The Proportional Relationship Between Topographical Elevation Levels and Eutrophication-Induced Harmful Algal Blooms

Brianna Estocapio
Institute for Systems Biology (ISB)
Environmental Systems in the Outdoors Research Experience (ESORE)
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Contents

Abstract

Eutrophication and the proliferation of Harmful Algal Blooms (HAB's) have become commonplace in Washington State's freshwater ecosystems in recent years during higher UV exposure months. With the primary contributing variables being nutrient pollution of excess phosphorus (phosphate PO_4) and Nitrogen (ammonia NH_3 / nitrates $NO^-{}_3$ / nitrites $NO^-{}_2$), ultimately such eutrophication-driven hypoxic dead zones[1] can be linked to agricultural sources and incompetent drainage systems. These factors pose the question of how the proportionate relationship between increased nutrient pollution and HAB's could indicate similar proportionality between topographical elevation levels and the growth of phytoplankton and cyanobacteria. Additionally, the water samples taken to test this hypothesis were solely from Washington State freshwater and saltwater sites with relative proximity within or near Seattle. Each site was specific in different elevation levels and water testing strips were compared accordingly.

Introduction

One of the stakeholders in the degradation of United States water quality is the presence of nutrient pollution. This form of aquatic pollution occurs when a surplus of nitrogen (typically nitrate or nitrite) or phosphorus (typically phosphate) enters surface and ground water through upstream freshwater sources such as creeks, natural streams, or rivers. A natural excess supply of such nutrients in bodies of fresh and saltwater may be prevalent because of the erosion of minerals through weathering, human-driven activities like agricultural fertilizer use and improper livestock waste disposal, emission from septic systems and sewage treatment plants, or general storm drain water runoff and incompetent drainage. For comparative measures, the standards that were used as a baseline for these nutrients are outlined by the Environmental Protection Agency (EPA) and Agency for Toxic Substances and Disease Registry (ATSDR) where the aquatic maximum contaminant level (MCL) for nitrites is <1ppm (1mg/L) and <10ppm (10mg/L) for nitrates.[2] Furthermore, nutrient pollution contributes to the development of HAB's through cultural eutrophication. This is the process where humans introduce an abundance of nutrient sources to marine ecosystems so that photosynthetic organisms such as cyanobacteria, noxious phytoplankton, dinoflagellates, and diatoms can easily grow. During the height of a Cyanobacteria Algal Bloom (CyanoHAB), cyanotoxins are heavily produced, and during the height of a noxious phytoplankton's Red Tide the unicellular microalgae also contribute toxins

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[1]Defined by The United States Environmental Protection Agency (EPA) as a decrease in dissolved oxygen levels, killing marine life, as a result of exponential growth of algal blooms that decompose organic matter: Hyde, James B. *Documented Hypoxia and Associated Risk Factors in Estuaries, Coastal Waters, and the Great Lakes Ecosystems*, Environmental Protection Agency (EPA), 30 Nov. 2023 www.epa.gov/nutrientpollution/documented-hypoxia-and-associated-risk-factors-estuaries-coastal-waters-and-great.

[2] Smith, Bailey. *Nitrate & Nitrite Rule for Transient Non-Community Water Systems*, Environmental Protection Agency (EPA), 2018, www.epa.gov/sites/default/files/2018-05/documents/nitrate_and_nitrite_rule_training_presentation.pdf

that are fatal to other marine organisms like shellfish and oysters; Additionally, the presence of such algae overgrowth depletes sunlight from other photic zone marine life and raises Potential Hydrogen (pH) levels ($\geq$9.2)[3]. In death HAB's also pose a detrimental risk to the aquatic habitat as the decomposition of dead algae exhausts oxygen levels, creating hypoxia.

Relating back to nutrient pollution, because phosphorous and nitrogen-rich drainage filters into upstream waterways that are a convoy for such nutrients, the structuring hypothesis for this paper and accompanying experimentation is that higher geographic elevation levels are correspondent to higher risk of cultural eutrophication and development of HAB's or CyanoHAB's in bodies of water that surround or at the base of those climaxed elevations. The purpose of this research is therefore to analyze trends in qualitative ecological details and relating pH, nitrite, and nitrate parts per million (ppm) levels while connecting them to topographical elevation data that is approximate to the sample site location. While preceding studies on elevated nutrient levels in Puget Sound and Washington State waterways haven't analyzed a specific connection to elevation, they have outlined trends of change, nitrogen pathways, and the relationship between nutrient concentration and water quality. In a computer-rendered Salish Sea Model from the Washington State Department of Ecology (WSDOE) there are data outputs that suggest the presence of excess phosphorous and nitrogen in the Puget Sound to be linked to the contamination of upstream rivers from wastewater treatment plants.[4] Similarly, WSDOE's "Story Map" of nitrogen in Puget Sound records the nitrogen concentrations from anthropogenic activities. From this report wastewater with dissolved inorganic nitrogen in addition to septic system effluent, both contributed >10mg/L of nitrogen into Puget Sound while natural sources only contributed <1mg/L of dissolved inorganic nitrogen.

Methodology

Water samples were taken from 5 freshwater stations within Washington State (Bitter Lake, Green Lake, Ballinger Lake, Pine Lake, and Lake Serene) and 1 saltwater location from Puget Sound (Eagle Harbor). A method of simple probability sampling was exercised as at each of the given locations 3 samples were taken from differing points around the body of water – with the exception being Bitter Lake where 2 samples were collected - and subsequent data was averaged. This ensured the invalidating of research bias and allowed generalizations to be made about the average nutrient levels around the perimeter of such locations. Below, the provided graphic outlines the connections each of the sample locations has with elevation levels and GPS coordination.

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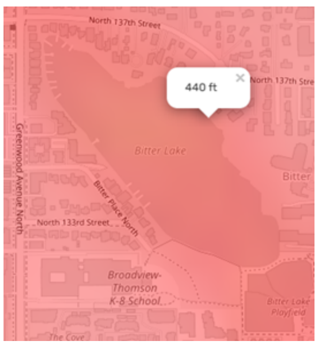
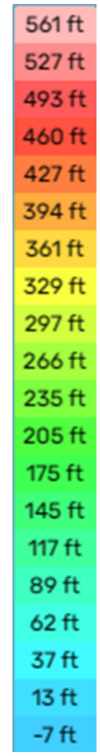
[3] Gann, Eric R., et al. "Elevated pH Conditions Associated with Microcystis Spp.. Blooms Decrease Viability of the Cultured Diatom Fragilaria Crotonensis and Natural Diatoms in Lake Erie." Edited by Brittany N. Zepernick, *Frontiers*, 20 Jan. 2021, www.frontiersin.org/articles/10.3389/fmicb.2021.598736/full.

[4] Figueroa-Kaminsky, Cristiana. "Washington State Department of Ecology Salish Sea Model." *(EPA)*, 2019, ecology.wa.gov/Research-Data/Data-resources/Models-spreadsheets/Modeling-the-environment/Salish-Sea-modeling.

Table 1 - Topography Spectrum

<table>
<tr><th>High Elevation (440ft-540ft)</th><th>Medium Elevation (270ft-400ft)</th><th>Low Elevation (0ft-200ft)</th><th>Topography Spectrum</th></tr>
<tr>
<td>Bitter Lake (BIL): 47°43'39"N 122°21'05"W</td>
<td>Lake Ballinger (BAL): 47°47'01"N 122°19'34"W</td>
<td>Green Lake (GRL): 47°40'57"N 122°20'22"W</td>
<td></td>
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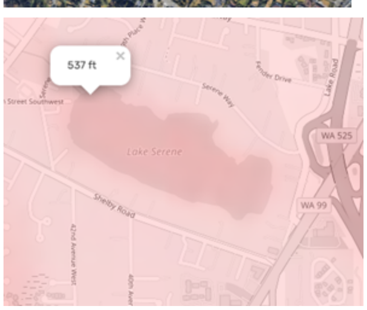
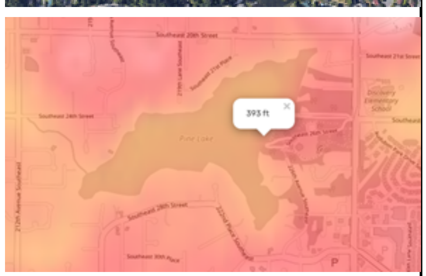
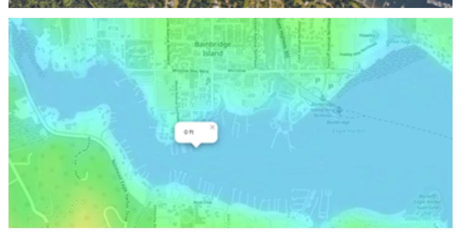
<td>Lake Serene (SEL): 47°52'17"N 122°17'24"W</td>
<td>Pine Lake (PIL): 47°35'13"N 122°02'29"W</td>
<td>Eagle Harbor (EAH): 47°37'30"N 122°32'18"W</td>
<td></td>
</tr>
</table>

Table 2 – Exact Elevation Values (ft)

High Elevation	**Medium Elevation**	**Low Elevation**
Bitter Lake (BIL): 440ft	Lake Ballinger (BAL): 274ft	Green Lake (GRL): 154ft
Serene Lake (SEL): 537ft	Pine Lake (PIL): 393ft	Eagle Harbor (EAH): 0ft

Throughout the experimentation process, the materials used were as follows: 15ml Centrifuge Tubes (sterile) and rack, dial thermometer, glass thermometer, GPS device (digital), Tetra Easy Strips, and API Test Strips.

Procedure

The procedure and protocol taken for equipment was consistent for every sampling and data collection segment. Preceding every location visit, 2 different types of thermometers – both a dial and glass – were calibrated back to the candid starting value of 0°F (≈-18°C) by placing them in separate 8oz glasses filled with water and halfway with ice. The thermometers were removed when both read 0°F. As for during a location visit, U.S. Geological Survey (USGS) water quality sampling techniques were applied.[5] For every 3 vertical sections of the body of water chosen, a different centrifuge tube was used by moving the tube vertically from a lower depth up towards the surface. After the samples were successfully collected, the temperature in both Celsius and Fahrenheit was collected by almost completely submerging both the dial and glass thermometers in the given locations for >3 minutes. In regards to the sample testing procedure with both the API and Tetra test strips, each strip was dipped directly into the sample, swirled 2 times for 20 seconds, the removed with the pH, $NO^-_{3,}$ $NO^-_{2,}$ KH, and GH (general hardness) pads facing upward. >30 seconds were suspended before reading the $NO^-_{3,}$ $NO^-_{2,}$ or pH values.
Criteria was also attributed to analyzing the qualitative data from ecological signs upon arrival at each location. For this collection of qualitative data, characteristic standards were taken from the Washington State Department of Health (DOH)[6] and pertained to determining how much sunlight the sample site received and therefore how much surrounding foliage there was, if algal mats or foam were present on the surface, if green or opaque discoloration was present as a result of cyanopigments (Blue-Green Algae), and presence of dead marine life.
After the collection process, samples were stored in a 34°F container and covered completely by a dark cloth.

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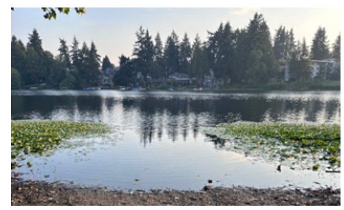
[5] Miller, Cheryl Eddy, et al. "Water Quality Sampling Techniques." *Water Quality Sampling Techniques | U.S. Geological Survey*, (USGS), www.usgs.gov/special-topics/water-science-school/science/water-quality-sampling-techniques. Accessed 22 Dec. 2023.

[6] Lindquist, Scott. "Epitrends - Washington State Department of Health." Edited by Marcia J Goldoft, *WADOH*, June 2021, doh.wa.gov/sites/default/files/legacy/Documents/5100/420-002-epitrends2021-06.pdf.

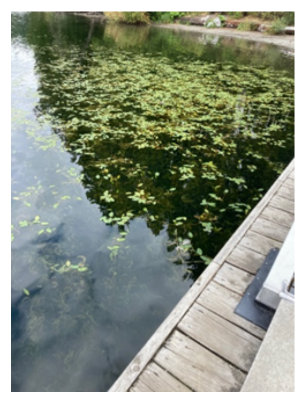
Results

The data for this experimentation is two-fold, with the qualitative being aquatic characteristics of the sample locations and the quantitative being the Tetra and API test strip values for pH, NO^{-}_{3}, NO^{-}_{2}, KH, GH, and Cl (Chlorine only applicable to Tetra).

*Table 3 – Qualitative and Temperature Values**[7]***

#	Location	Temperature (°F)	Water Type	UV Exposure	Ecological Characteristics	Visuals
1	BIL NE	≈70°F	Freshwater	Part Shade	Consolidation of some algae mats, on-water lily pad foliage, limited green discoloration	
2	BIL N	≈70°F	Freshwater	Full Sun	Mostly clear, no foliage	
1	GRL NW	≈72°F	Freshwater	Full Shade	Medium to dense surrounding foliage, green organic matter clots, hydrilla noxious aquatic weed growth	
2	GRL W	≈77°F	Freshwater	Part Shade	Dense surrounding foliage, no discoloration, clear shoreline	

[7] In accompaniment to location abbreviations: N – North, E – East, S – South, W - West

3	GRL NE	≈80°F	Freshwater	Full Sun	No surrounding foliage, brown discoloration	
1	BAL E	≈65°F	Freshwater	Full Sun	Sparse foliage, very clear shoreline	
2	BAL NE	≈65°F	Freshwater	Part Shade	Dense surrounding Blue Lyme Grass, lily pad growth, iridescent gasoline film on shore	
3	BAL N	≈60°F	Freshwater	Full Sun	Sparse low foliage, slight algal matting, large lily pad growth	
1	PIL E	≈72°F	Freshwater	Full Sun	Semi-dense surrounding foliage, clear shoreline water	
2	PIL E	≈71°F	Freshwater	Full Sun	No surrounding foliage, noxious aquatic weed growth (water lilies)	

3	PIL NE	≈73°F	Freshwater	Part Shade	Dense surrounding foliage, dense noxious aquatic weed growth, no discoloration	
1 2 3	SEL W	≈72°F	Freshwater	Full Sun	Minimal surrounding foliage, dense lily pad growth, visible marine life	
1	EAH W	≈77°F	Saltwater	Full Sun	Dense surrounding foliage, extremely opaque water, shoreline clay	
2 3	EAH W	≈62°F	Saltwater	Full Sun	No surrounding foliage, mostly clear shoreline	

Table 4 – Quantitative API Test Strips and Tetra Easy Strips (Cl Values)

Sample Number	Location	pH	NO^{-}_{2} (Nitrite) ppm (mg/L)	NO^{-}_{3} (Nitrate) ppm (mg/L)	KH (Carbonate Hardness) ppm (mg/L)	GH (General Hardness) ppm (mg/L)	Cl (Chlorine) ppm (mg/L)
1	BIL NE	7.5	0.5	20	40	30	0.5
2	BIL N	6.5	0	0	0	30	0
1	GRL NW	8.0	1	20	40	120	0
2	GRL W	8.0	0.5	0	40	60	0
3	GRL NE	8.0	0	0	40	60	0
1	BAL E	7.5	0	0	40	60	0
2	BAL NE	7.5	0	0	40	60	0
3	BAL N	7.5	0	20	80	120	0
1	PIL E	6.5	0	0	0	30	0
2	PIL E	6.5	0	0	0	0	0
3	PIL NE	7.0	0	0	0	0	0.5
1	SELW	7.0	0	0	40	30	N/A[8]
2	SEL W	7.0	0	0	40	0	N/A
3	SEL W	0.5	0	0	40	0	0
1	EAH W	7.5	0	0	120	180	N/A
2	EAH SE	7.5	0	0	80	180	N/A
3	EAH SE	7.5	0	0	80	180	N/A

Table 5 – Averaged Quantitative data

Location	pH	NO^{-}_{2} (Nitrite) ppm (mg/L)	NO^{-}_{3} (Nitrate) ppm (mg/L)	KH (Carbonate Hardness) ppm (mg/L)	GH (General Hardness) ppm (mg/L)	Cl (Chlorine) ppm (mg/L)
BIL	7.0	0.2	10	20	30	0.2
GRL	8.0	0.5	10	40	80	0
BAL	7.5	0	10	53.3	80	0
PIL	6.6	0	0	0	10	0.2
SEL	4.8	0	0	40	10	N/A
EAH	7.5	0	0	93.3	180	N/A

[8] N/A Indicates that not enough Tetra strips were available

Analysis and Discussion

Note: As KH, GH, and Cl are not primary indicators of phytoplankton growth or eutrophication, only pH, inorganic nitrite and nitrate will be considered when analyzing the relationship between elevation and nutrient pollution.

Despite not aligning with the rudimentary conclusion that higher elevation creates higher risk for eutrophication, the pH, NO^{-}_{3}, NO^{-}_{2}, and ecological observations did relate to topographical elevation through the criteria of surrounding urbanization and difference in elevation between encircled terrain and the given body of water. When applying this criteria, urbanization was considered first and in order to gage the extent of surrounding urbanization near a sample site the United States Census Bureau demographic data map[9] was used. The highest population levels were found within or just north of Seattle as Green Lake had an approximate 5,355 surrounding population and Lake Ballinger had an approximate 5,693 surrounding population. These statistics align wholly with the quantitative pH results which show GRL and BAL to also have the highest average pH levels of 8.0 and 7.0. Because both nutrients such as nitrogen and a phytoplankton abundance such as HAB's raise pH, the higher average for GRL and BAL indicate more nutrients which could be sourced from the greater surrounding population and urbanization that contribute to elevated runoff percentage. In addition to this, the stark pH fluctuations that occur from such excess nutrients and subsequent photosynthesis (from benefiting algae) were accounted for as samples were taken in the afternoon when pH levels were at their highest. In order to connect these GRL and BAL pH levels and generalized urbanization relation back to elevation levels, the difference in feet between elevation of the lakes and surrounding elevation must be considered because nutrient-permeated runoff and drainage is more likely to flow toward the freshwater lakes in steeper terrain. GRL had the highest difference of 199ft as the lake itself had an elevation of 154ft and the surrounding area had an average elevation of 343ft. The second highest difference of 81ft was at BAL. Again, this aligns with the qualitative data for sample site locations with the highest pH and therefore risk of developing HAB's or CyanoHAB's.

Because of such imperative conclusions, the connection can be made that both the variables of urbanization percentage and elevation difference between sample site and surroundings have a proportional relationship with subsequent nutrient pollution, eutrophication, and potentially harmful phytoplankton (cyanobacteria, noxious phytoplankton, dinoflagellate, or diatom) blooms.

This verdict also matches the quantitative data for low pH, population levels, and elevation difference (PIL and SEL), and medium pH, population levels, and elevation difference (EAH and BIL), however the qualitative data is slightly more difficult to categorize. While there were visual sections of noxious aquatic weed growth and algal matting at Green Lake in both high and low UV exposure areas (and corresponding temperature), ultimately Lake Ballinger had less

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[9] US Census Bureau. "2020 Census Demographic Data Viewer." *Census.Gov*, 8 Dec. 2020, www.census.gov/programs-surveys/geography/data/interactive-maps.html.

conspicuous aquatic attributes and instead had prominent drainage attributes of drainage domes directly on the shoreline which filtered into the lake itself. This offsetting of different attributes was prevalent for other sample locations as well, making the signs of nutrient pollution less straightforward.

In regards to quantitative data for inorganic nitrate and nitrite levels, the criteria of population size and elevation difference was also applicable. The primary difference between average nitrogen statistics and pH statistics was the absence of a "medium level" categorization for nitrogen parts per million (ppm). Despite this, the higher NO^-_3 ppm was found at GRL, BIL, and BAL while the higher NO^-_2 ppm was found at GRL and BIL. The lower NO^-_3 ppm was found at PIL, SEL, and EAH while the lower NO^-_2 ppm was found at PIL, SEL, EAH, and BAL. Once again the higher and comparatively lower NO^-_3 and NO^-_2 levels match the percentage of population size and elevation difference as outlined by the pH's relation. As both NO^-_3 and NO^-_2 can be later converted into ammonium (NH4 +) which is the most bioavailable for cyanobacteria or other HAB phytoplankton to use as biomass, these higher ppm levels at GRL, BIL, and BAL indicate an inflated probability that nutrient pollution is prevalent within those freshwater lakes and therefore a possibility for HAB's to develop. Now, focusing on the lower inorganic nitrate and nitrite levels attributed to PIL, SEL, and EAH, the surrounding population size for each of the respective locations was below 3,810 (SEL/EAH being in the "low" category and PIL being in the "medium" category), and they each had a much lower elevation difference of >425ft. These statistics align with the subordinate NO^-_2 and NO^-_3 ppm while additionally matching the qualitative data. While noxious aquatic weed growth (such as water lilies) was prevalent at SEL, EAH, and PIL, ultimately there was little to no discoloration or algal matting in the water and the shoreline for each location was relatively clear.

Conclusion

Considering that when surrounding population influence and elevation difference is proportionally lower, the nitrogen and pH levels are also lower, a correlation of a directly proportional relationship between elevation difference, urbanization, and eutrophication of surface water (greater possibility for HAB development) can be derived. Photosynthesizing organisms and toxin-producing phytoplankton thrive in higher nitrogen ppm and create more drastic fluctuations in pH. These attributes were seen prominently at the sample locations that had the most surrounding urbanization and population in addition to having the greatest elevation difference between surrounding terrain and the given body of water.

Limitations

The primary limitations of the preceding experimentation were the lack of access to phosphorus sensors and electrochemical probes for dissolved oxygen. The data from such equipment could have further corroborated my hypothesis and supported or modified conclusions based on the pH levels and inorganic nitrate or nitrite ppm levels. As phosphorous is a large component of nutrient pollution and elevated phytoplankton or dinoflagellate growth heavily depletes dissolved oxygen levels creating hypoxic "dead zones", such sensors – if used – could verify which locations were susceptible to eutrophication. Additionally, the use of a light microscope could have aided the identification of which sample sites had the most prevalent phytoplankton or dinoflagellate growth, and therefore which sites could develop HAB's, CyanoHAB's or non-toxic algal blooms with increased UV exposure and nutrients.

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