
Effects of Eutrophication on benthic life within the littoral zone of freshwater lakes

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ABSTRACT

Lakes are mainly divided into three trophic levels, oligotrophic, mesotrophic, and eutrophic. A study performed over a three month period during the summer of 2010 recorded the amounts of cladocera, copepods, and rotifers present at three lakes each with a different trophic status. The theory is that a lake with greater nutrient levels, such as a eutrophic lake, will contain higher numbers of zooplankton than a lake with lower nutrient levels, such as an oligotrophic lake. The research did not show any significant difference in the abundance of these three microorganisms within the different lakes based on their trophic status.

Keywords: Trophic status, zooplankton, trophic classification, lakes, nutrients.

1. Introduction

In the early 1900's, lakes began to be classified by their trophic status based on the amount of nutrients present in the water (www.waterontheweb.org). Generally, there are three different types of classifications that can be assigned to a lake, oligotrophic, mesotrophic, and eutrophic.

An oligotrophic lake is described as having low amounts of nutrients with mean phosphorus levels around 8 mg/m^{-3} and low plant growth with mean chlorophyll levels around 1.7 mg/m^{-3} . A mesotrophic lake is described as having moderate levels of plant growth with mean chlorophyll levels around 4.7 mg/m^{-3} and having moderate levels of nutrients with mean phosphorus levels around 26.7 mg/m^{-3} . A eutrophic lake is described as having high levels of nutrients with mean phosphorus levels around 84.4 mg/m^{-3} and heavy plant growth with mean chlorophyll levels around 14.3 mg/m^{-3} (Wetzel 1983).

Eutrophication usually occurs when a lake system obtains high levels of phosphorus ranging between $16\text{-}386 \text{ mg/m}^{-3}$ (Wetzel 1983) either by natural means, such as the geology around the lake, or by manmade causes like industrial or farming practices used on the land surrounding a lake. Phosphorus is not the only substance that aids in eutrophication, nitrogen plays a minor role, but phosphorus is the limiting agent (Logan 1987). Figure 1 represents nutrient levels for the trophic classification of lakes (Wetzel 1983).

Adding high amounts of phosphorus to a lake system allows organisms, such as planktonic diatoms, present in the water to have more nutrients and thrive in the lake environment. Lakes with a high number of plant growth will have lower amounts of dissolved oxygen because some of the plant material will die and settle to the bottom. The decaying material will use up the dissolved oxygen in the hypolimnion and with a density difference between the thermal layers of the epilimnion and hypolimnion, the well oxygenated top layer of a lake

will not mix with the bottom layer causing the bottom layer to become anoxic. If the rate of respiration exceeds that of photosynthesis, anoxic conditions will occur on the bottom region of the lake (Wetzel 1983).

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General Trophic Classification of Lakes and Reservoirs in Relation to Phosphorus and Nitrogen

PARAMETER (ANNUAL MEAN VALUES)	OLIGOTROPHIC	MESOTROPHIC	EUTROPHIC	HYPEREUTROPHIC
Total phosphorus (mg m^{-3})				
Mean	8.0	26.7	84.4	-
Range	3.0-17.7	10.9-95.6	16-386	750-1200
N	21	19	71	2
Total nitrogen (mg m^{-3})				
Mean	661	753	1875	-
Range	307-1630	361-1387	393-6100	-
N	11	8	37	-
Chlorophyll a (mg m^{-3}) of phytoplankton				
Mean	1.7	4.7	14.3	-
Range	0.3-4.5	3-11	3-78	100-150
N	22	16	70	2
Chlorophyll a peaks (mg m^{-3}) ("worst case")				
Mean	4.2	16.1	42.6	-
Range	1.3-10.6	4.9-49.5	9.5-275	-
N	16	12	46	-
Secchi Transparency Depth (m)				
Mean	9.9	4.2	2.45	-
Range	5.4-28.3	1.5-8.1	0.8-7.0	0.4-0.5
N	13	20	70	2

Based on data of an international eutrophication program. Trophic status based on the opinions of the experienced investigators of each lake. (Modified from Vollenweider, 1979.)

Figure 1: General trophic classification of lakes and reservoirs. (Wetzel 1983)

The research performed for this paper is testing the assumption that a lake with greater nutrient levels, such as a eutrophic lake, will contain higher numbers of zooplankton than a lake with lower nutrient levels, such as an oligotrophic lake. The theory is that higher nutrient levels will produce a greater food source and allow the zooplankton to thrive and multiply more readily than in a lake with lower nutrient levels. If this is the situation, it is expected that a eutrophic lake will have the highest counts of zooplankton, followed by the mesotrophic lake and an oligotrophic lake will have the lowest counts of zooplankton. The organisms analyzed for this study were rotifers, copepods, and cladocera.

The idea is to find three lakes that are similar in size, depth and shape, but each having a different trophic status. The experiment was performed in RI, so it is important to understand the RI lake trophic classification system to help determine which lakes shall be used in this study.

1.1 RI Lake Trophic Classification System

The Rhode Island Department of Environmental Management (RIDEM) classifies a lake as oligotrophic when it has a secchi depth transparency of greater than 4m, contains less than 2.6 ppb of chlorophyll, has less than 12 ppb of phosphorus, and has a trophic state index less than 40 (RIDEM 2008).

According to the EPA, a trophic state index is a log transformation of Secchi disk values for a measure of algal biomass on a scale of 0-110.

A mesotrophic classification must have a secchi depth transparency of 2-4 m, have a chlorophyll content between 2.6-7.2 ppb, a phosphorus content between 12-24 ppb, and a trophic state index between 40-50 (RIDEM 2008).

When a lake is classified as eutrophic it must have a secchi depth of less than 2 m, contain more than 7.2 ppb of chlorophyll, have more than 24 ppb of phosphorus, and a trophic state index greater than 50 (RIDEM 2008).

1.2 The Lakes

Based on the RI lake trophic classification system, Spring Lake, Lake Washington, and Warwick Pond were selected for this study because they are about the same shape, size and each lake represents a different trophic classification.

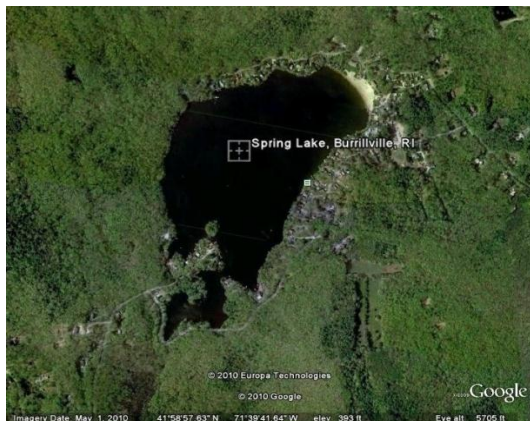


Figure 2: Google Earth image of Spring Lake. **Figure 3:** Google Earth image of Lake Washington

1.2.1 Spring Lake

Spring Lake, figure 2, is an oligotrophic body of water (www.dem.ri.gov), located off Spring Lake Road in Burrillville, RI ($41^{\circ} 58' 57.71''$ N, $71^{\circ} 39' 37.18''$ W). It is 0.39 km^2 wide with an average depth of 3.05 m and total volume of $1.18 \times 10^6 \text{ m}^3$ (www.blackstonedaily.com). The background data for Spring Lake, Lake Washington, and Warwick Pond are unpublished and received from the RIDEM by request.



Figure 4: Google earth image of Warwick Pond



Figure 5: GIS map of RI showing locations of three selected lakes

Table 1: Spring Lake Background Data

Year	Depth(m)	Annual Mean Total N($\mu\text{g/l}$)	Annual Mean Total P($\mu\text{g/l}$)	Annual Mean Chlorophyll($\mu\text{g/l}$)	Annual Mean pH(S.U.)	Annual Mean Secchi Depth(m)
2005	1	347	8	---	6.81	---
2006	1	363	11	1.64	6.81	---
2007	1	263	13	1.26	4.22	4.42
2008	1	388	12	---	---	---

Table 1 summarizes background data from Spring Lake. The information presented is from the four most recent years data was collected from 2005-2008. During these years the annual mean for phosphorus ranges between 8-13 $\mu\text{g/l}$. In 2007 the annual mean for phosphorus was above the threshold level of 12 ppb and in 2008 was at the threshold level, while the remaining years were below 12 ppb. The chlorophyll levels present are below 2.6 ppb and the secchi depth recorded in 2007 was greater than 4 m, which meet the RI criteria for an oligotrophic lake.

1.2.2 Lake Washington

Lake Washington, figure 3, is a mesotrophic body of water (www.dem.ri.gov), located off Rt. 44 in Glocester, RI ($41^{\circ} 54' 26.31''$ N, $71^{\circ} 45' 26.31''$ W) and has an area of 0.17 km^2 (www.dem.ri.gov). It is the shallowest of the three lakes and according to a 1989 diagnostic feasibility study has an average depth of 1.22 m, giving it a total volume of $0.21 \times 10^6 \text{ m}^3$.

Table 2: Lake Washington Background Data

Year	Depth(m)	Annual Mean Total N($\mu\text{g/l}$)	Annual Mean Total P($\mu\text{g/l}$)	Annual Mean pH(S.U.)
2005	1	1280	55	6.82

There was limited amount of data available for Lake Washington. The annual mean for total phosphorus was 55 ppb, which is above the RI mesotrophic range of 12-24 ppb for phosphorus levels. This represents only one year, there may be other data showing levels within the mesotrophic range. It is unclear what length of time is used to gather the readings to determine a lakes trophic status. The data presented in Background Tables 1-3 are yearly averages to condense the data received by the RIDEM to be included in this paper. Despite the 2005 background, the RIDEM has Lake Washington classified as mesotrophic.

1.2.3 Warwick Pond

Warwick Pond, figure 4, is a eutrophic body of water, (www.dem.ri.gov) located off Edgehill Road in Warwick, RI (41° 43' 21.11" N, 71° 24' 33.91" W). It has an area of 0.35 km², (www.dem.ri.gov) and an average depth of 4.27 m with a total volume of 1.47x10⁶ m³ (www.exploreri.org).

Table 3: Warwick Pond Background Data

Year	Depth(m)	Annual Mean Total N(µg/l)	Annual Mean Total P(µg/l)	Annual Mean Chlorophyll(µg/l)	Annual Mean pH(S.U.)	Annual Mean Secchi Depth(m)
2005	1	730	25	---	8.02	---
2006	1	1050	33	23.9	7.59	---
2007	1	733	26	26.5	7.82	1.31
2008	1	778	32	---	---	---

Table 3 summarizes the average annual data collected from Warwick Pond between 2005 and 2008. These are also the most recent years readings were collect. The annual mean for total phosphorus was above 24 ppb and has a secchi depth less than 2 m, which meet the RI criteria for a eutrophic lake.

1.3 The Organisms

The organisms observed for this study are zooplankton and the three main groups that were counted are Cladocera, Copepods, and Rotifers.



Figure 6: Cladocera



Figure 7: Copepod



Figure 8: Rotifer

Images from <http://mrskingsbioweb.com/Limnology.html>

1.3.1 Cladocera

Cladocera, figure 6, are small crustaceans belonging to the phylum Arthropoda. Their size can range from less than 0.5 mm to greater than 5 mm (www.glerl.noaa.gov). They are often referred to as the water flea and occupy many different types of waters. A large number of species live within freshwater lakes, swamps, and ponds (Eddy & Hodson 1961).

Perennial species of cladocera have lower populations in the winter months and increase in the spring when the food supply also increases. Cladocera populations in vary throughout the

summer due to reduced food supply, shifts in the quality of food, and predation by other organisms (Wetzel 1983).

1.3.2 Copepods

Like the cladocera, copepods, figure 7, are also small crustaceans belonging to the phylum Arthropoda. Their size can range from 1 mm to 2 mm in length and are mostly found dwelling in the muddy bottoms of lakes, but they can be found within the water column as well (Eddy & Hodson 1961).

The population dynamics for certain copepods is heavily dependent on the abundance of cyclopoid copepods, which are carnivorous and have predation behavior that can have a major effect on the population of other copepods (Wetzel 1983).

Adult copepods feed highly on rotifers during the winter time. Cyclopoid copepods can maintain during periods of reduced growth in eutrophic lakes (Wetzel 1983).

1.3.3 Rotifers

Rotifers are small organisms ranging in size between 0.1-0.5 mm and are part of the phylum Rotatoria. They are normally found in waters living attached to objects present in the water, on the bottom surface, and swimming free in the water column (Eddy & Hodson 1961).

Differences in seasonal patterns for rotifer abundance are difficult and generalizations are tough to determine because different species of rotifers can be present in higher numbers at different times of the year (Wetzel 1983).

2. Materials and Methods

2.1 Sample collection

Samples were gathered over three months from June to August, 2010. Five replicate samples were collected each month at the three different lakes. Starting at the shoreline to a depth of 1m from the lake bottom, a 3 L volume of water was collected at a depth of 0.5 m using a Schindler trap. The 3 liters of water were strained by a filter cup attached to the bottom of the Schindler trap leaving behind the organisms. This condensed the 3 L sample to a more manageable volume. The filter cup was rinsed using pure water containing borax which was then collected into a jar. After collection, 26 ml of 75% ethanol was added to each sample for preservation. A few drops of rose bengal were also added to each sample to stain the organisms so they would become visible under the microscopic.

2.2 Sample preparation and slide counting

Each sample was passed through a 64 μ filter. The filter was then rinsed over a graduated cylinder to a volume of 50 ml. 1 ml was pipetted from the cylinder and placed onto a slide matrix.

The slide matrix was placed under a microscope and counts were recorded for the number of cladocera, copepods, and rotifers present in each sample. A back calculation was performed to determine the number per liter for each of the three organisms.

3. Results

The mean abundance for cladocera, copepods, and rotifers were calculated for each month at the three different lakes, figures 9 through 11. An analysis of variance statistical test, table 4, was performed comparing means for the total abundance of the three different zooplankton at each lake over the three month period the study was conducted.

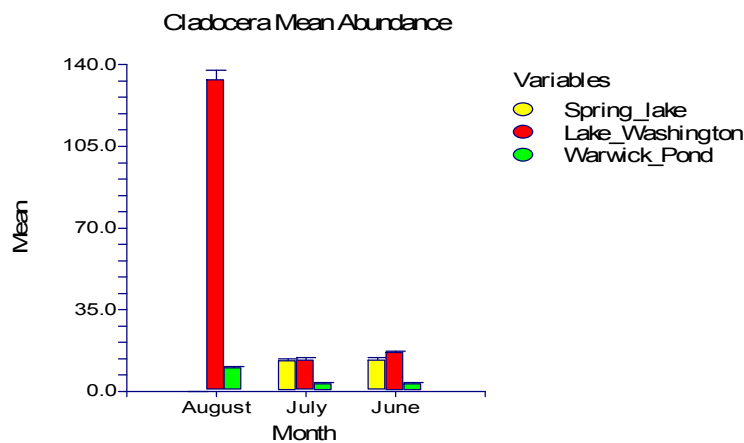


Figure 9: Error plot for Cladocera Mean abundance

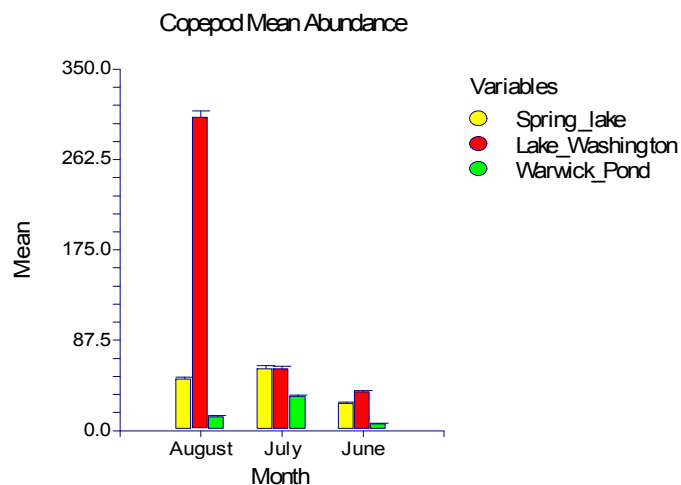


Figure 10: Error Bar Plot for Copepod Mean Abundance

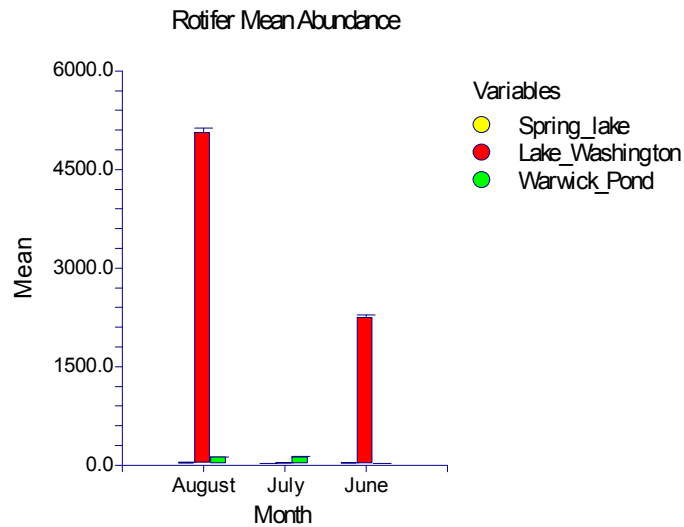


Figure 11: Error Bar Plot for Rotifer Mean Abundance

The amount of copepods and cladocera are highest in August, while rotifer counts are greater in June and August at Lake Washington compared to Spring Lake and Warwick Pond.

Table 4: Analysis of Variance

Organism	Source of Variance	Sum of Squares	Degrees of Freedom	F ratio	F Critical	P value
Cladocera	Between Lake Samples	1.176954E-03	2	1.27	3.68	0.31
	Within Lake Samples	6.944595E-03	15			
Copepods	Between Lake Samples	1.118191E-03	2	2.20	3.32	0.13
	Within Lake Samples	7.60942E-03	30			
Rotifers	Between Lake Samples	4.446623E-03	2	8.82	3.25	0.0007
	Within Lake Samples	9.324098E-03	37			

The results of the ANOVA show that there are no significant differences between trophic status and the amount of cladocera and copepods. The results do indicate a significant difference in the numbers of rotifers present between one or more of the three lakes. A Fisher's LSD multiple comparison test determined that the amount of rotifers did differ greatly at Lake Washington compared to Spring Lake and Warwick Pond.

Appendix A- Graphs of raw data

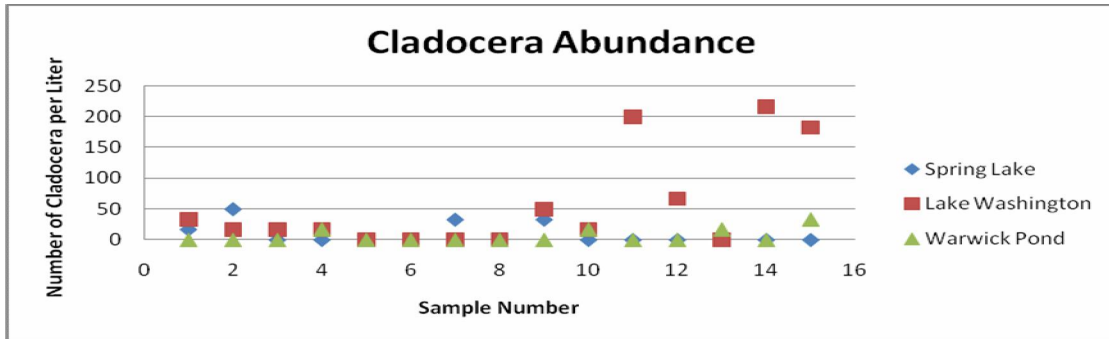


Figure 12: Graph of raw data for cladocera abundance

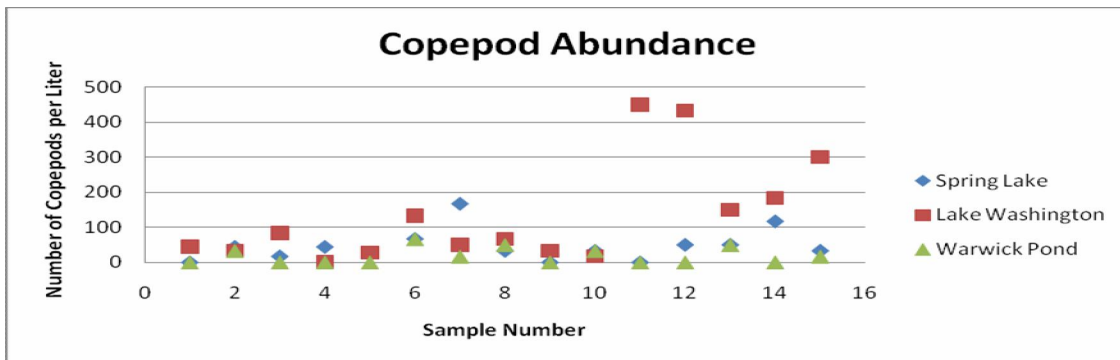


Figure 13: Graph of raw data for copepod abundance

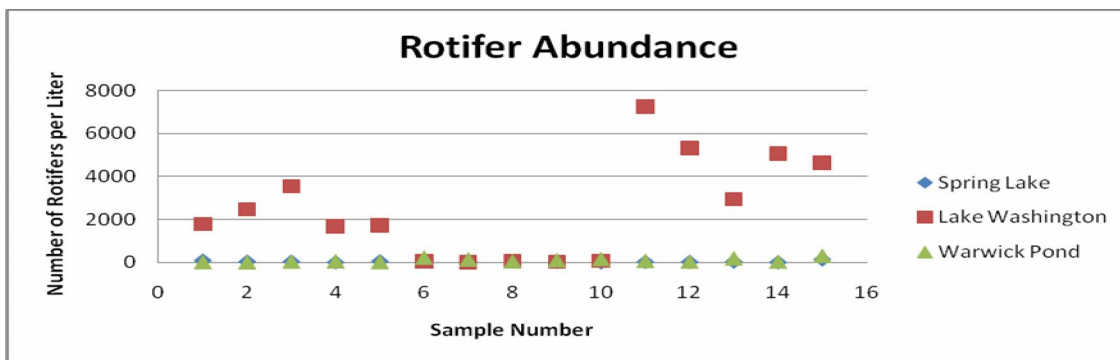


Figure 14: Graph of raw data for rotifer abundance

4. Discussion and Conclusions

The high amount of cladocera present in August may be due to an increase in food availability or lack of predation compared to June and July. According to Wetzel these are known factors to contribute to the variability in cladocera counts during the summer. The high amount of copepods present in August may be due to a decrease in the presence of

cyclopoid copepods, which as mentioned earlier are carnivorous and have predation behavior that can have a major effect on the population of other copepods.

The only organism to show a significant difference was the rotifers at Lake Washington compared to Spring Lake and Warwick Pond. The difference is not believed to be caused by trophic status. Lake Washington is a mesotrophic lake and if trophic status was responsible we would expect that Warwick Pond, the eutrophic lake, would contain the highest counts. As stated by Wetzel, the abundance of rotifers is hard to generalize and we may be just seeing normal fluctuations based on the type of species of rotifers present. Eutrophication may have many impacts to a lake's well being, for example, pristine lake becoming overgrown with weedy material, anoxic conditions, no mixing within different layers of the lake. However, it does not seem that trophic status has an effect or plays a role in the abundance of zooplankton present within the lakes studied for this paper.

Between 1982 and 1986 a study was conducted on the Loosdrecht lakes located in Amsterdam (Gulati 1990). The research focused on zooplankton structure related to trophic status and remediation efforts within three eutrophic lakes. The results of the research did not show any significant changes in zooplankton structure even when there was a major reduction in phosphorus loading (Gulati, 1990). This research helps support the idea that trophic status plays no role in the abundance of zooplankton present in lakes, but it doesn't definitively mean that it can't have an influence. It just didn't have an influence on the three lakes studied during this experiment.

A possible reason for not seeing any difference between the lakes is this study did not distinguish between the different types of species for cladocera, copepods, and rotifers. Had we further divided the counts into separate species of each type of zooplankton, we may have obtained different results. We saw that cyclopoid copepods have an influence on other species of copepods. Another reason for seeing no difference may be due to the short period of time the research was conducted. Perhaps three months is not a long enough period of time to make the determination if trophic status has an effect on zooplankton abundance. If this study was performed over a year there would be a lot more data and perhaps the overall results may be different.

6. References

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