

THE EFFECT OF THE COVID-19 PANDEMIC ON BACKYARD BIRD FEEDING HABITS
AND POPULATIONS USING A CITIZEN SCIENCE APPROACH

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A professional paper submitted in partial fulfillment
of the requirements for the degree

of
Master of Science
in
Land Resources and Environmental Sciences

MONTANA STATE UNIVERSITY
Bozeman, Montana

August 2021

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ABSTRACT

Citizen science is an effort to engage the public in scientific practice and enhance the educational experience for science students. The COVID-19 pandemic has forced most residents to isolate themselves in an effort to control the spread of the disease. As a consequence, backyard birdwatching and feeding have become increasingly popular, but the ecological effects of increased supplemental feeding for backyard birds are largely unknown. Monitoring changes in the abundance of common backyard bird feeder species in the towns of Scotch Plains-Fanwood Ecosystem (SPFE), New Jersey through the Great Backyard Bird Count (GBBC) could provide insights into motivating students through authentic, community-based learning and how changes in human behavior during the pandemic have contributed to population dynamics of the bird community of the SPFE through changes in resource availability. Students at Scotch Plains-Fanwood High School participated in a minimum of 15 consecutive minutes of bird watching during the GBBC in 2020 and 2021 at locations within the SPFE. In addition, students were asked to complete a survey evaluating the effectiveness of the Great Backyard Bird Count in engaging the public through citizen science. The results indicated that fewer total individual backyard birds were reported during the COVID-19 lockdown compared to the count before the lockdown in 2020 within the SPFE. In contrast, the increases in adjusted Simpson and Shannon indices suggest an increase in species diversity by 9-21% from 2020 to 2021. The increase in diversity may be partly explained by the 25% increase in the number of feeding stations. However, the data potentially have considerable uncertainties associated with small sample size, inconsistencies in observation duration, available resources (training, equipment, available instructors, etc.), all of which are challenges typical of citizen science and working with teenagers during a global pandemic. Finally, participant feedback regarding the effectiveness of citizen science was overwhelmingly high and demonstrated clear public engagement in and admiration of the scientific process.

CHAPTER ONE

INTRODUCTION

The Citizen Science Approach

The use of citizen science projects to augment educational experiences for students has become an important field of research in recent years. The exact definition of citizen science varies (NJDEP, 2020), but generally speaking, citizen science is categorized into one of two major ideas. The first refers to large scale data collection and analysis projects relying on crowds of citizens to assist with observations and data classification while the second describes citizen science as an attempt to provide stakeholders with the opportunity to participate in collecting data, influencing policy in their community and promoting democracy in issues of the environment and public health (Kullenberg and Kasperowski, 2016).

In regards to the first concept of citizen science, research has shown both the drawbacks and potential of citizen science projects as a tool to enhance research. In an analysis of the accuracy of citizen science-based lady beetle monitoring programs, it was found that data collected through citizen science overestimated species richness and diversity when compared to verified data (Gardiner et al., 2012). However, while citizen science may be less accurate than data collected by experts, citizen science data were more effective than traditional scientific practices in regards to data gathered per dollar spent (Gardiner et al., 2012), hence providing experts with a wealth of data to analyze and inform management decisions.

The second concept of citizen science cannot be ignored; citizen science projects have benefits beyond providing scientists and experts with large volumes of data for analysis. Citizen science projects provide a wealth of benefits to non-science stakeholders in local communities and can indirectly benefit scientific research through better public education, understanding and engagement (Jordan et al., 2012). Citizen science allows the general public to participate in the scientific process in real and meaningful ways, fostering an appreciation of scientific research and enriched support for scientific pursuits (Jordan et al., 2012). In this manner, citizen science provides benefits at the individual level including awareness and knowledge of important scientific issues, an understanding of the scientific process and engagement and interest in science and nature stewardship (Jordan et al., 2012).

The Great Backyard Bird Count

The Great Backyard Bird Count (GBBC) is an annual bird count conducted every February in association with the Audubon Society, the Cornell Lab of Ornithology and Birds Canada. The GBBC is a citizen science project meant to engage the general public in the scientific process. During the GBBC, people from across the world make observations about the birds they find in their communities, submitting their results to assist scientists in understanding patterns in global bird populations.

The reason that the Audubon Society, the Cornell Lab of Ornithology and Birds Canada put so much emphasis on studying bird populations through the GBBC is because birds provide a number of ecologically and economically important ecosystem services.

Ecosystem services are defined as the processes by which life-supporting services are produced by healthy, functioning ecosystems (Friedland and Relyea, 2015).

The GBBC was first established in 1998 by the Audubon Society and the Cornell Lab of Ornithology and was one of the first online citizen science projects (Rodonsky-Bish, 2020). Birds Canada joined the project in 2009 and the GBBC became a global venture in 2013, with the introduction of the eBird webservice and app to facilitate data submission (Rodonsky-Bish, 2020).

In 2016, an estimated 45 million bird watchers joined with other wildlife enthusiasts in contributing an estimated \$80 billion to the U.S. economy (U.S. Fish & Wildlife Service, 2018) clearly demonstrating the high level of cultural services birds provide through the intrinsic value and spiritual connection people identify with birds (Friedland and Relyea, 2015). Of course, a healthy bird community provides a litany of other important ecosystem services such as the balance that bird regulating services provide including pest control through insectivory, bird-plant mutualisms through pollination and seed dispersal services and the role birds take as ecosystem engineers through the construction of nests (Wenny et al., 2011).

COVID-19 and Backyard Bird Watching

COVID-19 has proven to be an infectious disease, prompting healthcare experts to recommend citizens avoid meeting in confined spaces and remain socially distanced whenever possible (CDC, 2020). As such, COVID-19 quickly developed numerous indirect impacts for wildlife as people are forced abide by lockdown restrictions and protocols. For example, on social media, people began reporting a spike in rare animal

sightings, especially urban environments, including pumas in downtown Santiago, Chile, dolphins in the calmer than normal harbor of Trieste, Italy and even jackals in Tel Aviv, Israel (Rutz, et al., 2020). Whether wildlife populations were truly increasing in prevalence or simply being observed more by a public looking for something to do during the lockdown remains an unresolved question (Zellmer et al., 2020). None-the-less wildlife had clearly captured the interest of the public during the COVID-19 restrictions as many were fascinated by the changes the restrictions brought to wild populations.

In light of calls by public health officials to maintain social distancing and public interest in wildlife during the pandemic, outdoor recreational activities became increasingly popular, especially backyard bird watching (Fortin, 2020). Downloads for popular birding apps spiked as home-bound residents search for new hobbies and outlets during the pandemic (Flaccus, 2020). Less anthropogenic noise has allowed many citizens to hear bird calls more often and report a deeper connection to the nature around them (Fears, 2020)

Backyard bird watching is frequently associated with backyard bird feeding as participants want to attract more birds for viewing. Suppliers of bird seed, bird houses and other small businesses associated with backyard birding such as Lizzie Mae's Bird Seed are reporting sale increases of 50% compared to last year due to the pandemic and increased interest in backyard birdwatching and feeding (Dhanesha, 2020).

Despite the popularity of backyard bird watching and feeding, the impacts of supplemental feeding via backyard bird feeders are largely unknown. According to a presentation from FeederWatch, most species that occupy feeders are doing well, in fact

better over time (Frank et al., 2019), suggesting that supplemental feeding can increase population sizes. Such a conclusion is in line with other research showing the positive ramifications of supplemental feeding on populations of wild animals for the benefits of tourism (Orams, 2002) as well as for management of elk and bison in national parks (Franke, 2005). As such, it is hypothesized that increased interest in backyard bird watching increased the prevalence of backyard bird feeding, allowing for increased population sizes of common backyard bird feeder species.

Project Objectives

My study has multiple but overlapping objectives in the context of the citizen science projects like the GBBC. The goals of my study are to: 1) engage students in and educate students with the citizen science approach through the GBBC; 2) evaluate the biodiversity of the bird community in the Scotch Plains-Fanwood Ecosystem (SPFE) and explore how the COVID-19 pandemic has affected the community of common backyard bird feeder species through changes in human behavior and 3) evaluate how the COVID-19 pandemic has altered human behavior in regards to backyard bird watching and feeding in the SPFE.

Expected Outcomes

As there are multiple goals of my project, there are multiple expected outcomes as well. First, I expected that students will react positively to the citizen science approach and report feeling more confident in identifying bird species in the SPFE as well as describing the value of birds through the ecosystem services birds provide to society.

Second, I anticipated that the biodiversity of the SPFE common backyard bird feeder community will have increased from 2020 before the COVID-19 pandemic and lockdown, to 2021 during the COVID-19 pandemic. I based this on predicted changes in human behavior in regards to bird watching and bird feeding in the SPFE that will result in increased population sizes of common backyard bird feeder species from the 2020 to the 2021 Great Backyard Bird Count. Third, based on calls by health experts to stay home and remain socially distanced, I expected that more human residents of the SPFE will have participated in backyard bird watching and feeding in 2021 compared to 2020.

CHAPTER TWO

METHODS

Study Area

The study area for my research included the towns of Scotch Plains (9.06 mi²) and Fanwood (1.34 mi²) in Union County, New Jersey (Figure 1). I chose this specific area because my students attended Scotch Plains-Fanwood High School (SPFHS) which serves residents of these two municipalities. I allowed my students were able to participate from their backyards or local parks. Unfortunately, no school field trips were permitted during the pandemic meaning other research sites were not possible as had been done in the past such as the Great Swamp National Wildlife Refuge (Basking Ridge, NJ) or the Scherman-Hoffman Wildlife Sanctuary (Bernardsville, NJ) managed by the Audubon Society. The study area has a combined size of 10.4 mi².

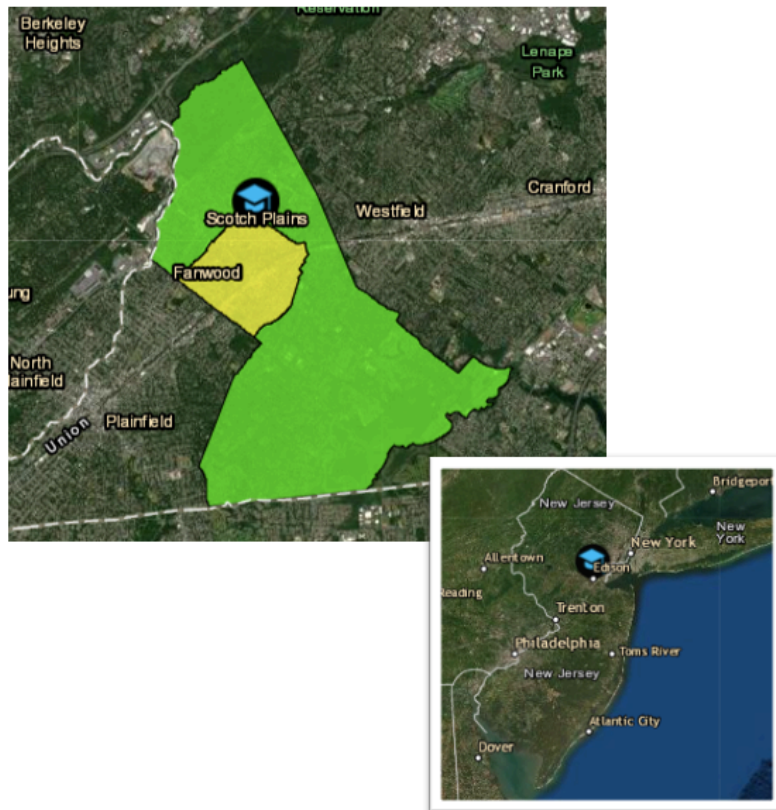


Figure 1. Area of study for the Great Backyard Bird Count (GBBC) in the Scotch Plains-Fanwood Ecosystem (SPFE). All observations made during the 2020 GBBC were made within the municipal boundaries of the towns of Scotch Plains and Fanwood in Union County, New Jersey. In the map to the left, the town of Scotch Plains is highlighted in green while Fanwood is highlighted in yellow. The location of Scotch Plains-Fanwood High School is depicted with a blue point of interest (POI) symbol. The bottom map depicts the location of the SPFE in relation to the state of New Jersey.

Student Preparation for the GBBC

In preparation for participation in the GBBC, I instructed my students participate in a “Birding Bootcamp” as a part of class in both 2020 and 2021. In 2020, there was only a single class of AP environmental science with a total of 18 students. The academic environmental class did not open until the 2021 school year. The 2021 GBBC involved 28 students from AP environmental science as well as 49 students enrolled in academic environmental science. It should be noted that while I had all 77 students participate in

the training and the actual GBBC, I only tasked the AP environmental science students with submitting their field data which was then included in this project. I made this because the students in my academic environmental science classes have proven to be a ‘high-needs’ population in context of virtual learning and could not be provided the in-person supports and supervision they would have needed to effectively and reliably submit timely data.

During their training, I instructed my students to learn the value of bird biodiversity in their community, review the protocols for the GBBC as set by the Audubon Society and Cornell Lab of Ornithology (The Cornell Lab, 2021) and practice identifying 15 of the most common backyard bird feeder species in New Jersey based on sight as well as sound.

To understand the ecological value of the bird community, my students learned about the ecosystem services provided by backyard birds including their roles as predators, pollinators, scavengers, seed dispersers, seed predators, and ecosystem engineers (Hill, 2021). In addition, I asked my students to read a 2016 study that found that backyard bird watching contributes an estimated \$80 billion to the U.S. economy, highlighting the cultural services that birds provide through ecotourism (U.S. Fish and Wildlife Service, 2018).

With the value of the bird community clearly established, I asked students to consider meaning and value of citizen science projects. I explained to students how citizen science projects serve two major functions: first, to greatly enhance data collection and/or analysis by relying on amateur scientists and everyday citizens, and

second, to promote environmental equity by engaging stakeholders in the scientific process in an authentic and meaningful way to inform public policy and promote democratic ideals (Kullenberg and Kasperowski, 2016).

To prepare my students for their work in the field, I required them to learn 15 common backyard bird feeder species including: American Crow (*Corvus brachyrhynchos*), American Goldfinch (*Spinus tristis*), American Robin (*Turdus migratorius*), Black-capped Chickadee (*Poecile atricapillus*), Blue Jay (*Cyanocitta cristata*), Common Grackle (*Quiscalus quiscula*), Downy Woodpecker (*Dryobates pubescens*), European Starling (*Sturnus vulgaris*), House Finch (*Haemorphous mexicanus*), House Sparrow (*Passer domesticus*), Mourning Dove (*Zenaida macroura*), Northern Cardinal (*Cardinalis cardinalis*), Red-tailed Hawk (*Buteo jamaicensis*), Tufted Titmouse (*Baeolophus bicolor*) and White-breasted Nuthatch (*Sitta carolinensis*).

"Common backyard bird feeder species" are historically some of the most common birds in the area and are frequently observed at bird feeders. This excludes predatory birds and others that do not frequent bird feeders such as waterfowl. Species including American Crow (*Corvus brachyrhynchos*), Canada Goose (*Branta canadensis*), Cooper's Hawk (*Accipiter cooperii*) and Red-tailed Hawk (*Buteo jamicensis*) were excluded from the data set for this project for this reason.

I expected my students to be able to recognize all 15 assigned species. This was meant to provide some practical experience in properly identifying bird species including the most common bird species student might have encountered during the actual GBBC. I assessed my students through a short birding quiz before the start of the GBBC. The

average score for the academic students was 80% while the AP students had an average score of 94%, another reason why only the AP students' field data were included in this project.

I provided students with a number of resources to assist them in identifying unfamiliar birds while working in the field. In a normal year, my students would be asked to establish bird feeding stations on the school campus, but this was not possible in the 2021 school year due to the on-going pandemic and school safety protocols during virtual instruction. Instead, students were provided numerous field applications to use on their mobile devices including Seek by iNaturalist, the Audubon Field Guide app, eBird from the Cornell Lab of Ornithology and Survey123 from Esri.

The Seek app allows users to identify a variety of species, including birds, by taking pictures with the camera of their device. The Seek app uses the iNaturalist data base to identify the species. Although the Seek app has many advantages, the Audubon Field Guide App was the preferred tool of choice by students for identifying bird species. The app contains numerous user-friendly tools such as the "Find a bird" feature that allows users to plug in features like size, color, and flight path to narrow down the list of candidate species. The colorful pictures of each species and library of bird calls made it easy for students to study from and use in the field.

The eBird app is provided by the Cornell Lab of Ornithology and allows users to create a free account to participate in the GBBC and submit their data. The app digitized the checklists needed to record species, simplifying the process of data collection and submission greatly. Finally, Survey123 allowed students to record their species numbers

for class, while also geo-locating their results and enabling easy integration with ArcGIS for data visualization and analysis. It should be noted that Survey123 was only available for our district in 2021 and was not used by students in 2020. Only the AP students used the Survey123 app which was used to compile the data collected in the field.

GBBC Rules for the SPFE

The Great Backyard Bird Count is a citizen science project designed to engage citizen scientists and birders of all backgrounds and expertise levels. There are no pre-requisites to participate, but there are certain guidelines to which participants are expected to adhere to (Cornell University, 2021). As such, the students adhered to the guidelines developed by the Audubon Society and the Cornell Lab of Ornithology as the baseline for establishing the protocols used by students and staff during the GBBC in the SPFE for both 2020 and 2021.

Based on these guidelines, I required all participants to collect data for at least 15 consecutive minutes at least one of the four days of the GBBC. This ensured that participants spend enough time observing to report significant results. Additionally, participants were required to only report the maximum number of birds of the same species seen at the same time. This is because birds may leave the observation area and then return later inadvertently inflating reported numbers (Cornell University, 2021).

According to the official guidelines of the GBBC, if a participant hears a bird that they can identify but is unable to physically see the bird, they may report that species as an “X” to signify the species was present but an accurate number could not be determined

(Cornell University, 2021). When compiling data for this project, I decided that an X would be counted as a 1 since at least one member of the species have to had been present. Finally, results were reported to Cornell via the eBird application as well as through the Survey123 app for our own data collection purposes.

Field Work 2020

My 18 AP environmental science students collected GBBC data within the local community. I excluded four observations from this project because students collected data from outside the SPFE. In addition to the “Birding Bootcamp”, I was able to have students in the 2020 GBBC visit the Audubon center at the Scherman-Hoffman Wildlife Sanctuary. At the sanctuary, students participated in a “Feathered Friends” workshop that reviewed how to use binoculars and practice birding in the field.

During the GBBC, I had my students collect their data on printed checklists provided by Audubon as well as submitting their data through the eBird app. Students recorded the location of their observations manually using Google Maps which were compiled into the class data set. Many students elected to collect data on their own, with nine students attending an on-site field trip on the high school campus to collect data with teachers present on the morning of February 14, 2020.

Field Work 2021

Due to the on-going pandemic, I asked all students to independently participate in the GBBC. Unlike in the past, there was no opportunity for field trips such as to the Audubon Center at the Scherman-Hoffman Wildlife Sanctuary or even to the high school campus per district safety policy.

I allowed students to choose their own research site within the SPFE with the majority participating from home and some traveling to local parks such as the Fanwood Nature Center, Ponderosa Farm Park and Ash Brook Reservation, all of which are located within the municipal boundaries of Scotch Plains and/or Fanwood. I instructed students to collect field data in their notebooks before compiling the final bird lists into eBird and Survey123 for submission. Again, it should be noted that I only asked the 28 AP environmental students to submit data through Survey123 for inclusion in this project. I excluded the students in academic environmental science due to concerns over the lack of in-person support to ensure reliable and timely data submission. Both the eBird and Survey123 app were completed in the field to ensure that data were geotagged appropriately.

Student Survey Analysis

For the 2021 school year, I instructed all 77 students from my AP and academic environmental science classes to complete a short survey upon completing their field research. The survey I designed had students reflect on their experience with the GBBC as well as changes in backyard bird watching and feeding in their households during the pandemic. Questions and prompts included:

1. Prior to participating in the Great Backyard Bird Count, how would you rank your knowledge of the birds in your community?
 - a. Respondents rank their response on a scale of 1-5, with a 1 indicating they had no knowledge of any birds in their community and 5 indicating they could identify any species in the community.
2. After participating in the Great Backyard Bird Count, how would you rank your knowledge of the birds in your community?
 - a. Respondents rank their response on a scale of 1-5, with a 1 indicating they had no knowledge of any birds in their community and 5 indicating they could identify any species in the community.
3. Participation in the Great Backyard Bird Count is a worthwhile and meaningful experience.
 - a. Respondents choose their level of agreement from strongly disagree to strongly agree.
4. After participating in the Great Backyard Bird Count, I can explain the significance of birds, ecosystem services and citizen science to a friend who was unfamiliar with the topic.
 - a. Respondents choose their level of agreement from strongly disagree to strongly agree.
5. Prior to the COVID-19 pandemic, how many people in your household regularly participated in bird watching?
 - a. Respondents can select from choices of 0, 1, 2, 3 or 4 or more.
6. Since the start of the COVID-19 pandemic, how many people in your household have been regularly participating in bird watching?
 - a. Respondents can select from choices of 0, 1, 2, 3 or 4 or more.
7. Prior to the COVID-19 pandemic, how many bird feeding stations were available at your home?
 - a. Respondents can select from choices of 0, 1, 2, 3 or 4 or more.
8. Since the start of the COVID-19 pandemic, how many bird feeding stations have been available at your home?
 - a. Respondents can select from choices of 0, 1, 2, 3 or 4 or more.

The results of the student survey were collected via Google Form and then compiled into Excel for analysis. The results of questions 1 and 2 were compiled into a single table of values to illustrate the growth in student expertise from the start of the GBBC to its completion. The same approach was taken with questions 5 and 6 as well as 7 and 8 to show the impact of the COVID-19 pandemic on bird watching and bird feeding respectively.

Weather Data

I collected weather data for both the 2020 and 2021 GBBC in the SPFE from timeanddate.com. Specifically, the data I collected included the daily high and low temperatures as well as any precipitation recorded for each of the four days of the GBBC in 2020 and 2021. These data values were used to establish the minimum, maximum and mean temperature during the GBBC in 2020 and 2021.

Data Analysis

My analysis of data for this project largely centered on exploring changes in the bird community between the 2020 GBBC and the 2021 GBBC in the SPFE. The data the students collected were filtered to only include common backyard bird feeder species, primarily, but not exclusively song birds, while predatory birds and others that do not frequent bird feeders such as waterfowl were not included in this analysis of “common backyard bird feeder species”.

Data trends I evaluated included the mean number of common backyard bird feeder species individuals per observation by year, the mean number of recorded common backyard feeder species reported per observation by year, the frequency of each species of common backyard bird feeder species by year, the percentage change of the common backyard bird feeder species from 2020 to 2021, changes in frequency of the top five most commonly reported species by year and the changes in biodiversity of the community of common backyard bird feeder species in the SPFE in 2020 and 2021.

To compensate for the different number of observations in the 2020 GBBC ($n = 8$) and the 2021 GBBC ($n = 33$) for the SPFE, I developed the metrics of individuals per observation (IPO) and species per observation (SPO). I defined IPO as the mean number of recorded common backyard bird feeder species individuals per observation by year in the SPFE. Similarly, I defined SPO as the mean number of recorded common backyard bird feeder species per observation by year in the SPFE. Calculation of IPO and SPO allowed for direct comparison of the data between years with different numbers of students and the number of observations.

To monitor changes in the populations of individual common backyard bird feeder species from year to year, I calculated the frequency and percentage change of each species. I accomplished this by using the formulas provided in Appendix A, specifically equations 1 and 3. Six common backyard bird feeder species could not be included in this specific analysis because they were not observed in the initial year (2020) and had to be excluded from the table. These included the Brown Creeper, Fox Sparrow, Hairy Woodpecker, Northern Flicker, Northern Mockingbird and Red-breasted Nuthatch.

I identified the five most common species based on the calculated frequency of each species for comparison between the 2020 GBBC and the 2021 GBBC. Some species including the European Starling, House Sparrow and Mourning Dove overlapped between years while others such as the Blue Jay, Common Grackle, Dark-eyed Junco and North Cardinal did not.

To assess the biodiversity of the SPFE, I calculated the Simpson (1-D) and Shannon indices using the formulas described in Appendix A. The Simpson index

measures the probability that two randomly selected individuals from the target population will be from the same population (Kiernan, 2020). As such, the Simpson index is considered a dominance index, giving weighting preference to more dominant species (Kieran, 2020). As such, an advantage of the Simpson index is that the addition of rare species has minimal effect on biodiversity, making the index less sensitive and avoiding data bias. By contrast, the Shannon index is an information statistic index and assumes all species are randomly represented (Kiernan, 2020). According to the Shannon index, if community diversity is low a randomly selected individual is more likely to belong to the dominant species (Kiernan, 2020). In comparison to the Simpson index, an advantage of the Shannon index is that it is more sensitive to both the richness of species in a sample and the distribution of those species, known as evenness.

Although both the Simpson (1-D) and Shannon indices are useful for estimating biodiversity, the drawback is that results are relative as both indices require context and comparison to have real meaning (Friedland and Relyea, 2015). One way to accomplish this is to use the indices values to calculate the effective number of species. This value is equivalent to the number of equally-common species needed to generate a specific value of a biodiversity index such as the Shannon's index or Simpson index (Joust, 2007). In this manner, the effective number of species provides the true diversity of the community in question (Joust, 2007). This transformation was accomplished using the formulas in Appendix A, specifically equations 5 and 7.

As such, I compared both indices for 2020 and 2021 GBBC for the SPFE to provide context for changes in the common backyard bird feeder community. I was also

able to calculate percentage change for the calculated effective number of species for each index using the formula provided in Appendix A, equation 1. Additionally, I calculated the mean length of each observation for the 2020 and 2021 GBBC. This step was taken to better assess the differences between the results of the 2020 and 2021 GBBC in the SPFE given that all observers collected data for at least 15 minutes, but some went for substantially longer.

For all appropriate samples, I calculated standard error and used those values to establish error bars for error bar analysis of statistical significance. Additionally, I performed a one-way analysis of variance (ANOVA) whenever appropriate data were available to further evaluate statistical significance. However, I used a Mann-Whitney Test to evaluate the data collected from the student survey in place of ANOVA to reflect the ordinal data of a Likert scale. All calculations were performed using Microsoft Excel for Mac Version 16.46.

CHAPTER THREE

RESULTS

Analysis of Goal #1:**Engagement and Education of Student Through the Citizen Science Approach**

Following completion of field work, I asked students to complete a brief survey meant to reflect on their experiences with the GBBC. When I asked students to identify their level of knowledge of the birds in their community on a scale of 1-5, the mean response increased significantly from a value of approximately 2 to 3.5 following participation in the GBBC (Figure 2, $p < 0.001$). Furthermore, 74% of my students agreed that the GBBC was a worthwhile and meaningful experience (Figure 3). Finally, 65% of my students reported that following their experiences in the GBBC they felt confident explaining the value of birds, ecosystem services and citizen science projects to a peer (Figure 4).

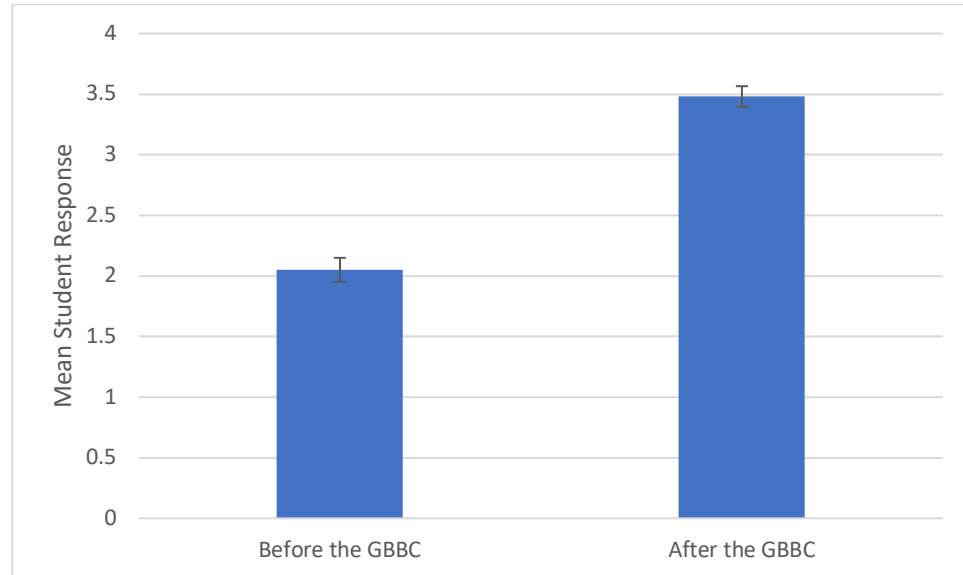


Figure 2: Mean impact of the citizen science approach on student knowledge of the bird community through the GBBC. This chart illustrates the response of students to the prompt, “Prior to and after participating in the Great Backyard Bird Count, how would you rank your knowledge of the birds in your community?” A 5 indicated the highest possible level of knowledge and a 1 indicated the lowest level of knowledge. A Mann-Whitney test was performed on the ordinal data from the Likert scale used in the survey, which indicated that the data were statistically significant ($p < 0.05$).

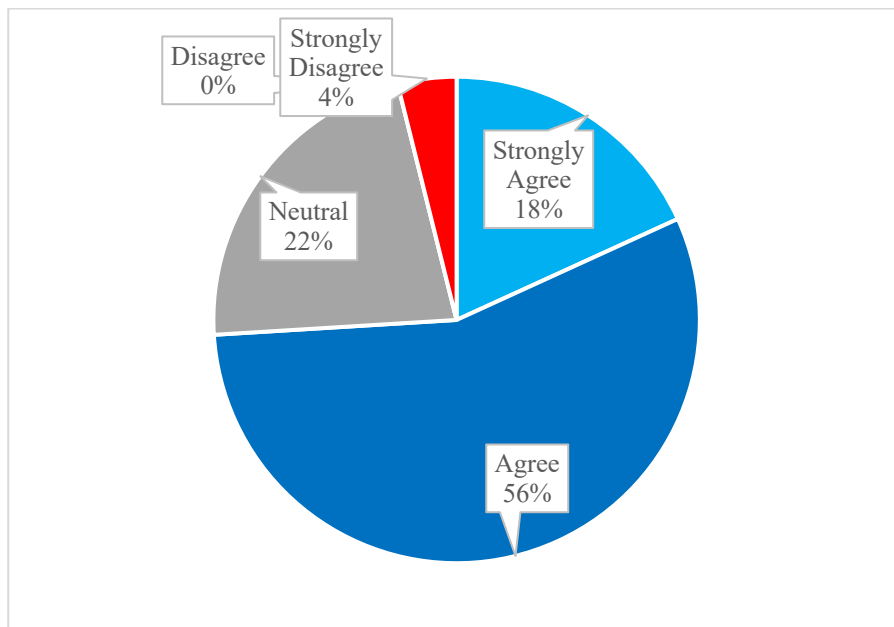


Figure 3: The value of the GBBC to students. This chart illustrates the response of students to the prompt, “Participation in the Great Backyard Bird Count is a worthwhile and meaningful experience.”

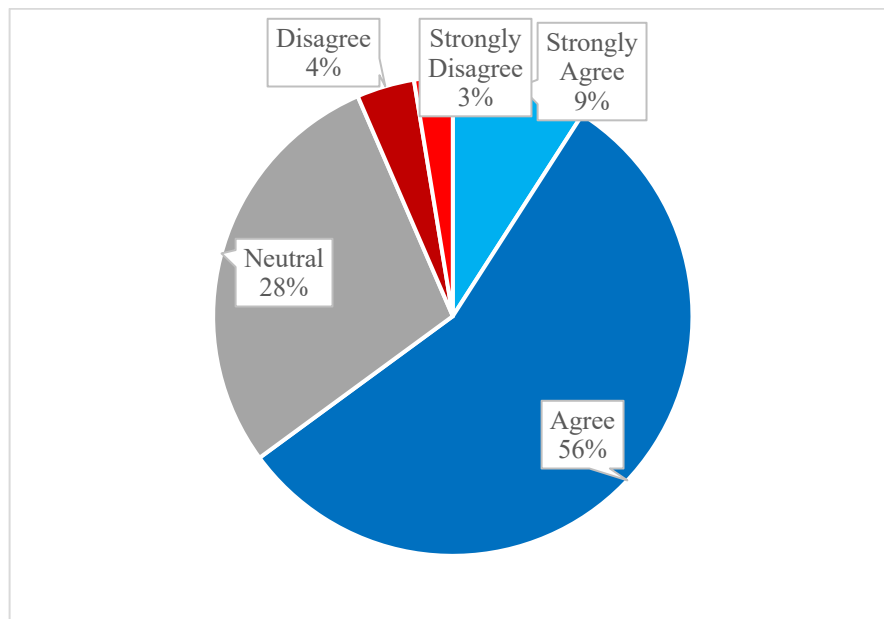


Figure 4: Student understanding of the value of birds, ecosystem services and citizen science. This chart illustrates the response of students to the prompt, “After participating in the Great Backyard Bird Count, I can explain the significance of birds, ecosystem services and citizen science to a friend who was unfamiliar with the topic.”

Analysis of Goals #2 and #3:

Biodiversity of and Impact of COVID-19 on the Community of Common Backyard Feeder Species in the SPFE

After all GBBC observations had been made and submitted, I compiled data for analysis. This included geospatial data to track where observations had been made (Figure 5) as well as compiling totals for individual species counts. The most significant changes from 2020 to 2021 are the 46 fewer observed individuals despite one additional species being observed and more than four times the total number of observations (Table 1). As mentioned previously, my project focused on the impacts of COVID-19 on common backyard bird feeder species. As such, I excluded birds not commonly associated with backyard bird feeders from the data compiled for this project (Table 2).

The weather in both years was very similar in regards to temperature and precipitation with the one major exception being the presence of snow on the ground during 2021, but not in 2020 (Table 3).

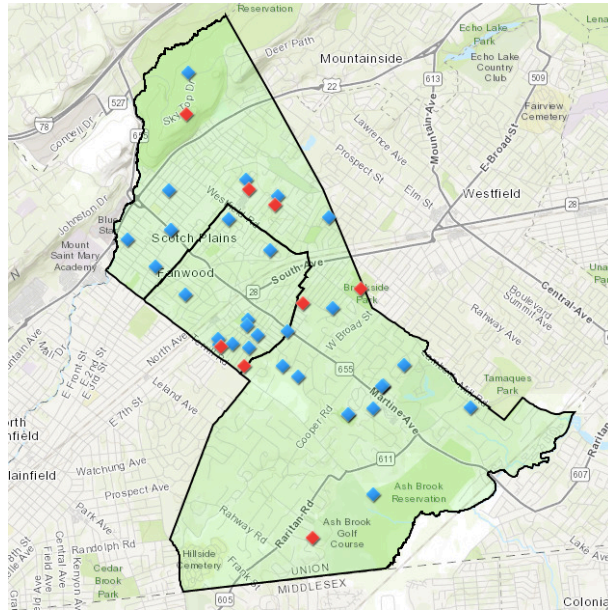


Figure 5: Location of observations and data submission for the 2020 and 2021 GBBC in the SPFE. The location of observations made in the 2020 GBBC are indicated in red while observations made in the 2021 GBBC are indicated in blue.

Table 1: Summary of common backyard bird feeder species individuals observed by year in the SPFE. All observations of common backyard bird feeder species submitted in 2020 (n = 8) and in 2021 (n= 33) were compiled by species. Predatory birds and other species not commonly found at bird feeders were excluded from the list.

Common Name	Scientific Name	Individuals 2020	Individuals 2021
American Goldfinch	<i>Spinus tristis</i>	1	0
American Robin	<i>Turdus migratorius</i>	13	15
American Tree Sparrow	<i>Spizella arborea</i>	1	0
Black-capped Chickadee	<i>Poecile atricapillus</i>	1	8
Blue Jay	<i>Cyanocitta cristata</i>	13	16
Brown Creeper	<i>Certhia americana</i>	0	1
Brown Headed Cowbird	<i>Molothrus ater</i>	1	0
Carolina Wren	<i>Thryothorus ludovicianus</i>	3	0
Catbird	<i>Dumetella carolinensis</i>	1	0
Common Grackle	<i>Quiscalus quiscula</i>	51	5
Dark-eyed Junco	<i>Junco hyemalis</i>	26	10
Downy Woodpecker	<i>Picoides pubescens</i>	8	8
European Starling	<i>Sturnus vulgaris</i>	25	20
Fox Sparrow	<i>Passeralla iliaca</i>	0	3
Hairy Woodpecker	<i>Dryobates villosus</i>	0	6
House Finch	<i>Haemorhous mexicanus</i>	17	15
House Sparrow	<i>Passer domesticus</i>	61	67
Mourning Dove	<i>Zenaida macroura</i>	48	24
Northern Cardinal	<i>Cardinalis cardinalis</i>	6	19
Northern Flicker	<i>Colaptes auratus</i>	0	1
Northern Mockingbird	<i>Mimus polyglottos</i>	0	1
Red-bellied Woodpecker	<i>Melanerpes carolinus</i>	6	9
Red-breasted Nuthatch	<i>Sitta canadensis</i>	0	1
Song Sparrow	<i>Melospiza melodia</i>	3	3
Tufted Titmouse	<i>Baeolophus bicolor</i>	2	9
White-breasted Nuthatch	<i>Sitta carolinensis</i>	7	5
White-throated Sparrow	<i>Zonotrichia albicollis</i>	8	10
TOTAL INDIVIDUALS		302	256
TOTAL SPECIES		21	22
TOTAL OBSERVATIONS		8	33

Table 2: Summary of species not included as “Common Backyard Bird Feeder Species” by year within the SPFE. Birds not commonly associated with backyard bird feeders were excluded from the data compiled for this project. This exclusion was performed to better evaluate the impacts of COVID-19 on backyard bird species through anticipated changes in backyard bird feeding. The table below summarizes the excluded bird species counts by year.

Common Name	Scientific Name	Individuals 2020	Individuals 2021
American Crow	<i>Crovis brachyrhynchos</i>	15	46
Canada Goose	<i>Branta canadensis</i>	0	37
Cooper's Hawk	<i>Accipiter cooperii</i>	0	1
Red-tailed Hawk	<i>Buteo jamaicensis</i>	2	4
Turkey Vulture	<i>Cathartes aura</i>	0	1
TOTAL INDIVIDUALS		17	89
TOTAL SPECIES		2	5

Table 3: Summary of weather conditions during the 2020 and 2021 GBBC in the SPFE. Weather conditions were recorded during each of the four days of the GBBC in both 2020 and 2021. No precipitation occurred during either year, although notably there was abundant snow cover on the ground only during the 2021 GBBC.

	GBBC Day 1	GBBC Day 2	GBBC Day 3	GBBC Day 4
2020 High (°F)	39	30	45	50
2021 High (°F)	30	30	37	36
Precipitation	None	None	None	None
2020 Low (°F)	18	15	30	37
2021 Low (°F)	19	25	27	30
Precipitation	None	None	None	None

	Minimum Temperature (°F)	Maximum Temperature (°F)	Mean Temperature (°F)	Additional Notes
GBBC 2020	15	45	33	None
GBBC 2021	19	36	29	Snow cover on ground throughout all four days

My analysis of the data using the both the Simpson and Shannon indices indicated that there was an increase in the biodiversity of the community of common backyard bird feeder species in the SPFE from 2020 to 2021 (Table 4). I drew this conclusion using the effective number of species values calculated from each biodiversity index. According to my analysis, the biodiversity of the community of common backyard bird feeder species actually increased by 20.92% and 9.09% from 2020 to 2021 based on the effective number of species values based on the Shannon and Simpson indices respectively (Table 4). Some species of common backyard birds associated with feeders were more common than others; European Starlings, House Sparrows, Mourning Doves were some of the most prevalent for both years (Table 4).

Notably, this increase did not include the values adjusted by observation as the individuals per observation (IPO) and the number of species per observation (SPO) both decreased significantly from 2020 to 2021 (Table 4). When I adjusted IPO and SPO to IPO/min and SPO/min to account for the differences in the average length of observation, IPO/min had also decreased from 2020 to 2021, but SPO/min actually increased by about 17% (Table 4). Table 5 summarizes the percentage change of common backyard bird feeder species in the SPFE from 2020 to 2021, drawing attention to the top five most common each year.

According to my analysis, there were some dramatic changes in population sizes of the “Top 5 Most Common Backyard Bird Feeder Species” by year (Figure 6). Notably, populations including the Common Grackle, Mourning Dove and Dark-eyed Junco crash while House Sparrow, Northern Cardinal and Blue Jay populations spiked (Figure 6).

Table 4: Biological diversity of the common backyard bird feeder community in the SPFE measured by year. Also included for the sake of context are the number of recorded species per observation (SPO) and the number of recorded individuals per observation (IPO). The percentage change for each metric was calculated from 2021 to 2020. The Simpson and Shannon Index values were generated from the raw data, not IPO and SPO values.

	2020	2021	Percentage Change (%)	P Value
IPO	41.75 (SE = 3.26)	7.76 (SE = 2.59)	-81.42%	p < 0.05 (ANOVA)
IPO/min	0.73	0.31	-56.65%	
SPO	7.00 (SE = 1.32)	3.52 (SE = 0.39)	-49.78	p < 0.05 (ANOVA)
SPO/min	0.12	0.14	17.13%	
Simpson Index	0.88	0.89		
Shannon Index	2.42	2.61		
Shannon Index				
Effective Number of Species	11.25	13.60	20.92%	
Simpson Index				
Effective Number of Species	8.33	9.09	9.09%	

Table 5: Summary of the frequency and percentage change for all common backyard bird feeder species in the SPFE. Species highlighted in yellow were one of the top 5 most common species for that year.

Species	Species Frequency 2020 (%)	Species Frequency 2021 (%)	Percentage Change
American Goldfinch	0.33	0.00	-100.00
American Robin	4.30	5.81	15.38
American Tree Sparrow	0.33	0.00	-100.00
Black-capped Chickadee	0.33	3.10	700.00
Blue Jay	4.30	6.20	23.08
Brown Creeper	0.00	0.39	N/A
Brown Headed Cowbird	0.33	0.00	-100.00
Carolina Wren	0.99	0.00	-100.00
Catbird	0.33	0.00	-100.00
Common Grackle	16.89	1.94	-90.20
Dark-eyed Junco	8.61	3.88	-61.54
Downy Woodpecker	2.65	3.10	0.00
European Starling	8.28	7.75	-20.00
Fox Sparrow	0.00	1.16	N/A
Hairy Woodpecker	0.00	2.33	N/A
House Finch	5.63	5.81	-11.76
House Sparrow	20.20	26.36	9.84
Mourning Dove	15.89	9.69	-50.00
Northern Cardinal	1.99	7.36	216.67
Northern Flicker	0.00	0.39	N/A
Northern Mockingbird	0.00	0.39	N/A
Red-bellied Woodpecker	1.99	3.49	50.00
Red-breasted Nuthatch	0.00	0.39	N/A
Song Sparrow	0.99	1.16	0.00
Tufted Titmouse	0.66	3.49	350.00
White-breasted Nuthatch	2.32	1.94	-28.57
White-throated Sparrow	2.65	3.88	25.00

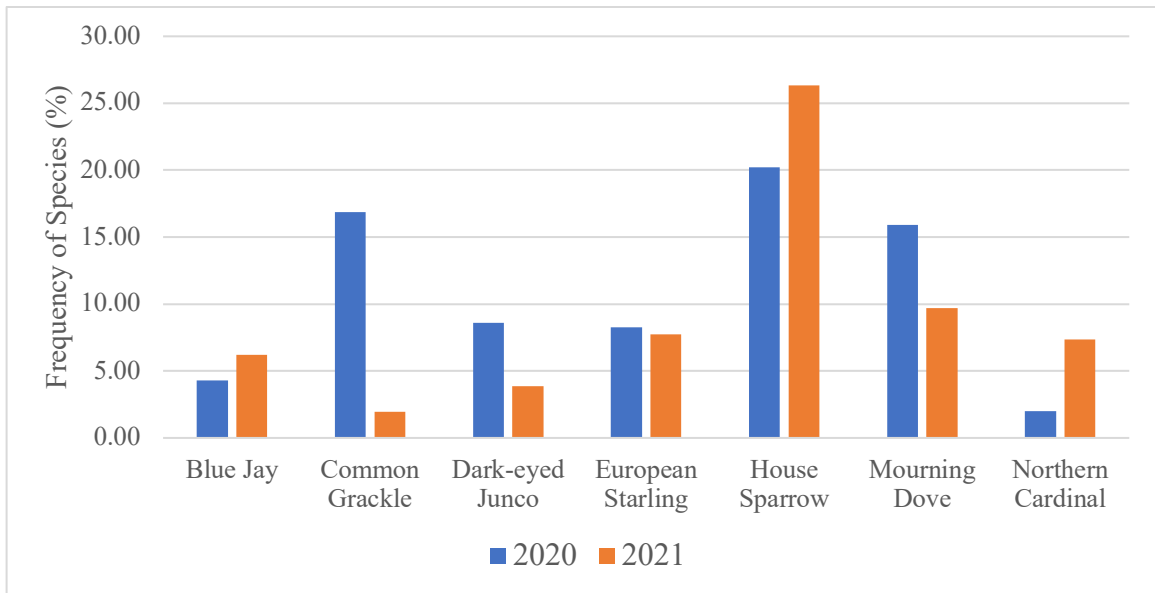


Figure 6: Changes in frequency of the top five most commonly reported common backyard bird feeder species by year in the SPFE.

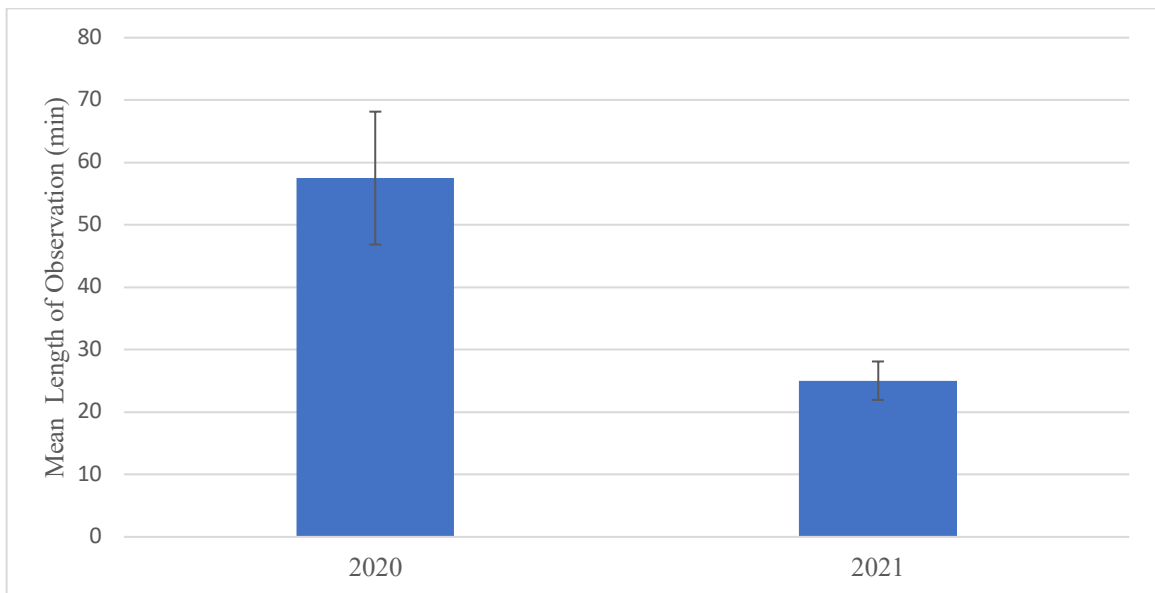


Figure 7: Mean length of observation in minutes by year. Standard error was used to develop error bars for analysis. Additionally, a single factor analysis of variance (ANOVA) was performed which indicated the data were statistically significant ($p < 0.05$).

The COVID-19 pandemic generated many significant changes of habit for people all over the world. The results of my survey indicated that in the SPFE before the start of the COVID-19 pandemic, a total of 20 individuals and a mean of 0.26 individuals per household regularly participated in backyard bird watching, but these numbers increased to 42 total and 0.55 per household following the pandemic (Figure 8 and Table 6) and a Mann-Whitney test indicated the increase in individuals per household was significant (Table 6, $p < 0.05$). This change represents about a 110% increase in the total number of individuals and individual per household participating in backyard bird watching respectively before and after the start of the pandemic.

Before the start of the pandemic, I found that the total number of bird feeder stations in the SPFE was 40 with 0.52 bird feeder stations per household, but these numbers rose to 50 total and 0.65 feeder stations per household following the start of the pandemic. This change represents a 25% increase for both the total number and mean number per household of feeder stations, but the Mann-Whitney test indicated the increase in individuals per household was insignificant (Figure 9 and Table 6, $p = 0.3$).

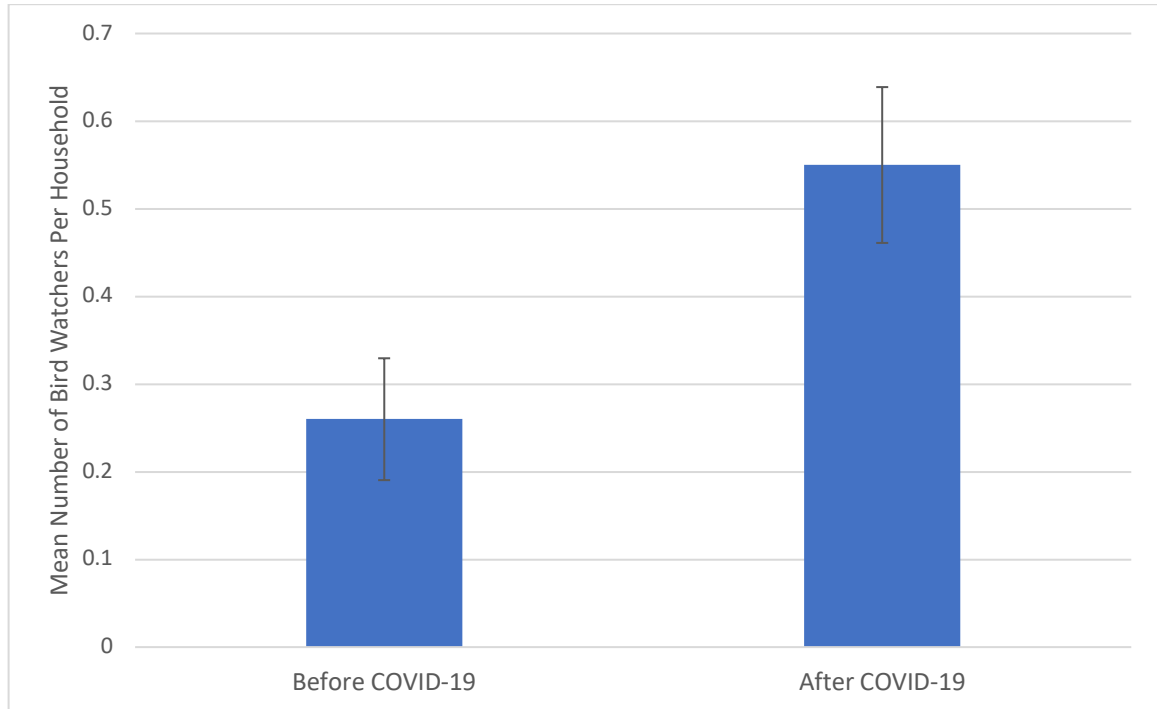


Figure 8: Mean impact of COVID-19 on the number of people regularly participating in bird watching per household in the SPFE. This chart illustrates the response of students to the prompt, “Before and after the start of the COVID-19 pandemic, how many people in your household regularly participated in bird watching?” A Mann-Whitney test was performed on the ordinal data from the Likert scale used in the survey, which indicated that the data were statistically significant ($p < 0.05$).

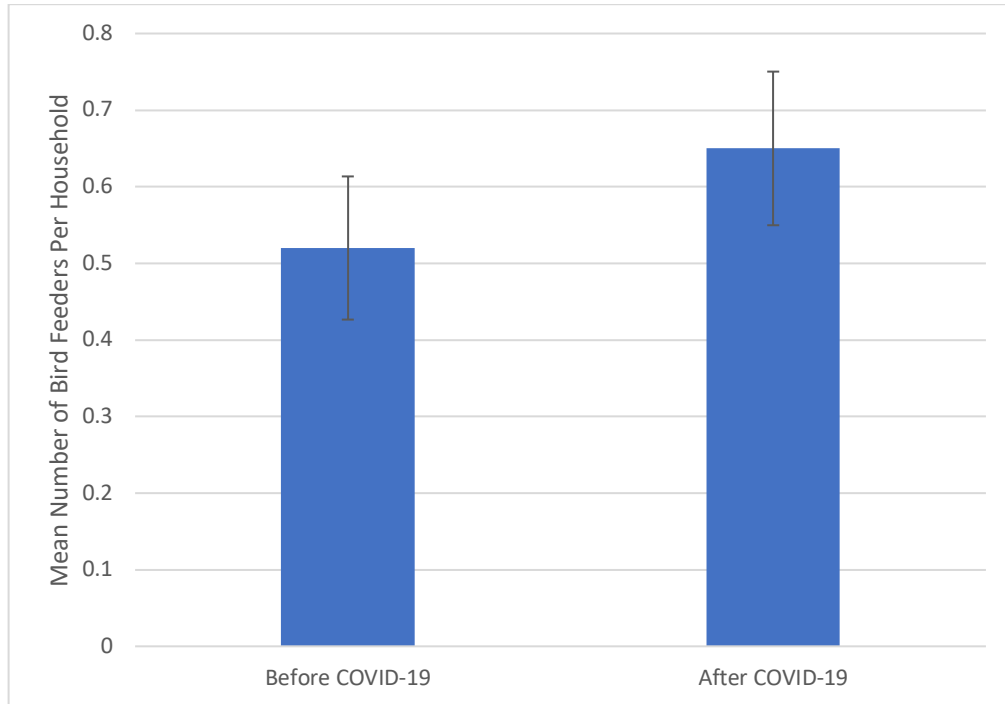


Figure 9: Mean impact of COVID-19 on the number of bird feeding stations per household in the SPFE. This chart illustrates the response of students to the prompt, “Before and after the start of the COVID-19 pandemic, how many bird feeding stations were available at your home?” A Mann-Whitney test was performed on the ordinal data from the Likert scale used in the survey, which indicated that the data were not statistically significant ($p = 0.3$).

Table 6: Summary of student survey data. The mean response on a scale of 1 to 5 is reported for each metric along with percentage change and the p-value from a paired t-test.

	Mean Response Before the GBBC	Mean Response After the GBBC	Percentage Change	p-value
Student knowledge of birds	2.05	3.48	69.76%	<0.00001
Total bird watchers	20	42	110%	
Bird watchers per household	0.26	0.55	111%	0.0424
Total bird feeders	40	50	25%	
Bird feeders per household	0.52	0.65	25%	0.3524

CHAPTER FOUR

DISCUSSION

Goal #1:**Engagement and Education of Students Through the Citizen Science Approach**

The first major goal of my research project was to gauge how effectively students were engaged with and benefitted from the citizen science approach. The data I collected demonstrate that the citizen science approach used in my project significantly improved student knowledge of the birds in their community and highlights the effectiveness of the citizen science approach to supporting students' understanding of the Great Backyard Bird Count as well as the value of birds and ecosystem services.

These findings are consistent with other studies that have explored this relationship between citizen science and student engagement. Inquiry-based learning experiences like the citizen science approach are known to promote engagement in the process of science, which has been well documented in supporting student learning in grades K-12 (Oberhauser & LeBuhn, 2012). To further explore this idea, a recent study of 72 participants explored the cognitive, affective, social, behavioral and motivational aspects of citizen science (Phillips et al., 2019). The research found that the effectiveness of citizen science was not only due to its ability to tap into these fundamental dimensions of research but also because the citizen science approach provided personal relevance to participants which supported interest and engagement (Phillips et al., 2019).

The really exciting piece was that the citizen science approach of the GBBC allowed my students to participate in the authentic experience of scientific research in

their own community. This helped students feel like their work was meaningful and as a result they felt more engaged, empowered, motivated and ultimately confident with that they had been studying. According to one of my AP environmental science students, the citizen science approach we used for class drastically differed from other class activities used in other courses, “My favorite part of the GBBC was that we actually got out in the field to collect real data. And unlike for more traditional laboratory activities, the data we collected were for our actual environment, it really meant something and I liked seeing how the data displayed in ArcGIS.” Other students felt the same way and underscored the effectiveness of the citizen science approach as an engaging, authentic experience. In both years of the GBBC, students were fascinated to learn just how many different species of birds were living in the community effectively ‘hiding in plain sight’ in the words of another student from 2020.

Citizen science projects like the GBBC are so important because they not only expand the pool of scientific data available for experts, but such projects help to cultivate long-term interest in science and a more complete understanding of important scientific ideas and concepts. For weeks and now months after the event, students would come in to class excited to tell me about the birds that had been in their backyard over the weekend. When writing their reports, students showed mastery of concepts including ecosystem services, the intrinsic value of birds and the value of citizens science projects like the GBBC in promoting environmental equity, all of which improved their ability to communicate with their peers when the reports were shared with other students and staff.

Goals #2 and 3:
Biodiversity of and Impact of COVID-19 on the Community of Common Backyard
Feeder Species in the SPFE

The second and third goals of my research project were to evaluate the biodiversity of and influence of COVID-19 through changes in human behavior on the common backyard bird feeder community in the Scotch Plains-Fanwood Ecosystem. During this project, my students and I found 23 and 27 total species including common and non-common backyard bird species in 2020 and 2021, respectively. These results seem lower than expected considering New Jersey ranked #12 in the nation in bird diversity with a total of 340 species. The lower numbers of observed species in this project may be partly because we only focused in the towns of Scotch Plains and Fanwood. Therefore, only a small fraction of the total bird population in the state were observed since observations only occurred in February.

Biodiversity, including species richness, is an important metric and indicator of the health of an ecosystem (Friedland and Relyea, 2015) and higher levels of biodiversity translate to greater ecosystem services from both an ecological and economic perspective (Mace et al., 2012). Furthermore, ecosystems that exhibit higher biodiversity are more resilient to environmental changes including climate change (Oliver et al., 2015).

To better assess the biodiversity of the nation, the Nature Conservancy developed a State of the Union report that outlines the biodiversity of each state in the nation. This report provides a convenient metric for comparison for the data collected in this project. In regards to species diversity, risk of extinction, number of endemic species and number of species that have been extirpated, the State of New Jersey ranks 32, 38, 51, and 25,

respectively of the 50 states and the District of Columbia states with a lower-ranking indicative of greater diversity, risk of extinction, etc. (The Nature Conservancy, 2002). As an example, New Jersey ranks 51 in the number of endemic species, which is the lowest possible score, reflective that New Jersey has 0 endemic species.

These rankings provide greater context for the data students collected in this project and provide a baseline for comparison. For example, New Jersey ranks moderately in regards to overall species diversity for all forms of life including plants, animals, fungi, microbes, etc. (rank 32 of 51; 3,022 species in total) according to the Nature Conservancy which aligns well with the data we report from the GBBC in the SPFE.

Next, I can consider the differences between how the two years' data were collected. If I only consider the biodiversity index values returned by the Simpson and Shannon's indices, there seems to be a small increase in biodiversity from 2020 to 2021. However, when I consider the effective number of species for each index bird diversity increased by 20.92% and 9.09% for the adjusted Shannon and Simpson indices respectively.

The increase in diversity may be partly explained by the increase in the number of feeding stations. As noted in the results section, the change in the number of individuals participating in backyard bird watching and feeding was 110% and 25%, respectively. Running a simple calculation based on the US Census estimate of about 31,000 residents living in about 11,000 homes in the SPFE with the percentage increase observed for the surveyed 77 household, we might expect that there were about 2,800 residents

participating in bird watching in 2020 and about 6,000 in 2021. For bird feeder stations, I can make a similar extrapolation of 5,720 bird feeding stations in 2020 compared to 7,150 in 2021.

These estimates are supported by the reported 20% increased sale of bird food and backyard birding equipment including feeders following the start of the pandemic at Wild Bird Unlimited in Scotch Plains in 2021 compared to 2020 (personal communication). Although the birding equipment was not sold exclusively to the SPFE residents, the customers were returning more frequently to restock (personal communication). Such data support the original hypothesis that biodiversity of the common backyard bird community in the SPFE would improve from 2020 to 2021 due to the indirect effects of the COVID-19 pandemic and ensuing lockdowns. Such numbers of participation could have had major implications for the common backyard bird community. This has been documented in other scientific studies, such as a review of the influence of garden bird feeding in Britain which found the Simpson index for the bird community of the nation increased from about 0.85 to 0.95 over a 40-year period (Plummer et al., 2019). Alternatively, the difference in diversity between the two years may be explained by shifts in species interactions or irregular migratory patterns (Somveille et al., 2013).

It should be noted that changes in bird watching and feeding behaviors were not the only impacts of the COVID-19 lockdown on wildlife. With residents remaining indoors and socially distanced, background noise levels declined significantly in urban environments (Derryberry et al., 2020). In response, bird populations demonstrated a high degree of resilience, quickly changing their behavior in response to the lack of human

activity and generating higher performance songs at lower amplitudes (Derryberry et al., 2020). Such findings raise additional possible explanations for the changes in bird community observed in my research project beyond changes in birding behaviors such as supplement feeding.

Additionally, some evidence suggests that bird populations were not becoming more diverse during the lockdown, but rather more detectable (Gordo et al., 2021). In a study of citizen science data for bird populations in Northern Spain, it was determined that the birds were not recolonizing urban environments in the absence of humans during the lockdown as had been expected, but rather had become more likely to be observed (Gordo et al., 2021). This once again highlights the ability of bird populations to rapidly adapt to changes in human behavior. It is therefore possible that the increase in diversity I had demonstrated in this project within the SPFE may have been due to an increased ability of students to be able to find birds during their observations in 2021 compared to 2020 as opposed to an actual increase in biodiversity of the SPFE.

Regardless of the reason why the composition of the bird community in the SPFE changed during the pandemic, an interesting observation was the increase in the frequency of Blue Jays from the 2020 to 2021 year. While the change in frequency was relatively small, 13 to 16 individuals or 4.3% to 6.2% frequency, Blue Jays become one of the 5 most common species in 2021. Further, Blue Jays can have a disproportionate influence on other species of common backyard bird feeder birds because of their aggressive behavior (Dockett, 2021). Blue jays are loud, aggressive and often intimidating to other birds, frequently working together to harass or even outright kill

other bird species when acquiring food at bird feeders (Dockett, 2021). As such it is possible the increase in Blue Jays from increased bird feeding during the pandemic partly contributed to the decline of other common backyard bird feeder species such as the comparatively tiny Dark-eyed Junco and the larger but passive and unassuming Mourning Dove. The Blue Jays may also simply have been more visible to observers given their loud, aggressive behavior while simultaneously forcing the other bird species to stay out of sight making counting them more difficult.

Notably, the American crow, Northern Cardinal, and House Sparrow populations also increased dramatically from 2020 to 2021. Although these species are not known for being especially aggressive or combative like Blue Jays are, the fact that there were more crows, cardinals and sparrows in the SPFE may have translated to enhanced competition with other common species and generated a cascade of indirect impacts on species like the Dark-eyed Junco or Mourning Dove, especially in the context of climate change which can benefit some species at the expense of others (Princé & Zuckerberg, 2014).

An additional irregularity to consider here is the tendency of some common backyard bird feeder species like the American Goldfinch (*Spinus tristis*) to have irregular seasonal migratory patterns and hence significant fluctuations in population size from year to year that could have influenced the results described above (Audubon Society, 2020). The local weather was likely not an important factor contributing to the differences in bird diversity between the two years since the weather both leading up to and during the GBBC and was similar for both years.

One final irregularity to consider is the selection of observation sites within the SPFE by students. Reviewing the locations where observations were recorded, there seemed to be a greater preference to make observations at residences compared to local parks and nature centers in 2021 compared to 2020. As such, it is possible that the location of the observation biased the data collected in this project and could help explain the apparent fluctuations in population size.

It is important to note that these data should be interpreted with caution due to small sample sizes for some common backyard bird feeder species in one or more years. Noticeably rare species with small sample sizes including but not limited to the American Goldfinch (*Spinus tristis*), American Tree Sparrow (*Spizella arborea*) and Northern Flicker (*Colaptes auratus*) were absent in one year and only represented by a single individual in the other year, which would have had a large impact on a diversity assessment using a limited data set such as the one gathered by the AP environmental science students.

Herein lies a major drawback to the GBBC and the citizen science approach in general: lack of consistency. This has been a challenge for other citizen science-based bird counts such as the Christmas Bird Count (CBC), which exists in the same family of bird counts as the GBBC. The CBC has been running since 1900 and has been used as a source of data for hundreds of publications on a wide variety of topics (Dunn et al., 2005). However, a major drawback to using this data is the lack of consistency the CBC provides. For instance, the rules for making observations during the CBC are not consistent because the CBC was never designed as a census (Dunn et al., 2005).

Furthermore, like many other wildlife surveys, survey effort during the CBC tends to vary from site to site and year to year (Link & Sauer, 1999). This is because some sites will have greater numbers of volunteers to count birds and some observers are willing or able to spend more time in the field making more observations and collecting more data than others (Link & Sauer, 1999).

These patterns of inconsistency applied to our work in this project as well. For example, the number of student participants differed between the two years (8 in 2020 compared to 28 in 2021). To help address these inconsistencies and changes in student population two metrics were developed, the number of recorded individuals and recorded species per observation, IPO and SPO respectively. From 2020 to 2021, the IPO and SPO declined significantly, -81.42% and -49.78% respectively (Table 4). These data could be the result in resource limitations for the 2021 GBBC as students were unable to attend the same Audubon workshop they did in 2020 and did not have access to binoculars from the school.

There was another inconsistency between the 2020 and 2021 bird counts that undermines the IPO and SPO results, time per observation. The average length of time of each observation was significantly longer in 2020 compared to 2021, 57.50 and 25.05 minutes, respectively, a factor of nearly 2.5x ($p < 0.05$, Figure 7). During bird watching a longer period of observation generally correlates to a greater number of observed organisms (Lund, 2017). As such, this inconsistency may have biased the IPO and SPO numbers. To compensate for this, IPO and SPO were adjusted by dividing by the mean time per observation. For both values, this correction reduced the difference between the

two years and ultimately supports the idea that setting a stricter guideline for a consistent length of observation in the future will improve data quality.

Ground conditions may also have been a contributing the differences between the two years. While the weather was mostly consistent, with the mean temperature being slightly warmer in 2021 by about 4 °F and no precipitation occurring during either bird count, there was abundant snow cover on the ground during the 2021 GBBC, while there was no snow cover at all in 2020. It is possible that the snow cover de-incentivized students to stay out as long as they did during the 2020 GBBC leading to the trend of significantly shorter observations during the 2021 GBBC. Alternatively, snow cover may have limited student movement resulting in more stationary observations as opposed to being able to walk around the observation area to get better angles to look for birds.

Notably, there was a lot of variability in the number of reported individuals from each species from 2020 to 2021. This can be seen in the changes in frequency of each species, especially the top five most commonly reported ones. This could be due to small sample sizes described earlier, especially in the 2020 GBBC, that would have biased results. Of course, other potential explanations exist such as the increase of aggressive Blue Jays described earlier as well as the increase of crows, cardinals, and sparrows noted earlier or changes in preference of observation sites.

Although there is some evidence to suggest that the biodiversity improved following the pandemic, including the increase in SPO/min and effective number of species from 2020 to 2021, the inconsistencies in resources, small sample sizes, and variable lengths of observation make it difficult to draw definitive conclusions regarding

both the biodiversity of the community of common backyard bird feeder species and the impact of COVID-19 on that community.

It would be interesting to explore future data sets with a larger number of observations of standardized length and more consistent student preparation and access to tools as well as across multiple years as opposed to just two thereby allowing us to explore long-term trends in various species such as the Blue Jay and American Goldfinch outlined earlier. These changes could help improve the strength of the results.

Additionally, future research could place more emphasis on predator bird species such as the Red-tailed Hawk as changes in predatory species would have an impact on the common backyard bird feeder species. Bird species found at backyard feeder generally serve as prey for larger predatory birds like the Red-tailed Hawk. Expanding the scope of the species examined could yield more insight in the population dynamics of all bird species in the SPFE.

Conclusions and Thoughts for the Future

The results of the student survey are promising and indicate students expanded their knowledge of birds and largely valued the concepts they explored including ecosystem services and citizen science projects through the GBBC.

The value of the citizen science approach and in this case the GBBC is in being able to engage the public in the scientific process. As participants in the GBBC, students played an authentic and meaningful role in the scientific process and helped to develop their role as community stakeholders.

Students reported a much greater understanding of the bird community following the GBBC. Furthermore, students overwhelmingly agreed that the GBBC was a worthwhile and meaningful project, one that many look forward to participating in again in the future. Finally, the vast majority of students felt confident in describing the significance and value of birds, ecosystem services and citizen science to a friend following their participating in the GBBC.

Some data, especially the Simpson and Shannon indices and corresponding effective number of species transformations, suggest that the diversity of common backyard bird feeder species improved from 2020 to 2021. This could be due to a variety of factors including but not limited to increased bird feeding by residents of the SPFE. Ultimately, it is difficult to conclude what effect, if any, the COVID-19 pandemic and the ensuing global lockdown has had on the bird community of the SPFE based on the data collected in this project alone. This is in large part because of the pervasive and systemic high variance of data and procedural inconsistencies, including the number of participants and observation duration, typical of large-scale projects including citizen science ones (Irwin, 2018).

With the lessons of the past two GBBCs in hindsight, several adjustments in protocol could be made to improve the quality of the data reported. For one, being present in person with students would be helpful and reduce instances of misidentification. This was obviously not possible in 2021 because of the pandemic, but hopefully that will not be the case in the future. A second major improvement would be to reinforce the guidelines put forward by the Audubon Society and Cornell Lab of

Ornithology. Instead of assigning a minimum length of each observation, a protocol could be established where students make observations for a set amount of time to ensure greater consistency in data collection. Additionally, students could be asked to make multiple observations during the GBBC to improve the amount of data collected and reduce sampling bias. Finally, with the end of the pandemic and the lifting of school restrictions, students could be provided with better equipment and training as they were in 2020.

Regardless of the data inconsistencies, the GBBC is a citizen science project I would love to continue with future environmental science classes. It is a wonderful, authentic and meaningful experience that helps students understand the value of the environment around them and how they can play a meaningful role in its stewardship through citizen science. The New Jersey Department of Environmental Protections (NJDEP) certainly agrees and is currently looking for ways to expand citizen science because of the many benefits the citizen science approach provides including “Leveraging of agency resources by partnering with nongovernmental organizations and volunteers; Increased scale and cost-effectiveness of data collection; New ways to identify and address the environmental science and health needs of state residents and Enhanced community engagement, environmental health literacy, and public support for the agency” (NJDEP, 2020).

Putting aside the challenges of the current data set on the birding behaviors of SPFE residents such as bird watching and feeding, it would be interesting to continue examining this trend in future years. Even assuming there was an increase in backyard

bird watching and feeding participation for residents in the SPFE following the pandemic and ensuing lockdown, participation would be expected to quickly wane with the release of the COVID-19 vaccines, lifting of lockdown protocols and a return to “normalcy”.

Future endeavors should focus on expanding the data set to improve results and explore other metrics of engagement in backyard bird watching practices beyond a survey. This could be achieved by partnering with other organizations beyond Scotch Plains-Fanwood high school, including but not limited to other local high schools, local college institutions, local Audubon Society chapters and local business with a vested interested backyard bird watching and feeding such as Wild Birds Unlimited.

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APPENDICES

APPENDIX A

DATA ANALYSIS EQUATIONS

Indices	Equations	Variables
Frequency of Species	$\left(\frac{n}{N}\right) * 100\%$	n = the number of individuals of each species N = the total number of individuals of all species
Mann-Whitney U Test	$U_A = n_A * n_B + \frac{n_A * (n_A + 1)}{2} - R_A$ $U_B = n_A * n_B + \frac{n_B * (n_B + 1)}{2} - R_B$	n_A = sample size for sample A n_B = sample size for sample B R_A = sum of ranks in sample A R_B = sum of ranks in sample B
Percentage Change	$\frac{(F - I)}{I} * 100\%$	F = Final value I = Initial Value
Shannon's Index	$-\sum_{i=1}^n p_i \ln(p_i)$	p = relative abundance
Shannon's Index Effective Number of Species	$\exp(x)$	x = Shannon's Index value for sample
Simpson Index	$1 - \frac{\sum n(n - 1)}{N(N - 1)}$	n = the number of individuals of each species N = the total number of individuals of all species
Simpson Index Effective Number of Species	$\frac{1}{1 - x}$	x = Simpson Index value for sample
Standard Error	$SE = \frac{\sigma}{\sqrt{n}}$	σ = standard deviation n = number of samples