Aquatic Bird Densities and Water Quality: An Empirical Study

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Abstract

Aquatic birds are effective bioindicators because their populations can reflect water quality parameters. This study examines the relationship between bird populations and water quality parameters across six freshwater sites in the North Carolina Piedmont region. Bird density data was obtained from eBird, and water samples were collected from each site with different testing kits to measure parameters including pH, metals, nutrients, and hardness. Correlations analysis revealed strong positive and negative associations between certain birds and water quality parameters. Species like the Prothonotary Warbler and the Osprey had lower numbers in areas with elevated metals, ammonia, and other parameters. Overall, the results support the use of aquatic birds as indicators of localized water quality conditions and long term monitoring to inform conservation and management of freshwater ecosystems.

Introduction

Aquatic ecosystems are important for biodiversity, nutrient cycling, and water purification. They support many species of plants and animals. Birds, fish, insects, and amphibians may rely on these bodies of water as habitat or feeding ground. Birds play a big role in aquatic ecosystems as top predators, seed dispersers, and overall indicators of ecosystem health. If birds that eat insects are doing well, we can infer that the aquatic insect population is also doing well. If birds that eat fish are doing well, then we can infer that the fish population is also doing well. If the population of birds lowers, then something may be wrong with either the water itself or the prey the birds depend on. Water quality parameters influence oxygen levels, nutrient balance, and the availability of prey species. Changes in pH can affect the eggs and larvae of aquatic insects. Ammonia is toxic to aquatic organisms. Higher levels, typically caused by agricultural runoff or sewage pollution, can cause aquatic prey populations to decrease. Excess metals in the water can reduce oxygen levels and affect plant growth. These parameters and many more play a major part in determining the availability of food for bird species.

Previous research has shown that aquatic birds respond to water quality changes and pollution levels (Birds as Monitors of Environmental Change, 2025) (Eeva et al., 2020) (Lakes Environment, n.d.) (Lakes Environment, n.d.) (Maznikova et al., 2024) (Ormerod & Tyler, 1993) (Piroska Tóth et al., 2023) (Thapa & Saund, 2012) (When Birds of a Feather Poop Together: Excessive Birds Feces and Algal Blooms, n.d.). However, much of it focuses on a single parameter or single species. There is also very limited data on localized ecosystems in North Carolina, especially comparing data across multiple lakes in the Triangle Area. Studies do not usually take place in such a local setting, so this one can bring results and awareness to the local community.

This study provides evidence of how specific characteristics of water influence avian population patterns. Understanding these correlations can increase the value of using birds as bioindicators or water quality. It also supports long term monitoring efforts of North Carolina lakes. Policymakers and conservationists can focus their efforts on preserving the parameters most critical to certain bird populations. It encourages bird population monitoring into water quality assessments, which could improve early detection of ecosystems declines.

Objective

The objective of this study is to find correlations between different water quality parameters and bird populations. In addition, we aim to find observable differences in aquatic bird densities in areas with varying water quality and find which water quality parameters are most strongly associated with increases or decreases in bird populations. Lastly, we will determine whether certain bird species serve as reliable indicators for specific types of pollution or habitat degradation.

Methodology

Six freshwater sites were chosen in the central North Carolina Piedmont region: B. Everett Jordan Dam, Jordan Lake State Recreation Area, Harris Lake Country Park, Lake Raleigh, Lake Crabtree County Park, and Fred B. Bond Metro Park. These sites were chosen based on public accessibility for water sampling, high numbers of bird observations on eBird, and proximity to the researcher's location. Once they were selected, bird data was collected for each site. B. Everett Jordan Dam is a dam that was created by the State of North Carolina and the US Army Corps of Engineers to hold water (Falls and Jordan Lakes Monitoring | NC DEQ, 2015). It creates Jordan Lake, in which Jordan Lake State Recreation Area exists. They are used for flood damage reduction, water supply, water quality control, fish and wildlife conservation, and outdoor recreation. The lake has a long history of eutrophic conditions and is listed on North Carolina's 303d list for impaired waters because of nutrient enrichment and sediment load. These impairments are a result of chlorophyll a, turbidity, and pH water quality violations. Since the lake's creation, the surrounding region has changed from rural to suburban. There are a lot of homes being built around the lake, which could be a driver of the impairments. Harris lake County Park has a lake that is owned by Duke Energy Progress (Krogman, 2021). It is used as make up cooling water for Shearon Harris Nuclear Electrical Generation Station and general operational water supply for the nuclear station. The nuclear power plant doesn't have an environmental impact on the lake. It has many types of fish and aquatic plants and is managed to reduce algae and other problems. Outside of being used as cooling water for the power plant, many people use it as a recreational park, similar to Jordan Lake. Lake Raleigh is a lake located at NC State's Centennial Campus (Lake Raleigh Recreation Area, 2025). It is used mainly by NC State community members for walking, running, sustainability projects, and small recreational activities. It is managed by NC State for habitat sustainability. Routine campus monitoring and management limit large scale pollution, unlike bigger lakes. However, local runoff could affect this lake. After I collected data from Lake Crabtree, redevelopment has been called for. The Raleigh Durham Airport Authority decided to develop part of the area into a recreation campus in June. Before that, the park was used for recreational activities, similar to Jordan lake. As the Research Triangle Park (RTP) Area develops and more people move in, more land gets converted into building land. The land around Lake Crabtree has been under pressure from this and the resulting pollution like trash, metals, and runoff. Fred G. (Fred B.) Bond Metro Lake is part of a municipal park that is highly recreational. Many people use the park for walking, sports, hosting events, boating, and fishing. There is significant activity around it. Bond Lake is managed by the town. The water quality is checked by the town for safety.

Bird data was obtained from eBird, a global database maintained by Cornell Lab of Ornithology (Bar Charts - EBird, 2025). A total of 10 birds were chosen for investigation: Bald Eagle (Haliaeetus leucocephalus), Great Blue Heron (Ardea herodias), Osprey (Pandion haliaetus), Pied-billed Grebe (Podilymbus podiceps), Double-crested Cormorant (Nannopterum auritum), Redhead Duck (Aythya americana), Prothonotary Warbler (Protonotaria citrea), Common Loon (Gavia immer), Northern Shoveler (Spatula clypeata), and Great Egret (Ardea alba). These birds were chosen based on the types of water parameters they were sensitive to. Bald eagles, Ospreys, Common Loons, and Double Crested Cormorants all rely heavily on fish populations. A decrease in fish populations due to certain chemicals will deplete their food source, resulting in fewer individuals. Furthermore, chemicals in the water can affect their health and reproduction rates. Great Blue Herons and Great Egrets rely on prey species like amphibians, fish, and invertebrates. Pollution can decrease the populations of these prey species, causing less available food for these birds. Pied-Billed Grebes, Redhead Ducks, and Northern Shovelers rely on aquatic invertebrates and plant life to survive. Loss of these species can lead to a lowered population. Prothonotary Warblers are insectivores, feeding on many aquatic insects. Changes in the make-up of water can reduce the number of aquatic insects available for consumption, which can lower the number of warblers present. Data was taken from months February and May for each location to find basic trends in populations. To minimize variability, total counts and average counts were taken for each location for both months.

The water that these birds rely on to survive will have certain parameters that help them survive. Knowing these parameters will help build a correlation. Water quality was sampled at each site on June 13, 2025, between 9:33AM and 3:00PM. At each site, water was collected from the shoreline using clean plastic cups. The water collected was then used to test for water parameters. The first water quality kit used was the SJ Wave 11 in 1 Aquarium Test Kit. This kit tested for pH, carbonate, hardness, chlorine, nitrite, nitrate, copper, iron, and ammonia. It was chosen because it tested for many different parameters in one strip, making it efficient for the study. The test strips were dipped directly into the water samples collected. Timers were set based on the instructions provided by the manufacturer. Afterwards, the strips were inspected against the color chart provided and results were recorded as accurately as possible. This process was done twice with separate water samples to reduce variability. The second water quality kit used was the bestprod 17 in 1 drinking water test kit. This kit tested for pH, carbonate, hydrogen sulfite, sodium chloride, fluoride, manganese, zinc, lead, copper, mercury, iron, nitrite, nitrate, and sulfate. The same steps taken for the first one were repeated for this kit. The researcher used two different samples from each location in order to test both kits twice each time. This was done to lower any variability and discrepancies that may have occurred. All instructions were followed as precisely as possible. Timers were used for the duration of the testing as per instructions and comparing the strips with the key given by the kits was done by the same person to reduce variables. Water parameters were measured on the same day to prevent major weather changes.

After collecting all the data and streamlining it to keep only the best water parameter data, I put the data into Pandas, a tool that can store CSPs in a format and make manipulations to make it usable for machine learning processes. Then, I ran basic summary statistics of each of the columns on all the inputs. Afterwards, I tried to run an exploratory data analysis pipeline and perform correlations between the columns, but the data format was incorrect. I needed to do some data preprocessing. I handled the formatting and reran it. Afterward I used Pandas to calculate the correlation matrix for the numeric columns of the DataFrame. Using seaborn and matplotlib, I converted the matrix into a heatmap to better visualize the correlations. The heatmap shows the correlations between each group. I found that NaCl had high correlations, so I trained Random Forest and Logistic Regression models to predict NaCl using the other columns of the dataframe. I dropped NaCl from the database and trained the models on the data to make the predictions. The Random Forest Model had a higher r squared value, so I chose it as the model I was going to use

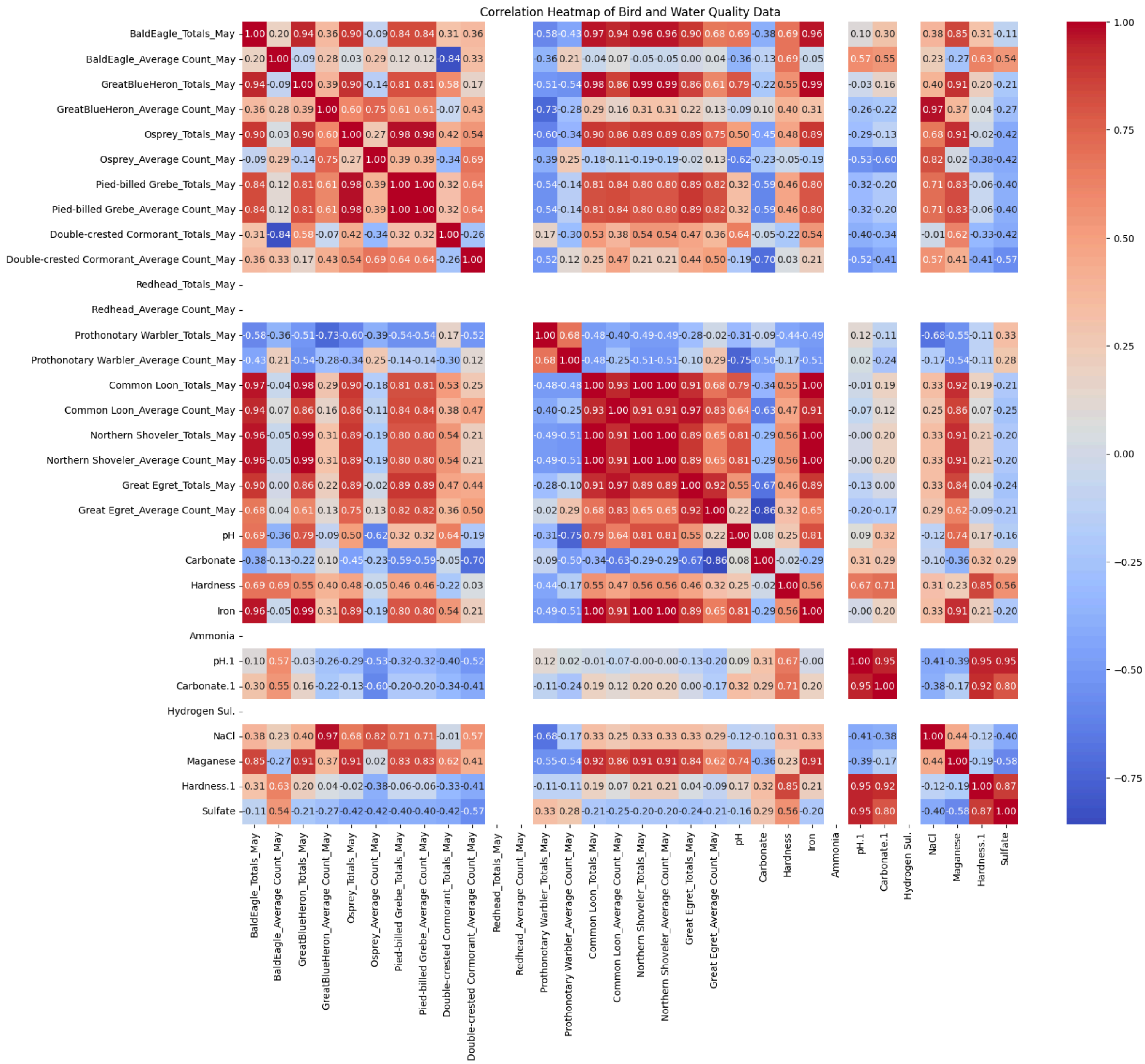

Figure 1. Heatmap of water quality and bird density metrics leveraged in AI/ML pipeline. Leveraging pandas and associated libraries, a heatmap denoting correlation (red = positive and blue negative) between model input features was created. The closer the reported value is to 1 or -1 indicates the stronger the correlation/anti-correlation between the target features, which is also visually apparent through the shading (e.g. blue vs. red). The primary heatmap diagonal displays 1.00 correlation as expected, due to self-correlation between input features and themselves.

Results and discussion

Kit 1 showed a pH between 6.4 and 6.8 for all sites, which is slightly acidic, but still within natural freshwater range. Carbonate was within 20 to 40 ppm for all sites, which gives a moderate buffering capacity for all sites. The hardness was measured between 12.5 and 50 ppm, which means that the water across the sites varied from soft to moderately hard. Kit 2 presented a pH between 6 and 6.4 for all sites, which is slightly more acidic compared to Kit 1 readings. Carbonate was measured between 0 and 20 ppm, which is lower than Kit 1. NaCl had a lot of variation, from 87 to 150 ppm. Lake Raleigh had the highest NaCl levels. Manganese was found to be relatively low at 0 to 0.3 ppm. Jordan Lake had the highest manganese levels. Hardness was measured between 13 and 38 ppm, which somewhat matches Kit 1. It means that the water may have been softer than Kit 1 showed. pH showed an overall trend of slightly acidic. Carbonate was higher in Kit 1 than in Kit 2. Hardness was found to be soft overall, with the two sites from Jordan Lake on the higher end. Only trace evidence of manganese was found, with the most being found at Jordan Lake. Salinity was moderate across all sites, with Lake Raleigh being the highest.

I found that there were several high positive and negative correlations between the columns. There were high positive correlations between iron, ammonia, and manganese (Figure 1; r~0.86-0.99), which suggests that there is a shared source of these parameters, like industrial runoff or pollution. pH, hardness, carbonate, and sulfate correlate highly (Figure 1; r~0.94-0.95), which may represent connected alkalinity and mineral balance in water. There are strong bird total and average count correlations, which confirms the reliability of the data. High NaCl and great blue heron correlations (Figure 1; r=0.97) may indicate tolerance of or attraction to mineral rich feeding zones. Pied-billed Grebes correlate highly with manganese levels (Figure 1; r=0.83), which may be because of the same reason as the herons. Overall, positive trends highlight interlinked water parameters and consistent bird data, with a few high correlations between certain birds and minerals. Strong negative correlations mainly link pollutants (iron, ammonia, and manganese) to the Prothonotary Warbler (Figure 1;r~ -0.95 to -0.80), which may mean that this species avoids degraded water conditions. Osprey counts drop with high iron, ammonia, and manganese levels, implying sensitivity to pollution affecting their prey, fish. Great Egret and Double crested Cormorant counts decrease with higher carbonate levels, possibly reflecting avoidance of more alkaline or mineral heavy waters. Negative bird to bird correlations (Pied-billed grebe vs. Prothonatory Warbler, Figure 1;r= -0.76) may reflect the differences between their habitat preferences, with grebes living in more open water areas and warblers living in forested wetlands. Overall, the data suggests that cleaner and less mineralized waters support more sensitive species like warblers, while pollution indicators (metals and ammonia for example) align with lower bird abundance.

Top 20 Negative Correlations:

		0
Osprey_Average Count_May	pH	-0.616599
Common Loon_Average Count_May	Carbonate	-0.634414
Pied-billed Grebe_Average Count_May	Osprey_Average Count_May	-0.643944
Carbonate.1	Prothonotary Warbler_Totals_May	-0.654620
Great Egret_Totals_May	Carbonate	-0.673565
NaCl	Prothonotary Warbler_Totals_May	-0.680706
Osprey_Average Count_May	Maganese	-0.689467
Double-crested Cormorant_Average Count_May	Carbonate	-0.703763
Ammonia	Prothonotary Warbler_Totals_May	-0.712977
Prothonotary Warbler_Totals_May	Iron	-0.744912
Prothonotary Warbler_Average Count_May	pH	-0.753003
Pied-billed Grebe_Average Count_May	Prothonotary Warbler_Average Count_May	-0.755965
Maganese	Prothonotary Warbler_Average Count_May	-0.806394
Ammonia	Osprey_Average Count_May	-0.838969
Osprey_Average Count_May	Iron	-0.843303
Carbonate.1	Prothonotary Warbler_Average Count_May	-0.853545
Great Egret_Average Count_May	Carbonate	-0.857994
Carbonate.1	Osprey_Average Count_May	-0.860088
Prothonotary Warbler_Average Count_May	Ammonia	-0.935773
Iron	Prothonotary Warbler_Average Count_May	-0.949453

Figure 2. Top 20 Negative Correlations. Consolidation of highest negative correlations found on heatmap.

Top 20 Positive Correlations:

		0
Iron	Ammonia	0.993730
Double-crested Cormorant_Totals_May	Double-crested Cormorant_Average Count_May	0.983216
Pied-billed Grebe_Totals_May	Redhead_Totals_May	0.976911
NaCl	GreatBlueHeron_Average Count_May	0.974758
Sulfate	pH.1	0.948683
Carbonate.1	pH.1	0.948683
pH.1	Hardness.1	0.946071
Common Loon_Average Count_May	Common Loon_Totals_May	0.941095
Northern Shoveler_Totals_May	Northern Shoveler_Average Count_May	0.935428
Carbonate.1	Ammonia	0.885525
	Iron	0.885054
Northern Shoveler_Totals_May	Hydrogen Sul.	0.876094
Hardness.1	Sulfate	0.873144
Ammonia	Maganese	0.871245
Iron	Maganese	0.859847
Great Egret_Totals_May	Great Egret_Average Count_May	0.852030
Redhead_Average Count_May	Redhead_Totals_May	0.850789
Hardness.1	Hardness	0.849979
Prothonotary Warbler_Average Count_May	Prothonotary Warbler_Totals_May	0.835747
Pied-billed Grebe_Average Count_May	Maganese	0.834776

Figure 3. Top 20 Positive Correlations. Consolidation of highest positive correlations found on heatmap.

Discussion

There are very strong negative correlations between metals/nutrients (iron, ammonia, manganese, etc.) and bird species like the Prothonotary Warbler and Osprey. There are strong positive correlations among the water parameters themselves (Iron and Ammonia have a correlation of about 0.99 (Figure 2)). This implies that water parameters are a dominant axis explaining bird-density variation.

There are observable density differences across the sites. Sites with higher levels of pollutants and minerals tend to have lower densities of certain species of birds. Prothonotary Warblers and Osprey have large negative correlations with pollutants and metals (Figure 2), which shows a preference for cleaner habitats. This means that sites with higher levels of these parameters have lower densities of these species. Other bird densities are less affected by the parameters, which may mean they aren't as sensitive to them. There is a strong correlation between water quality and bird densities. Species that are more sensitive to certain parameters will have lower population densities when those parameters are present. Certain species have strong negative correlations with water parameters. I found that the Prothonotary Warbler has a strong negative correlation to pollutants like iron, ammonia, and manganese. Sites that had higher levels of these parameters had a lower population density of warblers. Similarly, Ospreys have a strong negative correlation with iron, carbonate, and ammonia (Figure 2).

The absence of certain species can help researchers infer certain parameters. Having a lower amount of Prothonotary Warblers can mean there are higher levels of iron, ammonia, and manganese. Lower populations of Ospreys can lead researchers to infer there are higher levels of iron, carbonate, and ammonia. Higher levels of metals and other pollutants can degrade aquatic invertebrate communities (Tabassum et al., 2024). This can negatively impact the rest of the ecosystem, reducing prey availability for species higher up the food web, like birds. High carbonate/hardness and elevated pH can change the bioavailability/toxicity of contaminants (Levit, 2010). The negative correlations found between pH and the Prothonotary warbler suggests that they are less common in environments where mineralization/alkalinity is high. Positive correlations among parameters suggest a common source like runoff, low-oxygen sediment release, or agricultural inputs. Knowing these correlations can help researchers and conservationists to better understand the needs of certain species. By identifying which water parameters most strongly affect a species' abundance, conservationists can target management actions more effectively. For example, this study found that there is a negative correlation between Prothonotary Warblers and metal levels. Maintaining cleaner, less polluted wetlands can help restore the habitat these birds use. Similarly, monitoring pollutants sources and regulating runoff can keep heavy metal concentrations low, which could help other birds. Studies show that higher levels of metals and other pollutants can reduce aquatic insect diversity and cascade to higher trophic levels. My finding that metals correlate negatively with warblers and ospreys aligns with this pattern. Prothonotary Warblers rely on aquatic insects directly, as they are insectivores. Ecology and Evolution researched the relationship between these warblers and insect availability and found that when mayflies were abundant, they were fed on the most and correlated with higher growth rates in chicks (Dodson et al., 2016). Ospreys are piscivores, meaning they only eat fish, and a reduction in fish populations will affect the population of the birds. All About Birds has discussed the relationship between menhaden and ospreys (Chesapeake Bay Ospreys Are Facing Persistent Nest Failures, 2025). Osprey populations are decreasing because they can't find enough menhaden to feed on.

These findings can help conservationists identify species that are most sensitive to pollution and prioritize protecting their habitats. Areas with high metal levels can be a great place to start because of negative correlations between them and bird populations. They can also use bird populations as an indicator for certain water parameters. Declines can hint at increasing pollutant levels, which can prompt investigations into certain areas.

Programs should regularly test for key pollutants that can affect bird populations, such as Iron, Ammonia, Manganese, and others. Any spikes or declines in these levels should be noted and steps need to be taken to reduce their levels. Monitoring bird populations can indicate when pollutants are harming the ecosystem. Recording population data can make water quality monitoring easier. This can create long term datasets that can be used to detect early signs of ecological degradation before they become significant.

Future developments and limitations

One technical limitation was the fact that the two kits did not present the same findings. Kit 1 only reliably measured pH, Carbonate and Hardness, while Kit 2 measured pH, carbonate, hardness, NaCl, and manganese. pH was found to be slightly acidic between both tests for all sites, but the exact values were not the same, with Kit 2 being consistently lower by around 0.4. Kit 1 reported higher values of carbonate compared to Kit 2. Hardness was indicated to be soft to moderately hard by both, with less variation compared to other parameters. Kit 2 measured more parameters, like manganese and NaCl, reliably compared to Kit 1, but Kit 1 is more accurate based on reviews.

The use of a public database allows for other researchers to replicate this study. Furthermore, it limits the amount of errors or variables that could occur in the collection of data. Using two water quality kits allows and doing multiple tests for each kit allowed me to account for many possible confounding variables that could have potentially affected the water parameter data.
If certain errors were entered into the public database, then that could affect the results of this study. Furthermore, water parameters were only collected for one month, reducing the ability to create a strong correlation with many parameters. The water quality kits also gave different results for certain parameters, which was a variable that was unable to be accounted for and resulted in the deletion of the water parameter in this study.

The next steps in this research would be collecting data on bird populations and water parameters year round to find stronger correlations between both groups. This would allow us to take factors like migration patterns and temperature into account as well. With that data, we could find much stronger correlations that we can look into. For example, one step could be looking at the effects of increased iron, ammonia, and manganese levels on prothonotary warbler health, since there was a high negative correlation between the parameters and the population of warblers.

Another step that could be taken is comparing different geographies for similar results. This could work because birds are affected by water parameters everywhere. The same steps in this study could be replicated anywhere for a comparison of correlations. Some challenges would include finding the bird population data for the area and acquiring the water quality kits. Using online databases would provide the bird data, but acquiring precise water quality kits is difficult. In the case that this is replicable, our results could be compared to theirs. If we have similar results between certain parameters and similar species of birds, we can create a stronger correlation between those parameters and species. This would make our study more credible as well.

Conclusion

Strong correlations were found between water quality parameters and bird populations. Pollution indicators like iron, ammonia, and manganese showed strong negative relationship with sensitive species like Porthonotary Warblers and Ospreys, which suggests these birds decline in poorer water conditions. Parameters associated with healthier water, such as balanced pH and lower pollutant levels, corresponded with higher densities of other bird species. These relationships indicate that bird communities respond predictably to changes in water parameters, making them effective indicators of wetland health.

These findings highlight the close connections between water quality and bird populations in wetland ecosystems. Researchers and conservationists can better protect habitats and vulnerable species by understanding these connections. This study reinforces the importance of maintaining clean water so that the ecosystem can remain healthy.

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