Analyzing the Impact of Environmental Factors on Aquatic Biodiversity in Toronto*

Wind, Waves, and Water Clarity: Impacts on Waterfowl Populations

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This report shows the relationships between wind speed, wave action, water turbidity, and their effects on waterfowl populations. The data from Toronto Beaches Observations shows how environmental variables influence water clarity and then affect waterfowls population. Results illustrate that higher wind speeds causes higher wave actions that further increases water turbidity and finally has negative impacts on waterfowl populations, which prefer clearer waters. The findings emphasize the importance of maintaining optimal water conditions for supporting biodiversity under changing climatic conditions.

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*Code and data are available at: https://github.com/Sophiaaa-Y/toronto-waterfowl-analysis.git

1 Introduction

Understanding the relationships between environmental variables such as wind speed and turbidity, and their effects on waterfowl populations and aquatic ecosystems is critical for supporting wildlife survive and improve water resources, especially under changing climatic conditions. In Canada, wetlands and aquatic ecosystems, including the prairie pothole region which is known as North America's "duck factory" (Withey and Kooten 2011), are important habitats for waterfowls, which also essential for supporting biodiversity. However, these habitats are very sensitive to climate changes and water quality, such as increased turbidity and temperature fluctuations, and need high level environmental conditions (Robel 1961). These changes in the climatic factors will cause the negative influence the turbidity levels in aquatic environments and wetland areas, and become the direct threat to the food supply and breeding patterns, which is harmful to overall waterfowl species.

Moreover, turbidity that used to reflect the clarity of water is an important factor in measure waterfowl habitat quality, which is influenced by wave action and wind speed. Wind-driven waves can cause sediment suspension, which lead to an increasing in turbidity levels and reducing in water clarity. This will lower the availability of aquatic vegetation and food for waterfowl (Van Onsem and Triest 2018). Research shows that higher wind speeds causes greater wave action, which in turn disturbs sediments and increases turbidity, and then leading to less suitable conditions for waterfowl (Roig et al. 2012). Another previous studies have also demonstrated that wind speed and wave action significantly affect turbidity levels in aquatic environments, and will further impacts the growth of aquatic vegetation, which is a important resource for waterfowl populations (Robel 1961). Furthermore, increased wind speed and wave action have already been shown to increasing turbidity level, causing a reduction in light penetration and the decline in aquatic plant life (Young, Zieger, and Babanin 2011) which are so important and meaningful to waterfowl species.

For doing this, Toronto Beaches Observations data (Parks 2024) from Open Data Toronto website (Gelfand 2022) was firstly obtained as described in Section 2.1. According to this dataset, we can analyze the relationships between wind speed, wave action, turbidity, and waterfowl populations by using different graphing methods. Then, by analyzing, we get the impacts of different environmental factors on waterfowls population and behavior (Section 2.2), providing a deeply understanding of the ecological consequences caused by changing environmental conditions. Understanding these dynamics is important for developing protection strategies to protect waterfowls population from the growing threats driven by climate change (Section 3). As a summary, the structure of this paper is: Section 2 includes an overview of the data and the results; Section 2.2 is about the different relationships of different variables and get the result for analyzing; Section 3 includes a discussion of the results, and Section A includes supplementary information.

2 Data

2.1 Overview

The dataset used in this analysis is the "Toronto Beaches Observations" (Parks 2024), which sourced from Open Data Toronto website (Gelfand 2022) and the data was last updated on September 13, 2024, and may keep update when available. The dataset was collected to track how environmental factors, such as wind speed and turbidity of water, influence the waterfowl populations. For data measurement, firstly, daily observations are conducted by city staffs at the Toronto's beaches (Parks 2024). Sometimes, they used some measure instruments like thermometers or turbidity meters in order to gather data such as variable named turbidity of water (Parks 2024). And then, other observations such as "waterfowl population" and "wave action" are estimated by these city staffs (Parks 2024). All of these observations are collected between mid May and mid September (Parks 2024) in order to capture changes under different conditions. As an open data resource, the data can be used in research and providing suggestions when making policies, particularly in managing water environment and protecting biodiversity under changing climate conditions. The link to the City of Toronto's Open Data License is here (City of Toronto 2024).

This dataset includes many different variables. The first one is "Wind Speed in km/h" and are called "windSpeed" in the raw dataset. This variable measures the speed of wind in km/h at different observation points. And the second variable "Waterfowl population", called "waterFowl" in the raw dataset, records the number of waterfowl observed in the water over time, offering data on how different environmental factors affect their populations. Then, the variable "Wave Action", called "waveAction" in the raw dataset, categorizes into 4 levels (e.g., high, moderate, low, none) excluding NA. NA means missing or undefined data of wave action. The last variable is "Turbidity of water (NTUs)", called "turbidity" in the raw dataset, indicates water clarity. Higher values representing more suspended particles in water (Parks 2024).

The `R` programming language (R Core Team 2023) was used to process and analyze the data. The `tidyverse` (Wickham et al. 2019) package and the `opendatatoronto` (Gelfand 2022) package are installed and library for data process and obtain data. And `ggplot2` (Wickham 2016) is used for data visualization, showing the relationships between different variables. Besides, all relevant data was sourced from the website "Toronto Beaches Observations" (Parks 2024) from "Open Data Toronto" website (Gelfand 2022), and get data by using library `opendatatoronto` (Gelfand 2022).

2.2 Results

After loading the dataset using the `R` programming language (R Core Team 2023) and the `opendatatoronto` package (Gelfand 2022), the `ggplot2` (Wickham 2016) package to generate graphs and show relationships. In doing so, R code was learned and adapted from Alexander (2023)

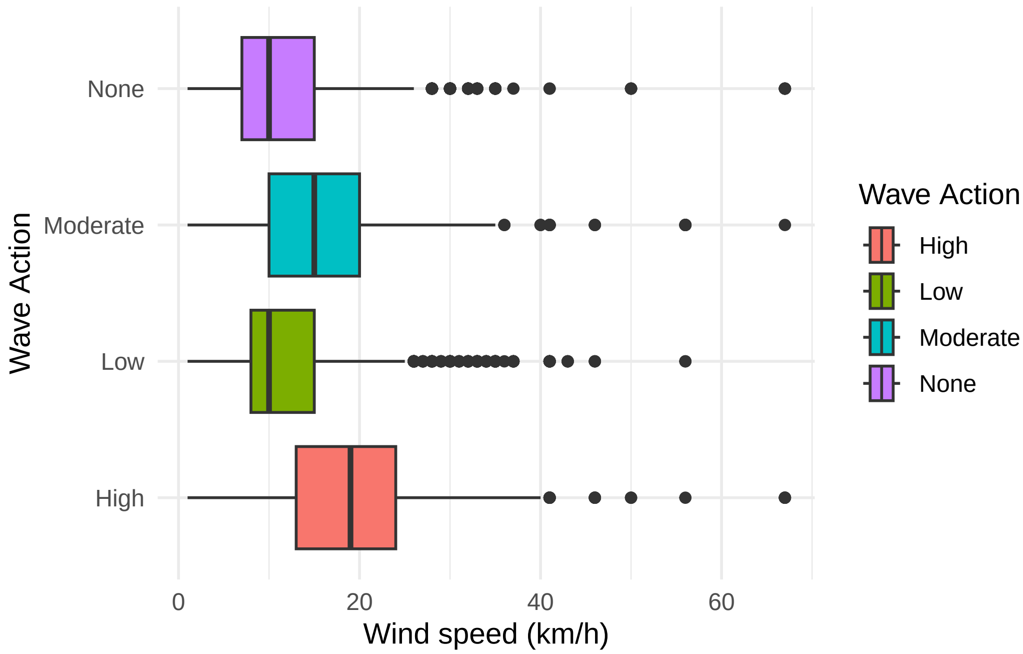

Figure 1: Wave actions observed under different wind speed

Figure 1 shows that higher wind speed leads to larger wave actions. When wave actions at high level, the median of wave action is around 20km/h speed of wind and most high wave actions gather between wind speed 10km/h and wind speed 25km/h. This means that when the wind speed is between 10km/h and 25km/h, it is easier to cause high wave actions. And there are some outliers when wind speed above 40km/h shows that some extremely high wind speed will cause very high waves. When at moderate wave actions, the median of wave action is around 15km/h speed of wind with most moderate wave actions falling within wind speed 10km/h to wind speed 20km/h. This means that when the wind speed is between 10km/h and 20km/h, it is easier to cause moderate wave actions. And there are some outliers when wind speed exceeds 35km/h. With low wave action, then median of wave action is about 10km/h speed of wind with most low wave actions falling within wind speed 5km/h to wind speed 15km/h. This means that as the wind speed is between 5km/h and 15km/h, it is more likely to cause low wave actions. Besides, there are still some outliers there when wind speed exceeds 25km/h and some even over 40km/h. This means that although sometimes with high wind speed, low wave actions can still happen. When there is no wave action, median of no wave action is around 10km/h speed of wind and most none wave action gather between wind speed 5km/h and wind speed 15km/h. There are some outliers occur when wind speed is over 25km/h. For above outliers, some may also be casued by different local environments conditions.

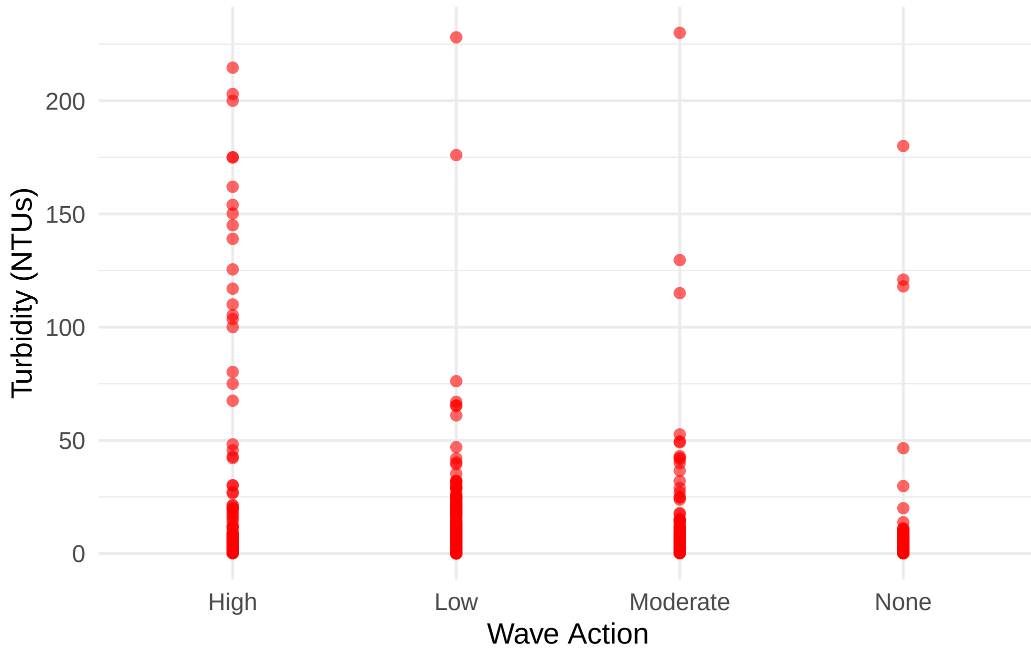

Figure 2: How the turbidity of water change with different wave actions

Figure 2 illustrates that higher wave actions are associated with large value of turbidity of water. With high wave action, turbidity values have a wide range from near 0 NTUs to over 200 NTUs, indicating that strong waves cause significant disturbances in the water, such as increasing sediment suspension in the water, and finally lead to an increase in the turbidity of water. When wave action is moderate, turbidity levels are relatively more stable, and always gather lower than 100 NTUs. This indicates that moderate wave action causes less disturbances in the water and result in clearer water. But there are some outliers at this wave level when turbidity exceeds 100 NTUs and even exceeds 225 NTUs. When wave action is low, most values of turbidity are gathered around 0 NTUs to 75 NTUs. This shows that although at low wave action level, there are still some sedments are disturbed in the water, with a lower impact compare to high wave action level. And there are some outliers occur when turbidity over 175 NTUs. Besides, when there is no wave action, most of the turbidity values are below 20 NTUs and so close to 0 NTUs, which is expected because there is less movement to disturb sediment in water. And there are some outliers occur when turbidity over 100 NTUs. Some outliers above may caused by some special local environment conditions such as pollutions or human activities.

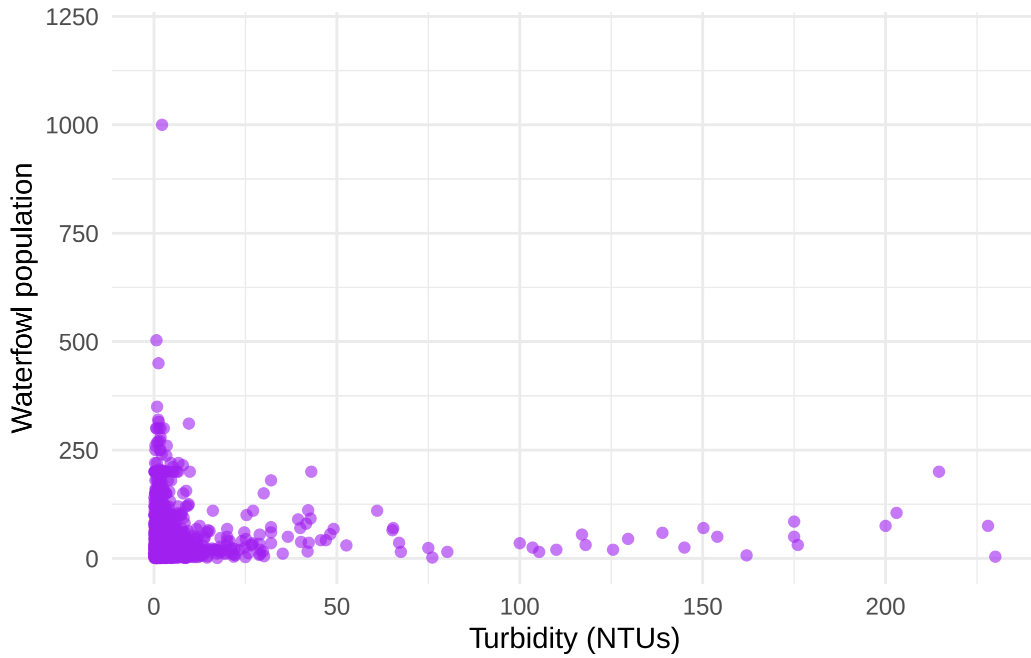

Figure 3: Number of waterfowls observed under different turbidity of water

Figure 3 illustrates that clearer waters are more benefit to waterfowl activity and higher value of water turbidity causes fewer number of waterfowl. According to the graph, it shows that the majority of waterfowl are observed when turbidity levels are low, particularly when turbidity is below 25 NTUs. As turbidity increases, the number of waterfowl decreases sharply, indicating that waterfowl may prefer clearer water environments where there is less suspended particulate matter. This may because clearer water supports better food resources, feeding conditions and visibility conditions for waterfowl. There are a few number of waterfowl being observed when the turbidity of water exceeds 50 NTUs and even higher. This means that waterfowl population are more likely to avoid living in the environment with high turbidity water. Also, there are some waterfowls are found with turbidity exceeds 150 NTUs, which are called outliers. This may also indicates that although waterfowl can exist in more turbid waters, they are less likely to be found. This may be caused by the impact on visibility, food availability, and overall habitat quality.

3 Discussion

3.1 Discussion

The section Section 2.2 shows the complex relationships between environmental factors and their impact on aquatic ecosystems by analyzing the data on wave actions, wind speed, turbidity, and waterfowl populations. According to Figure 1, the data and result show that wind speed is a primary driver of wave action. Higher wind speeds lead to larger and more frequent waves, as the boxplot shows. This is meaningful to sediment suspension. Based on the graph Figure 2, it shows that higher wave actions increase water turbidity, means that stronger waves disturb sediment more and reduce water clarity. This relationship is particularly critical in shallow water ecosystems where wave energy can significantly disturb sediment, affecting both water clarity and aquatic biodiversity.

Moreover, the direct impact on waterfowl populations is also very important. Based on the scatter plot Figure 3, the graph shows that waterfowl populations tend to be higher in clearer waters, with sharp declines in populations as turbidity increases. This suggests that waterfowls are sensitive to changes in water clarity, which may due to the reduced visibility for foraging and lower availability of food sources such as submerged vegetation. Besides, the correlation between low turbidity and higher waterfowl numbers may also reflect the overall health of aquatic ecosystems. Clearer water often means less disturbance and healthier habitats. However, there are some outliers in both turbidity and waterfowl populations, which maybe caused by special local environmental pollutions such as oil pollution (Stout and Cornwell 1976) (Hartung and Hunt 1966)or other human activity (Madsen 1995).

According to above discussion, there are some suggestions that may be useful to better protect ecosystems and make sure that both waterfowl and water quality can be protected under climate change and human activity. Firstly, control water pollution. Less water pollution will not only improve water clarity but also create healthier habitats for aquatic wildlife. Besides, increasing public awareness. It is important for people to raising awareness about the importance of water quality and biodiversity. Higher awareness may be helpful to protect waterfowl (Downes 1954).

3.2 Limitations and next steps

Although we have these results and findings, there are still limitations. The biggest limitation is that the dataset only have a limited time. For example, these data is about the observations during warmer months(between mid May and mid September) (Parks 2024). As a result, it cannot show how these relationships evolve throughout the year, especially during migration periods or breeding seasons, which may significantly alter the relationships observed in Section 2.2.

Besides, for future research, it should expanding the time to capture a longer time range of the dataset, such as including observations from multiple seasons. Then the dataset will show how seasonal changes and climate variability affect waterfowl population. Additionally, incorporating factors like human disturbances, pollution, and water chemistry will offer a more comprehensive view of the environmental challenges which ecosystems are facing now. Understanding deeper of these dynamics will be critical for designing more effective conservation strategies that protect both waterfowl populations and keep aquatic biodiversity under increasing climate stress.

A Appendix

A.1 Dataset and Graph Sketches

Sketches describes both the selected dataset and the graphs made by this analysis, and both of them are available in the GitHub Repository.

A.2 Data Cleaning

The data cleaning includes selecting some columns that we are interested in from the raw dataset, and renaming these selected columns for clarity and simplicity.

A.3 Attribution Statement

Contains information licensed under the “Open Government Licence – Toronto” website (City of Toronto 2024).

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