Nutrients from the deep: internal phosphorus loading in hyper-eutrophic Clear Lake

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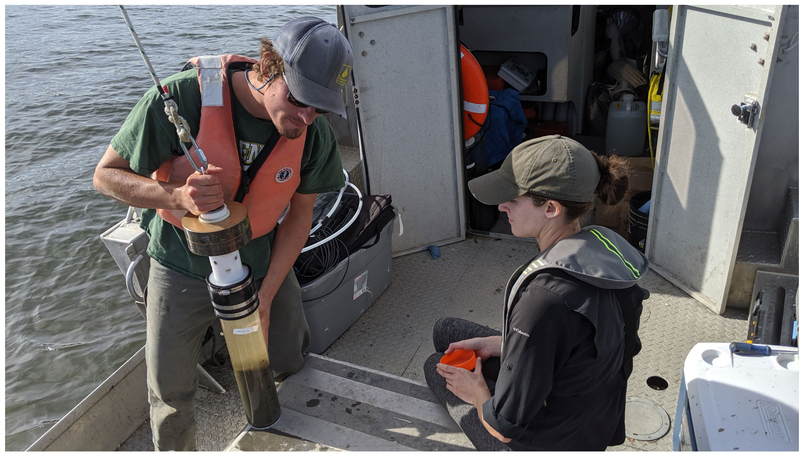


Introduction

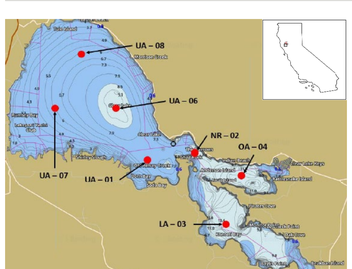
Eutrophication is a large problem globally that results from excess nutrients (i.e. nitrogen and phosphorus) entering aquatic systems. In the case of phosphorus, it enters lakes by external (runoff) or internal loading (from lake-bottom sediments). Efforts to restore Clear Lake, a hyper-eutrophic lake located in Lake County, CA, have largely focused on external loading as the cause of excessive phosphorus concentrations.

In this study, we sought to quantify the internal load of phosphorus for the first time in Clear Lake by measuring phosphorus flux rates from lake-bottom sediments.

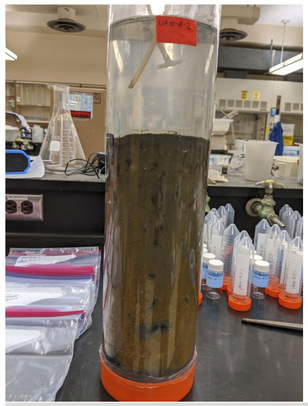
Results of this study will be incorporated into a whole-lake hydrodynamic model to aid in developing phosphorus management strategies for the lake.

Site Description

- Historically eutrophic lake due to high phosphorus content in parent material
- Likely the oldest lake in North America with sediments dating back to 450,000 years ago and beyond
- Lake is now hypereutrophic and suffers harmful algal blooms (HABs) that cause fish kills from anoxia and produce toxins

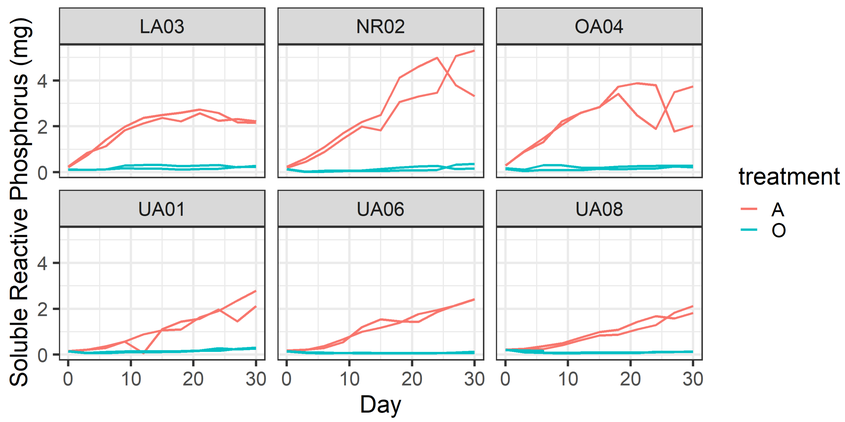


Materials & Methods

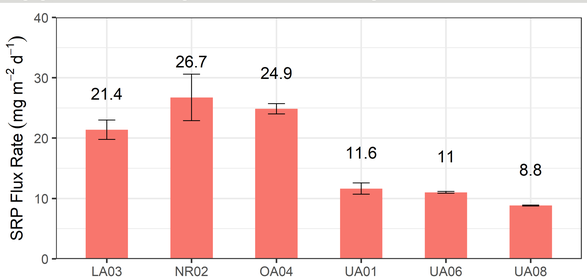


- Collected 4 cores per site from 6 sites across the lake
- We oxygenated 2 of the cores from each site by bubbling with air, the remaining 2 cores kept anoxic by bubbling with N2 gas
- Incubated cores at 15.2°C for 30 days, sampling every 3 days
- Analyzed water in cores for pH, ORP, SRP, DP, NO3, and NH4
- Calculated mass-balance of soluble reactive phosphorus (SRP), dissolved phosphorus (DP), nitrate (NO^{3}), and ammonium (NH^{4})
- Calculated maximum rate of flux of above analytes from linear portion of mass vs. time curves

Results



Flux rates of SRP. *Lines indicate SRP mass (mg) in individual cores taken from each of the 6 sites. Anoxic cores (red lines) exhibit highest rates of SRP flux with values ranging from 8.8 to 26.7 mg m^{-2} d^{-1}. Oxic cores (blue lines) exhibit much lower rates with values ranging from -0.14 to 1.16 mg m^{-2} d^{-1}. Site NR02 has the highest SRP flux rates–over 3 times the rate of site UA08.*

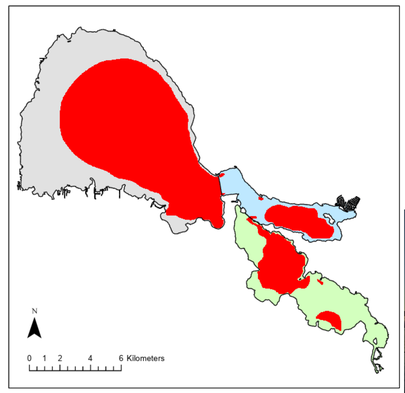


Anoxic SRP flux rates by Site. *Sites showed high spatial variability in SRP flux rates. Site NR02 had the highest rate (26.74 mg m^{-2} d^{-1}) and site UA08 had the lowest rate (8.83 mg m^{-2} d^{-1}).*

Annual Internal Load

P-Loading Source	P-Species	Annual Load (MT yr^{-1})	% Annual SRP load
External	SRP	37.1 - 51.4[1]	59-67%
Internal	SRP	25.6	33-41%
External	Total-P	89.9 - 125[1]	NA

Annual inputs from either external or internal sources shown in metric tons (MT). Internal loads of SRP contribute to 33-41% of the total SRP load to the lake each year.



The red portion of the lake-bottom represents the anoxic zone during the period of stratification in March-October 2019 that could allow sediments to actively exchange phosphorus to the water column.

Discussion

- High rates of SRP flux lead to annual internal loads nearly equal to external loads of SRP, thus contributing a significant source of phosphorus to the lake.
- Large spatial variability in anoxic phosphorus flux rates as sites NR02 and UA08 showed 3-fold differences.
- SRP is more biologically available to phytoplankton than other phosphorus species, thus internal loading likely contributes to harmful algal blooms seen in the lake.
- Even with reduction of external phosphorus loads, recovery of Clear Lake may be delayed as internal loading will likely continue to fertilize the lake until sediment-phosphorus is depleted.
- Managers pursuing restoration efforts should consider internal loading when examining current total maximum daily loads (TMDLs) of phosphorus.

Acknowledgments

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References:
[1]Lundquist, E., and Smythe, T. 2010. Clear Lake Integrated Watershed Management Plan. County of Lake Department of Public Works Water Resources Division. West Lake and East Lake Resource Conservation Districts, Lakeport, CA, USA.