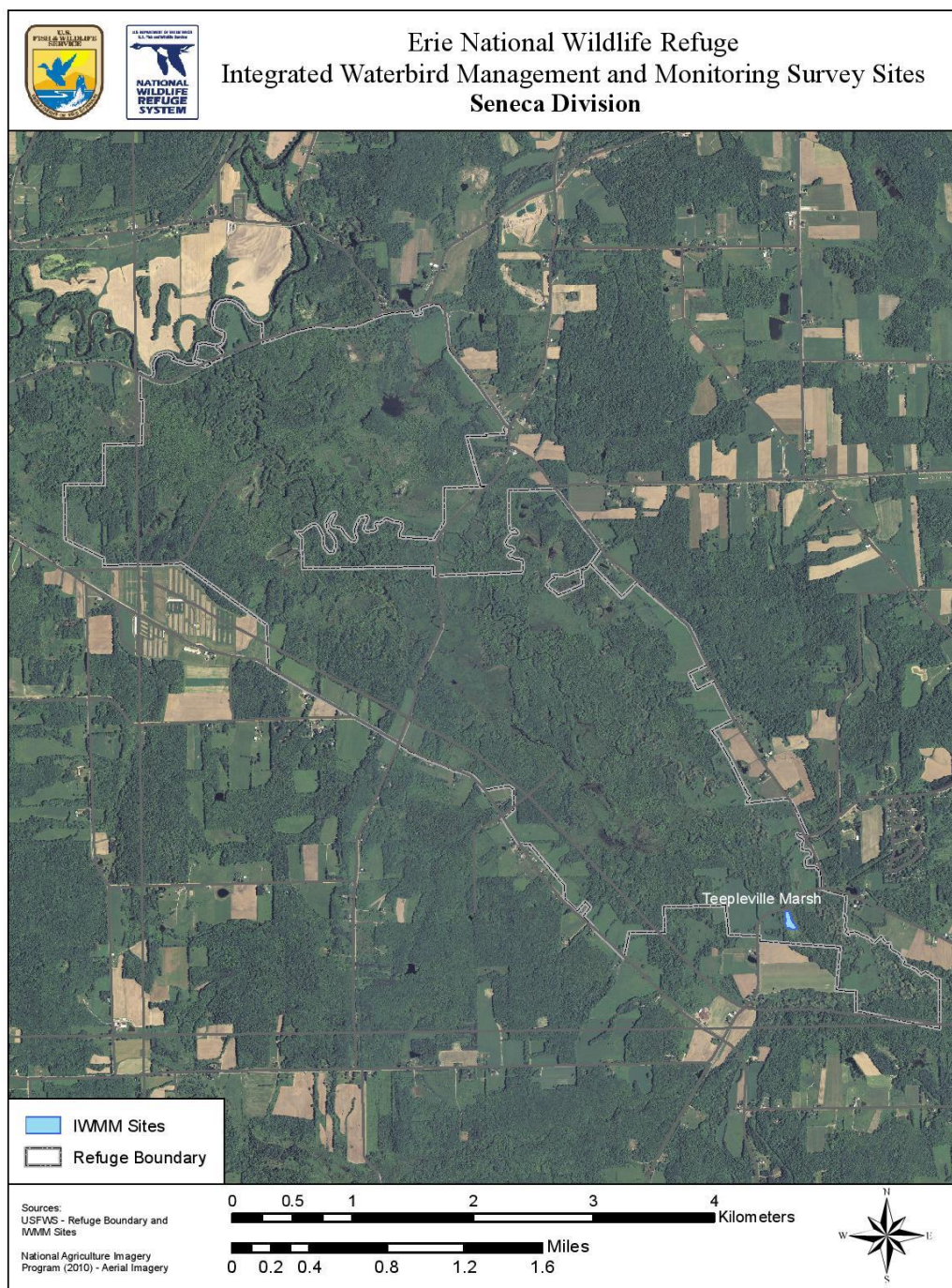


Figure 2. Aerial view of Erie National Wildlife Refuge Seneca Division with use of GIS and GPS with sites outlined in blue

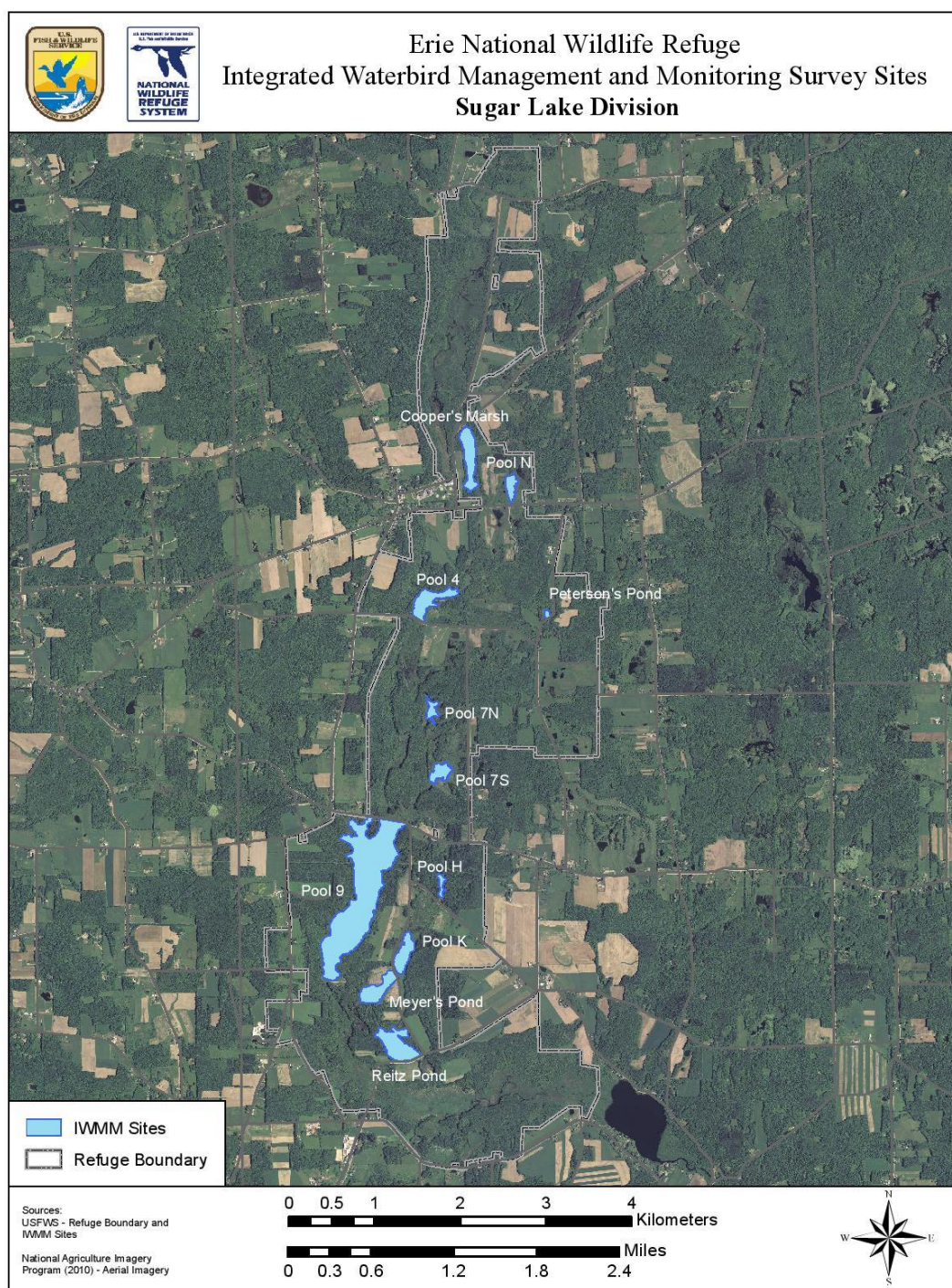


Figure 3. Aerial view of Erie National Wildlife Refuge Sugar Lake Division with use of GIS and GPS with sites outlined in blue

Results

Biological Monitoring Surveys

Survey results varied weekly for almost every impoundment. Data points that stayed the same weekly were survey types, and were constantly ‘whole area’. Percent ice cover remained at 0% throughout most of the study occasionally reaching 5% in mid-December. Water depths, habitat coverage, vegetation height, and abundance of waterfowl changed weekly as water level rose and vegetation died off as temperatures decreased later in the season. Waterfowl abundance and species changed weekly as well. Overall, above water vegetation decreased while water levels began to rise throughout the study. Results show that at the beginning of the study, pools TR, RP, CM, and PN held less than 50% water coverage while MP, PE, PL, PH, PA, PP, PF, and PK held greater than 50%. At the end of the study, all impoundments with the exception of CM were found to be greater than 50% water coverage, suggesting an overall increase in water levels throughout the study.

Overall wind speeds remained within the range of 0 mph to a max of 4 mph. On the first day of surveying (September 27, 2015) temperatures averaged 20.83 degrees Celsius. On December 9, 2015, survey temperatures averaged 4.21 degrees Celsius (Figure 4).

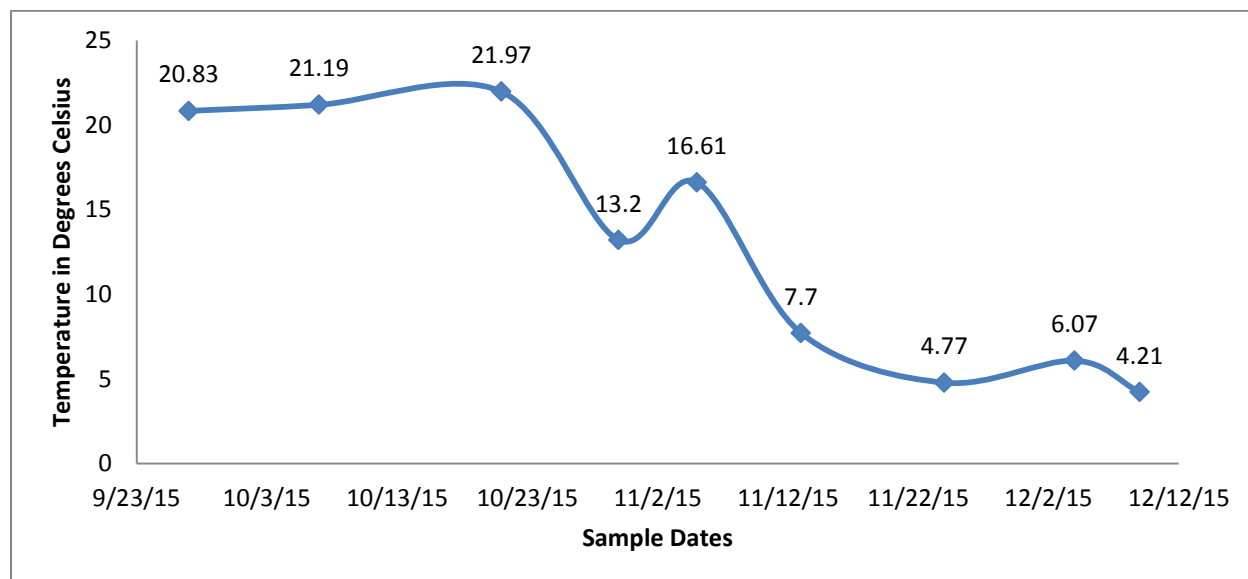


Figure 4. Temperature change over time throughout study.

Waterfowl Surveys

Twenty three bird species were discovered inhabiting the area of the entire refuge not limited to studied impoundments. Of these 23 species, 8 were found to be dabbling ducks, 4 species of diving ducks, Geese (*Anserini*), American Coots (*Fulica americana*), Herons (*Ardeidae*), Sandpipers (*Scolopacidae*), Sea ducks (*Merginae*), and Cranes (*Gruidae*). The majority of the waterfowl found were either in the family of Dabbling Ducks, Diving Ducks, or Canada Geese (*Branta canadensis*) (Figure 5).

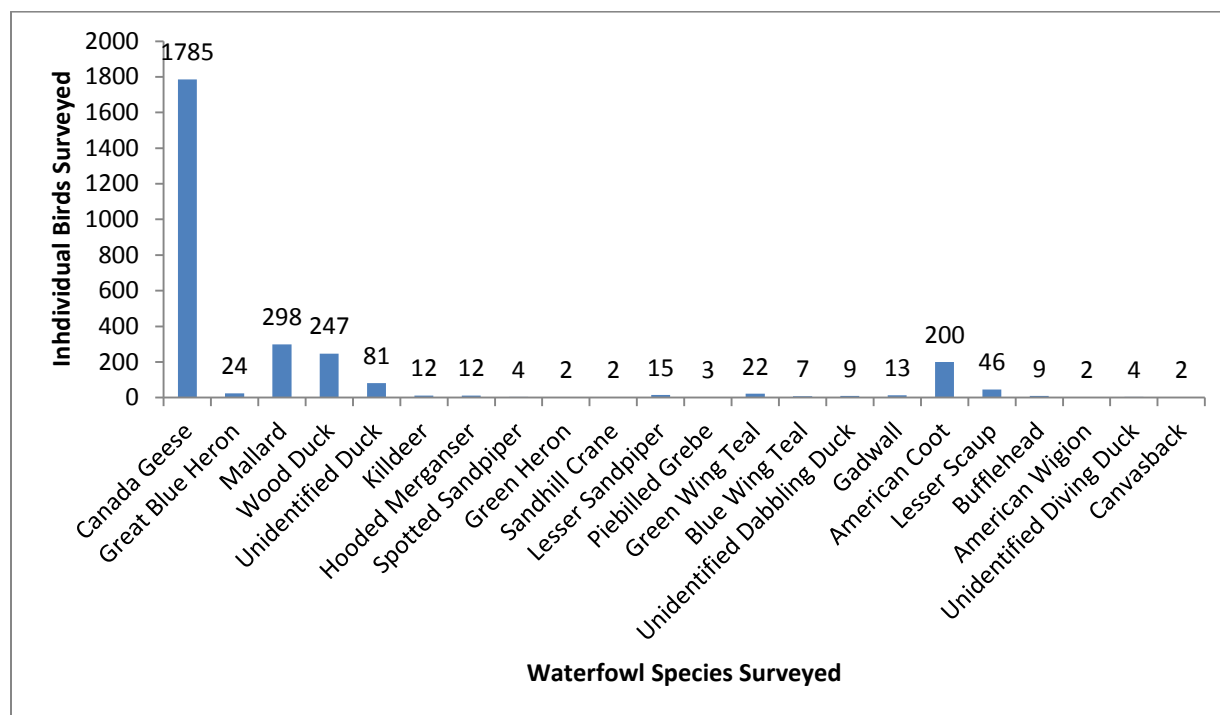


Figure 5. List of species found and a number of each individual surveyed throughout the study at all impoundments together.

Wood Ducks were more commonly found during the beginning weeks of the study while Canada Geese were more common at the end of the study. Among the 23 species surveyed, Canada Geese, American Coots, and Wood Ducks showed the greatest abundance change over time in regards to the duration of migration. Species density changed at different time frames throughout the entirety of the migration period in regards to pre-migration, mid-migration, and post-migration (Figure 6 & Figure 7).

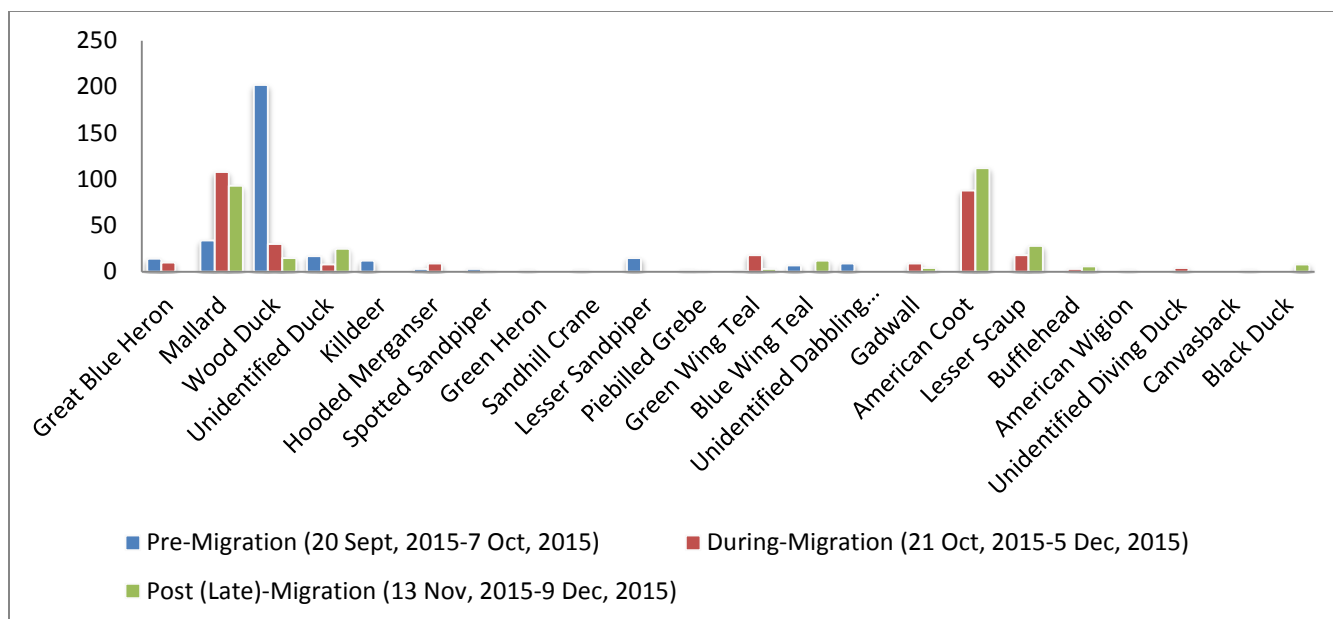


Figure 6. Changes in species density and abundance throughout migration.

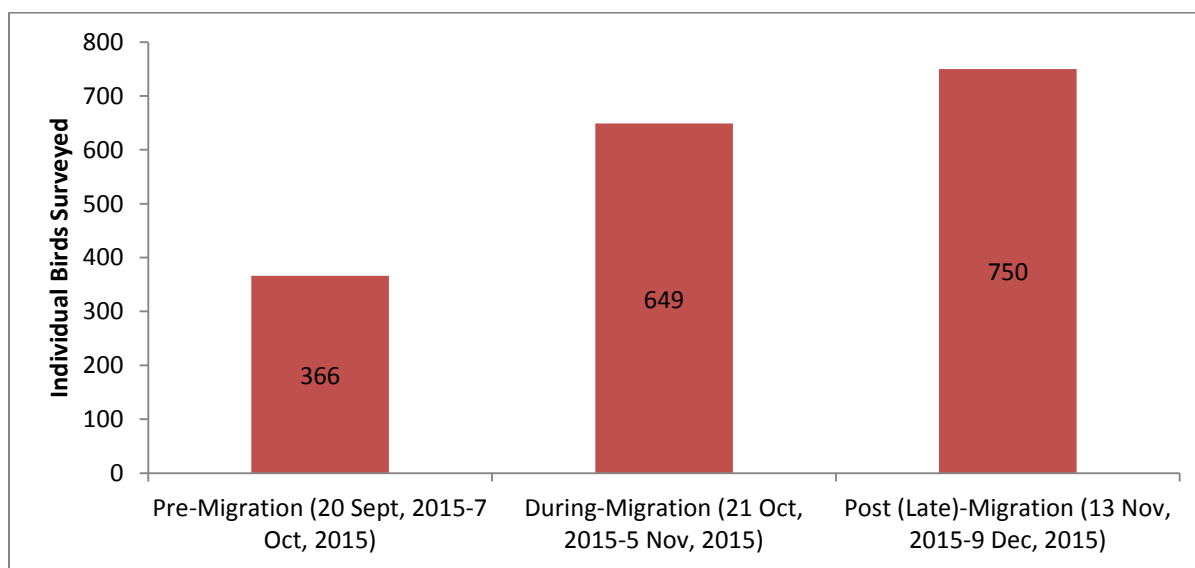


Figure 7. Changes in species abundance of Canada Geese throughout migration.

Waterfowl were also found to have varying populations in the area at certain times. As previously shown, individual species inhabited areas and migrated relatively early compared to other species; overall however, the greatest amount of waterfowl that were seen were in the last third of migration, or what this study has labeled, post migration. Pre-migration data shows 692 individual birds surveyed while mid-migration shows 960 birds surveyed (Figure 8). Post-migration or late migration surveys revealed the most amount of individuals at 1069 (Figure 8).

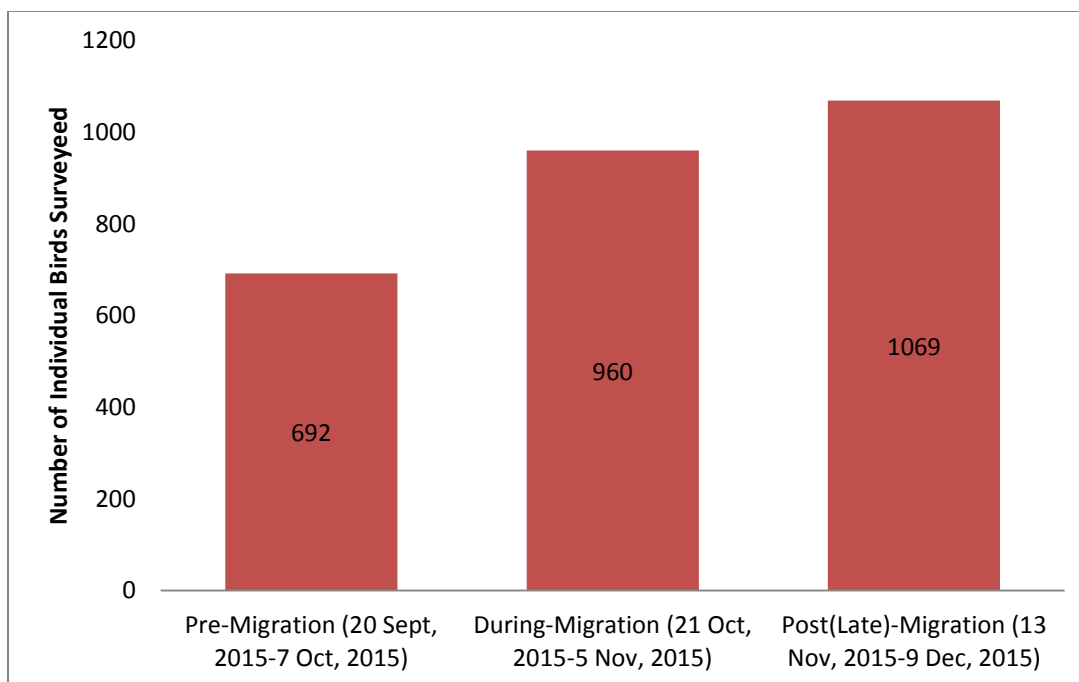


Figure 8. Abundance of birds surveyed at three times of migration.

Waterfowl Abundance at Studied Impoundments

Of the 12 studied impoundments or pools, two pools PL and PN stood out relative to the number of birds occupying the area. PL showed the greatest number of birds throughout the study with 1432 individuals surveyed while PN was a far second with 553 individual birds surveyed. The number of birds surveyed throughout the duration of the study at each respective studied pool is shown in Figure 9.

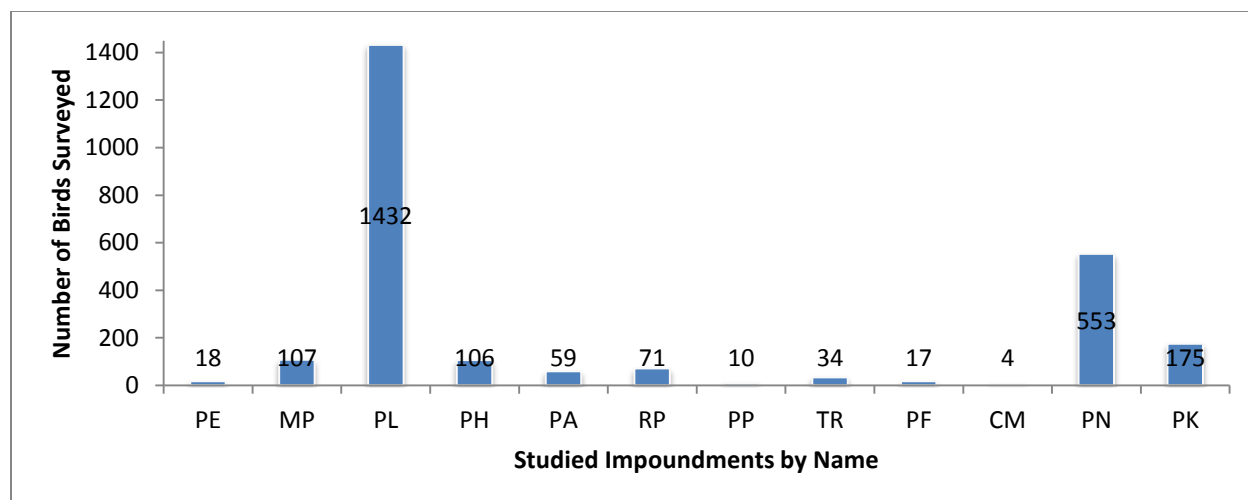


Figure 9. Number of birds surveyed at each studied pool throughout research.

Escherichia coli Analysis

No significant difference was found between *E. coli* levels and waterfowl abundance. Of the 12 studied impoundments, 42% of the pools resulted in the highest *E. coli* levels showing during migration. These pools were PE, MP, TR, CM, and PN. Twenty five percent of the pools showed that *E. coli* levels were lowest during migration and higher pre and post migration. These pools were RP, PP, and PF. Sixteen percent of the pools had the highest *E. coli* levels at post migration, with an increase from start to finish. These pools were PL and PK. The final 16% of the pools had the highest *E. coli* levels pre-migration, while levels decrease overtime from start of stud to finish. These pools were PH and PA. *Escherichia coli* levels were highest in pools PL, TR, and PN. PL had the highest *E. coli* levels throughout the study at 9.55 CFU/mL at the end of migration. TR was second with 9.4 CFU/mL during mid-migration and PN was third with 6.0 CFU/mL during mid-migration (Figure 10 & Table 2).

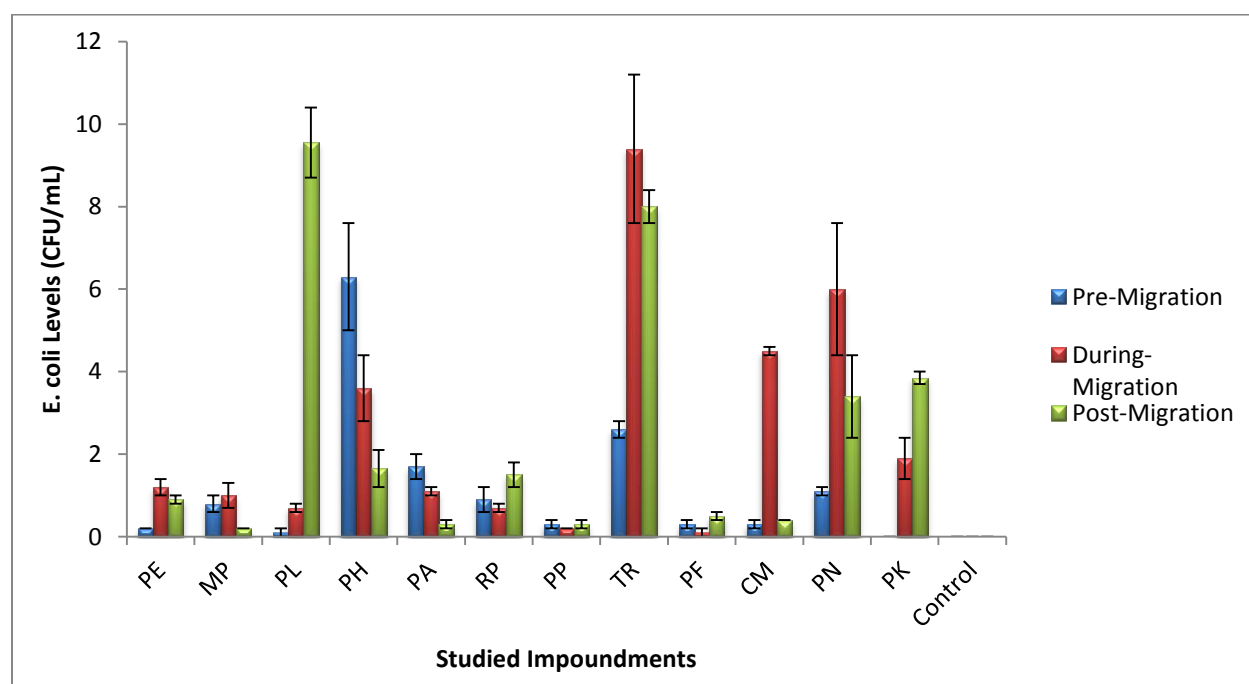


Figure 10. *Escherichia coli* levels throughout study at each respective impoundment

Table 2. Average data points for *E. coli* levels at each impoundment throughout the study

Impoundments	Pre-Migration (CFU/mL)	During-Migration (CFU/mL)	Post-Migration (CFU/mL)
PE	0.2	1.2	0.9
MP	0.8	1	0.2
PL	0.1	0.7	9.55
PH	6.3	3.6	1.65
PA	1.7	1.1	0.3
RP	0.9	0.7	1.5
PP	0.3	0.2	0.3
TR	2.6	9.4	8
PF	0.3	0.1	0.5
CM	0.3	4.5	0.4
PN	1.1	6	3.4
PK	0	1.9	3.85
Control	0	0	0

Discussion

The aim of the study was to find out how migrating waterfowl impact *E. coli* levels specifically within impoundments located in the Erie National Wildlife Refuge during the peak of the fall 2015 migration season. The use of these impoundments throughout the refuge by waterfowl has long been known and studied (Mohler, 2003). Today there is an influx in waterfowl populations due to the conservation techniques and management systems that have been put in place by federal and local agencies throughout the United States. With this being stated, it is clear that more information is needed in order to draw conclusions on the impacts that large numbers of waterfowl are having within their environments, particularly those used during high migration periods. This information helps researchers understand how increased waterfowl populations are impacting water quality during times of high usage and provide insight on

whether or not current management techniques of both waterfowl populations and water impoundments are sufficient in maintaining clean water. The hypothesis of the study was that more waterfowl activity will lead to higher *E. coli* levels at each respective impoundment. The results varied greatly in many aspects as seen previously in other studies.

During the study, it was thought that vegetation surveys would provide sufficient evidence of waterfowl predictability, meaning that both diving and dabbling duck species would prefer specific vegetation habitats over others (Kantrud, 1986). Previous studies have stated that waterfowl prefer wetlands and marshes with open fauna or an open canopy top. Researchers have also found that a decrease in usage of certain impoundments can be caused by decreased habitat with aspects such as tall woody species, undisturbed fauna, and thick edges (Kantrud, 1986). Throughout this study, all impoundments were consistently considered lentic (L) in the category of interspersation. This refers to relatively still terrestrial waters such as lakes and ponds (Prichard, 2003). Because all impoundments represented the same interspersation category and canopy cover, no data was found regarding favorable vegetation conditions. Though birds tended to inhabit certain areas over others, the data from this study could not explain vegetation coverage with regards to favorability.

Water levels themselves also changed throughout the study providing information on how seasonal changes impact impoundments water levels. Over the course of the study, vegetation increasingly died off as water levels increased and temperatures decreased. At the beginning of the study, four pools held less than 50% water while eight pools held greater than 50%. Over the timeframe of the study, all impoundments changed to over 50% with some reaching up to 80-90% water coverage. Previous studies have shown that water level fluctuations impact the structure and function of most wetland ecosystems. Biota can respond differently to times of high stress and low stress relative to water levels (Coops et al., 2003). From shallow turbid muddy waters, to deep slow waters, individuals living in the area are more likely to inhabit a stable environment rather than one constantly changing (Coops et al., 2003). Waterfowl in particular have been found to choose certain areas to inhabit over others based on water and vegetation fluctuation (Johnsgard, 1956). Though water levels changed throughout the study, no evidence showed that waterfowl preferred certain water levels more than others.

Temperature changes throughout the study were also interesting and possibly the most influential factor of the study. The study itself took place over the course of 5 months; late August to early December. The temperature dropped drastically which impacted the results (Figure 4). With a starting temperature of approximately 20.83 degrees Celsius, and an ending temperature of 4.21 degrees Celsius, this environmental change could have serious impacts on the data. Migration season has been roughly August through December within the Atlantic Flyway of Northwestern Pennsylvania, or until most of the waterways are completely frozen (Bellrose, 1957). Waterfowl rely on the certain environmental cues such as temperature changes and weather patterns in order to determine whether or not to begin migrating (Haywood, 2016). Migration itself is triggered by the need for habitat, resources, and mates. With colder and less hospitable weather conditions, birds will migrate south. Though migration is hard wired into most bird species, if weather patterns and temperatures stay favorable for longer than usual, a shift in migration can occur (Humburg, 2010). Throughout the beginning of the study, temperatures during surveys ranged from 20.83 degrees to 21.97 degrees until mid-November when temperatures dropped drastically to 7.7 degrees Celsius. Since migratory waterfowl rely on cold fronts to push their migration, this could be an explanation as to why this study saw an influx of species population towards the end of migration or the end of the study rather than throughout the study or in the middle of the average migration season (Alerstam, 1990). Most species were more prevalent during the later months of migration or from 13 November, 2015-9 December, 2015. This may be due to the lack of cold weather and other biological indicators during the beginning months of migration (Gill, 2007).

A few species that were found to be more populous during the warmer months tended to be Wood Ducks, Great Blue Herons, and other shore birds such as Killdeer and Sandpipers. This could imply that these birds have a much quicker migration period, or more simply put, begin migration more promptly in response to environmental changes. Wood Ducks, for example, are wary birds who prefer to be in groups of less than twenty, usually comprised of their own species. This could explain why they were primarily seen in the early months of migration, allowing ample room for space, safety from other species, and a more protected environment (Cornell, 2015). Other species, such as Canada Geese, were more prominent at the end of the migration season. This is significant when looking at the dates of the research. Post migration or late migration within this study was defined as 13 November, 2015-9 December,

2015. On November 12th, the day before the last third of the study, there was a temperature drop discussed previously. This temperature change could imply that waterfowl and other migratory species did not truly start their migration until mid-November or late migration, explaining the lack of birds surveyed within the first few months of the study. Previous studies have supported this theory of delayed migration. Researchers have found that six out of fifteen waterfowl species actually delayed their autumn migration due to long term climate changes within the area (Lehikoinen, 2012). Through weather patterns and in this case climate change, migration patterns have been significantly delayed. This implies that waterfowl and other migratory species can be bio indicators for climate change and upcoming weather patterns (Lehikoinen, 2012). In this study, however, it shows that migration season cannot be determined beforehand. Though birds have biological circadian and circannual clocks, a structural photo period, and other biological concepts such as Zugunruhe (migratory restlessness), hyperphagia (overeating), and flight muscle toning, studies have indicated that temperature, weather changes, and photoperiodic cues are the ultimate factor in determining migration (Helm, 2006; Odum, 1960; Coppack, 2002). Population numbers were high during the end of migration and low during the beginning of migration and can be explained by these environmental cues.

The biological factors that impacted this study have been discussed and will continue to pave an explanation for the results received in regards to *E. coli* levels and their relativeness to the abundance of waterfowl. Impoundment PL nearly tripled the next highest impoundment in regards to waterfowl surveyed throughout the study. PL was the largest impoundment at 175 acres; it was not surprising it was inhabited by the most individuals. Waterfowl tend to populate larger habitats providing more room for foraging and food availability (Smith et al., 1989). This is further supported by impoundment PP which is one acre in size and inhabited a low ten individuals throughout the study. Although habitat size seems to be correlated to the number of individuals who frequent the impoundment, there was no definite evidence that show it was the sole factor for bird abundance. Impoundments such as PH and PN were in the top four impoundments for bird abundance, however, had small acreages of four and eight. Impoundment PH held the fourth largest amount of waterfowl throughout the study regardless of its small size. This impoundment also was the third for *E. coli* levels with 6.3 CFU/mL at the beginning of migration. This was due to the large amount of Wood Ducks inhabiting the impoundment early in the migration season. Wood Ducks in this study were found to migrate in the first third of

migration season; or pre-migration, and could explain why *E. coli* levels were highest at this pool during pre-migration. PH was also set further into the woods, with a small acreage, explaining why PH was primarily inhabited by Wood Ducks given forests are their primary habitat (Bellrose & Holm, 1994).

Impoundment PL not only had the most amounts of birds throughout the study, but it also had the highest levels of *E. coli* at 9.55 CFU/mL at the post-migration mark. Impoundment PL with the highest *E. coli* levels fits into the original hypothesis stating that if more birds inhabit an area, *E. coli* levels will be directly affected in an increasing fashion. This impoundment, however, is the only case where this is true. Although PH and PN are both in the top four *E. coli* levels and population abundance, there was not significant data providing evidence showing that the number of birds directly impacts *E. coli* levels within an impoundment. PL was a unique case and can be explained with previous studies. Within the impoundment, Canada Geese were the primary inhabitants of impoundment PL. Canada Geese are known to fly in large flocks and are known to deposit much of their waste within water bodies, greatly impacting not only *E. coli* levels but also nitrogen and phosphorous levels (Kiefer et al., 2012). Canada Geese were primarily prevalent in the post-migration period as most species were in this study. This explains why the highest *E. coli* levels recorded within this study were at PL during the last third of migration.

Although PL and other impoundments seem to fit into the original hypothesis, that population abundance would increase *E. coli* levels therefore altering water quality, most of the studied impoundments showed no evidence of this. *Escherichia coli* levels at different impoundments at different time periods of migration were variable. One biological factor which could have impacted the study is again temperature. Previous studies have shown the die off rate of *E. coli* relative to temperatures, and show that *E. coli* will actually multiply in autoclaved water at 15 degrees Celsius, but will rapidly die off in non-sterile river water at lower temperatures (Medema et al., 1997). This explains why *E. coli* levels may have decreased over the study rather than increase throughout migration. *Escherichia coli* bacteria simply may have not been present because they were dying off in the colder untreated waters of the refuge. *Escherichia coli* are also susceptible to other compounds that can be found in water and are actively added to water. Chlorine, for example is a gas added to waters in order to kill bacteria

(*E. coli*). Chlorine can be found in a number of household items including treated waters, which can eventually run off into waterways (Study and Interpretation of the Chemical Characteristics of Natural Water, 1970). Studies have found that *E. coli* levels that are exposed to chlorine for less than one minute are drastically decreased (Rice et al., 1999). Though chlorine may or may not be found in the waters of the refuge, this idea explains why *E. coli* levels could have potentially been altered by other biological factors other than waterfowl abundance; such as natural occurring chemicals.

Water levels also throughout the study could have impacted *E. coli* levels. While water levels increased over the migration season, bacteria levels could have been diluted. Previous studies show that rainfall and water levels can impact *E. coli* levels. A study in Wisconsin found that directly after storms, beach waters showed no increase in *E. coli*, however further research was needed to be done in order to determine if runoff water was impacting *E. coli* levels (Kleinheinz et al., 2009). *Escherichia coli* are capable of growing in environments varying from diluted water solutions of nutrients to concentrations of salts or nonelectrolyte solutions (Record et al., 1998). Studies have found that *E. coli* can grow in waters as sparse or as concentrated as water found in the sand of the great lake beaches (Alm et al., 2003). This being said, *E. coli* levels were most likely not impacted by the different water levels at different times of the study.

Conclusion

This study aimed to determine how migrating waterfowl impact *E. coli* levels specifically within impoundments located in the Erie National Wildlife Refuge during the peak of the fall 2015 migration season. The hypothesis was that more waterfowl activity will lead to higher *E. coli* levels at each respective impoundment. The study shows a clear relationship between waterfowl abundance and weather changes at different times of migration, however, does not show a clear relationship between *E. coli* levels and abundance. *Escherichia coli* levels fluctuated throughout the study in no predictable way. Few impoundments did see an increase in *E. coli* relative to waterfowl abundance, but more research needs to be done with more water samples more often to determine significance.

Currently there are no waterfowl management techniques being used at the ENWR. Waterfowl are free to come and go as they please throughout their migration. Other refuges

across the country have been using management techniques such as dogs, in order to limit the abundance of species such as Canada Geese on refuge property. This cuts down on habitat destruction and also water quality impacts. Based off of the results of this study, no action is needed in order to limit populations. Water qualities are not being greatly impacted by waterfowl in the area. Though *E. coli* levels fluctuated, there is not enough evidence to say that waterfowl are the sole factor in respect to *E. coli*. The ENWR may be healthy in regards to water quality and waterfowl populations, but future research must be done to complete this study. Future research may include but is not limited to a much longer study, advancing into the spring migration period. This would allow researchers to determine if *E. coli* is impacted greater in the spring or the fall. A larger study might also be done. *E. coli* levels could be taken weekly rather than only three times throughout migration. Many variables could also be limited within the study. By concentrating on one or two impoundments and taking *E. coli* data weekly, one could see more accurate relationship between *E. coli* and waterfowl abundance throughout migration.

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