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Literature Review #1(annotated bibliography)

Preventing Eutrophication:
Nutrient loading, function, mechanisms and mitigation approaches in freshwater systems.

In freshwater systems, Phosphorous load, Temperature and dissolved oxygen are extremely important measurable qualities which can be reliable indicators of lake ecosystem productivity, trophic structure, and level of sustainability as their relative and individual values have important implications for lake primary producer population dynamics. It is necessary to continuously monitor these variables within lakes and watersheds of concern to guide mitigation strategies to which there are a variety of options. The need for protection of water resources is especially dire in light of the impacts of anthropogenic development and climate change.

French, T.D; Petticrew, E.L.(2007)Chlorophyll a seasonality in four shallow eutrophic lakes(northern British Columbia, Canada) and the crucial roles of internal phosphorous loading and temperature. Hydrobiologica.575, pp285-299

This article summarizes the Limnological research on Lakes Charlie, Tabor, Nulki and Tachick , British Columbia. The lakes have different Depth and local development conditions. Sampling was conducted on these lakes at different times per lake between 1990 and 2001 in all seasons and measured for chlorophyll a, Total dissolved Phosphorous, Dissolved oxygen, temperature, and Ph. The authors summarized the data and measured the correlation of variables to chlorophyll concentration to determine their reliability as predictors where they may theoretically have a positive correlation, and accounted for inconsistencies in the data to infer the magnitude of effect of the lakes internal nutrients and consequent chlorophyll concentrations. The authors found that among these lakes, models that incorporated Total phosphorous in addition to temperature accounted for 57-70% of within lake variations in chlorophyll on an instantaneous basis. They suggested the importance of temperature on algal productivity and refer to several studies which focused on the relationship between latitude and chlorophyll concentrations. The authors attribute differences in Oxygen and Phosphorous gradients in the lakes to their depth profiles and thermal stability over the seasons, postulating that internal phosphorous loads accounted for much of the productivity in these BC lakes however they also suggest that macrophyte decomposition at the bottom of these lakes contributes a significant amount of internal phosphorous loads based on previous studies conducted on the lakes.

Frost, P.;Schindler D; Porter-Goff, E.; Middleton, C.(2012) The Algae of Kawartha Lakes: Their place in the ecosystem, when they become a problem, and what controls their growth. Kawartha lake stewards association, 37 pp

This document was produced in response to concern of residential homeowners living near the shores of the Kawartha lakes continuum in southern Ontario. The authors summarize general relationships between algae and nutrients, provide a description of common algal species with suggestions of the implications of presence, and also provide current (to 2012) knowledge of algae community, population and nutrient loading conditions in the Kawartha lakes. They provide reference to some recent studies conducted in the Kawartha Lakes area, and conclude with suggestions for landowners. Reference to a study on the area is made which suggests that phosphorous load is positively correlated with lake location eastward. Another study undertook by the authors of the article demonstrated that the reduction of any nutrient in lake water, would limit growth and proliferation of algal communities, but they suggest continued focus on phosphorous due to the fact that it is limited, it is measurable, and there is already a body of information profiling the location of P in the Kawartha lakes.

J. Barica (1993) BOUNDARIES OF ECOLOGICAL SUSTAINABILITY OF PRAIRIE LAKES AND RESERVOIRS, Canadian Water Resources Journal, 18:3, 291-297

This document is a summary of the work author J Barica to 1993 on algal growth in prarie lake systems in Western Canada. The author focuses on the mechanisms involved in eutrophication, interactions between nutrients and phytoplankton species and makes some suggestions about development with some specific reference to qualities characteristic of shallow(~2-5m depth) prarie lake systems. Graphs explain the dynamics which are to be expected for important limnological variables before and after a eutrophication event in winterkill and summerkill situations, leading to eutrophication in prarie lakes. The author also delineates the difference in values to be expected for limnological parameters over the span of a year, to define what is considered a sustainable, unstable oscillating or unsustainable system with regards to nutrient inputs and consequent chlorophyll concentrations. The author suggests chlorophyll concentrations of 20 – 30 μg/l to be sustainable. His final point is that that the praries would be unsuitable for development as high productivity in lakes in these areas would need to be treated for, and also that the waters would be particularly vulnerable to nutrient loading through waste and agriculture as the carrying capacity of these lakes are almost fully utilized.

Mildner, J; Friedl, M.; Fresner, R.; Sena, F. Ghiani, M.; Noges, T.; Noges, P. (2011) Increased nutrient loading and rapid changes in phytoplankton expected with climate change in stratified south European lakes: Sensitivity of lakes with different trophic state and catchment properties. Hydrobiologica 667: pp255-270

Warming Temperature regimes associated with climate change are expected to impact nutrient cycling dynamics in freshwater systems with short residence times(time water stays before it is flushed out of the water body). Noges and Ghiani collected chemistry and phytoplankton data over two years in two stratified lakes to determine the potential impact that increasingly rainy winters would have on trophic status in northern Italy in relation to several lake characteristics. Each lake had a different trophic state and water retention time(ogilo mesotrophic,7.9 years, eutrophic, 1.7 years). They found that higher nutrient loading during a rainy winter and spring in the lakes studied functioned to increase nutrient concentrations(N, P Si) and also induce a *phytoplankton based* trophic state index, while at the same time, N/p ratio decreased in both lakes. Higher Si also resulted in increased Diatom concentrations. The eutrophic lake experienced an interruption of commonly occuring algal blooms , while the ogilo-meso trophic lake, chlorophyll *a* increased. The impact of rainy period on trophic state was more related to runoff/ in lake concentration of nutrients than the lakes retention time. Higher magnitude affects were also exhibited in the lake with a lower trophic state.

Orihel, D.; Baulch, H.; Casson, N.; North, R.; Parsons, C.; Seckar, D.; Venkiteswaran, J. (2017) Internal phosphorous loading in Canadian fresh waters: a critical review and data analysis. Can J. Fish. Aquat. Sci. 74, pp. 2005-2029

Phosphorous loading by means of sediment erosion is a primary mechanism responsible for the occurrence of algal blooms in freshwater systems. The authors of this study reviewed 43 Canadian studies on internal Phosphorous loading in freshwater lakes to obtain 618 estimates of internal phosphorous loading from Canadian freshwater ponds lakes, reservoirs and coastal wetlands. 618 estimates of internal phosphorous loading were derived from the studies. Oxygen pH, geology, and trophic state were found to be related to the variation in short term gross benthic phosphorous flux(Lgross) and net internal Phosphorous loading rate. They also found through their observation that prarie lakes had higher phosphorous loading rates, and also that loading was higher during the open-water season. The authors also suggest that there are holes in the research on phosphorous loading, particularly in the anthropogenic impacts of sulfur pollution and aquaculture, the relative impact of different mechanisms, especially in response to climate change and quantifying phosphorous loading rates in understudied systems of human importance such as reservoirs. They conclude that currently imposed regulatory schemes are based from incomplete knowledge, and more work must be done to establish a distinctive Canadian regulatory scheme that can sufficiently encompass all lake systems.

Paerl, H.; Gardner, G.;Havens, K.;Joyner, A.; McCarthy, M.; Newell, S.;Qin, B.;Scott, T.;(2015) Mitigating cyanobacterial harmful algal blooms in aquatic ecosystems impacted by climate change and anthropogenic nutrients. Harmful Algae 54, pp.213-222

The effectiveness of mitigation techniques to prevent algae blooms in aquatic systems concerns resource managers and researchers, as climate change and population growth will alter the physical context in which these events occur in terms of nutrient loading and temperature. The authors of this article explore the current mitigation strategies commonly applied to systems threatened by harmful cyanobacterial blooms, and address how they may be able to adapt to the coming conditions of the future. It is the expectation that harmful cyanobacterial species blooms will occur more frequently, given a climate trajectory that predicts higher temperatures and greater precipitation in the future. To reduce bloom occurences, a variety of approaches have been used by conservationists, including N and P reduction regulations, Increased flushing, Enhanced mixing of water, Manipulations of food webs, Ultrasonic treatments, upstream wetland development, treating chemically, encouraging macrophyte growth, and sediment capping or dredging, summarized in the article. To remain effective however, the authors assert that those mitigation strategies should correspond with climate change by adopting new targets for nutrient loading, and cyanobacterial growth.

Smith, V.H.; Schindler, D.W.(2009)Eutrophication science: where do we go from here?. Trends in Ecology and Evolution 24: 201-207

This is a review and Summarizes the effects of anthropogenic nitrogen and phosphorous pollution caused eutrophication on lakes reservoirs rivers and coastal zones. It includes a summary of the primary mechanisms involved in the process of nutrient contamination and eutrophication, implications for humans, including increased disease occurrence and increased virulence and abundance of water-borne human pathogens, evidenced from studies focused on sites where water has been commonly used for bathing and these effects bringing concerns in relation to climate change. Interestingly, the authors have included descriptions of novel mitigation and restoration examples in lakes exhibiting eutrophication symptoms. They describe biomanipulation as the removal or prevention of removal of species with activities and natural histories associated with increased or decreased phosphorous in lakes. They note work that suggests high biomass algal phases commonly occur when lakes contain one or 3 tropic levels, while low biomass phases are common with two or four trophic levels. Controlling trophic cascades appears to show promise in situations where there are few consumer species feeding at more than one trophic level. Referring to a few very reputable cases, including the famous Experimental lakes study area eutrophication experiment, the authors suggest that reducing phosphorous loads in rivers is a cost effective way to improve water quality since nitrogen abundances in water bodies are commonly attributed to nitrogen fixing cyanobacteria, who's concentrations are directly related to available phosphorous. They also discuss the successes in remediation and mitigation actions taken by researchers and conservationists in the past and suggest that watershed specific limitations on nitrogen phosphorous and other toxic contaminants be placed but that the effectiveness of methods is an area in the literature that still needs research.

Søndergaard, M. (2007) Chapter 2: Retention of phosphorous and nitrogen, (pp. 17 – 33) From: Nutrient dynamics in lakes – with emphasis on phosphorus, sediment and lake restorations. Doctor's dissertation (DSc). National Environmental Research Institute, University of Aarhus, Denmark. 276 pp.

This chapter is educational in nature and summarizes the conclusions of many peer reviewed authors and also includes his own study on the specific topic of deposition and resuspension of phosphorous and nitrogen in freshwater systems, with some mention of the implications that these dynamics have on lake trophic status. More specifically, the author describes several important points from the current literature. The author cautions that models quantifying phosphorous retention in lakes and for lakes in an equilibrium state may not account for high or low magnitude loading events because they do not address quantities of P seasonally but rather annually. The author applied phosphorous retention model to 9 Danish lakes and found that they had a tendency to overestimate the actual phosphorous retention. The author thus suggests which factors important to lake nutrient depositional dynamics may be considered and cannot be accounted for in the equation, and also emphasizes the point that the equations cannot estimate the differences in concentration attributable to lake turbidity, a substantial determinant of retention capability. Sondergaard also Makes note of the physical process of sediment accumilation at the bottom of lakes and where in the lake sedimentation may be more concentrated, in deep areas, and variation within and between lakes bearing different chemical physical and temporal properties as well as the close relationship sediment retention of P has with lake water P.

P concentration in the lake is equal to the difference of the input to the out put of phosphorous in the lake- and loss is closely associated with organic compound content.
He describes different processes of applying chemical treatments to samples to extract phosphorous content from the several forms it occurs in, and illustrates in simple terms that the quantity of phosphorous sampled will only depend on the specific chemical treatment which is applied, to which there are many, and all destroy the sample in the process of extraction with the suggestion there is potential for error in data acquired through these methods. Different forms of phosphorous also occur in different proportions throughout the year. Sondergaard notes the following mechanism high phytoplankton production → high pH → large pool of loosely bound phosphorus → high phosphorus release from the sediment → high phytoplankton abundance and suggests that the interaction between sediment phosphorous pools and phosphorous fractions of different types, and the interaction this may have with the water and sediment are unknown, and therfore modelling for the sediment phosphorous release predictions cannot be entirely accurate. Secchi depth conditions in relation to phosphorous retention are also considered. Some other less fundamental points are made, specifically regarding what is to be expected for seasonal dynamics, transitional periods and measurement in lakes which should constitute phosphorous retention dynamics.

Søndergaard, M. (2007) Chapter 3: Mechanisms behind the sediment release and uptake of phosphorous, (pp. 33 – 39) From: Nutrient dynamics in lakes – with emphasis on phosphorus, sediment and lake restorations. Doctor's dissertation (DSc). National Environmental Research Institute, University of Aarhus, Denmark. 276 pp.

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The third chapter of Sondergaards dissertation focuses on the mechanisms of the resuspension of phosphorous and nitrogen deposited in lake bottoms. Depth, wind, wind speed, exposed surface area/ wave height can have profound effects on sediment mixing at the bottom of lakes, especially where water is shallow. In addition to measuring the above to make determinations of lake sediment mixing state, established empirical equations can be used which utilize the relationship between secchi depth, and water depth as determinants of phosphorous. Higher wind speed is also noted to have a positive effect on Total Phosphorous, evident within days. When resuspension of lake bottom sediments occurs, it may also trigger the release of nutrients and impact phytoplankton development by the above mentioned, however the effect also depends on lake chemical properties and importantly, the proportion of particular bound phosphorous and dissolved phosphate present, under the conditions of the lake (such as Ph, Oxygen, iron content).

Temperature also impacts almost all processes and may be explanatory in empirical relations between nutrient input and nutrient concentration, since temperature increases the rate of chemical diffusion and chemical processes, but biological processes are most important since they have a large proportionate impact on nutrient release in lakes. High temperatures stimulate mineralization of organic matter in sediment and release of organic phosphate. Solubility of oxygen in water is temperature dependent which impacts organism and oxidation of minerals, importantly iron, and iron compounds which have implications for phosphorous release from sediment and concentrations in water.

The author also gives importance to the fact that the frequency of binding of phosphorous to iron compounds decreases when there are higher pH vales within water bodies. When there is high photosynthesis activity in a water body, this can increase pH and consequently stimulate phosphorous resuspension. Chemical diffusion flux to determine sediment phosphorous and water phosphorous exchange can be calculated using Ficks first law and depends on the concentration gradient, and porousity in the sediment. Some organisms such as chironomids and bottom feeding fish, also contribute to the resuspension of bottom materials through physical contact and excecretion, and the magnitude of their impact also depends on the properties of the sediment.
Submerged macrophytes impact the exchange of nutrients between sediment and water substantially and it can be a positive or negative relationship. They may limit water mixing which results in low dissolved oxygen at high elevations, Alter pH balances in water, or reduce the affect that wind has on water mixing. Some studies have shown however, that macrophytes do not significantly affect nutrient retention.

Conclusion

Water quality is detrimental to, and is also a reflection of local ecosystems. Excessive nutrient loading due to human activities is preventable and requires careful examination of the freshwater systems in question in order to develop plans for mitigation. Among a wide variety of variables to be considered in these determinations, Phosphorous is the most limiting, and central to studies which attempt to quantify and predict lake productivity. P loading flux appear almost as specific as the lakes themselves, and much has to be taken into account in the investigation of these dynamics, including lake depth, chemistry, climate, and surface area.

While the deposition of nutrients in lake systems can be a simple factor for various land users to regard and overlook, the complex processes which occur in streams and lakes are incredibly complex and still yet to be understood entirely. In addition to anthropogenic loading, the stability of aquatic systems is also threatened by climate warming which would imply faster chemical processes, less stratification, and ultimately increased lake productivity and increased global frequency of eutrophic conditions. The body

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of literature surrounding the dynamics involved in the process of eutrophication and human and environmental implications are practical, and should become more valuable overtime, considering the above.