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Forward

The Headwaters Student Journal showcases the research projects completed over the course of a semester by students who participate in the Headwaters Research Experience. The students drive their own research, starting by asking questions and doing background research, then designing their methods and collecting data, and analyzing their data and presenting their findngs.

The students in this issue worked to bring their projects to life over the course of their Research Experience journeys! I'm always most impressed by the variety of topics that students are interested in every semester. We have such a wide range of interests represented here, from human health to environmental issues to socioeconomics and sports. No matter the topic, each student saw improvement in their scientific research skills, ensured accuracy and reliability in their data, and represented their passions and interests in science.

Thank you to all of the wonderful mentors who worked with these students on their research, helping to guide and shape the process, but also allowing the students to grow and push themselves to search for answers. And thank you to the parents helping to support these students in their academic pursuits. Whether you drove to field sites, assisted with editing reviews, purchased experimental equipment, or watched practice presentations, your support along this journey means the world to your students and

I am so proud of each student published in this journal and all the current students participating in the Research Experience. Stay tuned for the next issue of the journal, because you'll want to read the following research articles as well. All are incredibly passionate about their research and I cannot wait for what is to come as they become the scientists and problem solvers of the future.

Congratulations to everyone - your hard work and creativity allowed you to make the most of each project and what is published here is the result of an incredible effort. I hope you are proud to see your work in print.

Megan Joyce

Communications Director and Research Experience Program Manager

Headwaters Science Institute

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STUDENT RESEARCH JOURNAL

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Environmental Impact of Traffic on Heavy Metals Concentration and Water Quality in Waterways in Pensacola, FL

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ABSTRACT

Water quality is a critical factor for sustaining environmental health and human well-being, yet it is increasingly threatened by various anthropogenic pressures. Among these, roadway traffic has emerged as a significant contributor to surface water contaminants through the release of metals and other containments, with exposure potentially leading to adverse health impacts ranging from neurological disorders to cardiovascular diseases and cancer. In this study, we analyzed water contaminant concentrations at four distinct sites along a gradient of traffic levels. We predicted that water contaminant concentrations would rise progressively with increased traffic intensity. These sites included brackish water and freshwater sites including Red Rock Creek, the Pensacola Bay, a retention pond, and Texar Bayou. From the data collected, three distinct trends emerged. Strontium, thallium, zinc, arsenic, copper, and molybdenum were found to have elevated concentrations only in the brackish water sites of low-medium and high traffic. Aluminum and iron were found in higher concentrations only at the freshwater sites of low and medium-high traffic. Additionally, antimony, lead, barium, and silver peaked in concentration at the retention pond site, likely due to the site acting as a long-term collector. The one-way ANOVA supported with extreme confidence that variation in mean values reflected true differences in value for all contaminants except chromium, as all had significant F-statistics ≥ 15 ($p < 0.01$). Silver, strontium, thallium, and lead exceeded EPA drinking water guidelines, with Tukey post-hoc tests confirming differences of statistical significance ($p < 0.01$) above the standards. None of the contaminants analyzed in the study followed the predicted hypothesis that concentrations would increase solely based on the designated traffic level. This analysis revealed that contaminant concentration is more dependent on water type than on traffic level. Despite the lack of correlation between traffic intensity and heavy metal concentration, many contaminants found could be attributed to traffic-related sources, including brake pads, tire wear, road paints, and metal wear. Our data suggest that water in this region contains heavy metal concentrations substantially higher than EPA drinking water guidelines and that current government testing is failing to document the danger to ecological and public health.

INTRODUCTION

Water quality is essential for maintaining environmental health and protecting human well-being (1). Groundwater and surface waters influence aquifers, drinking supplies, ecosystem function, and aquatic organisms, making their role fundamental to environmental and human health. However, urbanization and the expansion of anthropogenic influence across the Florida landscape can be detrimental to water quality. As groundwater and surface waters flow through these degraded systems, they accumulate excess nutrients and other contaminants (2). Among the many contributors to this degradation, roads represent a frequently overlooked but significant source of water pollution (3).

Automobiles, traffic, and roads can contribute to pollution in nearby waterways. Brake pads can leech pollutants, including copper, antimony, lead, iron, mercury, and chromium, into water sources when worn particles from vehicle brake friction materials deposit the pollutants onto roadways which stormwater runs off into nearby water sources (3,4,5). The EPA (Environmental Protection Agency) considers this method of copper entering water sources a primary concern (3). Traffic also pollutes water through sediments from construction and erosion, oil and grease leaks, and improperly discarded road salts (6).

The majority of highway runoff of pollutants and heavy metals comes from tire and pavement wear, with less prevalent sources including engine wear, brake wear, engine parts, rust, antifreeze, and exhaust (3,6). Additionally, documented pollution sources include millions of gallons of improperly discarded motor oil which pollute waterways yearly; this is a concerning figure, as one gallon of used oil can contaminate one million gallons of water (6). Pollution from surface water can also infiltrate and contaminate groundwater, and as of 2005, the EPA reported that more than 450,000 confirmed fuel leaks from underground storage tanks have contributed to pollutants in groundwater, necessitating many communities to seek alternative sources of drinking water (6). Heavy metals associated with automobiles and traffic, including copper, arsenic, chromium, and lead, can be toxic to human and ecosystem health (7).

In this experiment, we tested water sources for aluminum, antimony, arsenic, barium, beryllium, bicarbonate, boron, cadmium, calcium, chloride, chromium, cobalt, copper, dissolved solids (TDS), fluoride, grains per gallon, hardness, iron, lead, lithium, magnesium, manganese, mercury, molybdenum, nickel, nitrate, nitrite, pH, phosphate, potassium, radium, selenium, silica, silver, sodium, strontium, sulfate, thallium, tin, titanium, turbidity, uranium, vanadium, zinc, zirconium, ammonia, carbonate, conductivity, total alkalinity, total organic carbon, total dissolved nitrogen, and total suspended solids.

For most contaminants, the U.S. EPA primary standards for drinking water were used for comparison. These standards include the Maximum Containment Level Goal (MCLG), which represents the concentration in drinking water below which no known or expected health risk occurs (8). The primary standards also include the Maximum Containment Level (MCL), which is the highest concentration of a contaminant legally permitted in drinking water (8). The EPA secondary standards guided containment evaluation for contaminants that the primary standards did not apply to, and when guidance addressed non-aesthetic health impacts, applicable to silver, strontium, and total dissolved solids (TDS). When no EPA regulations existed, alternative benchmarks, from agencies such as the FDA (Food and Drug Administration) (aluminum) and the WHO (World Health Organization) (molybdenum) provided reference values (9,10). Drinking water standards served as indicators of water quality because no comprehensive benchmarks exist for general surface and ambient waters. These standards acted as proxies to evaluate overall water health and potential impacts on animals, aquatic organisms, the environment, and, hypothetically, on humans if the waters were consumed.

All locations tested were from the Pensacola Bay watershed in the Florida panhandle, listed from low to high traffic designations: Red Rock Creek (30.78533°N, 86.89123°W), the Pensacola Bay (30.40328°N, 87.21986°W), Admiral Mason Park retention pond (30.412514°N, 87.203564°W), and Texar Bayou (30.426446°N, 87.186206°W) (Figure 1). The Red Rock Creek site is rural, with less traffic due to single road access. The Pensacola Bay collection site is near a park with an infrequently used road. The retention pond is surrounded by frequently used roads, and the Texar Bayou site is directly beside a busy road. The sites included two freshwater and two brackish water sites. Brackish water is water where salt and freshwater sources mix, which includes both the Pensacola Bay and the Texar Bayou collection sites (11,12). Pensacola Bay, the retention pond, and Texar Bayou are located in urban Pensacola, and the rural Red Rock Creek located in Blackwater River State Park (Figure 2). Our hypothesis predicted that water contaminant concentrations would rise progressively with increased traffic intensity across the sites.

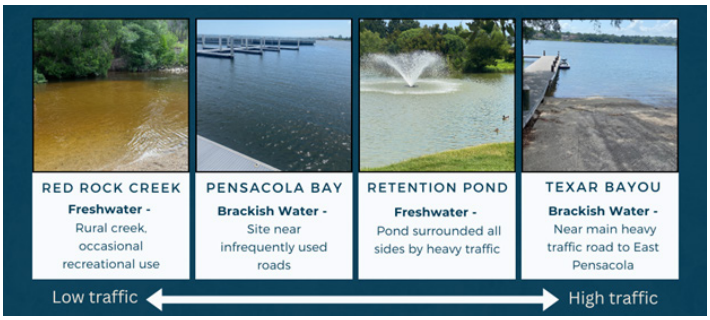

Figure 1: Surface water sampling sites in Pensacola, FL. (photographs taken by Benson, A)

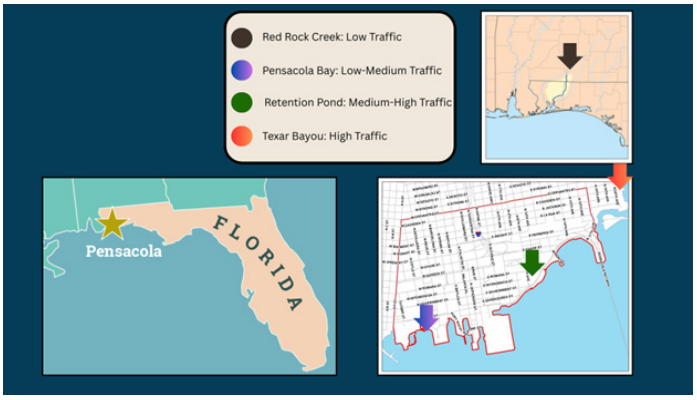

Figure 2: Geographic locations of the four collection sites in northwest Florida Images (13,14,15).

METHODS

To examine the impact of traffic on water quality, we selected four sites in northwest Florida and assigned a traffic level designation to each site ranging from low, low-medium, medium-high, and high. At each site, we collected water samples for three consecutive days from 7/11/25 to 7/13/25 during mid-day at approximately the same time to minimize changes in contaminant levels due to potential temporal variation (51).

We used the two provided collection cups from the Tap Score Essential Well Water Kit, to assess the water quality at each site (52). We shipped the water samples to Tap Score SimpleLab Water Testing Laboratory distribution center in Berkeley, California for sample processing.

We used a small, clean cup (Tap Score Essential Well Water Kit) to obtain the water for Collection Cup 1. We cleaned the small cup by flushed filling, and discarding site water several times, then transferred the sample to Collection Cup 1 and immediately sealed the cup to prevent contamination.

We collected the sample for Collection Cup 2 by flushing the cup thoroughly with site water multiple times. For the final sample, the cup was filled completely with water and sealed underwater to minimize trapped air bubbles.

We recorded environmental conditions at each site, including time, weather, surrounding activity, and any visible contaminants. All samples were taken at a depth of approximately 2 ft, in the same area in each location. After collection, we placed samples in a portable cooler with ice packs for transport and stored in a refrigerator at 4°C until shipped in the original container with the provided freezer pack to the Tap Score water testing laboratory.

The contaminants spotlighted in this report were chosen as they were the most significant to supporting and refuting the hypothesis and understanding the connection of traffic and water quality. All the contaminants tested for by the Tap Score testing kit were: aluminum, antimony, arsenic, barium, beryllium, bicarbonate, boron, cadmium, calcium, chloride, chromium, cobalt, copper, dissolved solids (TDS), fluoride, grains per gallon, hardness, iron, lead, lithium, magnesium, manganese, mercury, molybdenum, nickel, nitrate, nitrite, pH, phosphate, potassium, radium, selenium, silica, silver, sodium, strontium, sulfate, thallium, tin, titanium, turbidity, uranium, vanadium, zinc, zirconium, ammonia, carbonate, conductivity, total alkalinity, total organic carbon, total dissolved nitrogen, and total suspended solids.

In DataClassroom, the data were graphed, and statistical significance ($p = 0.05$) was determined using a one-way ANOVA and Tukey post-hoc tests. The one-way ANOVA is commonly applied in water pollution studies to assess whether variation in mean values reflects true differences rather than random fluctuation (16,53,54). The test separated variance attributable to variations within each site's data from differences between site means, with the resulting F-statistic representing the comparison of these two variances, indicating whether in-site variance is the cause of different contamination levels (54).

RESULTS

To analyze laboratory results, we used a one-way ANOVA to determine the statistical significance of the differences between contaminant levels at the four sampling sites. P-values generated from the ANOVA, with statistical significance defined as $p < 0.05$, indicated the probability that observed differences arose from random variation (16). A Tukey post-hoc test was then applied to identify which specific site means differed

from each other and from the relevant water quality standards, enabling detailed pairwise comparisons and grouping patterns within the dataset.

The overall trend demonstrated separation between the two brackish water sites (low-medium and high traffic) and the two freshwater sites (low and high-medium traffic) (Figures 3, 4). A few contaminants were found to be significantly more prevalent in the retention pond site, at medium-high traffic (Figure 5). Two contaminants were found in multiple sites but were highest in concentration at the retention pond (Figure 6).

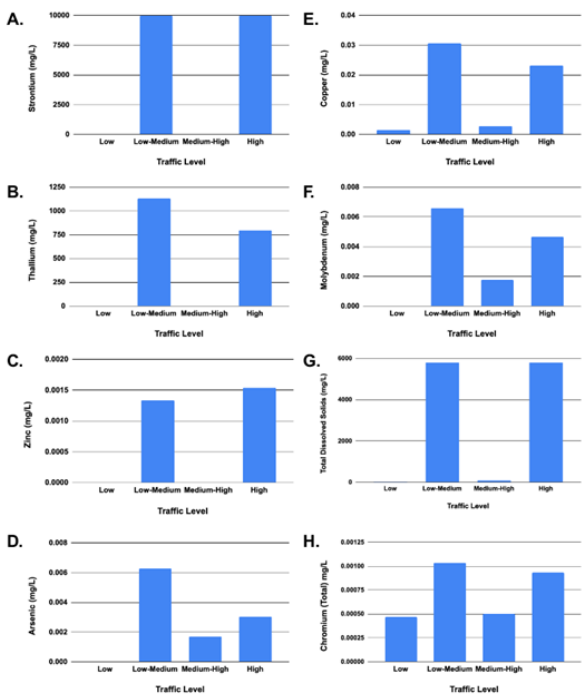

Figure 3: Water contaminants with higher concentrations in brackish sites (low-medium and high traffic). The concentrations of individual contaminants as measured at four different sites are represented by their designated traffic levels. The mean of three consecutive collection days for each of the four sites was graphed. A) Strontium - analysis produced a F-statistic of 64,000,000,000 ($p < 0.01$). Strontium EPA standard versus low-medium, medium-high, and high sites ($p < 0.01$). B) Thallium - analysis produced a F-statistic of 1,100 ($p < 0.01$). Thallium MCL and MCLG versus low-medium and high sites ($p < 0.01$). C) Zinc - analysis produced a F-statistic of 120 ($p < 0.01$). D) Arsenic - analysis produced a F-statistic of 1,500 ($p < 0.01$). E) Copper - analysis produced a F-statistic of 270 ($p < 0.01$). F) Molybdenum - analysis produced a F-statistic of 2,800 ($p < 0.01$). G) Total Dissolved Solids (TDS) - analysis produced a F-statistic of 700,000 ($p < 0.01$). H) Chromium (Total) - analysis produced a F-statistic of 2.2 ($p = 0.16$).

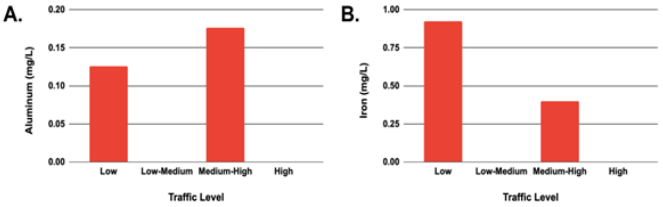

Figure 4: Water contaminants with higher concentrations in freshwater sites (low and medium-high traffic). The concentrations of individual contaminants as measured at four different sites are represented by their designated traffic levels. The mean of three consecutive collection days for each of the four sites was graphed. A) Aluminum - analysis produced a F-statistic of 30 ($p < 0.01$). B) Iron - analysis produced a F-statistic of 42 ($p < 0.01$).

The contaminants strontium, thallium, zinc, arsenic, copper, molybdenum, and chromium (total), and the indicator TDS, were higher in concentration at the brackish water sites than at the freshwater sites (Figure 3). All of these contaminants, except for chromium, were found to have high F-statistics, suggesting that the differences observed in site means are unlikely to be attributed to random variation ($p < 0.01$). For chromium, however, there is less confidence in difference in site means, with an F-statistic of 2.2 ($p = 0.16$), because chromium was found at all four sites. Zinc was the only containment found to have increased concentration at the higher traffic brackish site, while strontium and TDS remained at consistent levels at both brackish sites.

Higher concentrations of aluminum and iron were found

in the two freshwater sites compared to the brackish sites (Figure 4). Aluminum had an F-statistic of 30 ($p < 0.01$), and iron had an F-statistic of 42 ($p < 0.01$), indicating high confidence in the difference in means between the freshwater and brackish sites. Aluminum was found to have a higher concentration at the higher traffic level freshwater site.

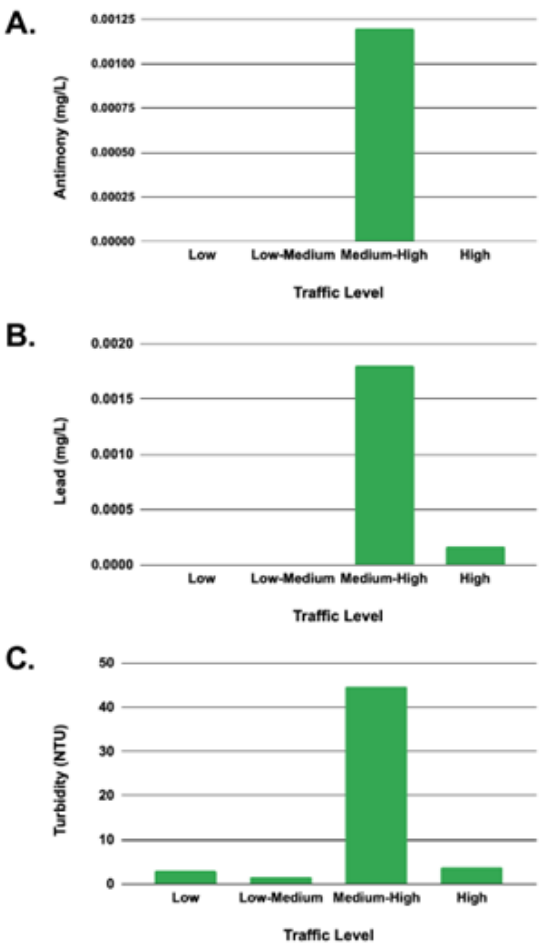

Figure 5: Water contaminants with higher concentrations in retention pond site (medium-high traffic). The concentrations of individual contaminants as measured at four different sites are represented by their designated traffic levels. The mean of three consecutive collection days for each of the four sites was graphed. A) Antimony - one-way ANOVA not applicable due to no concentrations detected at other three locations. B) Lead - analysis produced a F-statistic of 15 ($p < 0.01$). Lead MCL versus high site ($p < 0.01$). C) Turbidity - analysis produced a F-statistic of 170 ($p < 0.01$).

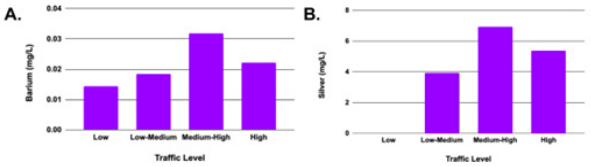

Figure 6: Water contaminants with highest concentrations in retention pond site (medium-high traffic) and other sites. The concentrations of individual contaminants as measured at four different sites are represented by their designated traffic levels. The mean of three consecutive collection days for each of the four sites was graphed. A) Barium -analysis produced a F-statistic 370 ($p < 0.01$). B) Silver - analysis produced a F-statistic of 780 ($p < 0.01$). Silver EPA standard versus low-medium, medium-high, and high sites ($p < 0.01$).

The retention pond site, with medium-high traffic, showed high concentrations of antimony and lead, as well as elevated turbidity levels which indicates reduced water quality; these patterns were not observed at the other three locations (Figure 5). Lead had an F-statistic of 15 ($p < 0.01$) and turbidity resulted in a F-statistic of 170 ($p < 0.01$). Antimony was only detected at the retention pond site and showed no measurable concentrations at the other three sites, so an ANOVA could not be performed (Figure 5). The contaminants barium and silver also had the highest concentrations found at the retention pond site (Figure 6). However, barium and silver were also present in significant concentrations in other locations (Figure 6). Barium had an F-statistic of 370 ($p < 0.01$), and silver had an F-statistic of 780 ($p < 0.01$).

The contaminants that exceeded the applicable drinking water quality standards were thallium, strontium, lead, and silver. At certain sites, all four contaminants were

measured at concentrations above their respective EPA water quality standards, with Tukey post-hoc tests confirming the statistical significance of these exceedances ($p < 0.01$).

Thallium concentrations exceeded the EPA MCLG of 0.0005 mg/L and MCL 0.002 mg/L at both brackish water sites (8). This is supported by the Tukey post-hoc test, proving with extreme confidence that the brackish water sites exceeded the standards with statistical significance ($p < 0.01$). Lead exceeded the MCL of 0 mg/L for all collection days at the retention pond, and the final collection at high-traffic Texar Bayou (8). Although the concentration of lead was lower at Texar Bayou than at the retention pond, the concentration exceeded the MCL with extreme confidence ($p < 0.01$). Silver exceeded the EPA secondary water quality standard of 0.1 mg/L in all sites besides the low traffic Red Rock Creek site (17). The Tukey post-hoc test supported with extreme confidence ($p < 0.01$) the statistical significance between the EPA standard and the collection sites. Similar to silver concentration, strontium also exceeded the EPA's lifetime health advisory limit of 4 mg/L at all sites except for Red Rock Creek ($p < 0.01$) (16). The Tukey post-hoc test also showed the difference of statistical significance between the freshwater and brackish sites ($p < 0.01$), indicating with extreme confidence that strontium exceeded standards more highly in the brackish water sites than in the freshwater retention pond site. Of all 54 contaminants tested for, concentrations of strontium and thallium were found to be the highest above the water quality standards.

DISCUSSION

In this experiment, we collected water samples over three consecutive days from four sites of increasing traffic levels and analyzed the samples for water contaminants. Analyzing the contaminants revealed three distinct groups of contaminant concentration: those higher in the brackish sites, those higher in the freshwater sites, and those highest in concentration at the retention pond. None of the contaminants analyzed in the study followed the predicted hypothesis that concentrations would increase solely based on designated traffic level.

The contaminants that followed a trend of increased concentration with increasing traffic levels were zinc, aluminum, barium, and silver. Zinc was significantly higher in concentration at the two brackish sites, with a higher concentration at the Texar Bayou, the higher traffic brackish water site. Aluminum, higher in concentration at only the two freshwater sites, showed an increased concentration at the higher traffic freshwater site. Silver and barium reveal a trend of increased concentration from the lower traffic sites to the higher traffic sites, with a peak concentration at the retention pond site, disrupting this trend. This peak in concentration at the retention pond site was also observed in antimony, lead, and turbidity, which were only observed at this site; this trend necessitates further examination.

Many of the contaminants tested and analyzed did not follow the anticipated trend, revealing that traffic may have less of an impact on water pollutants than anticipated. Analyzing the contaminants revealed that the type of water, fresh or brackish, had a larger impact on resultant concentrations of contaminants than the designated traffic level. Although traffic and automobiles may contribute to these contaminants entering water sources, the level of traffic appears to matter less than the type of water tested.

The brackish water sites exhibited elevated strontium, thallium, zinc, arsenic, copper, molybdenum, TDS and chromium, which could occur because of the nature of brackish water. Strontium is naturally enriched in seawater from carbonate and feldspar weathering, while molybdenum and arsenic often remain in solution in high salinities (18,19). Elevated chloride ion concretions from higher salinities allows for metals, including copper, zinc, and chromium, to remain dissolved in solution as salts ($CuCl_2$-, $ZnCl$+, $CrCl_2$+) (30,31). Increased ionic strength in higher salinity waters can allow for more particle-bound metals to desorb back into solution, releasing copper, zinc, thallium, and arsenic into water (20,21,22).

In contrast, aluminum and iron were found to be higher in the freshwater sites, likely due to greater suspended sediment loads from soil erosion, roadside embankment instability, and resuspension in low-energy environments such as retention ponds and rural creeks (23,24). These elements are abundant in clays and iron oxides, and in low-salinity conditions, such as freshwater sources, aluminum and iron remain

mobile as colloids. In saline conditions, rapid particle aggregation and precipitation remove them from the water column (25,26). The observed split between fresh and brackish water reflects how differences in water composition and subsequent contaminant reactions create differences in dissolved contents of these particles. Observing these changes, in comparison to traffic levels, can provide more insight into why certain areas have higher concentrations of these metals.

The data revealed that the retention pond had the highest concentrations among all sites of the following contaminants: antimony, lead, turbidity, barium, and silver. Iron and aluminum were also present at the retention pond site. The elevated concentrations of these contaminants in the retention pond can be explained by the pond's role as a long-term collector of sediments and associated contaminants from its surrounding catchment. Runoff from landscaped areas, footpaths, and nearby infrastructure can carry eroded soil particles, decomposed organic matter, and corroded metal fragments into the pond (39). Concrete weathering and soil erosion contribute aluminum and iron, while painted surfaces and corroding plumbing components, including building hardware and other metal infrastructure, can release antimony and lead (27,28,29,30). These metals tend to bind strongly to fine mineral and organic particles, which settle and accumulate in bottom sediments over time. Foraging wildlife such as ducks and turtles can disturb the pond bed, increasing suspended solids, while wind-driven surface mixing could enhance turbulence near the bottom, keeping particle-bound metals in suspension and raising both measured concentrations and turbidity levels (31,32,33,34). Because the pond is a permanent pool with limited outflow, it functions as a sink where contaminants accumulate, but it can also act as a source when sediments are resuspended. Without treatment or proper filtration, these containments build up and remain dissolved in the pond (28,30,34,35).

The contaminants zinc, copper, antimony, lead, barium, and chromium all have a high likelihood of an anthropogenic traffic-related origin (36,37). Brake pad wear and tear can contribute to zinc, copper, antimony, lead, and barium, and tire-related wear can contribute to barium, lead, and zinc (36,38). Additionally, radiator corrosion contributes to copper (60), lead can come from additives in legacy gasoline (39), alloys can contribute to barium (62), and chromium can come from general metal wear, coatings, and road paint (32). Of these, lead was found to exceed EPA limits at the medium-high and high traffic sites. The others were found in lower concentrations, yet their presence in the water is still an important indicator of traffic's adverse impacts on ecosystems and humans.

The contaminants iron, aluminum, molybdenum, silver, strontium, thallium, turbidity, and TDS have a lower probability of traffic-related origin. Iron, although often coming from geological sources, can be heightened by rotor and brake dust, as well as steel corrosion from automobile parts (40). Brake pad additives can include trace amounts of strontium, and molybdenum can come from lubricant additives (41,42). Aluminum, molybdenum, silver, strontium, and thallium can come from general vehicle, alloy, and electrical component corrosion and wear, entering water sources through particle runoff from moving cars and stormwater (41,43,44). Turbidity and TDS act more as indicators of contaminants and lowered water quality than pollutants, as they indicate the presence of other contaminant materials that can impact surface water and are not appropriate for drinking water (45). Corrosion products, erosion of highways, and stormwater runoff of various other pollutants contribute to the high concentration of turbidity and TDS (45,19). Arsenic has a very minimal tie to traffic-related causes, yet contaminated soils near roads could add to this chemical in waterways (48).

Of the contaminants analyzed in this study, lead, arsenic, total chromium, and thallium are the most high-risk to human and ecosystem health. Lead, even at low dosages, can be detrimental to children, causing developmental delays, lowered IQ, learning difficulties, and neurological impacts (47). Long-term ingestion of arsenic can lead to various cancers, including kidney and liver, and cardiovascular diseases (48). Total chromium can lead to allergic dermatitis, and hexavalent chromium is carcinogenic (49). Thallium, found in this experiment in high concentrations, well above EPA primary drinking water standards in the brackish sites, can cause gastrointestinal irritation, hair loss, and damage to the liver, nerves, and kidneys (50).

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Assessing the Correlation of Ocean Acidification Levels on Kelp Coverage in Southern California Following a 2014 El Nino Event

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ABSTRACT

Ocean acidification and warming oceans are important stressors for kelp ecosystems, which provide critical habitat for many marine species. We asked whether oceanographic variables – dissolved inorganic carbon (DIC), temperature, salinity, and total alkalinity – predict future changes in kelp canopy area in Southern California after the 2014 El Niño event. We analyzed quarterly data from 2015–2022 using statistical models in R. Non-lagged models were not significant, but lagged models showed that DIC and temperature strongly predicted decreases in kelp canopy in the following quarter. A combined lagged model including both DIC and temperature explained about 46% of the variation in future kelp canopy area. These results suggest that ocean chemistry and temperature stress may act together to drive delayed declines in kelp forests. Our findings highlight the importance of considering time lags in ecological research and have implications for predicting how climate change may impact marine ecosystems.

INTRODUCTION

Kelp forests play a vital role in coastal ecosystems, supporting high biodiversity and stabilizing marine environments. Their canopy provides food and shelter for fish, invertebrates, and marine mammals, while also protecting benthic (seafloor) habitats from disturbance (1). Kelp is considered a foundational species, meaning that the loss of kelp leads to declines across entire food webs (2).

One major cause of kelp decline is large-scale ocean disturbances, such as El Niño events. El Niño occurs when normal cold-water upwelling along the Pacific coast weakens, allowing warmer water to move northward (3). These events often lead to significant declines in kelp forests along the Southern California coast due to thermal stress and reduced nutrient availability.

Another major environmental concern is ocean acidification, which occurs when atmospheric CO_2 from fossil fuel combustion dissolves into seawater, lowering pH and altering carbonate chemistry (4). Ocean acidification threatens organisms that build shells and skeletons from calcium carbonate, such as corals and plankton, but its direct effects on non-calcifying species like kelp are less well understood.

Some studies have found that acidification alone may not directly harm kelp growth or photosynthesis (5). However, when combined with warming events like El Niño, acidification may create compounding stress on kelp forests.

This study investigates how ocean acidification and temperature relate to kelp canopy area after the 2014 El Niño event in Southern California. We asked:

"What is the relationship between ocean acidification levels and kelp coverage in Southern California since the 2014 El Niño event?" We hypothesized that higher dissolved inorganic carbon (DIC) and higher temperature levels would be associated with lower kelp coverage in the following quarter.

METHODS

Overview of Analytical Approach

We examined whether oceanographic variables measured during one quarter (three-month temporal intervals) could predict kelp canopy area in the following quarter, testing the hypothesis that seasonal changes in dissolved inorganic carbon, temperature, salinity, and total alkalinity (TA) influence kelp growth dynamics.

Materials and Methods

We used two open-access datasets:

1. Kelp Canopy Data — obtained from Kelpwatch, a collaboration among UCLA, NASA, and partners documenting kelp canopy coverage in Southern California.

2. Ocean Chemistry Data — obtained from the California Cooperative Oceanic Fisheries Investigations (CalCOFI) program, which provides long-term monitoring of ocean acidification variables.

Data were limited to 2015–2021 to focus on the period after the 2014 El Niño event. The CalCOFI dataset was filtered to match the spatial extent of the kelp data (≥32.4°N latitude). Monthly chemistry data were averaged to quarterly values to align with kelp observations. Lag variables were created by shifting the kelp canopy time series one quarter forward to test whether environmental conditions in one quarter predicted kelp canopy area in the next.

We used R (version 4.5.1) for data processing and analysis. Linear models were fit using the lm() function, and visualizations were created with ggplot2 (v3.5.1) and ggpubr (v0.6.0). Diagnostic tests included Cook's distance, leverage, and studentized residuals to identify influential points. Summary statistics for all oceanographic and biological variables are provided in Table 1.

Variable	Mean	SD
Mean Kelp Area	4718772	3482862
Mean Temp	12.56284	1.377791
Mean Salinity	33.68217	0.060699
Mean DIC	2109.228	32.60951
Mean TA	2249.673	5.879191

Table 1: Summary statistics for key oceanographic and biological variables (2015–2022). Mean and standard deviation (SD) are shown for kelp canopy area, temperature, salinity, dissolved inorganic carbon (DIC), and total alkalinity (TA) averaged across quarterly observations in Southern California.

RESULTS

Temporal Trends and Variable Correlation

Exploratory analysis showed strong seasonal cycles in kelp canopy area, with peaks during spring and summer and declines during fall and winter. Mean DIC and temperature were relatively stable but showed subtle increases before kelp declines, suggesting possible lag effects (Figure 1).

Seasonal comparisons confirmed significant variation in kelp area (ANOVA, $F(3,21)=8.41$, $p<0.001$). Non-lagged linear models of kelp area versus DIC, temperature, salinity, and TA were not significant ($p>0.1$, adjusted $R^2<0$; Table 1), indicating that same-quarter ocean conditions were poor predictors of kelp canopy extent.

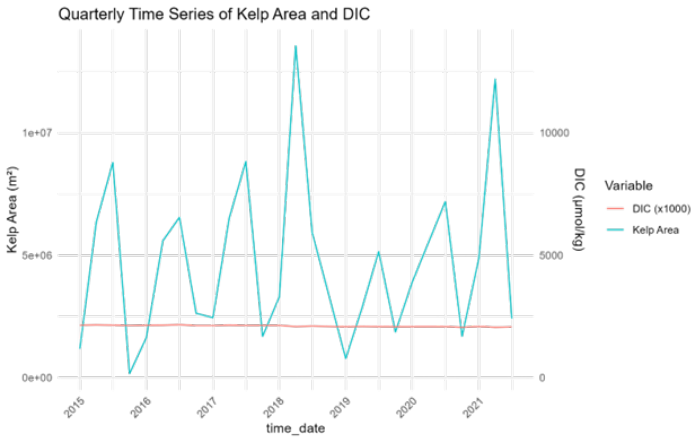

Figure 1: Quarterly time series of kelp canopy area and dissolved inorganic carbon (DIC) from 2015–2022 in Southern California. Kelp canopy area (blue) is plotted with DIC (green, scaled ×1000 for visibility). Kelp area showed strong seasonal cycles with summer peaks, while DIC exhibited subtle increases preceding kelp declines, suggesting a possible delayed response to ocean chemistry.

Lagged Linear Predictive Model

Lagged univariate regressions revealed significant negative relationships between both DIC and temperature and the next quarter's kelp canopy area (Figures 2 and 3; Table 2).

The simplified multivariate lagged model combining DIC and temperature explained 40% of the variation in future kelp canopy area ($F(2,21)=8.78$, $p=0.0017$, adjusted $R^2=0.40$; Figure 5; Table 3).

For each 1 µmol/kg increase in DIC, kelp canopy area decreased by approximately 155,000 m² ($p=0.002$). For each 1°C increase in temperature, kelp canopy declined by over 4 million m² ($p=0.0005$).

Including TA in the model did not improve explanatory power ($F(3,19)=5.43$, $p=0.007$, adjusted $R^2=0.38$), and TA was therefore excluded for parsimony.

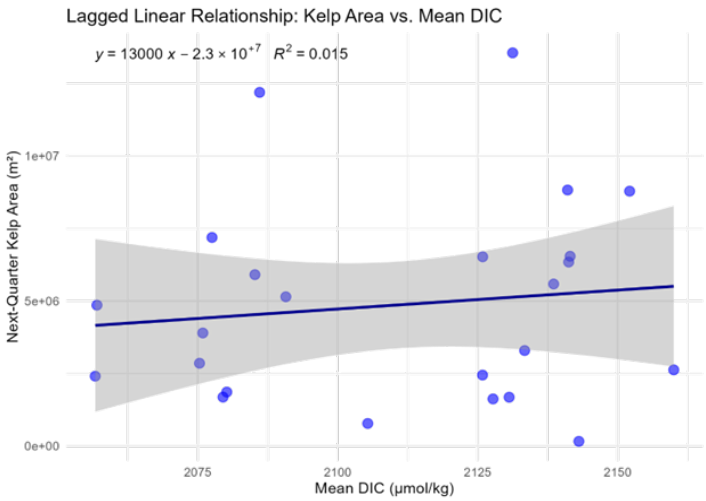

Figure 2: Lagged relationship between mean dissolved inorganic carbon (DIC) and next-quarter kelp canopy area. Each point represents a quarterly average from 2015–2022. The solid line shows the best-fit regression line with a 95% confidence interval (shaded area). Higher DIC levels in one quarter predicted significantly lower kelp canopy area in the following quarter ($p = 0.0017$, $r^2 = 0.48$).

Term	Estimate	Std Error	t Value	p Value
(Intercept)	3.25E+08	95425968	3.408172	0.002647
Mean DIC	-129041	39991.45	-3.22671	0.004045
Mean Temp	-3846598	970833.9	-3.96216	0.000711

Table 2: Regression coefficients from the simplified lagged linear model predicting next-quarter kelp canopy area. The model includes mean dissolved inorganic carbon (DIC) and mean temperature as predictors. Both variables showed significant negative relationships with future kelp canopy area.

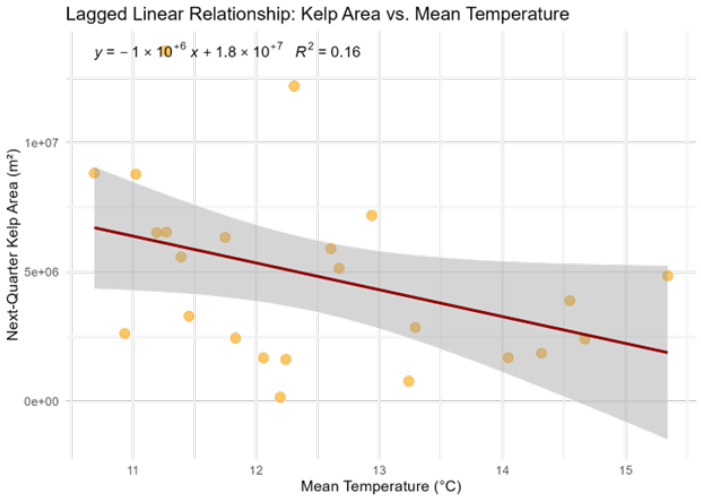

Figure 3: Lagged relationship between mean temperature and next-quarter kelp canopy area. Each point represents a quarterly mean. The solid line represents the best-fit regression with a 95% confidence interval. Higher temperatures were associated with reduced kelp canopy area in the following quarter ($p = 0.005$, $r^2 = 0.38$), consistent with thermal stress effects.

Outlier and Influence Diagnostics

Four quarters (2018 Q1, 2019 Q4, 2020 Q4, and 2021 Q1) were identified as outliers based on Cook's distance and leverage. These likely reflect unmeasured disturbances such as storms, herbivory, or disease. Removing them did not change model significance, confirming model robustness (Table 3).

Year	Quarter	Kelp Area	DIC	Temp
2018	Q1	High	High	Low
2019	Q4	Low	Moderate	High
2020	Q4	Low	Moderate	High
2021	Q1	High	Moderate	Low

Table 3: Summary of Outlier Analysis and Influential Observations that were flagged for consideration in the multivariate regression model.

Threshold Effects of DIC and Temperature

Before lagged models were applied, a two-sample t-test comparing high versus low DIC groups showed no significant difference in kelp area ($t=-0.41$, $p=0.68$). After applying the lag, kelp canopy area was significantly lower under high DIC conditions ($p=0.02$) and marginally lower under high temperature conditions ($p=0.10$) (Figures 2 and 3).

These findings suggest that elevated DIC and temperature levels exert delayed negative effects on kelp canopy formation in subsequent seasons.

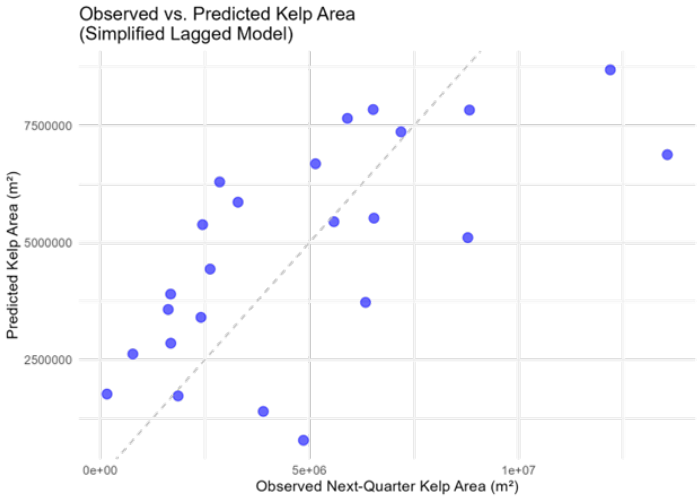

Figure 4: Observed versus predicted kelp canopy area from the simplified lagged model. Observed kelp area values are plotted against predicted values from a multiple regression model using DIC and temperature as predictors. The dashed gray line indicates perfect agreement (1:1). The model explained 46% of variation in next-quarter kelp area ($p = 0.0017$, adj. $r^2 = 0.40$).

DISCUSSION

This study provides new insight into how seasonal oceanographic conditions, especially dissolved inorganic carbon and sea surface temperature, influence kelp forest dynamics. The key finding is that lagged linear models uncovered significant relationships between environmental stressors and future kelp canopy areas that were not evident in same-quarter analyses.

This suggests that kelp responses to environmental change occur with a time delay, likely due to biological processes such as reduced photosynthesis, delayed reproduction, or slower recovery after disturbance.

The strong negative associations between DIC and temperature with future kelp areas (Figures 2, 3, 4) align with previous research showing that kelp forests are vulnerable to both warming and acidification (3, 4). While temperature directly limits kelp growth and survival, elevated DIC levels (indicative of acidification) may alter nutrient dynamics or indirectly stress the ecosystem.

Salinity and TA did not significantly affect kelp canopy, possibly because they were relatively stable in this region. The exclusion of these non-significant predictors improved model clarity without reducing explanatory power.

Although a few quarters were identified as outliers, they likely reflect localized environmental events. The model's robustness despite these points supports its reliability and ecological relevance.

Overall, our findings demonstrate that simple lagged linear models can reveal meaningful ecological patterns, highlighting how ocean chemistry and temperature changes predict kelp canopy decline after El Niño disturbances. Future studies should expand to include biological drivers (e.g., grazing and recruitment) and test whether similar lagged effects occur in other coastal systems.

This project also demonstrates how publicly available data and open-source tools such as R can be used by students to explore large-scale ecological questions. Future work could test whether similar lagged effects occur in other coastal ecosystems or incorporate biological factors such as herbivory, recruitment, or nutrient limitation to further explain variability in kelp canopy dynamics.

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Effects of the Allele of rs9939609 and Consumption of Ultra-Processed Food on Obesity

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ABSTRACT

With climate change becoming increasingly dire for all people living on Earth, a move to clean energy production is critical. One such alternative is wind energy. Wind energy is influenced by a variety of factors that contribute to its efficiency. In this study, latitude is explored to see if this factor has any correlation on the efficiency of wind turbines. The results showed that there was a weak, positive correlation between latitude and wind speed, which was largely insignificant. For latitude and wind power density, a weak, positive correlation as well, however they were significant. With this data, there's not a linear relationship between latitude and wind energy.

INTRODUCTION

Over recent decades, the global rise in obesity has prompted researchers to investigate both environmental and genetic contributors to this epidemic. Since 1980, obesity prevalence among US adults has substantially increased from 14% to 42%, with similar statistics in children. An increased concern for individuals consuming ultra-processed foods (UPFs), which are food products that are heavily processed in multiple steps and are typically high in sugar, fat, salt, and additives, but low in fiber and essential nutrients. Some examples of UPFs include packaged snacks, soda, and candy. These foods are designed for convenience and shelf-stability which is linked to adverse health outcomes, including weight gain and metabolic disorders (1).

At the same time, genetic factors such as variants in the fat mass and obesity-associated (FTO) gene have been shown to play a significant role in individual susceptibility to obesity. Specifically, the A allele of the FTO rs9939609 polymorphism has been associated with loss-of-control (LOC) eating and more frequent selection of energy-dense, palatable foods, leading to more unhealthy food habits (2). Understanding the interaction between UPF consumption and genetic predispositions to obesity, like with the FTO variant, is essential for developing targeted nutritional guidance and public health strategies.

Given the independent associations between UPF consumption and obesity, and FTO rs9939609, understanding how these factors interact is critical. Gene–environment interaction studies can reveal whether certain dietary patterns exacerbate genetic risk, providing evidence for personalized nutrition and targeted public health strategies.

The focus of this study is that the presence of the A allele of the FTO rs9939609 gene enhances the obesogenic effects of ultra-processed food (UPF) consumption. While the independent effects of UPF intake and the FTO rs9939609 variant have been studied separately, the objective of this study is to examine their combined influence. Specifically, this study aims to determine whether individuals carrying at least one copy of the A allele (AA or AT genotypes) are more susceptible to obesity when consuming high levels of UPFs compared to individuals without the risk allele (TT genotype). By comparing obesity prevalence between A-allele carriers and non-carriers under varying levels of UPF consumption, this research seeks to identify a potential gene–diet interaction in which genetic susceptibility amplifies the impact of unhealthy dietary patterns on body weight.

METHODS

We conducted a meta analysis to examine the relationship between ultra-processed food (UPF) consumption, the A allele of the FTO gene variant rs9939609, and the risk of obesity in children and adolescents. Relevant studies were identified through a structured search of Google Scholar between May

and July 2025. Search terms included combinations of: "FTO," "rs9939609," "obesity," "ultra-processed food," "children," and "adolescents." Only peer-reviewed articles published in English that reported quantitative data were considered (Table 1).

Study	*p*-value	Outcome	Study Type
L.-L. QUAN	0.03, 0.00001	FTO rs9939609 polymorphism was significantly associated with the increased risk of obesity in co-dominant model (AA vs. TT: OR = 1.91, 95% CI: 1.47-2.48, p < 0.01; AT vs. TT: OR = 1.18, 95% CI: 1.02-1.38, p = 0.03), dominant model (AA + AT vs. TT: OR = 1.47, 95% CI: 1.35-1.59, p < 0.01), recessive model (AA vs. AT + TT: OR = 1.79, 95% CI: 1.47-2.17, p < 0.01), and allelic model (A vs.T: OR = 1.39, 95% CI: 1.22- 1.58, p < 0.01).	Meta Analysis (12 studies)
Benilde Riffo	0.015	Each minor A allele of rs9939609 was associated with obesity (odds ratio (OR): 1.422 [95% confidence interval (CI) 1.068–1.868] p = 0.015), calculated using an additive model. In sex-stratified analysis we found that the risk variant (A) of rs9939609 was associated with a higher homeostasis model of assessment for insulin (HOMA-IR) in prepubertal obese girls. In male carriers of the A allele, HOMA-IR showed no further deterioration than that already associated with obesity.	Case Control Study
William J Heerman	0.007, 0.001	High UPF intake associated with a 1.2 higher BMI-Z at 36 months for 3-year-olds (95% CI = 0.5, 1.9; p < 0.001), a 0.6 higher BMI-Z for 4-year-olds (95% CI = 0.2, 1.0; p = 0.007). Not statistically significant for 5-year-olds or overall.	Randomized Trial
Min Yang	0.00000268	Subjects with a TA or AA genotype had an increased risk of obesity compared with the TT participants; the odds ratios (ORs) were 1.47 (95% CI: 1.25–1.71, P=1.73×10^-6), and 3.32 (95% CI: 2.01–5.47, P=2.68×10^-6)	Cross-Sectional Study
Rafael Molina-Luque	0.004, 0.001	Children with AA variant showed a higher average weight (p = 0.004), BM (z-score) (p = 0.001), higher mean values of fasting insulin (p < 0.001), HOMA-R (p = 0.004) and TC (p = 0.051), higher prevalence of MetS (p = 0.006), with 44.7%, compared to 23% and 15% present in children with TT (Wild type) and TA (Heterozygous) genotypes	Cross-Sectional Study

Table 1: Studies in Paper: This table shows the combined p-values from various tests used to create Fisher's statistical analysis (p < 0.000001, Fisher's statistic: 89.2332).

To ensure reproducibility, We selected studies based on the following inclusion criteria: human participants aged 0–18 years, a measurement of obesity, and either an assessment of UPF intake or the genetic analysis of rs9939609 (Table 3). All p-values were recorded for use with Fisher's method (a method to combine p-values to form a combination of p-values to evaluate the overall statistical significance of the association).

The five studies meeting the inclusion criteria were published between 2015 and 2024, reflecting nearly a decade of research on the combined influence of the FTO rs9939609 variant and ultra-processed food consumption in youth. The earliest included study was published in 2015 (4), followed by Yang et al. (1), Heerman et al. (5), and Molina-Luque et al. (6). This chronological spread allowed the meta-analysis to incorporate evolving dietary trends and advances in genetic analysis.

	UPF consumption ≤50th percentile	UPF consumption >50th percentile	Total
Median age (years)	4.0 (3.4-4.8)	4.4 (3.6-5.2)	4.3 (3.6-5.0)
Number overweight	105 (35.2%)	96 (32.3%)	201 (33.8%)
Number obese	3 (1.0%)	2 (0.7%)	5 (0.8%)

Table 3. Obesity rates and UPF consumption: Baseline characteristics, stratified by the median percent of ultra-processed foods and by overall percentages. Source: Heerman et al. 2023

RESULTS

Tables 2 and 3 show that the FTO rs9939609 A allele is consistently linked to a higher risk of obesity. Meta-analyses and case-control studies found strong associations, especially in children and in prepubertal girls with greater insulin resistance. Cross-sectional and randomized studies confirmed that A allele carriers have higher BMI, insulin resistance, and metabolic syndrome. Together, the findings highlight the combined influence of genetics and diet on obesity risk.

We used their p-values to generate an overall p-value to represent the entire study. Combined, the five studies collectively show a consistent link between the FTO rs9939609 genetic variant, ultra-processed food (UPF) consumption, and obesity-related outcomes in children. The large meta-analysis by L.-L. Quan found that the A allele was significantly associated with increased obesity risk across multiple genetic models, with a significant statistical value (3). Similarly, Riffo's case-control study reported that each A allele increased the odds of obesity by 42% (4).

Heerman's randomized trial demonstrated that higher UPF intake in early childhood was associated with significantly higher BMI z-scores at ages 3 and 4 (p

	T/T Genotype	T/A Genotype	A/A Genotype	p-Value (for z-scores)
Normal weight sample size	73	47	16	
Obese weight sample size	111	67	60	
Normal weight BMI z-score	0.43 ± 0.38	0.46 ± 0.28	0.38 ± 0.39	0.704
Obese weight BMI z-score	2.01 ± 0.24	2.12 ± 0.33	2.14 ± 0.28	0.003

Table 2z; BMI of genotypes: Descriptive anthropometric characteristics of the school children cohort by genotype and nutritional condition

= 0.001 - 0.007), though this effect was not seen in older children (5). In a cross-sectional study, Yang found that children with TA or AA genotypes had a substantially higher obesity risk compared to the TT genotype (1). Finally, Molina-Luque's cross-sectional research showed that children with the AA genotype had higher body weight and the highest prevalence of metabolic syndrome, with statistical significance across most measures ($p < 0.05$) (6). Together, these studies reinforce my hypothesis that genetic predisposition from the FTO A allele can magnify the harmful metabolic effects of high UPF intake in children.

Table 1 shows BMI z-scores across the three FTO rs9939609 genotypes. TA carriers have significantly higher BMI z-scores compared to TT, while AA carriers exhibit the greatest BMI values overall. Notably, the TT group's mean BMI z-score is already around +2, the clinical threshold for obesity in children, meaning all genotype groups in this cohort are in the obese range. This pattern mirrors findings from Riffo et al. (2), further supporting the association between the A allele and elevated BMI in children, and suggesting that genetic susceptibility may amplify the risk of excess weight gain.

There is a large statistical difference in BMI between those who consume high amounts of UPFs and those who do not (5), but it appears that this gap lessens as time goes on. While this was most apparent at 3 years old, the gap appeared smaller at 4 years old, and was nearly nonexistent at 5 years old. However, the maximum age of the study from which this conclusion was drawn was 5.0 years old, so the low number of participants who were close enough to that age limit may have meant that the results for 5-year-olds were inaccurate. These results could also suggest that high UPF consumption has the strongest impact on body weight in the earliest preschool years. The final p-value obtained (10^-6) provides evidence against the null hypothesis and supports the presence of a gene-environment interaction. This p-value also reveals a significant association between higher UPF consumption, the A allele of the FTO rs9939609 polymorphism, and an increased risk of obesity.

DISCUSSION

Overall, these results suggest that genetic predisposition, in conjunction with dietary habits, plays a critical role in shaping obesity risk during childhood and adolescence. Individuals carrying the FTO rs9939609 risk allele are more likely to consume diets high in energy-dense, nutrient-poor ultra-processed foods (UPFs) (2), which may promote overeating, excess calorie intake, and greater fat storage. This combination can accelerate weight gain and increase the likelihood of developing obesity-related health problems early in life (7).

Despite the strength of the observed associations, several limitations must be considered. Many included studies relied on self-reported dietary data, which may introduce recall bias or underreporting. Not all controlled for confounding factors such as socioeconomic status and physical activity, and genetic heterogeneity across populations may limit generalizability. Additionally, the relatively small number of studies available for this review may reduce the precision of effect estimates.

Nonetheless, the findings carry important public health implications. With UPF consumption rising globally—particularly among youth—targeted interventions may be warranted for genetically susceptible individuals. These could include personalized nutrition counseling, family-based dietary education, and policy measures aimed at limiting the availability and marketing of UPFs to children.

Five studies provide strong evidence that both genetics and diet independently influence obesity risk in children. The convergence of these findings suggests

that children carrying the A allele may be especially vulnerable to the harmful effects of high-UPF diets, highlighting a potential gene-diet interaction where genetic predisposition amplifies dietary risk. This underscores the importance of targeted nutrition strategies in genetically at-risk children to prevent early-onset obesity and related metabolic disorders.

Key scientific questions remain, particularly regarding the biological mechanisms through which FTO variants interact with dietary patterns to influence metabolism, appetite regulation, and food preference. While the association between genotype and diet, the underlying pathways are incompletely understood. Future studies using longitudinal designs, objective dietary assessments, and functional genomics could clarify how genetic risk translates into behavioral and physiological responses to food environments.

Intervention studies that specifically reduce UPF intake in genetically at-risk children could help determine whether early lifestyle changes can mitigate genetic vulnerability. Further research should also explore whether similar interactions exist for other obesity-related genes and whether particular components of UPFs—such as additives or emulsifiers—exert stronger effects in individuals with FTO risk alleles.

In conclusion, this synthesis underscores the need to consider both genetic and environmental factors when addressing the pediatric obesity epidemic. Tailored strategies that integrate genetic risk screening with targeted behavioral and environmental modifications may offer a more effective approach to prevention and long-term health promotion in adolescent patients.

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What Benefits Can Olympics Bring?

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ABSTRACT

Around the world, thousands of cities ask themselves how they can improve. How they can increase their GDP, their tourism levels, and their employment rates. When the Olympics go to a city they invest billions of dollars into constructing facilities and support infrastructure. The influence of the influx of governmental spending due to the Olympics allows the cities to completely transform their life. This spending allows the city to promote themselves to the world, which in turn creates more jobs for their citizens, increases the GDP of the country/city and increases tourism as well. The Olympics have tremendous power to create change for a city by revitalizing them and bringing them to the world stage. For Seoul, the Olympics was a resounding success in being able to boost its economy by 255 million dollars. Not only did they boost their tourism and economy, but they also integrated the Olympic facilities into their city which began to separate South Korea from North Korea on a global scale. Despite all the benefits that come from the Olympics, when resources are misutilized like in Athens, stadiums are built without purpose and the hope of revitalizing a city is not just slowed down, but killed as city officials look to avoid events like the Olympics in the future. In the future, the Olympics can and will bring massive benefits to cities given the proper care.

INTRODUCTION

Around the world, cities are constantly trying to improve and keep up with the demands of rising urban populations. .. budget constraints and policies make implementing sweeping changes incredibly hard.. In order for a city to meet the growing needs of its people in the modern era, the whole ecosystem surrounding it needs to change (1).

From transit, to housing, to local businesses, everything needs to adapt. For public transport, this means creating new lines that connect new areas of the city to older areas in need of more reliable and accessible mobility. In terms of housing, this could mean creating state-of-the-art apartments, suites, and hotels to accommodate the influx of tourism and population. Local businesses would have to adapt to the new environment and new ones would need to be created to support the growing population.

The Olympics are an amazing event that brings together cities, countries and athletes around the world to compete, show off their skills and also importantly show off the city. They can bring in money, infrastructure benefits and sponsorship like never seen at other types of events. As a result, the benefits that can come from the Olympics are immense. Despite these benefits, cities have been avoiding the Olympics like a plague to the point where the Olympics have to work personally with the cities to convince them to let them come. When the Olympics go to a city they invest billions of dollars into constructing facilities and support infrastructure. Thinking about this, cities are constantly saying they need new facilities, new infrastructure, yet they don't have the funds or support to complete these projects. Public transportation and new stadiums are often left out, or done poorly in a way that is unsustainable. In past games like Rio (2016) and Sochi (2014), new facilities have been made to accommodate the games. Sadly, these multi-million dollar stadiums and infrastructure only exist for a few months. After the events, they are left to rot and are called white elephant stadiums or do not serve the community they need to (2). Despite this, these events liven up a city and allow it to be much more successful in the coming years if the budget is utilized correctly. In cases like Vancouver, it brings massive upsides with more of the general population utilizing public transport after seeing it after the games. Athens and Atlanta completely revitalized their city and allowed them to host more events in the

future. In cases like Rio however, spending does not always provide benefits despite being a place with the most need for funding. In proper utilization cases (like Barcelona), however, public transportation and other factors can lead to decreased unemployment and increased tourism in the city and the country.

The vast amount of resources needed to create these changes is hard to come by, yet every 4 years, change can come. When events like the Olympics roll around, billions of dollars is invested into creating new infrastructure to support the event. The influence of the influx of governmental spending due to the Olympics can allow a city to completely transform. This investment allows the city to promote themselves to the world, which in turn can result in higher tourism, creation of jobs for their citizens, and increases the GDP of the country/city as well.

Hosting the Olympics can be a boon for a city, but it hasn't always been. Here, we look at the impact that hosting the Olympics has had on multiple cities in the past in order to understand the context of what the long term impacts have been. We conducted a review to gather data on GDP, unemployment, and tourism rates in 8 cities between 1984 and 2012 to assess how each of those cities was impacted by hosting the Olympics.

METHODS

The data for this research paper was collected through looking through databases that collected data on tourism, GDP, and unemployment figures. By focusing on graphs and specific timeframes, we were able to find the correct data points and visualize them year over year to see the impacts of the Olympics. However, One key thing we had to keep in mind was the effect of outside events besides the Olympics. As a result, we also had to research the key events that happened around the Olympics time and make note of them to ensure the data was reliable.

This research was conducted by using public databases accessed through Google Scholar. By searching for a graph of a city's respective relevant data points, I was able to access specific detailed data for each city based on each year. Search terms used included city name and year, GDP, unemployment/employment rates, population, and tourism. For example, by searching Sydney, 1990- 2010 GDP or population data, I was able to obtain graphs and detailed data breakdown of the different categories I was looking into.

RESULTS

This study was conducted to see how we can utilize a large influx of resources to better support an area. For example, in areas like Atlanta and Sydney, the allocation of resources from the Olympic Planning Committee helped them be put on the map allowing them to host other world wide events in the future. In addition, the unemployment rate within these areas was no less than the world at the worst and at times beat the world unemployment rate change by 16%. The GDP has consistently grown following the Olympics where in LA84, they gained 1200m in GDP following the Olympics. In Barcelona, public transport was revitalized as the local economy bounced back from trying times by going down 8.8%. Despite all the benefits that come from the Olympics, when resources are misutilized like in Athens, stadiums are built without purpose and the hope of revitalizing a city is not just slowed down, but killed as city officials look to avoid events like the Olympics in the future. Overall, when resources are utilized correctly when planning Olympics, a city can be completely revitalized and put back on the world map ready for more economical development.

The LA 84 Olympics became a baseline for how Olympics were to be modeled from in the future. Utilizing existing structures in order to keep costs down and creating jobs for the locals. As a result, the LA 84 Olympics turned a healthy profit of 234 million dollars and increased the state's overall GDP by 1,200 million dollars. For Seoul, the Olympics was a resounding success in being able to boost its economy by 255 million dollars. Not only did they boost their tourism and economy, but they also integrated the Olympic facilities into their city which began to separate South Korea from North Korea on a global scale. Barcelona saw a massive increase in tourism that helped bolster the local economy. As a result, unemployment was cut across the board partly due to infrastructure that was not just left to rot, but actually utilized by the citizens. The Atlanta Olympics despite its controversies put Atlanta on the global map.

Country, Year	GDP	Unemployment	Global Unemployment	Tourism
Los Angeles 1984	+1,200	-2.3% (7.7%-5.4%)		
Seoul, 1988	+255	0% (2%-2%)		
Barcelona 1992	+12	-8.8% (18.4%-9.6%)		
Atlanta 1996	+2,250	Unclear	+2.02%	+29%
Sydney 2000	+198	-.89% (6.29%-5.4%)	-.72%	+38%
Athens 2004	+115	-2.97% (10.63%-7.66%)	-2.97%	+3%
Beijing 2008	+3000	+.01% (4.58%-4.59%)	+17.07%	
London 2012	-18	-3.7% (10-6.3%)	-1.22%	+4%

Table 1: Effect on GDP, population, unemployment of a country/city 1-4 years after hosting the Olympics.

The LA 84 Olympics became a baseline for how Olympics were to be modeled from in the future. Utilizing existing structures in order to keep costs down and creating jobs for the locals. As a result, the LA 84 Olympics turned a healthy profit of 234 million dollars and increased the state's overall GDP by 1,200 million dollars. For Seoul, the Olympics was a resounding success in being able to boost its economy by 255 million dollars. Not only did they boost their tourism and economy, but they also integrated the Olympic facilities into their city which began to separate South Korea from North Korea on a global scale. Barcelona saw a massive increase in tourism that helped bolster the local economy. As a result, unemployment was cut across the board partly due to infrastructure that was not just left to rot, but actually utilized by the citizens. The Atlanta Olympics despite its controversies put Atlanta on the global map. The economic benefits of an increase of 2250 million usd for the country were superficial however, and their main benefits came from the city becoming more known globally. The Sydney Olympics brought Australia forward as a sophisticated country which allowed them to have other opportunities like the FIFA Women's World Cup. Their economic improvements were limited, with only a 198 million USD GDP improvement, but the tourism increase was immense at 38%. The Athens Olympics used the money to revitalize the city, but at the same time was misguided in its spending. Tourism increased by 3 percent after the Olympics, but it had the same global unemployment delta of -2.97%. The Beijing Olympics allowed China to spend much more money on urban Infrastructure and Development allowing them to be viewed differently at the world level and became much more sustainable with a .01% unemployment delta, and a 3000 million dollar GDP increase. The London Olympics led the citizens to feel better, but the economic effects were not there. A 18 million dollar deficit in terms of GDP and only 4% tourism increase is far below average for a successful Olympics.

DISCUSSION

Obviously, with the introduction of the Olympics to a city, their tourism will naturally increase. The real question however is how much will it increase, and how long it will last. With Olympics money being able to allow for better infrastructure in the city, tourism naturally increases. The city's overall presence becomes much larger in the overall scope of the world. As an example, for Sydney, the addition of the Olympics led to them being much better known and being able to host many more games such as the 2023 FIFA Women's World Cup. These events compound upon each other and lead to greater international representation and tourism for the country. In addition, speaking from pure tourism numbers, can receive a huge bump receiving nearly 4% extra tourism in a year and gaining 2.4 billion dollars of additional revenue from tourism (3). Being able to grow on the current infrastructure and designing stuff to help the city as a side effect helps the Olympics as well. In 1964, Tokyo introduced high-speed rail which is today a staple of Asian Olympics and Asian culture. The event of the Olympics brought historic change that improved the lives of tourists and the citizens of Japan. These efforts to make tourism easier for tourists not only improve the lives and experiences of the tourists but also work to improve the perception of the city and the environment people live in

To accommodate the addition of the increased tourism, more workers are needed. As such, employment is another way for the Olympics to help cities improve their economy. Without a doubt, unemployment drops the moment the Olympics are announced, cities need to be reconstructed and buildings need to be constructed. Recently, this number has reached roughly 150,000 part-time jobs for the Paris 2024 Olympics (Paris 2024 Olympic Games). The resulting factor though is what is interesting. If stadiums are built and then left to rot after the Olympics are over, we clearly have a problem. Cities spend far too much money creating temporary structures that could be used to help employ citizens if a plan was made beforehand. However, if the Olympics are run correctly, tons of jobs can be created. Jobs in retail, infrastructure upkeep and so much more are created when new infrastructure is created. As public perception of a city grows, so do the jobs needed to keep this perception. Thus, for Olympics that are wildly considered a success or even those that aren't they have historically been at or below the global average.

It is not like those not working have just disappeared as well, real jobs have been created from the Olympics. A well run stadium can create well over 5,000 jobs from maintenance to executive positions within a sports club. These stadiums as well can create nearly 40 million dollars towards the economy just with the sports team excluding other events that can now be hosted as well. (Stadium Employs Equivalent of 195 Full-Time Workers in First Year)

As stadiums that are built last for decades, part-time jobs are a common occurrence due to the different events that come to these stadiums. These events that occur in these cities are only possible due to the already existing infrastructure in these cities. For example, if Taylor Swift wanted a show in Athens, she wouldn't just create a stadium just for that concert. Instead, she would have to rent a venue that is pre-existing. Not many events have the power to have a city build a stadium just for them, but the Olympics do. These Stadiums constructed for the Olympics not only allow for jobs to be created from the Olympics but also a perpetual cycle that employs millions of part-time workers.

When comparing cities, Barcelona and Sydney are standouts in their numbers. Barcelona had a 8.8% decrease in unemployment and Sydney had a .89% decrease in unemployment. By analyzing the two cities and their actions taken to make their olympics how they were it is immediately clear why Barcelona had a much larger decrease in unemployment. They invested in better transportation that increased the demand for the service and in revitalizing the economy by building better infrastructure. Sydney, on the other hand chose to develop stadiums, that while good for the country and allowed them to decrease unemployment by making some jobs had a much less unemployment when compared to the world average (Table 1). The two cities took vastly different approaches to better their city. Sydney with more future proof big time events and Barcelona with more long term sustained effects. Nevertheless, both cities created an environment for their economy to prosper.

Finally, the Olympics improves perception of a hosting city and drastically increases their economic power. Cities that host the Olympics routinely increase their

GDP and beat the global unemployment rate (Table 1). In addition, cities that host the Olympics are given new state-of-the-art facilities that allow them to not only the Olympics but the Olympics of next time as well as other sporting events. As a result, the countries that host the Olympics routinely increase their tourism numbers and become better globally recognized. The Olympics have tremendous power to create change for a city by revitalizing them and bringing them to the world stage.

Gross domestic product (GDP) measures the total value that a country provides to the world. From its products to its services all of that is included. It is also an indicator of how well the country is doing. An uptick in GDP shows a better image of the country to the entire world. A single person from a certain country will not have a huge sway on that country's GDP, economic policies, government spending, business investments, and net exports are some contributors that determine the GDP of a country. The Olympics are such events. Most people believe that it drains the economy overall making it a bad event.(Youth Perceptions of the Olympic Games) The London 2012 Olympics contributed to an 18 mil USD loss in GDP for England (Table 1). However in most cases where proper planning takes place, the Olympics can turn a struggling economy into one that is prepared for the future. Korea is one such example. While not a country that was in the deepest trench as possible, they were still not at the best. Compared to Japan they are overall a smaller country. Less Population, less working force, and less GDP. Despite this fact after the 1992 Seoul Olympics, Korea was able to bounce back from the Asian Financial Crisis of 1997 within a year while Japan has never really recovered from this crisis. Similarly, in Thailand, the epicenter of the crisis, their economy also faltered under the crisis and flatlined for a while afterward.

Despite all these positive benefits from the Olympics, there are still cases like 2016 Rio where the investments Rio made into the Olympics did not pan out. Clearly something went wrong here. In the 2016 Olympics, the planning was very bad as planners constructed brand new venues with no plan for the future and essentially made billion-dollar structures that just sit there today. As a result of this, infrastructure that could have been built to better improve a city in a different city was not made in favor of having the Olympics in Rio which had very few sustainable structures. Despite cities viewing Los Angeles 1984 as a huge success in terms of hosting the Olympics, many of them have forgotten the principles that led LA 84 to be such a great Olympics. Creating minimal infrastructure and when creating these large buildings, having clear plans to reuse or have plans for organizations within the city to use them in the future. Many cities have begun creating new unsustainable stadiums that are left to rot, instead of creating new purposefully built stadiums, or utilizing existing structures. These actions lead to more and more waste within the world as cities create state of the art facilities with no real plan or purpose in the future.

In the future, the Olympics can and will bring massive benefits to cities given the proper care. Ideally, a city that is like Vancouver that has its own standing as a city in the world already, but can be propelled to greater heights later on is the ideal candidate.

Despite this, there are still gaps in data, with being unable to accurately measure the effects of new stadiums on the cities, it becomes hard to truly measure the impact of the Olympics. There is indeed a trade-off for how many stadiums you can build within a city and their benefit, however ,if we are able to better understand this, we can create much better host cities in the future.

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