Investigating the Impact of Wildfires and Air Quality on the Water Quality and Fish Species of Clear Lake, CA.

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ABSTRACT

Clear Lake is the largest natural freshwater lake in California, home for 31 species of fish. It has experienced various wildfires and storms throughout decades. Therefore, it is important to understand the effects of wildfires and air pollution on Clear Lake and organisms living in it. To address the correlations between those factors, I sampled from Clear Lake and recorded water quality data for around two weeks. In addition, I utilized data on historical air quality index values, temperatures, and fish observations from public databases such as the US Environmental Protection Agency and NOAA. All of the data I accumulated were generated into graphs using R version 4.3.3 and RStudio version 2023.06. From analyzing the graphs, I found that heavy snow, high wind, drought, and flood had negative correlations with fish abundance, and I've also found a positive association between wildfires/heavy rain and the fish abundance in Clear Lake. The results also note that the amount of lead and sulfite in Clear Lake was found to change in response to wildfires and other factors. Wildfires have shown a positive correlation with drought, while drought have shown a positive correlation with excessive heat. This study highlights the major issues affecting Clear Lake and its environment, and calls for changes to provide a healthier ecosystem and advanced human life.

Keywords: Clear Lake, freshwater fish, wildfires, extreme weather/storms, water quality, contamination, air pollution

1. INTRODUCTION

Elevated numbers of wildfires, storms, and other extreme weather events pose a concern to the environment. Examinations of freshwater ecosystems show that they have been affected by those events. Storms have transported terrestrial viruses to freshwater lakes and resuspended microbes from the bottom sediments, increasing dissolved oxygen numbers and affecting the microorganisms in the lakes (Williamson et al., 2014). Wildfires can transfer ash and toxic substances to freshwater lakes, which increases nutrient concentration, temperature, dissolved organic carbon, and turbidity in them, causing a change in the physicochemical properties of lake ecosystems (Morales et al., 2023). Human activities and events such as flooding have increased surface water area, pollutants, and decreased biodiversity in freshwater lakes (United Nations, n.d.). Freshwater ecosystems are affected worldwide, and many of them have not been meticulously examined, such as Clear Lake.

Clear Lake is the largest natural freshwater lake in California, United States (Lake County, n.d.). The area around Clear Lake has frequently experienced natural disasters such as wildfires and storms. Since 2012, there have been ten major wildfires, each burning thousands of acres (Rossmann, 2018). Wildfires globally release carbon stored in trees and plants, emitting approximately 5 to 8 billion tons of CO_2 to the atmosphere annually (Samborska, 2024). This excess carbon has decreased pH levels by 0.3 from 1981 to 2015, causing lake acidification and consequently increasing the vulnerability of aquatic life (Carey, 2018). Clear Lake also experiences heavy rainfalls and extreme weather conditions annually, affecting the water quality and wildlife in the ecosystem as well as potentially alternating carbon and nutrient cycles

(Stockwell et al., 2020). Heavy rainfalls will cause soil erosion and transport the nutrients to nearby streams and lakes, increasing pollutants in the water bodies (Qiu et al., 2021). Similarly, weather conditions such as extreme heat may increase decomposition of organic matter, inorganic salt concentrations, and the release of nutrients, which are harmful to organisms (Wang et al., 2022).

In addition to impacting water quality of Clear Lake, wildfires and storms have negatively affected the air quality of surrounding regions. Air quality, measured in Air Quality Index (AQI), indicates if the air contains chemical pollutants or other particles, particularly ground level ozone, carbon monoxide, sulfur dioxide, nitrogen dioxide, and aerosols (SciJinks, 2024). Higher AQI values represent substantial air pollution and a higher risk for human health. Air pollution also detrimentally affects the water qualities of lakes, which includes changes to the chemical, physical, and biological characteristics of the surrounding water body. Water quality testing can include parameters like temperature, dissolved oxygen, pH, oxidation-reduction potential (ORP), and tubility (YSI, 2024). These measurements are used to assess whether water bodies meet the criteria for water quality standards (WQS). Through this testing, these parameters indicate if pollutants and harmful chemicals are present in the water. Contaminated water poses significant health hazards for humans and wildlife in addition to altering the ecosystem and environmental conditions (Canon City, n.d.). Therefore, water quality testing is an important factor for maintaining environmental and ecological health.

Clear Lake houses in total 31 species of fish: 10 native and 21 non-native (Knight, 2021). It provides critical habitat for aquatic plants and larger organismal populations like largemouth bass, bluegill, catfish, ducks, and blue herons (Clear Lake, n.d., para. 2). Aquatic plants such as water lilies and water hyacinths are essential organisms that maintain the health of Clear Lake by absorbing excess nutrients like nitrogen and phosphorus (Phillips, 2023). Elevated nutrient levels facilitate excessive algae growth, and as they die, the decomposition of their tissues removes oxygen from the water column, creating low oxygen or hypoxic zones, or dead zones (U.S. Geological Survey, 2020). Aquatic plants decrease the number of algae blooms and toxic dead zones that kill aquatic organisms. Contrary to these mutually beneficial relationships, there are harmful aquatic plants in the lake that affect fish stocks. For example, Hydrilla (*Hydrilla verticillata*), also known as water thyme, is an invasive species which notably outcompetes native species and forms dense mats that clog water control structures and threaten aquatic communities (Ohio Department of Natural Resources, n.d.). In addition, invasive carp increase nutrient levels by kicking up sediment and releasing the nutrients from the lake bottom (Nguyen, 2023). Likewise, invasive fish species such as dreissenid mussels can also pose a substantial threat to native wildlife in Clear Lake. Dreissenid mussels are known to compete with and destroy the habitats of native fish species as well as obstruct waterway operations (California Water Resources Department, n.d.).

There is currently a lack of in-depth studies on the environmental and biological changes of Clear Lake despite its crucial role in local economies and ecosystems. Clear Lake, one of the oldest lakes in the United States, supports a diverse range of aquatic life and life-forms that help maintain ecosystem balance and functions.

2. METHODOLOGY

2.1 Aim of Study

In an effort to aid in sustainable environmental management of the Clear Lake area, this research aims to determine the role that wildfires and air quality play in documented environmental changes and water quality measurements of Clear Lake. This data addresses questions like: How do wildfires contribute to air pollution? What are the negative effects on the water quality? and What effects does air pollution and extreme weather conditions have on the fish abundance in the lake?

2.2 Research Design

To investigate these issues, I studied and analyzed water and air quality data from watershed areas near Lake County, CA, a county by the side of Clear Lake. I analyzed the response of native and nonnative fish numbers to storms, extreme weathers, and air quality. I also studied the effect of extreme events on air quality index values around Clear Lake.

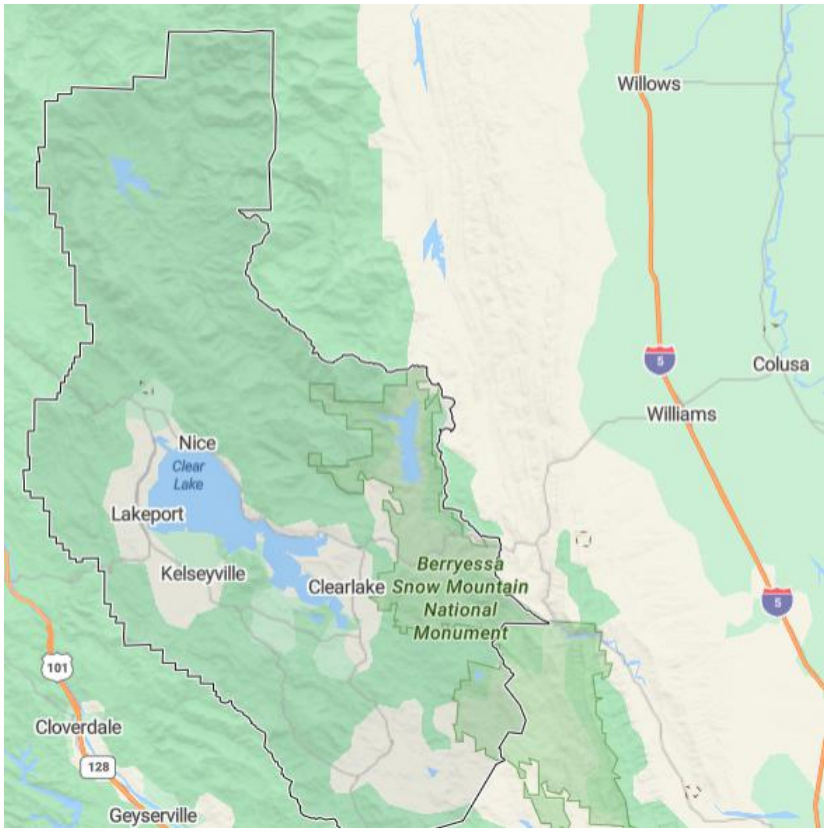

Figure 1. Maps showing the exact location of Lake County, CA (in orange), counties surrounding it, and Clear Lake.

2.3 Data Collection

I conducted experiments using a water quality test kit to collect data on the water quality of Clear Lake. I set the sample location at Lakeport Library Park and sample time at 3:30 PM, during August and September of 2024 (Figure 2). I performed sampling everyday for a course of two weeks. The tests measured pH, nitrate, nitrite, total hardness, free chlorine, total chlorine, bromine, MPS, copper, iron, lead, nickel, sulfite, cyanuric acid, carbonate, and total alkalinity. I also took notes on the weather, events, and organisms around or in the lake. I collected data for wildfires, storms, and AQI values from publicly available data and organizations.

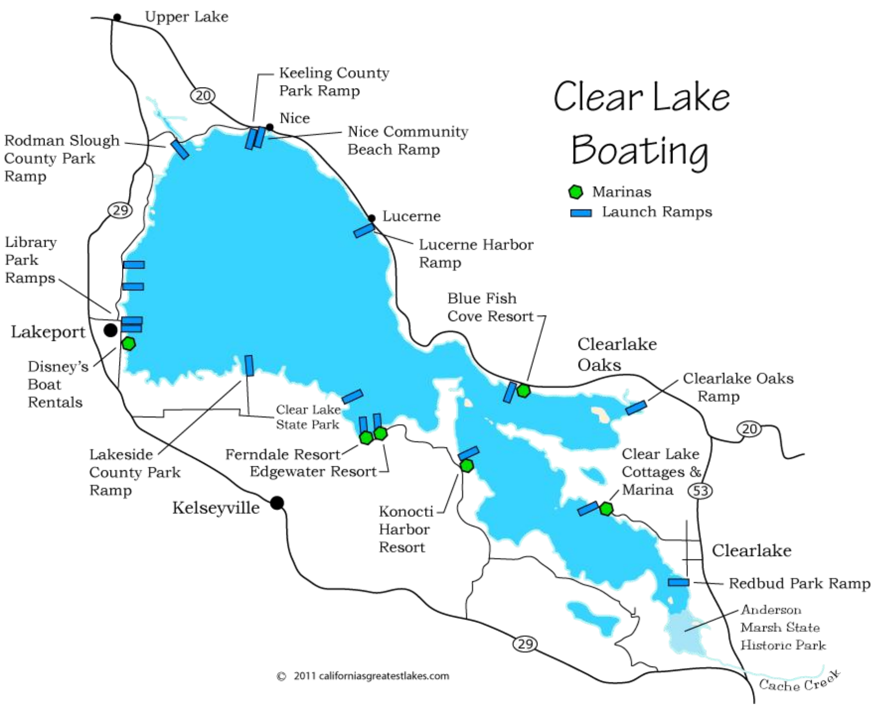

Figure 2. Cities and locations applicable for sampling in Clear Lake. Samples were taken from the Library Park Ramps area in Lakeport.

I downloaded fish observation, water quality, and air quality data from different public databases. The number of fish observed in Clear Lake from 2005 to 2024 was obtained through Fish Reports from Clear Lake Environmental Research Center and recorded on spreadsheets (*Fish Observation Reports*, 2024). I downloaded the data for fish distribution as a csv (spreadsheet) file from the U.S. Geological Survey (Palm, 2023). It includes the species' name, genus, and height that was observed from 2017 to 2023. I also downloaded AQI, ozone (O_3), PM10, and PM20 values in Lake County, California from the US EPA as csv. Lake County is a county on the side of Clear Lake (CivicPlus, n.d.). I downloaded the average temperature of Lake County over time since January of 2024 from NOAA as csv. I then downloaded the number of observations of extreme weather and storm events in Lake County from 2005-2024 as csv files from National Centers for Environmental Information (NOAA, 1999).

2.4 Data Analysis

I analyzed downloaded data using R version 4.3.3 and RStudio version 2023.06.1 (https://www.r-project.org/) and the following R packages were used for data wrangling: googlesheets4 version 1.1.1 (Bryan, 2023), tidyverse version 2.0.0 (Wickham et al. 2019), readxl version 1.4.3 (Wickham and Bryan, 2023), strex version 2.0.0 (Nolan, 2024), lmtest version 0.9-40 (Hothorn et al., 2022), and MASS version 7.3-61 (Ripley and Venables, 2024). I visualized the data with ggplot2 version 3.5.1 (Wickham, 2016) to depict the changes in environmental or biological variables over time. I then analyzed relationships between data using lmtest tests version 0.9-40 and used backward variable selection to help improve relevance between the variables.

3. RESULTS

Biological Observations

The number of fish reported seen in Clear Lake over the years 2005-2024 shows a range of approximately 0-180 individuals. Across 19 years, the number of fishes showed an overall decline in numbers (Figure 3) and an altering pattern between decrease and increase which indicates periods of growth and death for the hitches. Note that an event likely occurred in 2017 that resulted in no fish reports being provided.

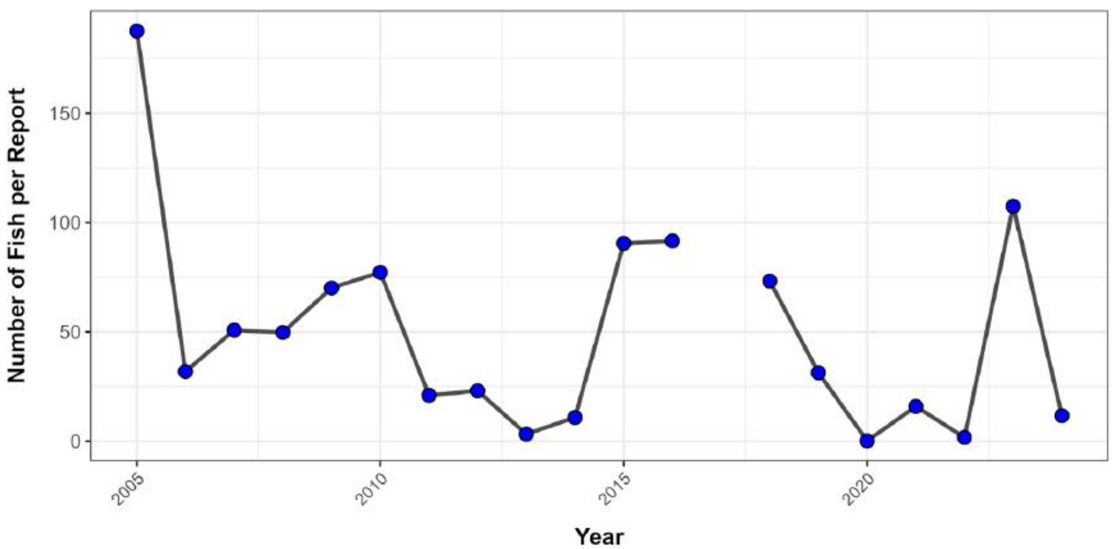

Figure 3. The number of fish per report from the years 2005 to 2024. There were no fish reports for the year 2017.

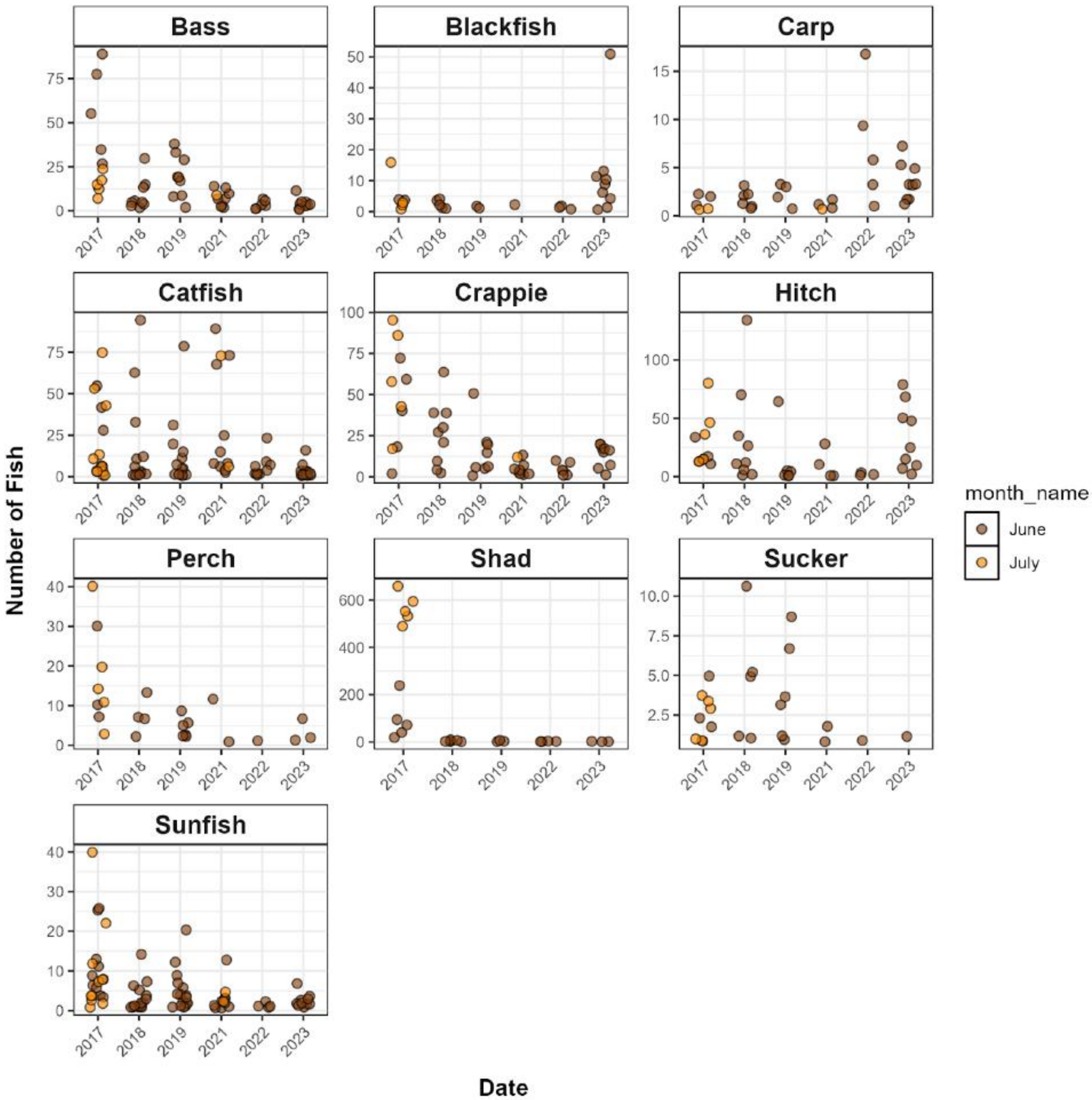

Figure 4. Reported observations of different fish species in Clear Lake from 2016 to 2023.

Thirteen fish species were observed during the months June and July from 2016 to 2023, excluding 2020. Channel catfish and white catfish were regarded as the species “catfish,” while bluegill sunfish and redear sunfish were regarded as “sunfish.” Goldfish were only observed a few times in 7 years, therefore discarded. All 10 species of fish except for Carp and Blackfish show an overall decrease over time (Figure 4).

Water quality observations

Data regarding carbonate, MPS, Bromine, Nitrate, and Nitrate had little or no change in value, thus not shown. Air temperatures during sampling time were between 29-34 ℃. Main activities near Clear Lake include fishing, boating, and swimming. Sudden increases in Copper, Cyanuric Acid, and Free Chlorine were also seen.

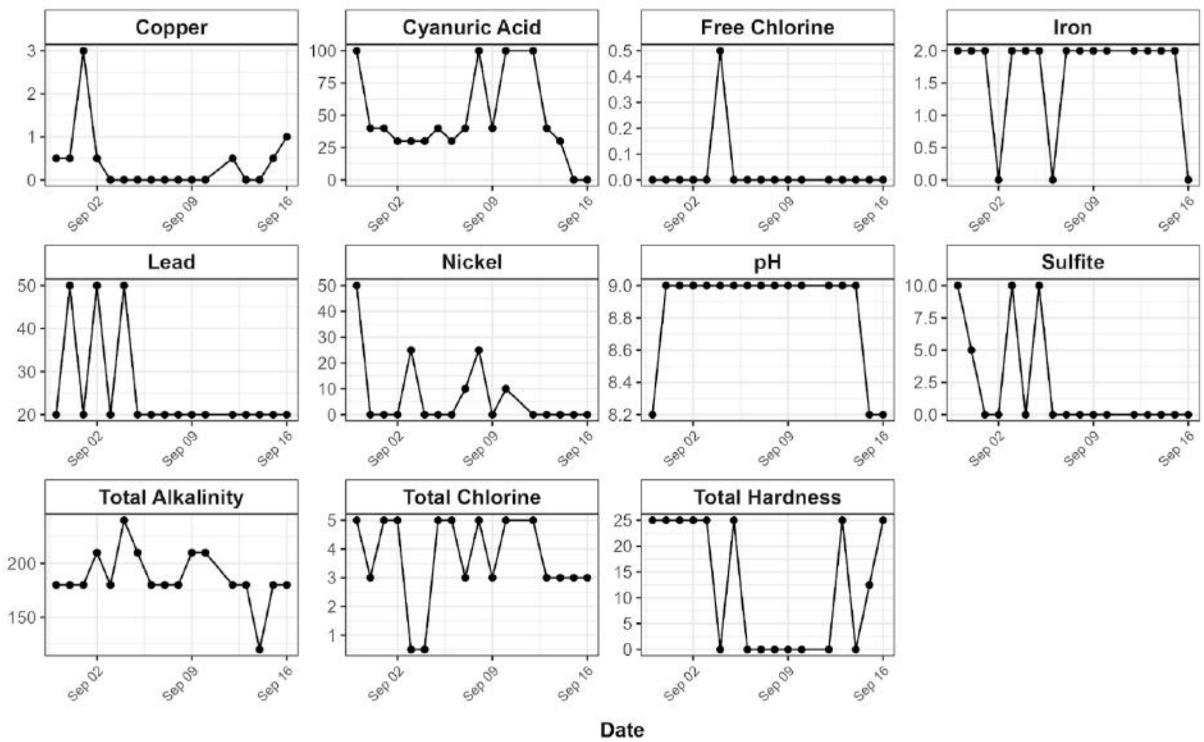

Figure 5. Eleven parameters measured regarding Clear Lake water quality. The values were measured using test strips for approximately two weeks starting from August 26, 2024. All parameters except pH were measured in parts per million (ppm).

Date	Time	Notes on the weather and events	Notes on the activity around the area	Notes on organisms seen
8/30/2024	3:30 PM	Sunny, 33 ℃	Swimming; boating	Ducks, dragonfly
8/31/2024	3:30 PM	Sunny, 33 ℃	Fishing; boating	Ducks
9/1/2024	3:30 PM	Sunny, 31 ℃	Children playing	Ducks
9/2/2024	3:50 PM	Sunny, 29 ℃	Boating	Ducks
9/3/2024	3:30 PM	Sunny, 34 ℃	Boating	Ducks, dragonfly
9/4/2024	8:30 PM	Sunny, 29 ℃	Fishing	Ducks
9/5/2024	3:30 PM	Sunny, 36 ℃	Swimming, construction	Ducks
9/6/2024	3:30 PM	Sunny, 33 ℃	Swimming	Ducks
9/7/2024	3:30 PM	Sunny, 33 ℃; Wildfire 27 miles away	Boating, fishing	Ducks, dragonfly
9/8/2024	3:30 PM	Sunny, 33 ℃; Fire on one side of the lake	Swimming, fishing	Ducks
9/9/2024	3:30 PM	Windy, 34 ℃; Wildfire 17 miles away	Swimming	Ducks
9/10/2024	3:30 PM	Windy, 30 ℃	Boating	Ducks, dragonfly, birds
9/12/2024	3:30 PM	Sunny, 29 ℃	Swimming	Ducks, unknown particles
9/13/2024	3:30 PM	Sunny, 31 ℃	Swimming, fishing	Ducks, dragonfly
9/14/2024	3:30 PM	Windy, 29 ℃	Fishing	Ducks, catfish
9/15/2024	3:30 PM	Windy, Partial Cloudy; 25 ℃	Boating	Ducks, unknown particles
9/16/2024	3:30 PM	Windy, Partial Cloudy; 22 ℃	Fishing	Ducks

Figure 6. Table concerning the dates, time, and observations on surroundings of sample point.

Air quality observations

Air temperatures near Clear Lake showed an overall increasing trend throughout the year 2024. Starting from an average temperature of about 45 ℉ in the beginning of January, it reached its peak of about 98 ℉ in July. Near August, the heat starts to drop (Figure 7).

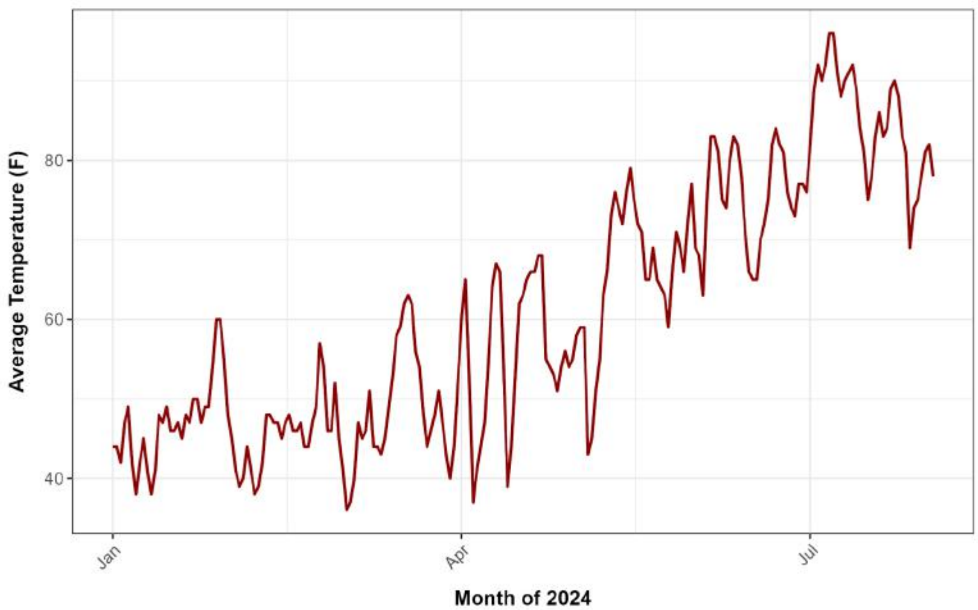

Figure 7. The average temperature (in Fahrenheit) in Lake County each day of 2024.

Most AQI values from 2021 to 2024 stayed near or under 50. A dramatic peak is shown in the middle of the year 2021. Two small peaks occur at the same months in 2022 and 2023 (Figure 8). The variations in Figure 8 indicate changes in AQI values during different seasons: AQI values increase during the summer months and start to decrease in winter months.

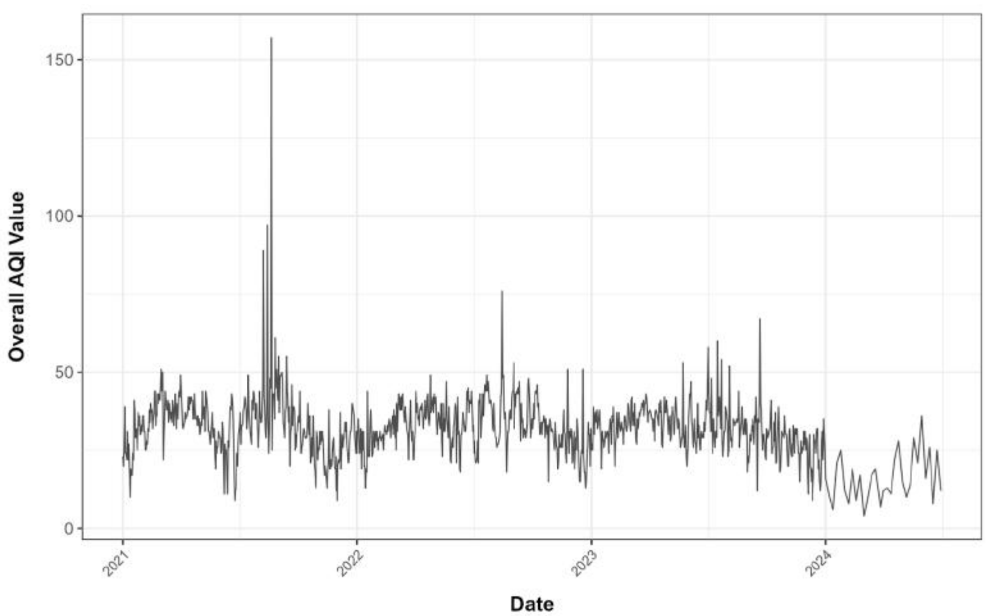

Figure 8. Average Air Quality Index values throughout the years 2021-2024. AQI values range from 0-500. Source is from EPA.

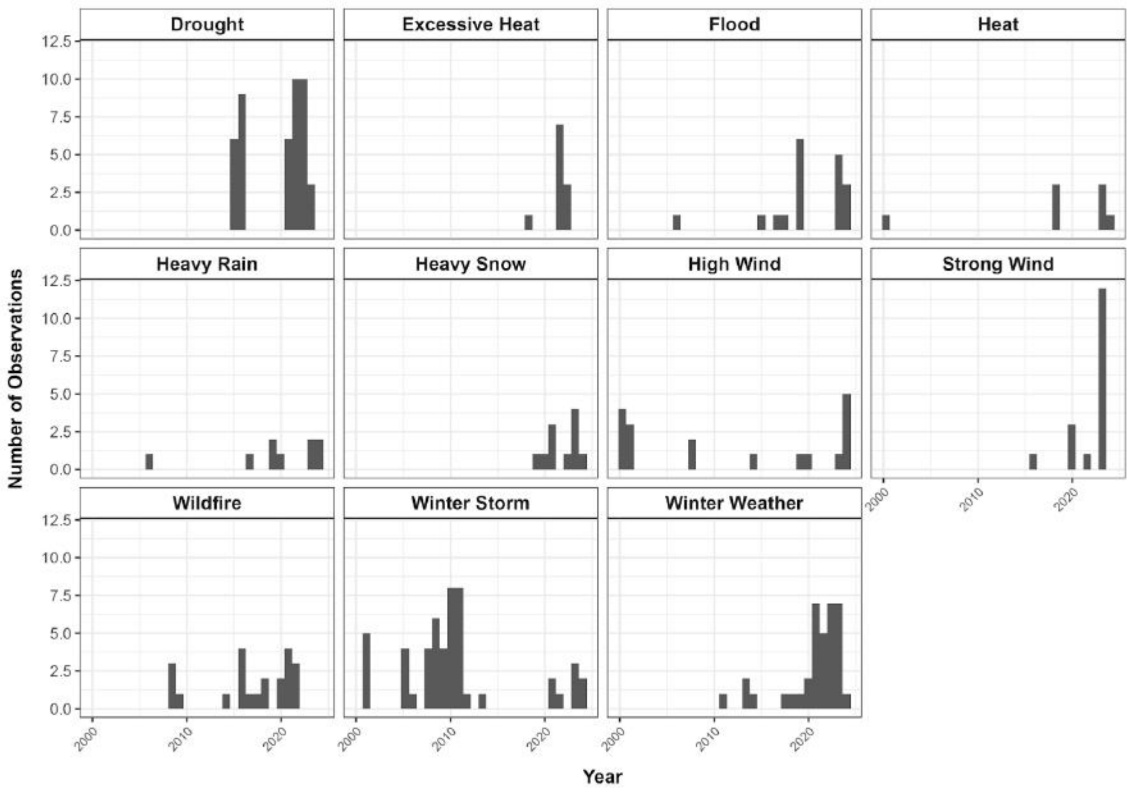

Figure 9. Types of extreme weather in counties seen near Clear Lake over the years 2000-2024.

The amount of strong winds and high winds observed reached their peak at about 12.5 and 5.0 times on average, respectively (Figure 9). Strong winds and excessive heat both appear frequently after the year 2020. It is important to note that droughts and winter storms and weather have occurred the most frequently from 2000 to 2024. Those weather events should be few of the significant influential factors regarding air or water quality (Figure 9).

Table 1 below indicates a high significance in the relationship between the response variable (fish seen per report) and the predictor variables with p-values of less than or equal to 0.01 (≤ 0.01). Based on the model, heavy snow, high wind, drought, and flood have a negative correlation with the number of fish seen per report. However, heavy rain and wildfire have a positive correlation with the number of fish seen per report. Further investigations have also shown a significant positive correlation ($p < 0.05$) between excessive heat and the number of droughts (Table 2). It is notable that the number of droughts have caused an increase in the number of wildfires (Table 3).

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	48.704	6.860	7.099	<0.001
Heavy.Rain	135.115	16.934	7.979	<0.001
Heavy.Snow	-50.465	8.719	-5.788	<0.001
Wildfire	18.415	5.013	3.674	<0.001
High.Wind	-31.932	5.996	-5.326	<0.001
Strong.Wind	5.302	3.260	1.626	0.135
Drought	-6.657	2.084	-3.194	0.010
Flood	-36.241	6.054	-5.987	<0.001
Heat	12.697	7.725	1.644	0.131

Table 1. Linear Regression model after variable selection testing the influence of the extreme weather conditions, listed in the table above, on the number of fish seen per report. P-value < 0.01 = highly significant.

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	1.289	0.644	2.001	0.057
Excessive.Heat	0.980	0.419	2.337	0.028

Table 2. Linear Regression model after variable selection testing the influence of extreme weather conditions on the number of droughts. P-value < 0.05 = significant.

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.409	0.222	1.839	0.079
Drought	0.250	0.060	4.182	<0.001

Table 3. Linear Regression model after variable selection testing the influence of extreme weather conditions on the number of wildfires.

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	26.542	1.165	22.777	<0.001
Drought	0.382	0.277	1.381	0.181
High.Wind	-1.025	0.682	-1.502	0.147

Table 4. Linear Regression model after variable selection testing the influence of extreme weather conditions on AQI values.

4. DISCUSSIONS

From the biological observation results, the number of largemouth bass and perch catched has a negative correlation with the number of carps catched (Figure 4). There may be a predator and prey relationship between those fish species since certain organisms in the same family are known to prey on others for food. When the predator group population increases, more prey are being killed for food, causing a decline in their population. The results build on the existing theories that carp prey on perch occasionally for food and that several species of carp (e.g. bighead carp) are vulnerable to largemouth bass. Therefore, carps may serve as an indicator of largemouth bass or perch in the area.

In contrast to the big catch year in 2017, where adequate amounts of Shads appeared, 2005 and 2006 were harsh years: there was a dramatic downfall from 160 to 25 fish per report. In the same years, winter storms and floods frequently occurred (Figure 9). In addition, according to Table 1, an increase in heavy snow and floods have marked a decrease in the amount of fish per report. This demonstrates an ecological relationship between water quality and fish population. Floods can carry chemicals and contaminants with them into the lake water. Similarly, an irregular number of winter storms may cause stormwater runoffs. The induced chemicals likely lead to a change in the lake environment, introducing fish to a new and unfamiliar habitat and affecting their health.

In terms of air quality, for every year 2021-2024, AQI values increase from the beginning of the year to around the end of summer, and then start to decrease. There is a similar trend in 2024 AQI values and the 2024 average temperature, indicating higher temperatures cause more air pollution. However, Table 4 does not show heat as a predictor variable of AQI values, which means it is unlikely, or there is not enough statistical evidence, that heat is a cause of poor AQI values.

Notably, in the summer of 2021, the AQI value suddenly intensified to a peak of 150, three times greater than average values (Figure 8). Although the frequent occurrence of drought (around 5-10 times), excessive heat (around 7 times), and extreme weather conditions (around 6-7 times) were spotted in the same period, there is insufficient evidence to assume that those factors have caused the sudden increase in AQI value (Table 4).

It is interesting to note that wildfires have shown a positive correlation with AQI values in 2021-2022, but no reports of fires have shown a relationship with the slight increase of AQI in the summer of 2023. Therefore, the conclusion that wildfires will increase AQI values can’t be derived. In fact, increases in fish seen per report were related to increases in wildfires. The positive correlation between the wildfires and fish abundance indicates that wildfires benefit the health of fish populations (Table 1). Past research has shown that periodic wildfires would help improve the habitats of fish species by, for instance, increasing debris flow, which provides protection for fish species living logjams (Frisch, 2019). Increases in wildfires have occurred with increases in droughts (Table 3), and droughts have increased when excessive heat was present (Table 2), which means excessive heat would lead to drought conditions that are vulnerable to wildfires.

Figure 6 presents the factors that have caused changes in the parameters of water quality. When the fire retardants are used to put down wildfires, the chemicals in them dissolves lead and other compounds in the lake (Wandersee et al., 2023). Since lead is a toxic element that alters the biological systems of organisms, less Pb exposure implies a higher and safer water quality. In contrast, unknown particles floating on the water surface of Clear Lake during September 12 and September 15 marked a gain in total hardness.

The findings of water quality should be seen in light of a change in sample time (sample taken at 8:30 PM on 9/4 instead of 3:30 PM) and an absence of values for 9/11 (Figure 6). These possible limitations might have caused inconsistency and data variation due to a difference in temperature, humidity, and other factors (e.g. human activities).

Due to time constraints, water quality sampling spanned for a short period of time. Combined with the lack of historical water quality data and variability in sampling points, the data collected can't be used to represent all information or details about Clear Lake's water quality. The lack of prior research also poses an obstacle to data comparisons.

These issues need to be addressed in order to lessen negative effects on Clear Lake and provide a healthier ecosystem. It is important for further research on the extent of wildfire and air quality impacts and the role of other factors (e.g. agriculture) for more detailed analysis and new insights on Clear Lake's environment.

Finally, since this study is a localized study that focuses on Clear Lake, global freshwater lakes may likely also suffer from the same issues mentioned. Freshwater lakes have intertwined with the environment and human life. They are of crucial importance to biological diversity and ecological balance. Therefore, it is also necessary to observe other lake ecosystems and provide more evidence on the negative effects of natural disasters for more generalized results.

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