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The Effects of a Five Degree Fahrenheit Increase in Average Water Temperature on the Growth of Ceratophyllum Demersum, Within a Simulated Tempe Town Lake Environment

Jack Fujino[1] and Kate Nall[#]

[1]Basha High School, USA
[#]Advisor

ABSTRACT

Due to human-driven climate change, the shifting environment of Tempe Town Lake has begun to bring questions to the environmental health of the aquatic plants in the area. This study aimed to investigate a five-degree Fahrenheit temperature increase on the growth of Ceratophyllum Demersum, an aquatic plant native to the North American Continent. This was tested via experimentation, by manipulating the temperatures of two fish tanks containing samples of Ceratophyllum Demersum, before measuring growth through both mass (g) and height (cm). All other nutrient concentrations were matched to Tempe Town Lake to determine the future growth of plants in the area within the context of global climate change. Ceratophyllum Demersum did not appear to experience significant changes in growth due to an increase in temperature; however, the importance of testing all plants due to differing reactions was made apparent in the available literature. This suggests future testing on other plants must be done to determine climate changes' future effects on the health of aquatic ecosystems.

Introduction

There is a problem with plant growth and the environmental state of Arizona waterways such as Tempe Town Lake due to climate change. Slight changes in temperature should not drastically affect the environment of Tempe town lake or the plants that grow there, however as climate change advances, it is inevitable that changes to aquatic ecosystems will occur. This problem has negatively impacted the ecosystem of Tempe Town, as major changes in temperature can affect the growth and health of aquatic plants (AP). APs purify water, and provide aquatic organisms to spawn and feed, if these plants are negatively affected the health of the environment of Tempe Town Lake is put into jeopardy. Despite the need to examine the effects of temperature on specific ecosystems due to the different reactions of each one highlighted in the available literature, research has yet to investigate the effects of temperature increases upon the Tempe Town Lake (TTL) environment. This paper aims to address the aforementioned gap: How does an increase of water temperature by five degrees Fahrenheit affect the growth of Ceratophyllum Demersum (CD) in mass (g) and height (cm) in order to determine Climate Changes effects on a simulated TTL environment?

Literature Review

Search Strategies

The sources were obtained through accredited databases such as EBSCO, Gale Academic OneFile, Google Scholar, etc. To ensure the credibility of the sources, constraints were enacted during the research process, that being, peer-reviewed and full texts. Keywords used during the research were: aquatic plants, aquatic plant growth, plant growth, climate change, and temperature.

Lake Climate History

Researchers in China concluded the major factors that influenced the surface water temperature of multiple lakes located across China's five lake regions. They determined that the most influential factors were air temperature, humidity, surface pressure, wind speed, shortwave radiation and longwave radiation, however their respective influence shifted depending on the season and region (Wang, X., Shi, K., Zhang, Y., Qin, B., Zhang, Y., Wang, W., Woolway, R. I., Piao, S., & Jeppesen, E. 2023). Specifically, air temperature showed the largest effect on lake surface water temperature which can be connected to observed climate change. Wang also reasoned that the increase in lake temperature alongside nutrient rich water would cause increased algae growth, supported by similar events happening globally. It is important to note that in a study done on lake Trasimeno, Chlorophyll-a (the photosynthetic green pigment cells in plants) blooms didn't occur earlier, however a longer, warmer season that occurred earlier in the year would limit the bloom's duration, presumably limiting algae growth as well. The causes were expected to be due to chemical reactions that occurred at higher temperatures, causing more calcium carbonate to precipitate, and lower available nutrients in the water (Free, G., Bresciani, M., Pinardi, M., Peters, S., Laanen, M., Padula, R., Cingolani, A., Charavgis, F., & Giardino, C. 2022). This conflict results from Wang, however the regions are important to consider. As stated by Wang, China is currently using significant amounts of fertilizers, while Free does not explicitly state anything of the sort, it can be assumed that less fertilizers would be used in the region due to socio-economic reasons. This would explain the change in results as less nutrients would be available for algae growth, thus considering nutrient content of the water as a factor while analyzing results of the experiment would be imperative.

Bringing into account the physiological responses to changes in temperature on lake environments, the trends of eutrophication on Poyang Lake support the previous understanding. Both algae and APs grew linearly alongside phosphorus levels, suggesting that it plays a major role in plant growth. It was determined that climate played a large role in determining phosphate levels, and by extension AP and algae growth. This trend continued until reaching half of the biological maximum, or the limit of organisms an ecosystem can sustain (Liao, M., Yu, G., & Guo, Y., 2017). The main factor tested was nutrient levels, however as the concentration is directly related to climate, it is relevant to assume that a change in climate will result in altered plant growth, this connects with both previous phenomena. The increase in temperature could alter phosphorus levels within an ecosystem causing the biological maximum to fluctuate, this could either be seen in increased plant growth seen by Wang, or decreased plant growth seen by Free. The existing research on lake climate history has shown a connection between climate and plant growth, yet it is unknown whether the temperature itself, or other confounding variables that occur due to the temperature, are responsible for the observed plant growth.

Environmental Factors on Terrestrial Plants

While terrestrial plants (TP) are distinct from their aquatic counterparts, they both share similar physiological systems, thus recognizing TP's reactions to environmental conditions brings necessary context to understanding

AP growth. Oxidative damage to plants can be mainly attributed to reactive oxygen species. A buildup of these compounds, which is associated with heat stress in plants, can cause less photon absorption which leads to cell death (Qureshi, H., Abbas, M. H., Jan, T., Mumtaz, K., Mukhtar, H., & Khan, U., 2022). Qureshi found other aspects that affect plant health include: enzymes susceptible to temperature, protein deformation and damage to other areas of the plant. As these phenomena are related to heat stress, increased temperature could be connected to the observed reduction in mass. An article from the Institute of Botany, at the University of Basel found that "Spring development in many ornamental plants from warm regions, such as lilac (Syringa), is primarily controlled by temperature", although other plants will use photoperiods and/or other stimuli to encourage spring development (Körner, C., & Basler, D., 2010). While the study is on TPs, the above phenomenon could explain possible fluctuations in growth of an AP native to a warm climate.

Contrasting those results, a study on Tuber fields in Brazil did show regional changes in the growth of the plants and their fruit, however associating it to a different cause. Potato yields in some areas of Brazil diminished from 21-61%, caused by increased CO_2 causing higher photosynthesis rates and higher temperatures, the higher temperatures caused increased rainfall variability, resulting in many plants experiencing heat stress and dehydration (Bender, F. D., & Sentelhas, P. C., 2020). Bender also determined that the southern region would be one of few regions to benefit from climate change, however it was attributed to increased water availability due to geography, meaning it can be ignored for this study.

The increased CO_2 levels, increased photosynthesis (Bender, F. D., & Sentelhas, P. C., 2020), alongside excess water seen in aquatic environments would suggest increased plant growth, however as temperature is being tested and has been seen to decrease chlorophyll levels in basil plants, decreasing photosynthetic rates (Al-Huqail, A., El-Dakak, R. M., Sanad, M. N., Badr, R. H., Ibrahim, M. M., Soliman, D., & Khan, F., 2020), it is safe to assume that high temperatures could affect TP health and growth.

Environmental Factors on Aquatic Plants

Understanding the reactions of different APs to environmental stimuli provides vital context to understanding observed CD growth. Vallisneria americana is a submerged, perennial plant that overwinters as buds and is commonly found in open, impounded waters (Carhart, A. M., Rohweder, J. J., & Larson, D. M., 2023): Similarly, CD is a submerged, perennial plant that has thread-like leaf divisions, overwinters at the base with broad green tissue and winter buds, typically found in marsh-like, slow moving water, and is native to the North American continent (Halldorson, M., 2022). Global average temperature has seen a gradual increase over time, which is connected to excessive greenhouse gas emissions. V. americana was found to increase its biological niche over time (Carhart, A. M., Rohweder, J. J., & Larson, D. M., 2023), the rise in temperature serves as a possible reasoning for this trend suggesting CD could act similarly in a warmer environment as the plants share many traits. A possible reasoning could be due fluctuations in spring development seen in the study by Körner and Basler, as stated above in the "Environmental Factors on Terrestrial Plants" section.

While it is important to note that specific species will react differently towards environmental stimuli such as: temperature, and light, CO_2 was still deemed a major factor for growth for Hydrilla verticillata, Egeria densa, Lagarosiphon major, and Myriophyllum triphyllum (Hussner, A., Hofstra, D., Jahns, P., & Clayton, J., 2015). As all of these are submerged plants, CO_2 could be responsible for the growth increases seen, however "changes in atmospheric levels, climate change will also cause increasing temperatures (Hussner, A., Smith, R., Mettler-Altmann, T., Hill, M. P., & Coetzee, J., 2019), which will reduce the CO_2 absorption by the water column. Moreover, elevated temperatures will in a given range cause an increasing CO_2 and HCO_3 demand by primary producers, which might limit the effects of the atmospheric CO_2 increase on submerged plants" (Hussner, A., Smith, R., Mettler-Altmann, T., Hill, M. P., & Coetzee, J., 2019). This discrepancy supports the previous idea of specific plants reacting differently to specific environmental factors.

Desmarestia spp., a perennial, Antarctic algae species was shown to be minimally affected by both temperature and CO2 levels; this could be due to the species not estimated to be physiologically stressed in near-future conditions (Schoenrock, K., Schram, J., Amsler, C., McClintock, J., & Angus, R., 2015). These results contrast with a study that found average growth increases on all four APs studied, as temperature increases during a simulated spring environment, increased growth was not seen in the summer environment (Gillard, M., Thiébaut, G., Rossignol, N., Berardocco, S., & Deleu, C., 2017). This was attributed to changes in reactions during each season that stimulated growth in APs. This supports the previous hypothesis that different species will have different reactions to environmental factors, however as the AP, M. scorpioides was conducted in an environment closer than that to Desmarestia spp., temperature may have a higher likelihood to be a major factor in AP growth.

Tempe Town Lake (TTL)

TTL is a man-made body of water located in Tempe, Arizona; management and monitoring of it is done by both the Tempe government and the Salt River Project (SRP) (City of Tempe, AZ, 2023). Monitoring of the lake's vitals showed no drastic changes in PH levels; however, a two-degree Celsius increase in average lake temperature over 4 years was observed (City of Tempe, AZ, 2017-2021). This change in lake temperature could have drastic effects discussed above on the environment of TTL, so testing of the future impacts of climate change must be conducted. Nitrate levels in TTL were suspected to be caused by fertilizer run-off, however it is important to examine how it interacts in the environment. The levels ranged from undetectable to seven parts per million (ppm), while organic carbon was registered as undetectable to 2.9 ppm (City of Tempe, 2022). Overall, the major increase in temperature of TTL, while the pH stays the same, reinforces the proposition that temperature could be affecting AP growth. The levels of nutrients in the water allow for context of plant growth and supplies necessary context to simulate the TTL environment.

Summary

Overall, significant changes to the environment have been seen, mainly the temperature and CO_2 levels, however there is stark debate on whether temperature, CO_2, both or none are the main factors in AP growth. Many researchers found heat stress to limit plant growth both in TPs and APs, however some found higher temperatures increased growth patterns. Similar results were also found with CO_2 levels. The common consensus is that each plant reacts differently to different stimuli, therefore it is imperative to test these factors on specific plants in specific environments. There is a gap in the research on how specifically temperature affects the growth of CD in TTL.

Methods

Study Design

This study explores temperature effects on the growth of CD within a simulated environment, in order to assess the future state of the aquatic environment in TTL. This is important because the growth of APs directly affects the health of the environment, allowing the prediction of future developments associated with climate change.

An experimental study was conducted, which allowed for a quantitative analysis of CD growth. This is important because it will determine whether temperature is an influential factor of growth for CD, which can be generalized to plants of similar physiology. This will allow for a greater understanding of aquatic environments within the context of future climate change. While this design tested the influence of temperature on CD growth; it didn't test the extent of different factors, such as CO2, meaning this study cannot determine whether temperature is the sole factor in AP growth. However, it provided insight on temperatures' effect on AP growth, thus making it applicable to predict the minimum effects of climate change on AP growth through the context of temperature, but not CO2.

Study Method

There is a split among the data in the design of the experiment, but most data are typically experimental. Some studies chose to employ a non-experimental, observational approach to study climate change and AP growth (Free, G., Bresciani, M., Pinardi, M., Peters, S., Laanen, M., Padula, R., Cingolani, A., Charavgis, F., & Giardino, C., 2022). This approach tested both modern and historical observations to determine Chlorophyll-a blooms within Lake Trasimeno, which I connected to algae growth as it is one of the main photosynthetic cells in algae. While this design does highlight the phenomenon of bloom durations of chlorophyll-a, it cannot determine a cause-and-effect relationship between the temperature and the bloom duration, even though the data correlates to that conclusion. Thus I chose to follow the majority of the data and conduct a quantitative, experimental study such as the study done by Chen, Cheng, Zhu, Bañuelos, Shutes, and Wu, which used pure quantitative data, obtained through the manipulation of a specific variable in order to establish a cause-and-effect relationship as their conclusion. They manipulated the salinity of multiple waterbeds, all water was extracted from the same source, and plants were put in all experimental groups and the control group.

The data of the experimental groups were compared against the control to determine a conclusion. These methods resulted in a cause-and-effect relationship between salinity levels and AP survivability. Similarly, my experiment also used experimental and control groups: these consisted of randomly assigned groups of CD. The experimental group would receive the independent variable: a five-degree Fahrenheit increase in average temperature, the control group would remain at average temperature. The dependent variable of both groups would be both the mass and height. A quantitative, experimental method allows for the manipulation of a variable to determine a conclusion, as seen above. This conclusion can be stated as a cause-and-effect relationship, meaning that under the same conditions within the experiment, the same outcome will occur. This method was used within my experiment for that exact reason, as it could determine if temperature actually played a role in the growth of CD, which could be generalized to similar APs. Overall, the observational studies gave a better understanding of the relationship dynamics between temperature and AP growth, which in turn fueled the hypotheses. However, as those studies provided no cause-and-effect relationship, a quantitative, experimental study was executed to determine if temperature increases influence the growth of CD.

Procedures

Firstly, a one week-long testing period of TTL water samples occurred. These tests assessed: ammonia (NH_3), nitrate (NO^-_3), nitrite (NO^-_2), and pH. NH_3, NO^-_3, and NO^-_2, were tested using an API™ freshwater master test kit, and pH was tested using a VIVOSUN stick pH tester. Hours of daylight and temperature were collected by the Tempe Government as about 12 hours a day and an average temperature of TTL over the last five years was recorded in Table.1 (City of Tempe, AZ). These data points were recorded with both the date and time of collection. After the week of testing was over the average was taken of each primary nutrient and pH, then recorded in Table.2.

Secondly, a tank was set up and cycled to introduce necessary bacteria that are present in environments such as TTL. This tank used: a filter to cycle and move water, a heater, and a grow light to match the averaged data points recorded before in Table.2. Because the levels of NO^-_3 and NO^-_2 were insignificant, there was no need to chemically-add concentration of the compounds to the water, since any traces of them were produced or restored through natural biological processes. Temperature needed to be set higher at 82 degrees Fahrenheit (control) and 87 degrees Fahrenheit (experimental) respectively. This temperature was warmer than in the observed period of TTL, which insinuates the results are applicable to a later season than currently observed at TTL. After all parameters were met, CD plants were randomly assigned to either the experimental or control group and tagged appropriately. The light was set for 12 hours a day to match the observed daytime at TTL. Plants were massed and measured, and all data was recorded with the date of collection. This process was repeated for 18 days to gather proper data.

Table 1. TTL Lake Temperature over five years (2017-2021)

Year	°C	°F
2017	20.1	68.18
2018	20.4	68.72
2019	21.01	69.82
2020	22.04	71.67
2021	23.69	74.64
	21.41	70.57

Table 2. Preliminary Water Testing Data of TTL

Date	ppm NH3/NH4+	ppm NO2-	ppm NO3-	pH
3-Jan	0.25	0	0	8.82
4-Jan	0.5	0	0	8.47
5-Jan	0.25	0	0	8.26
6-Jan	0.5	0.25	0	8.35
7-Jan	0.25	0	0	8.51
8-Jan	0.25	0	0	8.42
9-Jan	0.25	0	5	8.61
	0.32143	0.03571	0.71429	8.49143

Statistics

Finally, the results were put through a Multivariate Analysis of Variance (MANOVA) to determine if the temperature caused a significant change in the dependent variables of mass or length. After, tests of variability upon the data were run to confirm whether the data was evenly distributed, and thus, if the MANOVA results were reliable. Following the MANOVA, an independent samples T-Test was performed to further justify the results of the MANOVA.

Results

Length

Table 3. Plant Length in Centimeters for Treatment Group at 82 degrees Fahrenheit (control group)

Plant #	26-Jan	29-Jan	1-Feb	5-Feb	8-Feb	9-Feb	13-Feb
1	22.6	22.7	22.5	22.6	21.9	21.2	20.2
2	8	8.6	9.4	9.1	11.1	11.2	11.4
3	9	8.6	8.7	9	9.1	9.3	9.5
4	12.3	12.5	14.7	15	15.2	15.3	15.3
5	14	14.4	14.5	14.6	14.5	14.5	14.6
6	10.1	10.3	9.8	12.1	12.2	12.3	12.5
7	12.5	12.1	12.3	12.3	12.5	12.7	12.4
8	20.5	20.5	21	21.2	21.3	20.9	21
9	23.9	24.1	23.1	22.6	22.6	22.2	22.4
10	17.3	17.6	17.1	17.3	17.4	17.2	17.4
11	10.2	10.2	10.4	12	12.1	12	12.1
12	17.2	17.2	17.2	17	17.2	17.3	17.5
13	19.5	20.5	21.2	21.3	21.3	21.5	21.7
14	20.9	21.2	22.8	23	23.1	23.2	22.6
15	7.4	8	8.5	8.7	8.6	8.7	8.7
16	8.7	8.6	8.4	8.3	8.9	9.1	9.1

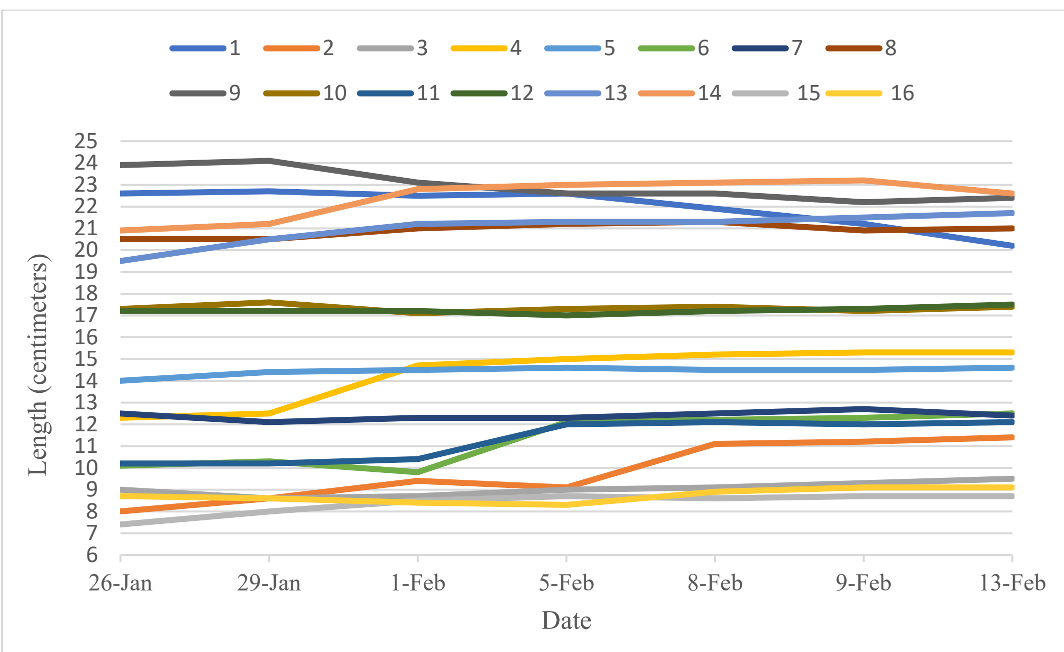

Figure 1. Graph of Plant Length in Centimeters for Treatment Group at 82 degrees Fahrenheit (control group)

In Table.3 and Figure.1, a similar growth in length of CD sample number: 15, 14, and 4 were observed on January 29th. Other slight trends in the data between two or more CD samples occurred at other dates, including but not limited to: February 1st, February 5th, and February 9th. A common trend seen across samples of the control was a stagnation of growth as the experiment continued, seen as almost all samples averaged out to a length value within the last days of the experiment. Overall, no drastic, observable change in length was observed within the control.

Table 4. Plant Length in Centimeters for Experimental Group at 87 degrees Fahrenheit (experimental group)

Plant #	26-Jan	30-Jan	1-Feb	2-Feb	6-Feb	8-Feb	12-Feb
17	13.3	13.5	14	14.2	14.1	14.1	14.2
18	13.1	13.1	13.4	13.6	13.6	13.8	13.9
19	16.8	17	17.3	17.1	17.6	17.7	17.5
20	9.8	9.8	10.3	10.4	10.6	10.5	10.7
21	10.7	10.7	10.3	10.5	10.3	10.5	10.4
22	15.1	16.5	17.5	17.2	17.2	17.2	17.7
23	22.5	21.6	21.2	21.3	21.4	21.3	21.2
24	28.5	28.5	25.6	25.6	26	25.5	25.3
25	13.1	15.5	14.5	14.2	14.4	14.6	14.7
26	14.2	14.6	15	15.3	14.9	15.1	15.3
27	14	15.6	12.2	12.4	14.5	14.7	14.6
28	14.2	15.8	16.5	16.6	16.5	16.7	16.8
29	11.5	11.8	12.1	12.1	12.2	12.3	12.4
30	12.7	13.5	13.2	13.3	13.4	13.8	14
31	9.6	10	10.2	10.3	10.2	10.2	10.1
32	8	7.7	7.3	7.1	7.1	7.3	7.5

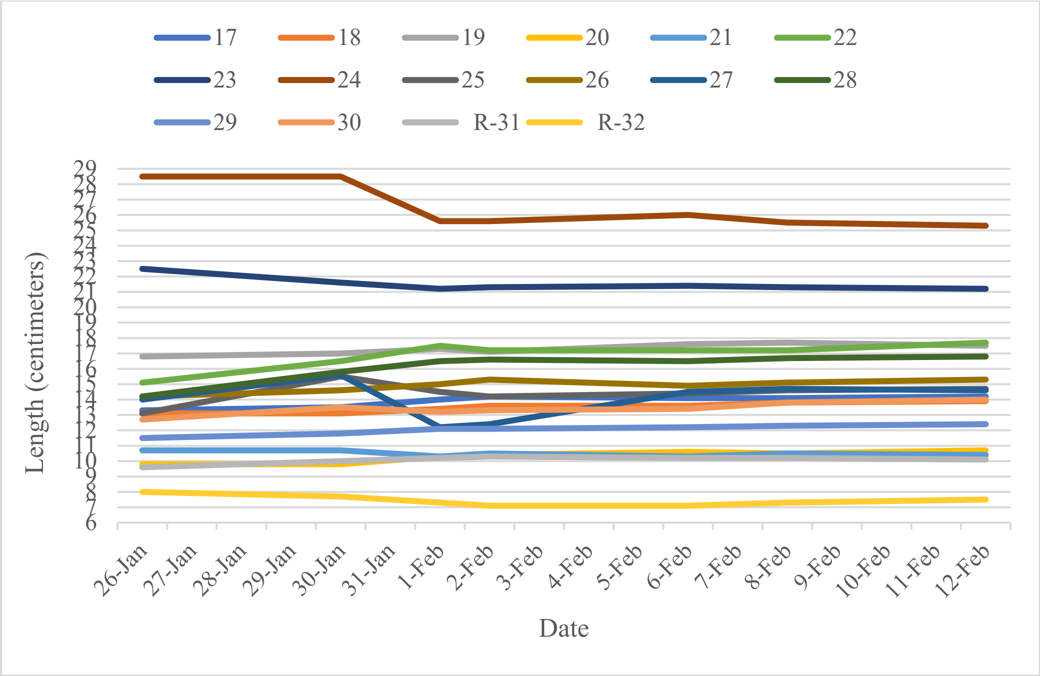

Figure 2. Graph of Plant Length in Centimeters for Experimental Group at 87 degrees Fahrenheit (experimental group)

Similarly, Table.4 and Figure.2 experienced a comparable pattern of growth to that seen in Table.3 and Figure.1. The experimental group concurrently went through a stagnation of growth rates to approximately zero. It is important to note, the more drastic drop in length values on January 30th seen in Figure.2, where a significant amount of CD samples appeared to have shrunk. Overall, there is no observable significance in the change of length in the experimental group.

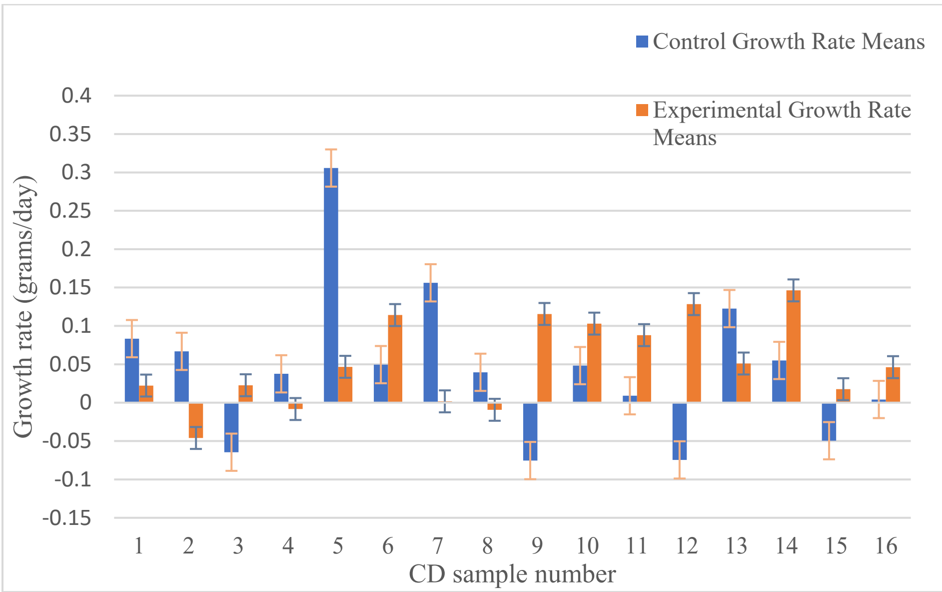

Figure 3. Growth Rate of CD in Centimeters Over the 18 Day Period (cm/day). Samples labeled 1-16 for their respective treatment group.

The growth rate of CD samples among all experimental groups was shown in Figure.6; despite sample #5 being a major outlier, generally the growth rate of the samples relatively averaged in comparable values. It was observed in Table.3 of CD sample #12, that some drastic growth appeared to occur over small spans of time which explains the high growth rates present in Figure.6.

Mass

Table 5. Plant Mass in Grams for Experimental Group at 82 Degrees Fahrenheit (control group)

Plant #	26-Jan	29-Jan	1-Feb	5-Feb	8-Feb	9-Feb	13-Feb
1	0.87	1.341	1.128	0.998	1.207	1.112	1.454
2	0.9	1.135	1.256	1.234	1.368	1.388	1.368
3	3.57	3.332	3.381	2.868	3.12	3.4	3.118
4	1.91	2.07	2.414	2.03	1.905	2.208	2.173
5	4.5	5.466	5.8	6.624	5.322	6.747	6.64
6	4.12	4.382	4.693	4.882	3.731	4.945	4.467
7	2.57	3.125	2.663	2.876	3.182	3.076	3.663
8	1.57	1.825	1.668	1.288	1.647	1.7	1.847
9	1.64	1.73	1.538	1.728	1.434	1.816	1.112
10	1.94	2.14	2.532	1.997	2.196	2.148	2.278
11	1.74	1.956	2.385	1.606	1.821	1.976	1.803
12	4.5	4.763	4.135	4.668	3.659	4.01	3.978
13	3.58	3.862	3.878	4.343	3.584	4.328	4.438
14	2.53	2.554	3.078	2.817	2.538	3.004	2.915
15	2.48	2.415	2.305	2.583	2.376	2.838	2.133
16	2.73	2.84	3.216	2.448	2.624	3.006	2.759

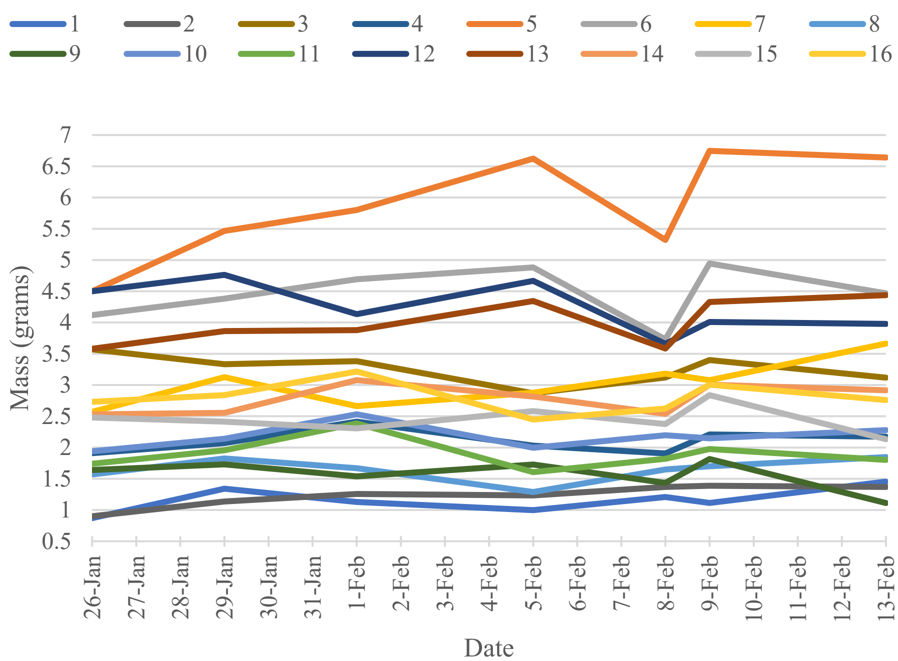

Figure 4. Graph of Plant Mass in Grams for Experimental Group at 82 Degrees Fahrenheit (control group)

In Table.5 and Figure.3, both the mass values and the mass growth rate (MGR) had significantly distinct inclination compared with the control group data seen in Table.3 and Table.4. These growth rate trends stayed consistent among the control CD samples, this can be especially seen in the large number of samples of Figure.3, following the mass rise on January 29th, and the mass drop on February 8th. The MGR did not decline as heavily as seen in length measurements of Table.3, which stresses the importance of evaluating growth in both contexts.

Table 6. Plant Mass in Grams for Experimental Group at 87 Degrees Fahrenheit (experimental group)

Plant #	26-Jan	30-Jan	1-Feb	2-Feb	6-Feb	8-Feb	12-Feb
17	1.3	1.472	1.789	1.639	1.792	1.595	1.456
18	1.73	2.2	2.245	2.085	1.822	1.682	1.408
19	3.59	3.941	4.42	4.238	4.015	3.934	3.749
20	1.62	1.784	1.989	1.819	1.686	1.416	1.562
21	1.65	2.195	2.402	2.229	2.134	1.96	1.977
22	2.15	2.751	2.838	2.553	2.906	2.723	2.949
23	1.78	2.009	2.076	1.631	1.534	1.264	1.792
24	1.7	1.245	1.886	1.456	1.631	1.162	1.635
25	2.98	3.27	3.639	3.429	3.48	3.122	3.789
26	2.65	3.183	3.738	3.598	3.365	2.664	3.371
27	2.83	3.118	3.332	2.951	3.025	3.028	3.446
28	2.31	3.072	3.62	3.43	2.881	2.903	3.209
29	0.85	1.164	1.194	0.988	1.097	1.027	1.207
30	1.57	2.31	2.456	2.596	2.37	2.231	2.594
31	1.97	2.208	2.42	2.481	2.513	2.16	2.093
32	0.55	0.752	0.817	0.917	0.786	0.772	0.874

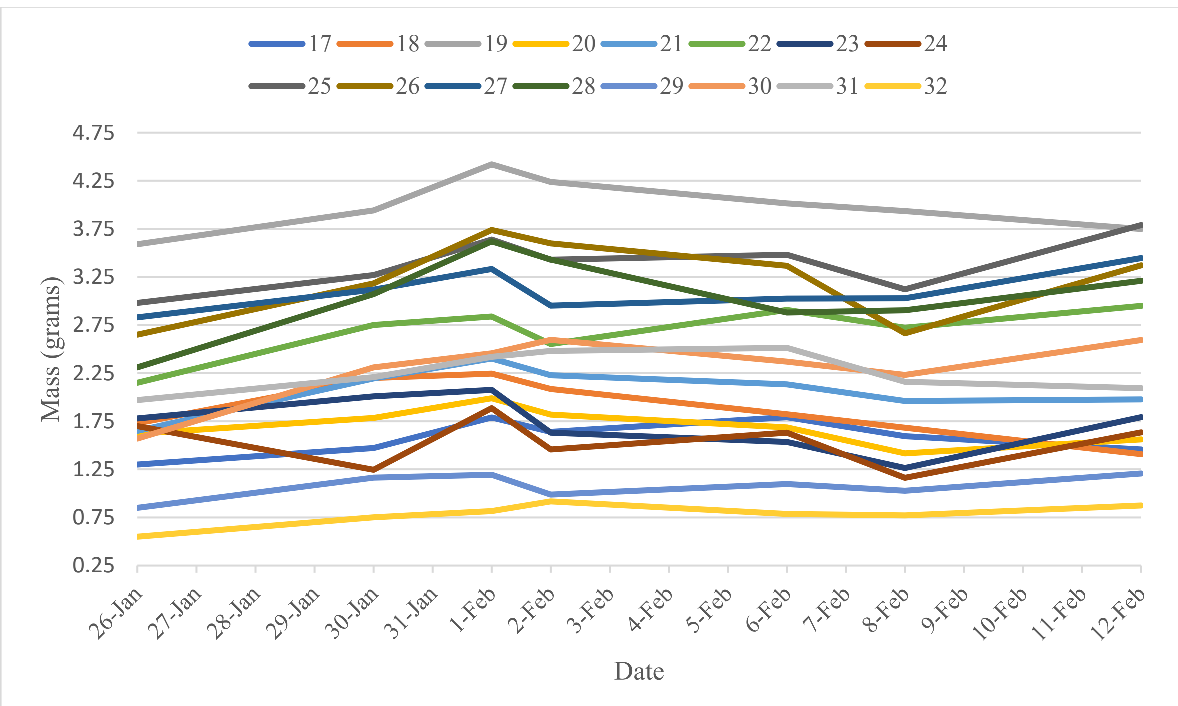

Figure 5. Graph of Plant Mass in Grams for Experimental Group at 87 Degrees Fahrenheit (experimental group)

The trend stays consistent throughout the treatment groups; in which, the growth trends stay consistent throughout a majority of the samples, in Table.6 and Figure.4, in conjunction with the rest of the data. The growth in mass spiked on February 1st, and a mass drop on February 8th similar to that of the control in Figure.3. In terms of mass, the growth rates stagnated less than in comparison to length.

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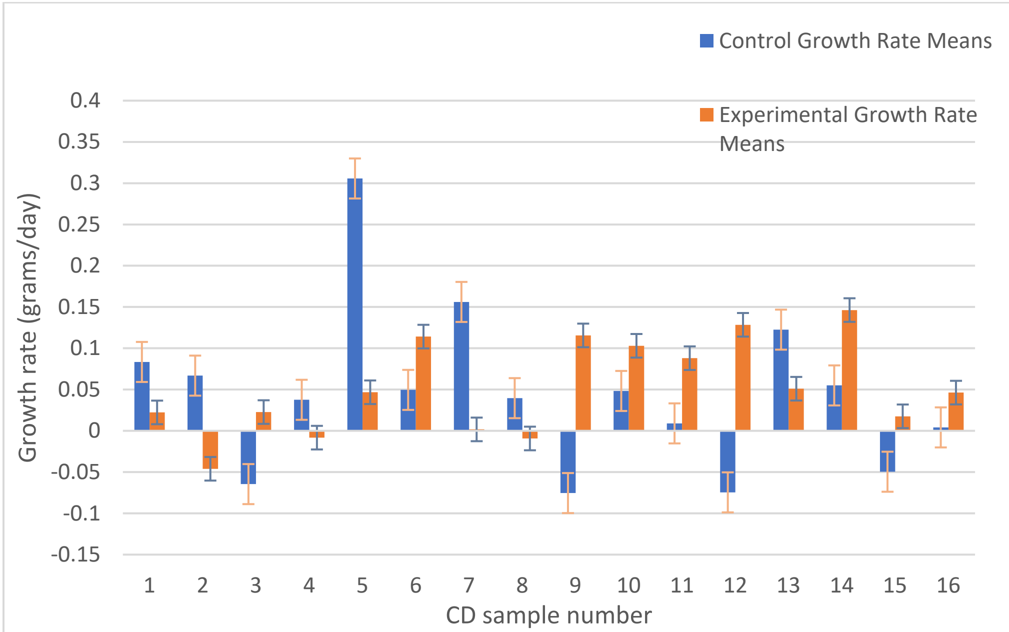

Figure 6. Growth Rate of CD in Grams Over the 18 Day Period (g/day). Samples labeled 1-16 for their respective group.

While the mass of CD samples fluctuated heavily, they generally remained at a similar mass throughout experimentation overall. The MGR seen in Figure.5, seems to be more consistent within the experimental group; concurrently, less drastically different between the two treatment groups than the length growth rate (LGR) in Figure.6. The data appears unaffected by increasing temperature among all data sets; but apparent trends in the data are present, specifically within the treatment groups.

Statistics

Table 7. MANOVA Table Testing the Experimental Groups on Growth Rates

Multivariate Tests[1]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[3]
Intercept	Pillai's Trace	.401	9.693[2]	2.000	29.000	<.001	.401	19.386	.970
	Wilks' Lambda	.599	9.693[2]	2.000	29.000	<.001	.401	19.386	.970
	Hotelling's Trace	.668	9.693[2]	2.000	29.000	<.001	.401	19.386	.970
	Roy's Largest Root	.668	9.693[2]	2.000	29.000	<.001	.401	19.386	.970
Group	Pillai's Trace	.046	.704[2]	2.000	29.000	.503	.046	1.408	.157
	Wilks' Lambda	.954	.704[2]	2.000	29.000	.503	.046	1.408	.157
	Hotelling's Trace	.049	.704[2]	2.000	29.000	.503	.046	1.408	.157
	Roy's Largest Root	.049	.704[2]	2.000	29.000	.503	.046	1.408	.157

1. Design: Intercept + Group
2. Exact statistic
3. Computed using alpha = .05

After conducting the MANOVA, the results were presented in Table.7. The group sig. value represents the probability value of the data, it being .503 or 50.3% that the data was due to chance. This p-value was validated by the Levene's Test of Equality of Error Variance as its significance value was above .05 with both treatment groups supporting the validity of the MANOVA. However, the p-value was not supported by Box's Test of Equality of Convergence Matrices and the Inter-item Covariance Matrix as the significance values were so low, suggesting the MANOVA could be insufficient in determining significance. Alongside the drastic difference in the length growth rate mean between the treatment groups seen in Figure.7, an Independent Samples Test was also run to determine if length had a significant result. The P-values of the test were .125 and .251 which remained above the .05 significance value.

Discussion

MANOVA and Independent Samples T-Test

The MANOVA produced a p-value of .503, which is denoted as a 50.3% chance that the results were due to random chance. This severely exceeds the 5% significance value, however due to the low values of Box's Test of Equality of Convergence Matrices and the Inter-item Covariance Matrix, an Independent Samples T-Test was run to validate the results. This was arguably necessary as Box's Test of Equality of Convergence Matrices had already somewhat lost credibility; however, confirming the results through another statistical test would ensure the credibility of the interpretation. The Independent Samples T-Test was only run for the LGR as the MGR was not significant enough to consider testing. Still, the Independent Samples T-Test came back with a similarly high p-value. Asserting that a rising temperature in the context of future climate change did not have a significant effect on the growth of CD.

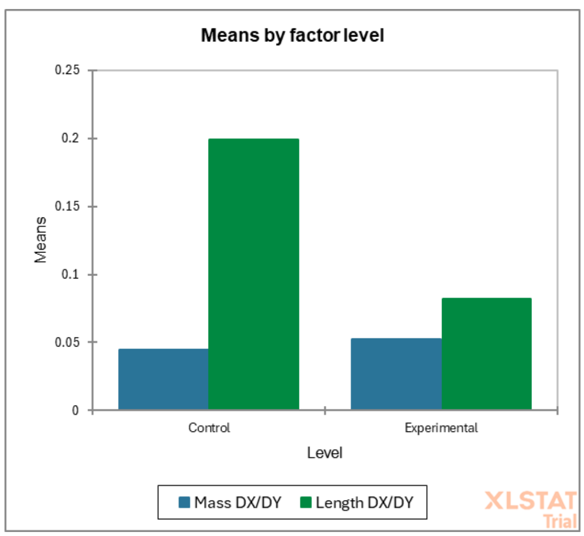

Figure 7. Means of Experimental Groups (control and experimental) Growth Rate by Both Mass and Length

Table 8. Independent Sample T-Test of Experimental Groups on Length Growth Rate

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance				95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
Length	Equal variances assumed	1.920	.176	1.176	30	.124	.249	.11696	.09946	-.08617	.32009
	Equal variances not assumed			1.176	24.344	.125	.251	.11696	.09946	-.08816	.32209

Growth Trends

The general observed phenomena were that both CD samples would follow a similar trend within their respective treatment groups. This was shown especially in Figure.3 on February 8th, where a drop in mass occurred among a significant amount of CD samples. Surprisingly, a similar mass drop occurred on February 8th in Figure.4, suggesting that the plants reacted similarly despite the temperature difference. This could insinuate a few possible conclusions, such as: 1.) The plants are not affected by changes in temperature to the degree experimented on, like that of *Desmarestia spp.* (Schoenrock, K., Schram, J., Amsler, C., McClintock, J., & Angus, R., 2015), or 2.) Both the treatment groups reacted to an external factor that was not controlled. Due to the fact the that a spike of growth was observed in Figure.4 for the experimental group on February 1st, while the control group did not experience it as harshly, and the MANOVA supporting little evidence of temperature significantly affecting the dependent variables, it is reasonable to assume that the first conclusion is correct, in that the trends seen confirms that the data is consistent as the plants all grew at similar rates within the treatment groups, but were not significant despite the temperature difference.

The growth trends in terms of length were less observable but were still present similar to that of mass. Overall, the more significant trend in terms of LGR was the stagnation of growth as the experiment continued as seen in Figure.3 and Figure.4. This is surprising as the mass generally fluctuated until the end of the experiment, supporting the hypothesis that temperature could negatively affect growth in terms of length. This is supported further by the high difference in LGR between the treatment groups and the negative effects associated with heat stress highlighted by Bender and Sentelhas in their article discussing the effects of heat stress on plant growth and health; however, no statistical test supports this conclusion, suggesting more research should be conducted upon the topic.

Implications of the Study

The major implications of the study are that the growth of CD is not significantly affected by the temperature increase examined in the study that models future climate change temperatures. This suggests the health of TTL's ecosystem is not in dire threat, at least in terms of CD levels within the lake. It's important to note that CO2 was determined to be possibly responsible for the growth alterations seen in APs (Hussner, A., Hofstra, D., Jahns, P., & Clayton, J., 2015); however, rising CO2 levels would simultaneously cause rising temperatures (Hussner, A., Smith, R., Mettler-Altmann, T., Hill, M. P., & Coetzee, J., 2019). This suggests that the case study of V.americana saw increases of its biological niche due to rising CO2 levels rather than temperature (Carhart, A. M., Rohweder, J. J., & Larson, D. M., 2023). It is important to note, that not only would more testing need to occur; but also, the hypothesis that every plant reacts differently to the external stimuli still stands, meaning more testing would need to occur for all APs to determine the stability of various environments in context of future climate change.

Conclusion

The main conclusion derived from this study is that the temperature increase used to model future climate change did not show a significant effect on the growth of CD in either length (cm) or mass (g). Therefore, in terms of the prevalence of CD in TTL, the data suggests resilience through future climate changes; however, more testing should be done to validate these results. Some growth trends suggest that the temperature had a negative effect in terms of length; but again, future, more accurate studies, should aim to investigate this. Future research should also focus on testing more APs for their reactions to rising temperatures to further predict the health of future aquatic environments.

Limitations

As stated within the subcategories: "Environmental Factors on Terrestrial Plants" and "Environmental Factors on Aquatic Plants" of the literature review, there are a multitude of factors that impact the growth of AP. Specifically, Hussner and his team of researchers found that the main factors in the growth of Myriophyllum triphyllum in New Zealand was: light, temperature, and CO2 availability. While this plant is not directly similar to CD; alongside Hussner, the available literature shares similar trends that these factors impact plant growth. It is important to note an increase in CO2 levels would increase average global temperature through the greenhouse effect (Hussner, A., Smith, R., Mettler-Altmann, T., Hill, M. P., & Coetzee, J., 2019). As this study only tested temperature effects on AP growth, it leaves gaps in research on the relationship between CO2 levels, and its possible combined effect with temperature on plant growth. Furthermore, it was found that increasing temperatures would increase the CO2 and HCO3 demand by primary producers (Hussner, A., Smith, R., Mettler-Altmann, T., Hill, M. P., & Coetzee, J., 2019). It is possible that the stagnated growth seen in CD was caused by CO2 deficiency as a result of the higher environmental temperature. This mainly implies two ideas: 1.) Plant growth patterns seen in this experiment could have been affected by CO2 deficiency rather than just temperature, and 2.) This study could portray a somewhat inaccurate simulation of future climate change, as CO2 did not increase alongside the temperature. Lastly, the low macronutrient levels seen in TTL's environment during the City of Tempe's Annual Water report, and water testing of TTL, could also serve as variables in the growth patterns of CD. Phosphorus and other macronutrients were deemed important to the levels of plant growth in an environment; thus, the low levels of these available nutrients could explain the stagnant growth seen throughout the experimenting period. The environment at TTL also has a complex web of biological processes that were unable to be replicated in this experiment; therefore, this study cannot fully predict the outcome of future climate change on the aquatic environment at TTL.

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