Hannah Axtell

Microbial Mêlée: Investigating Population Growth and Competitive Interactions

Abstract

Understanding the dynamics of population growth and interspecific competition is pivotal in ecology, shedding light on ecosystem stability, species coexistence, and biodiversity maintenance. Our study investigates the population growth of three microorganisms, *Euglena*, *Paramecium*, and *Colpidium*, both individually and in combination, to explore how interspecific competition influences growth patterns and carrying capacities within microbial communities. Through a series of laboratory mesocosm experiments and statistical analyses, we uncovered significant differences in final population sizes, growth patterns, and carrying capacities across various treatments. Our results demonstrate complex dynamics influenced by both intrinsic factors and interactions with other species. Specifically, we found that competition between heterotrophic species substantially impacted the growth dynamics of autotrophic *Euglena*, with significant reductions in both maximum growth rate and carrying capacity. These findings underscore the critical role of resource competition in driving population dynamics and community structure in microbial communities, contributing to a deeper understanding of ecological interactions and mechanisms governing species coexistence and biodiversity maintenance in simple ecological systems.

Introduction

Population growth and competition are fundamental concepts in ecology, crucial for understanding the dynamics of ecosystems and species interactions. Patterns of population growth and competition provide insights into ecosystem stability, species coexistence, and biodiversity maintenance. Understanding how populations grow and interact under different

conditions is vital for predicting ecological patterns and managing natural resources effectively. Previous research has extensively explored population dynamics and competitive interactions in ecological communities.

There are two models of population growth models: exponential and logistic models. These models provide frameworks for understanding population dynamics. The main difference between these models lies in their assumptions regarding resource availability and carrying capacity. While the exponential model assumes unlimited resources and unrestricted growth, the logistic model incorporates environmental constraints, such as carrying capacity, leading to sigmoidal growth curves. Bacterial growth life cycles demonstrated exponential growth in laboratory cultures of microorganisms under optimal conditions (Allen et al. 2019), other microorganisms exhibit logistic growth patterns in natural populations (Chapman 1928). These findings highlight the importance of environmental factors and resource limitations in shaping growth rates and models.

Additionally, interspecific competition can influence growth curves, carrying capacities, and growth rates by affecting resource availability and niche partitioning. Competitive interactions between species can lead to changes in population sizes and community composition, ultimately influencing ecosystem structure and function (Svanbäck et al. 2007). Experimental evidence supporting the effects of competition on population growth demonstrates how interspecific competition influenced growth rates and carrying capacities in experimental communities (Violle et al. 2010). These findings underscore the significance of competitive interactions in shaping ecological communities and driving population dynamics.

Our study will advance current knowledge by examining the population growth of three microorganisms: *Euglena*, *Paramecium*, and *Colpidium*, when grown individually and in

combination in laboratory mesocosms. We aimed to uncover insight into how interspecific competition influences growth patterns and carrying capacities within microbial communities. This research will contribute to a deeper understanding of population dynamics and competitive interactions in simple ecological systems. 1 mL of the specific microorganism culture treatment is added to the test tube containing hay infusion, along with grains of wheat and rice. For treatments requiring darkness, such as Euglena alone in the dark, test tubes are covered with aluminum foil. Each test tube is labeled with both the student's name and the assigned treatment and placed in wooden test-tube racks near a window. The experiment involves weekly sampling procedures to monitor population dynamics, including the counting of organisms on microscope slides. Data collection and analysis are conducted following standardized protocols to assess population growth patterns and our two main hypotheses within the microbial communities.

Euglena, *Paramecium*, and *Colpidium* have rapid reproduction rates and are therefore suitable for laboratory experiments. *Euglena* is an autotrophic organism capable of photosynthesis, while *Paramecium* and *Colpidium* are heterotrophic protists that consume bacteria. These differences in feeding strategies may influence competitive interactions within the experimental communities (Gause 1931). We hypothesized that when each species was grown alone, *Euglena* would exhibit logistic growth due to its autotrophic capabilities, while *Paramecium* and *Colpidium* would demonstrate similar growth patterns supported by bacterial populations. We also hypothesized that when grown in combination, competition would occur between the heterotrophic species, *Paramecium* and *Colpidium*, leading to reduced population sizes and altered growth curves. We anticipated that the presence of Euglena might mitigate competition through resource partitioning or facilitation, resulting in modified growth dynamics within the communities.

Materials and Methods

The experiment comprised a total of 10 treatments: *Euglena* alone in the light, *Euglena* alone in the dark, *Paramecium* alone, *Colpidium* alone, *Euglena* with *Paramecium*, *Euglena* with *Colpidium*, *Paramecium* with *Colpidium*, *Paramecium* with *Euglena*, *Colpidium* with *Euglena*, and *Colpidium* with *Paramecium*. For each treatment, 1 mL of the specific microorganism culture was added to test tubes containing hay infusion, along with grains of wheat and rice. Test tubes designated for darkness treatments were covered with aluminum foil to maintain light exclusion. The assignment of treatments to test tubes was randomized to minimize bias. The 10 experiment treatments were each replicated six to fifteen times depending on the number of lab section participants. Each test tube was labeled with treatment details and placed in wooden test-tube racks near a window to ensure consistent environmental conditions.

The experiment spanned a duration of 6 weeks, with weekly sampling conducted to monitor population dynamics. Data collected included the population sizes of microorganisms measured in number of individuals per milliliter (#/mL). Population counts were performed using microscope slides and standardized counting protocols. Data collection occurred weekly, and each sample was analyzed for population size at seven time points: weeks 0 through 6.

Statistical analyses were conducted to compare final population sizes under different experimental conditions. Specifically, t-tests were performed to assess differences in final population sizes when each species was grown alone versus when each species was in combination with another species. Additionally, t-tests were employed to compare the final population sizes of Euglena when grown in light versus dark conditions. Graphs depicting overall growth trends were generated to compare observed growth patterns with theoretical models. Maximum growth rates and carrying capacities for each organism in each treatment

were determined. Maximum growth rate was defined as the largest change in population size over one week, while carrying capacity was determined based on population size asymptotes or other appropriate criteria. Data analysis procedures followed standardized protocols to ensure consistency and reliability in the assessment of population dynamics and growth parameters.

Results

In this study, we investigated the population growth of three microorganisms: *Euglena*, *Paramecium*, and *Colpidium*, both alone and in combination with each other. Our results illuminate differences in final population sizes, growth patterns, and carrying capacities across various treatments. T-tests were performed to analyze differences between the growth patterns of the ten treatments in seven comparison scenarios: *Euglena* alone in the light vs. *Euglena* alone in the dark, *Euglena* alone in the light vs. *Euglena* with *Paramecium, Euglena* alone in the light vs. *Euglena* with *Colpidium, Paramecium* Alone vs. *Paramecium* with *Colpidium, Paramecium* Alone vs. *Paramecium* with *Euglena, Colpidium* Alone vs. *Colpidium* with *Paramecium,* and *Colpidium* Alone vs. *Colpidium* with *Euglena*. The null hypothesis (H_0) of each t-test being that there is no significant difference in the growth patterns between the two respective treatment scenarios. The alternative hypothesis (H_A) of each of the seven t-tests being that there is significant difference in the growth patterns between the two respective treatment scenarios.

The differences between the two treatments, *Euglena* alone in the light and *Euglena* alone in the dark, are illustrated through t-test analyses. Due to a determined p-value of 0.0335 ($p<0.05$), we reject the null hypothesis that there is no significant difference in the growth patterns between the *Euglena* alone in the light and *Euglena* alone in the dark treatment conditions. Absence of light had a significant negative effect on *Euglena* population growth, with

Euglena experiencing a 200% lower final population size when grown in the dark vs. cultured in the light (t-test, p=0.0335, Figure 1).

Analyzing t-test results between the *Euglena* alone in the light and *Euglena* with *Paramecium* treatments, we find a p-value of 0.0577. Due to this p-value of 0.0577 ($p>0.05$), we fail to reject the null hypothesis that there is no significant difference in the growth patterns between the *Euglena* alone in the light and *Euglena* with *Paramecium* treatment conditions.

T-test comparisons of the *Euglena* alone in the light and *Euglena* with *Colpidium* treatments determine a p-value of 0.0751. Due to this p-value of 0.0751 ($p>0.05$), we fail to reject the null hypothesis that there is no significant difference in the growth patterns between the *Euglena* alone in the light and *Euglena* with *Colpidium* treatment conditions.

The differences between the two treatments, *Paramecium* Alone vs. *Paramecium* with *Colpidium*, are illustrated through t-test analyses. Due to a determined p-value of 0.00496 ($p<0.05$), we reject the null hypothesis that there is no significant difference in the growth patterns between the *Paramecium* Alone and *Paramecium* with *Colpidium* treatment conditions. Presence of *Colpidium* had a significant negative effect on population growth, with *Paramecium* experiencing a 190% lower final population size when cultured with *Colpidium* vs. grown alone (t-test, p=0.00496, Figure 3).

Analyzing t-test results between the *Paramecium* Alone and *Paramecium* with *Euglena* treatments, we find a p-value of 0.403. Due to this p-value of 0.403 ($p>0.05$), we fail to reject the null hypothesis that there is no significant difference in the growth patterns between the *Paramecium* Alone and *Paramecium* with *Euglena* treatment conditions.

T-test comparisons of the *Colpidium* Alone and *Colpidium* with *Paramecium* treatments determine a p-value of 0.138. Due to this p-value of 0.138 ($p>0.05$), we fail to reject the null

hypothesis that there is no significant difference in the growth patterns between the *Colpidium* Alone and *Colpidium* with *Paramecium* treatment conditions.

The differences between the two treatments, *Colpidium* Alone and *Colpidium* with *Euglena*, are illustrated through t-test analyses. Due to a calculated p-value of 0.466 ($p>0.05$), we fail to reject the null hypothesis that there is no significant difference in the growth patterns between the *Colpidium* Alone and *Colpidium* with *Euglena* treatment conditions.

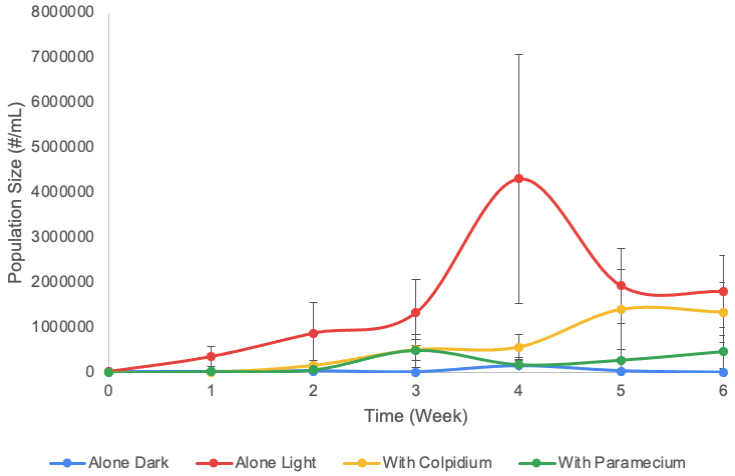

Figure 1: *Euglena* Population Growth Over Time

Line graph of *Euglena* population size (#/mL) over six weeks under four treatment conditions: *Euglena* in the light, *Euglena* in the dark, *Euglena* with *Colpidium*, and *Euglena* with *Paramecium*. The dependent variable in this trial experiment is population size (#/mL) as it is the focus of this study and as it is the response variable and changes based on the manipulation of time. The independent variable in this experiment is time (x-axis) as it is controlled in each of the treatments.The standard error of each treatment was calculated and custom positive and negative y-error bars were added to the figure. A trial average was calculated for each of the six weeks for each treatment and these data values were plotted along with their standard error.

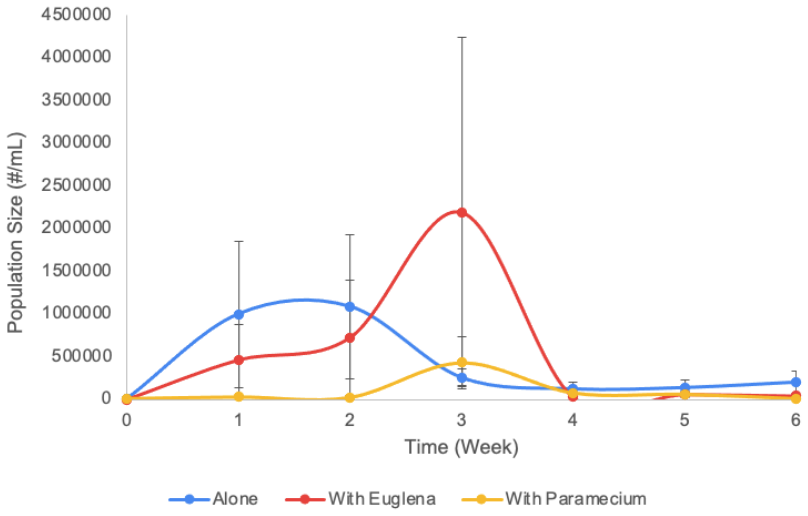

Figure 2: *Colpidium* Population Growth Over Time

Line graph of *Colpidium* population size (#/mL) over six weeks under three treatment conditions: *Colpidium* Alone, *Colpidium* with *Euglena,* and *Colpidium* with *Paramecium*. The dependent variable in this trial experiment is population size (#/mL) as it is the focus of this study and as it is the response variable and changes based on the manipulation of time. The independent variable in this experiment is time (x-axis) as it is controlled in each of the treatments.The standard error of each treatment was calculated and custom positive and negative y-error bars were added to the figure. A trial average was calculated for each of the six weeks for each treatment and these data values were plotted along with their standard error.

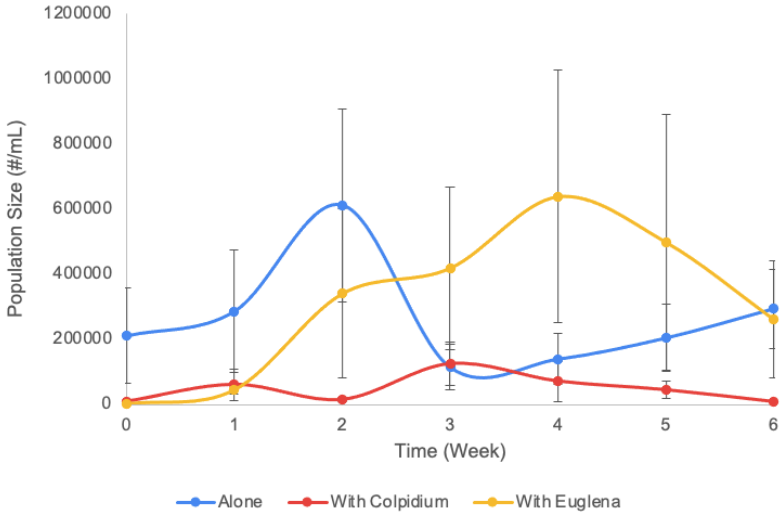

Figure 3: *Paramecium* Population Growth Over Time

Line graph of *Paramecium* population size (#/mL) over six weeks under three treatment conditions: *Paramecium* Alone, *Paramecium* with *Colpidium*, and *Paramecium* with *Euglena*. The dependent variable in this trial experiment is population size (#/mL) as it is the focus of this study and as it is the response variable and changes based on the manipulation of time. The independent variable in this experiment is time (x-axis) as it is controlled in each of the treatments.The standard error of each treatment was calculated and custom positive and negative y-error bars were added to the figure. A trial average was calculated for each of the six weeks for each treatment and these data values were plotted along with their standard error.

For *Euglena* under different treatment conditions (Figure 1), the population growth patterns varied significantly. In the light, *Euglena* exhibited an exponential growth pattern, starting at 22,742 cells/mL and rapidly increasing to 1,930,356 cells/mL by week 6. Conversely, in the dark, *Euglena* initially decreased in population size but then experienced a sharp spike from week 3 onwards, peaking at 328,815 cells/mL in week 5 before dropping to 183 cells/mL by week 6. When co-cultured with *Colpidium*, *Euglena* showed an initial lag phase followed by exponential growth, reaching 1,341,172 cells/mL by week 6. However, when co-cultured with *Paramecium*, *Euglena* displayed an irregular growth pattern, with an initial increase, followed by a decline, and then a subsequent increase, peaking at 465,707 cells/mL by week 6.

Colpidium under different treatment conditions' (Figure 2) population growth patterns also varied. When alone, *Colpidium* initially exhibited exponential growth, reaching 1,088,111 cells/mL by week 2 before declining sharply to 201,273 cells/mL by week 6. When co-cultured with *Euglena*, *Colpidium* showed erratic population dynamics, with fluctuations in growth but an overall decline to 41,361 cells/mL by week 6. Similarly, when co-cultured with *Paramecium*, *Colpidium* experienced fluctuations in population size, peaking at 76,274 cells/mL in week 4 before declining to 9,056 cells/mL by week 6.

Similarly, when alone, *Paramecium* (Figure 3) initially exhibited exponential growth, reaching 611,561 cells/mL by week 2 before sharply declining to 293,938 cells/mL by week 6. When co-cultured with *Colpidium*, *Paramecium* initially experienced an increase in population size, followed by a decline to 7,611 cells/mL by week 6. Similarly, when co-cultured with *Euglena*, *Paramecium* showed an initial increase in population size, reaching 638,392 cells/mL by week 4 before declining to 262,184 cells/mL by week 6.

Overall, the growth patterns of these microorganisms demonstrate complex dynamics influenced by both intrinsic factors (i.e. carrying capacity) and interactions with other species, with some populations exhibiting exponential growth followed by decline while others displayed irregular fluctuations. To learn more about the population growth dynamics of *Euglena, Colpidium,* and *Paramecium,* we compared their Maximum Growth Rates (Table 1) and Carrying Capacities (Table 2) when each species was alone and in combination.

Table 1: Maximum Growth Rate

The tables provides maximum growth rate data (#/mL/week) for three types of microorganisms (*Euglena*, *Colpidium*, and *Paramecium*) under ten various treatment conditions over the span of 0-6 weeks. The growth rate was approximated by calculating the difference in population size between consecutive weeks. The maximum growth rate and the corresponding week were then identified for each of the treatment conditions, providing insights into the growth dynamics of the microorganisms under different experimental setups.

Treatment	Max. Growth (#/mL/week)	Time (Week)
Euglena alone in the light	3,017,064	4
Euglena alone in the dark	149,829	4
Paramecium alone	395,618	2
Colpidium alone	1,083,494	2
Euglena with *Paramecium*	196,692	4
Euglena with *Colpidium*	1,174,481	4
Paramecium with *Colpidium*	66,663	1
Paramecium with *Euglena*	238,307	4
Colpidium with *Euglena*	1,969,383	3
Colpidium with *Paramecium*	409,187	4

Table 2: Carrying Capacity

The tables provide population data (#/mL) for three types of microorganisms (*Euglena*, *Colpidium*, and *Paramecium*) under ten various treatment conditions over the span of 0-6 weeks. To calculate the carrying capacity, we identified the point at which the population growth leveled off or stabilized, indicating that the environment reached its maximum capacity to support the microorganism population. The time of occurrence indicates the week in which this stabilization or leveling off of population growth occurred.

Treatment	Carrying Capacity (K) (#/mL)	Time (Week)

Euglena alone in the light	4,312,345	5
Euglena alone in the dark	32,469	2
Paramecium alone	611,561	2
Colpidium alone	1,088,111	2
Euglena with *Paramecium*	491,379	4
Euglena with *Colpidium*	1,401,650	5
Paramecium with *Colpidium*	124,918	3
Paramecium with *Euglena*	638,392	4
Colpidium with *Euglena*	2,194,391	3
Colpidium with *Paramecium*	431,457	3

Comparing *Euglena* Alone vs. *Euglena* with *Colpidium*, the carrying capacity of Euglena was reduced by 66% when grown with Colpidium compared to when it was alone (Figure 1, Table 2). The maximum growth rate of Euglena was reduced by 98% when grown with Colpidium compared to when it was alone (Figure 1, Table 1).

Comparing *Euglena* Alone vs. *Euglena* with *Paramecium*, the carrying capacity of Euglena was reduced by 67% when grown with Paramecium compared to when it was alone (Figure 1, Table 2). The maximum growth rate of Euglena was reduced by 89% when grown with Paramecium compared to when it was alone (Figure 1, Table 1).

Comparing *Colpidium* alone vs. *Colpidium* with *Euglena*, the carrying capacity of *Colpidium* was reduced by 97% when grown with *Euglena* compared to when it was alone (Figure 2, Table 2). The maximum growth rate of Colpidium was reduced by 96% when grown with Euglena compared to when it was alone (Figure 2, Table 1).

Comparing *Colpidium* Alone vs. *Colpidium* with *Paramecium*, the carrying capacity of Colpidium was reduced by 92% when grown with Paramecium compared to when it was alone

(Figure 2, Table 2). The maximum growth rate of Colpidium was reduced by 92% when grown with Paramecium compared to when it was alone (Figure 2, Table 1).

Comparing *Paramecium* Alone vs. *Paramecium* with *Colpidium*, the carrying capacity of *Paramecium* was reduced by 97% when grown with *Colpidium* compared to when it was alone (Figure 3, Table 2). The maximum growth rate of *Paramecium* was reduced by 94% when grown with *Colpidium* compared to when it was alone (Figure 3, Table 1).

Comparing *Paramecium* Alone vs. *Paramecium* with *Euglena*, the carrying capacity of *Paramecium* was reduced by 87% when grown with *Euglena* compared to when it was alone (Figure 3, Table 2). The maximum growth rate of *Paramecium* was reduced by 95% when grown with *Euglena* compared to when it was alone (Figure 3, Table 1).

Discussion

First, we analyzed the growth patterns of *Euglena* Alone vs. *Euglena* with *Colpidium*. When *Euglena* was grown alone, it exhibited exponential growth in the light, typical of autotrophic organisms, but its growth was significantly reduced in the dark. When grown with *Colpidium*, *Euglena*'s growth pattern shifted, showing an initial lag phase followed by exponential growth. The presence of *Colpidium* significantly reduced both the maximum growth rate and carrying capacity of *Euglena*, indicating strong competition between the two species. This outcome was expected, as *Colpidium* likely consumed bacterial resources that *Euglena* depended on, leading to resource limitation and decreased growth. The results support our hypothesis that competition would occur between heterotrophic species, impacting the growth dynamics of autotrophic *Euglena*.

Next, we evaluated the growth patterns of *Euglena* Alone vs. *Euglena* with *Paramecium*. Similar to the previous scenario, *Euglena* alone exhibited exponential growth in the light, while

its growth was reduced when grown with *Paramecium*. The presence of *Paramecium* also resulted in a significant reduction in both maximum growth rate and carrying capacity of *Euglena*. This suggests competition between *Paramecium* and *Euglena* for shared resources, potentially leading to resource depletion and altered growth dynamics. Although the decrease in growth parameters was less pronounced compared to *Euglena* with *Colpidium*, the results still support the hypothesis of competition between heterotrophic species affecting autotrophic *Euglena*.

Then, *Colpidium* Alone and *Colpidium* with *Euglena* were compared. *Colpidium* alone exhibited exponential growth initially, followed by a decline, while its growth with *Euglena* showed erratic fluctuations with an overall decline. The presence of *Euglena* had a substantial negative effect on both maximum growth rate and carrying capacity of *Colpidium*. This suggests that *Euglena* may outcompete *Colpidium* for resources, leading to reduced growth and population sizes. The observed decrease in growth parameters supports the hypothesis of competition between *Colpidium* and *Euglena*, although the effect was more pronounced on *Colpidium* than on *Euglena*.

Colpidium Alone and *Colpidium* with *Paramecium* were also compared. *Colpidium* alone exhibited exponential growth initially, followed by a decline, while its growth with *Paramecium* showed fluctuations with an overall decline. The presence of *Paramecium* also had a significant negative effect on both maximum growth rate and carrying capacity of *Colpidium*, indicating competition between the two heterotrophic species. This suggests that *Paramecium* may compete with *Colpidium* for similar resources, leading to reduced growth. The results support the hypothesis of competition between heterotrophic species, impacting the growth dynamics of *Colpidium*.

Additionally, we evaluated the growth patterns of *Paramecium* Alone vs. *Paramecium* with *Colpidium*. *Paramecium* alone exhibited exponential growth initially, followed by a decline, while its growth with *Colpidium* showed a sharp decrease. The presence of *Colpidium* significantly reduced both the maximum growth rate and carrying capacity of *Paramecium*, indicating strong competition between the two species. This outcome aligns with expectations based on resource competition theory. The observed decrease in growth parameters supports the hypothesis of competition between heterotrophic species affecting *Paramecium*.

Lastly, *Paramecium* Alone and *Paramecium* with *Euglena* were differentiated. *Paramecium* alone exhibited exponential growth initially, followed by a decline, while its growth with *Euglena* showed fluctuations with an overall decline. The presence of *Euglena* also had a significant negative effect on both maximum growth rate and carrying capacity of *Paramecium*, suggesting competition between the two species. This supports the hypothesis of competition affecting *Paramecium* in mixed communities. The results align with expectations and provide evidence of competition between *Paramecium* and *Euglena*, influencing *Paramecium*'s growth dynamics.

The observed patterns of population growth and competition dynamics highlight the importance of interspecies interactions in shaping microbial communities. The significant impact on growth parameters emphasizes the role of resource competition in driving population dynamics and community structure. These findings contribute to a deeper understanding of ecological interactions and provide insights into the mechanisms governing species coexistence and biodiversity maintenance in simple ecological systems.

Literature Cited

Allen, R.J., and B. Waclaw. 2019. Bacterial growth: a statistical physicist's guide. Reports on Progress in Physics 82: 016601.

Champman, R. N. 1928. The Quantitative Analysis of Environmental Factors. Ecology. 9: 111–122.

Gause, G. F. 1931. The Influence of Ecological Factors on the Size of Population. The American Naturalist. 65:70–76.

Svanbäck, R., and D.I. Bolnick. 2007. Intraspecific competition drives increased resource use diversity within a natural population. Proceedings of the Royal Society B: Biological Sciences 274: 839-844.

Trussell, G. C., P. J. Ewanchuk, and C. M. Matassa. 2006. The Fear of Being Eaten Reduces Energy Transfer in a Simple Food Chain. Ecology 87: 2979–2984.

Violle, C., P. Zhichao, and L. Jiang. 2010. Experimental demonstration of the importance of competition under disturbance. Proceedings of the National Academy of Sciences of the United States of America 107: 12925-12929.