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Investigating Effects of *Lemna* Removal on Oxygen and Phosphorus Recovery in Urban Ponds

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Abstract

Traditional ecological models often assume a linear relationship between aquatic communities and water nutrient levels. However, certain aquatic systems more closely resemble an alternative stable state model, in which the system tends to gravitate towards one of two sets of ecological conditions based on a critical nutrient threshold. *Lemna*, an aquatic plant genus, has the ability to instigate eutrophic conditions in lakes by blocking sunlight at the water surface. This restricts photosynthesis in the water column, resulting in a low oxygen, high phosphorus ecosystem. As such, this study aims to determine if the presence of *Lemna* acts as a driver for the establishment and maintenance of an alternative stable state system in small pond ecosystems through modulation of oxygen and phosphorus levels. The levels of these nutrients were measured in four small *Lemna*-infested urban ponds over the course of one summer. The *Lemna* was manually removed from one of these ponds partway through the monitoring period. Following removal, the *Lemna*-free pond experienced rapid reoxygenation to levels characteristic of a non-eutrophic ecosystem. One of the control ponds experienced a marginally significant change as well, but at a much lesser magnitude. Total phosphorus in the water column of the experimental pond decreased, but it was not significant. These results indicate that the presence of *Lemna* can create an alternative stable state system, and that methods to remove or control *Lemna* growth can effectively reverse eutrophic conditions.

Introduction

The ecology of freshwater systems is heavily influenced by the chemistry and nutrient content of the water itself. While traditional ecological models often assume a continuous linear relationship between aquatic communities and water nutrient levels, Scheffer et al. identified numerous aquatic systems as having alternative stable states[1]. Ecosystems under this type of control tend to gravitate towards one of two sets of ecological conditions based on a critical nutrient threshold. A strong perturbation of water chemistry, usually a limiting nutrient, is necessary in order to switch from one state to another[1,2]. Despite theoretical and empirical support for the existence of alternative stable states in numerous ecosystems, the specific biotic or abiotic drivers that create and stabilize these states are not well understood[2,3].

One potential driver of alternative stable states in smaller water bodies is the presence of dense floating mats of aquatic plants. *Lemna* (duckweed) is a representative taxon of aquatic, free floating plants that commonly inhabit freshwater ponds and lakes. Despite being only about 5 mm in length, these plants form large, dense mats that span across the surface of the water. Under non-eutrophic conditions, photosynthetically active radiation (PAR) will enter into the water column and provide phytoplankton and other macrophytes with energy for photosynthesis. However, when *Lemna* mats are present, PAR is greatly reduced and total photosynthesis is diminished. This photosynthesis is the primary source of dissolved oxygen in many aquatic ecosystems, and without it, waters will quickly become anoxic[4,5]. Consequently, the aquatic environment will become more reducing, causing sedimentary iron (III) phosphate to dissociate as iron (III) is reduced to iron (II), which cannot bond ionically to phosphate[6]. This process causes a substantial increase in total phosphorus in the system[6], thereby allowing for further growth of *Lemna,* which is limited by phosphorus[7]. This self-reinforcement of eutrophic conditions could provide a mechanism for the existence of an alternative stable state. Although *Lemna* dominance results in a dramatic change in the ecological conditions of small ponds[4,5], this does not preclude a classical linear regime of nutrient levels. Data on the threshold and timescale of nutrient recovery in lakes where *Lemna* has been removed is needed in order to determine if *Lemna* dominant lakes constitute an alternative stable state system.

The precise nature of how *Lemna* maintains eutrophic conditions has important implications for environmental management of small lakes. Decline in the water quality of small lakes can compromise downstream water quality and freshwater ecosystems with high economic and social value[8]. The total cost of eutrophication in the United States has been estimated at roughly $2.2 billion per year[9]. However, current methods to remove *Lemna* using herbicides, mechanical skimming, or sediment removal are often temporary and constitute significant monetary costs[10]. The potential existence of an alternative stable state for *Lemna* dominant lakes could allow urban ponds to avoid infestation by setting target phosphorus levels that fall short of the critical threshold between states. Studying the effects of *Lemna* removal on nutrient levels will allow us to determine the existence of an alternative stable state in these systems.

Methods

Throughout the summer of 2020, 4 small ponds located in the Minneapolis/St. Paul area (Table 1) were studied through weekly measurements of water quality during the day using a kayak. Dissolved oxygen (DO), conductivity, and temperature were measured at both the surface and at 25 cm depth intervals at the pond's deepest point using a DO meter and a conductivity meter. One-liter water samples were also collected from the epilimnion (top 25 cm of water) at the center of the pond using sterilized plastic bottles. The water samples were then analyzed for total dissolved phosphorus (TDP) using persulfate digestion followed by molybdate colorimetry[11]. Particulate phosphorus (PP) was filtered from the water samples and analyzed with molybdate colorimetry as well. TDP and PP were summed to determine the total phosphorus (TP).

Beginning on July 22, *Lemna* cover was entirely removed from the Cleveland pond, while the other 3 ponds served as controls. The Cleveland pond was monitored for any *Lemna* regrowth, which was promptly removed in order to maintain a duckweed free environment for the duration of the removal period. Beginning on August 24, no additional *Lemna* was removed from the Cleveland pond. Finally, duckweed samples were collected from each pond using a small quadrat filter (area = 0.0153938 m^2), once before any removal had occurred, and once on the final day of measurement.

Results

Total phosphorus concentration decreased in the Cleveland pond following the removal of *Lemna* (pre-removal mean = 142.562 µg/L, active/post-removal mean = 40.109 µg/L). However, this change was not statistically significant (t=2.035, p = 0.291). The other three ponds which had no *Lemna* removed also experienced an insignificant decrease in phosphorus concentration (Table 1 & Figure 1). In the Cleveland pond, mean DO increased at all depths with each successive period; this change was most profound at depths greater than 50 cm (Figure 2). At 75 cm depth, mean DO increased by 1019% from the pre-removal period to the active/post-removal period, which was statistically significant (t= -4.538, p=0.003). McCaron E also experienced a significant increase at depth 75 cm, albeit at a much lesser magnitude (t=-2.729, p=0.026). Neither McCaron W nor RCCP experienced any statistically significant change. From July to September, the total phosphorus in the Cleveland pond water decreased by 90.3%, opposed to a 77.3% decrease in the RCCP pond during the same time period.

Discussion

In terms of both oxygen and phosphorus, the Cleveland pond showed dissipation of eutrophic conditions and improved water quality following *Lemna* removal (Figures 1 & 2). DO assumed a more uniform distribution

	Total Phosphorus Concentration (µg/L)			
	Cleveland - Experimental	McCarron East - Control	McCarron West - Control	Roseville Covenant Church Pond (RCCP) - Control
7/7/2020	93.382	282.523	315.652	228.375
7/14/2020	191.741	368.899	328.590	299.310
7/28/2020	98.475	NA	674.335	111.777
8/6/2020	23.828	82.587	265.820	109.811
8/13/2020	24.638	191.306	90.844	140.126
8/23/2020	47.476	102.161	74.001	265.572
8/30/2020	47.698	69.999	175.215	276.085
9/6/2020	20.050	321.615	55.811	164.973
9/13/2020	18.601	114.338	51.462	68.169

= Pre-removal Period

= Active Removal Period

= Post-Removal Period

Table 1. Concentration of phosphorus (including particulate and dissolved forms) in epilimnion (top 25 cm) water from each of the four ponds. Red cells indicate samples taken during the pre-removal period, blue cells indicate those taken during the active removal period (removal was only done on Cleveland) and green cells indicate those taken during the post removal period. One McCarron E sample is missing due to a misplaced sample. T-tests assuming unequal variances were performed for each pond individually, comparing the pre-removal period with the combined active/post removal. No significant difference between groups was found for Cleveland (t=2.035, p = 0.291), RCCP (t=2.179, p = 0.117), McCaron E (t=3.07, p = 0.055) or McCaron W (t=1.460, p = 0.194).

Phosphorus Concentration in Water Over Time

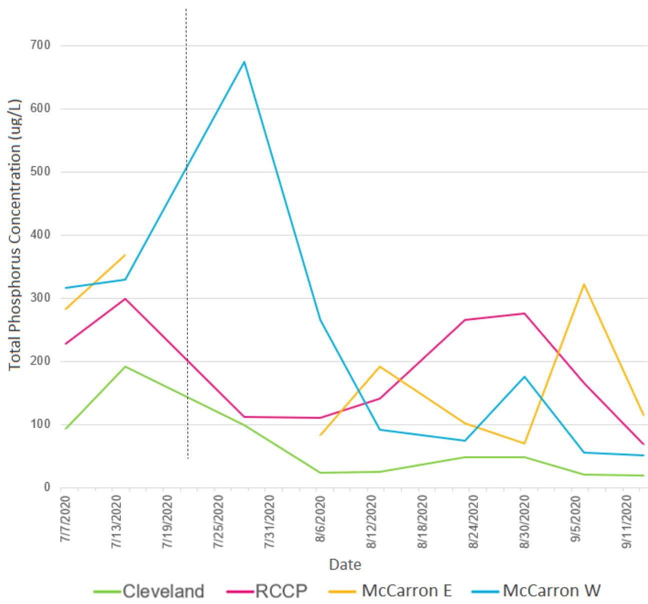

Figure 1. Concentration of phosphorus (including particulate and dissolved forms) in epilimnion (top 25 cm) water from each of the four ponds from 7/7/2020 to 9/13/2020. *Lemna* was removed from only the Cleveland pond on 7/22/2020 as indicated by the dotted line. One McCarron E sample is missing due to a misplaced sample.

throughout the water column (Figure 1), most likely due to an expansion of the euphotic zone when *Lemna* was no longer limiting PAR. This condition of high oxygen at a wide range of depths is characteristic of a non-eutrophic stable state and reduces sedimentary dissociation of phosphorus from iron[6]. However, this shift in phosphorus binding pattern towards sedimentary, rather than dissolved, forms of phosphorus is less clear when analyzing the TP concentration data directly. TP concentration declined in both the active and post removal periods (Figures 2 & 3), but the change was statistically not significant (Figure 1). Furthermore, all of the control ponds experienced a similarly insignificant decline in TP during the active/post-removal periods despite not being manipulated. This could

Oxygen-Depth Profiles Across Time Periods

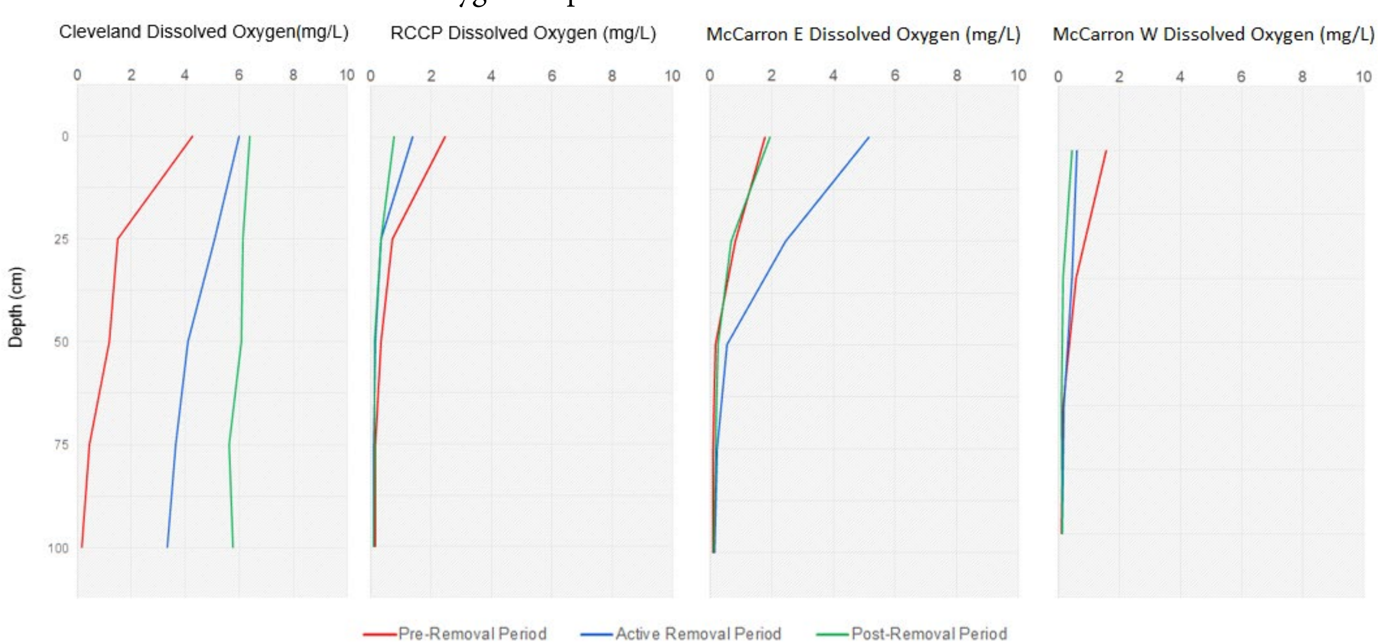

Figure 2. Average dissolved oxygen measured at each depth interval for each of the four ponds divided into 3 time periods: pre-removal, active removal, and post-removal. The pre-removal group consists of measurements taken from 6/15 to 7/21 (before any removal occurred). The active removal group of measurements were taken from 7/22 to 8/23, during which *Lemna* had been removed and was actively being removed in the Cleveland pond only. The post removal group of measurements were taken from 7/22 to 8/23, during which *Lemna* was no longer being actively removed. T-tests assuming unequal variances were performed for each pond individually comparing the pre-removal period with the combined active/post removal at depth 75 cm. A significant increase was found for Cleveland (t= -4.538, p=0.003) and McCaron E (t=-2.729, p=0.026). No significant change was found for RCCP (t=1.195, p=0.271) or McCaron W (t=-0.857, p=0.440).

Total Pond Phosphorus in Water and Duckweed

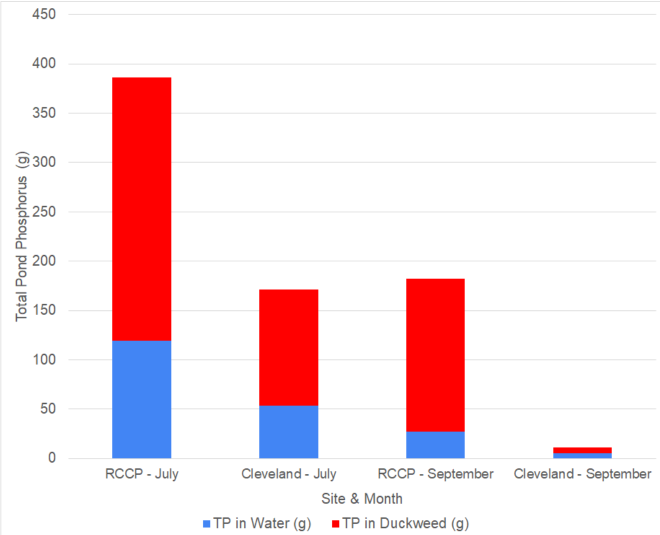

Figure 3. Total phosphorus contained in both water and *Lemna* in RCCP and Cleveland prior to Cleveland's removal (July) and at the end of the study period (September).

suggest that the decline in TP concentration seen in the Cleveland pond was a result of seasonal changes or local weather patterns rather than the removal of *Lemna.* Conversely, it could simply be a consequence of this study's small sample size, in which case, more extensive data could show significance.

It is also plausible that TP uptake out of the water and into the sediment is being impeded by "legacy phosphorus" to some extent. This phenomenon occurs when a water body has been exposed to extensive phosphorus runoff for many decades, resulting in a vast reserve of phosphorus in the sediments[12]. As a result, the ability of these sediments to uptake new phosphorus can be compromised until the reserve is reduced[13]. If the Cleveland pond has a large reserve of legacy phosphorus, it may take a multitude of years with non-eutrophic conditions for TP concentration to show a significant decrease. Such a decrease may be necessary to limit *Lemna* (which have high phosphorus uptake) over a large timescale and maintain a stable non-eutrophic state[1,2]. Despite the insignificant phosphorus response of the Cleveland pond, the *Lemna* and DO conditions during the post-removal period were indicative of the new nutrient regime's stability. Even after duckweed was no longer being manually removed from the pond, high DO conditions persisted (Figure 2) and *Lemna* regrowth was minimal. However, the post removal period happened mostly during September, rather than the earlier summer months when *Lemna* growth is typically highest.

Conclusion

From the DO and TP data collected, the Cleveland pond showed some indications of an alternative stable state change as a result of *Lemna* removal. This supports the hypothesis that *Lemna* can be a driver for alternative stable state systems in ponds. However, the broad timescale of phosphorus recovery is still questionable due to the scale limitations of this study, and the potential role of legacy phosphorus in sediment uptake. Additionally, the analysis of phosphorus data did not account for continual uptake of phosphorus by duckweed itself during the study period in the control ponds. Further analysis of these data or future data could account for this limitation and yield new findings. Additional study examining the effects of *Lemna* removal over multiple years and in multiple ecosystems is needed to fully understand the dynamics of *Lemna* alternative stable state systems. From this understanding, more efficient methods for addressing *Lemna* driven eutrophication can be devised. A precise knowledge of nutrient thresholds between states and the impact of legacy phosphorus on these thresholds could allow policy makers to avoid *Lemna*-dominant conditions by setting target phosphorus loads below the critical level.

Literature Cited

1. Scheffer, M., Hosper, S. H., Meijer, M. L., Moss, B. & Jeppesen, E. Alternative equilibria in shallow lakes. *Trends in Ecology and Evolution* **8**, 275–279 (1993). doi:10.1016/0169-5347(93)90254-M

2. Dent, C. L., Cumming, G. S. & Carpenter, S. R. Multiple states in river and lake ecosystems. *Philos. Trans. R. Soc. B Biol. Sci.* **357**, 635–645 (2002). doi:10.1098/rstb.2001.0991

3. Beisner, B., Haydon, D. & Cuddington, K. Alternative stable states in ecology. *Front. Ecol. Environ.* **1**, 376–382 (2003). doi:10.1890/1540-9295(2003)001[0376:ASSIE]2.0.CO;2

4. Pasztaleniec, A. & Poniewozik, M. The impact of free-floating plant cover on phytoplankton assemblages of oxbow lakes (The Bug River Valley, Poland). *Biol.* **68**, 18–29 (2013). doi:10.2478/s11756-012-0129-3

5. Ceschin, S., Sgambato, V., Ellwood, N. T. W. & Zuccarello, V. Phytoremediation performance of *Lemna* communities in a constructed wetland system for wastewater treatment. *Environ. Exp. Bot.* **162**, 67–71 (2019). doi:10.1016/j.envexpbot.2019.02.007

6. Vaalama, A., Hartikainen, H., Vallius, H. & Lukkari, K. Phosphorus exchange in eutrophied coastal brackish water sediments—sorption pattern, potential and factors affecting them. *SN Appl. Sci.* **1**, (2019). doi:10.1007/s42452-019-1374-7

7. Iqbal, J., Javed, A. & Baig, M. A. Growth and nutrient removal efficiency of duckweed (lemna minor) from synthetic and dumpsite leachate under artificial and natural conditions. *PLoS One* **14**, e0221755 (2019). doi:10.1371/journal.pone.0221755

8. Downing, J. A. Emerging global role of small lakes and ponds: little things mean a lot. *Limnetica* **29**, 9–24 (2008). doi:10.23818/limn.29.02

9. Dodds, W. K., Bouska, W. W., Eitzmann, J. L., Pilger, T. J., Pitts, K. L., Riley, A. J., Schloesser, J. T., & Thornbrugh, D. J. Eutrophication of U. S. freshwaters: Analysis of potential economic damages. *Environmental Science and Technology*, *43*(1), 12–19 (2009). https://doi.org/10.1021/es801217q

10. Ceschin, S., Ferrante, G., Mariani, F., Traversetti, L. & Ellwood, N. T. W. Habitat change and alteration of plant and invertebrate communities in waterbodies dominated by the invasive alien macrophyte Lemna minuta Kunth. *Biol. Invasions* 1–13 (2020). doi:10.1007/s10530-019-02185-5

11. Bratt, A. R., Finlay, J. C., Welter, J. R., Vculek, B. A. & Van Allen, R. E. Co-limitation by N and P Characterizes Phytoplankton Communities Across Nutrient Availability and Land Use. *Ecosystems* (2019). doi:10.1007/s10021-019-00459-6

12. Jarvie, H. P., Sharpley, A. N., Spears, B., Buda, A. R., May, L., & Kleinman, P. J. A. Water quality remediation faces unprecedented challenges from "legacy Phosphorus." In *Environmental Science and Technology* (Vol. 47, Issue 16, pp. 8997–8998). American Chemical Society (2013). https://doi.org/10.1021/es403160a

13. Ryan, R. J., Packman, A. I., & Kilham, S. S. Relating phosphorus uptake to changes in transient storage and streambed sediment characteristics in headwater tributaries of Valley Creek, an urbanizing watershed. *Journal of Hydrology*, *336*(3–4), 444–457 (2007). https://doi.org/10.1016/j.jhydrol.2007.01.021