Bear Lake Limnology & Nutrient Limnology

WATS 2015 Graduate Induction Course

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In 2015 we took our incoming graduate students to Bear Lake and one part of this introductory course focused on the limnology of the lake. Students were taken out on the lake in two groups to measure temperature, oxygen and chlorophyll profiles. The boat was not anchored for the first sampling trip, and because of inclement weather, the boat drifted, making the vertical profiles problematic. With the second group the boat was anchored so that accurate depths would be recorded

In addition to the profiles, an in-situ nutrient addition bioassay was done to demonstrate an experimental approach to understanding what nutrients might control production processes of phytoplankton at the base of the plankton food web. This was initiated on 20 August 2015 and the students sampled it on the 26th, given a 6-day incubation period in the lake. The bottles were subsequently sampled in the laboratory on the 27th.

Vertical profiling of temperature, oxygen and chlorophyll—A YSI Model 58 sensor was used to measure temperature and oxygen profiles at a station approximately 3 km east of Garden City. A Kemmerer bottle was used to collect water which was subsequently filtered on 1-um glass fiber filters and extracted with 95% ethanol to measure chlorophyll a concentrations with a Turner 10-AU fluorometer.

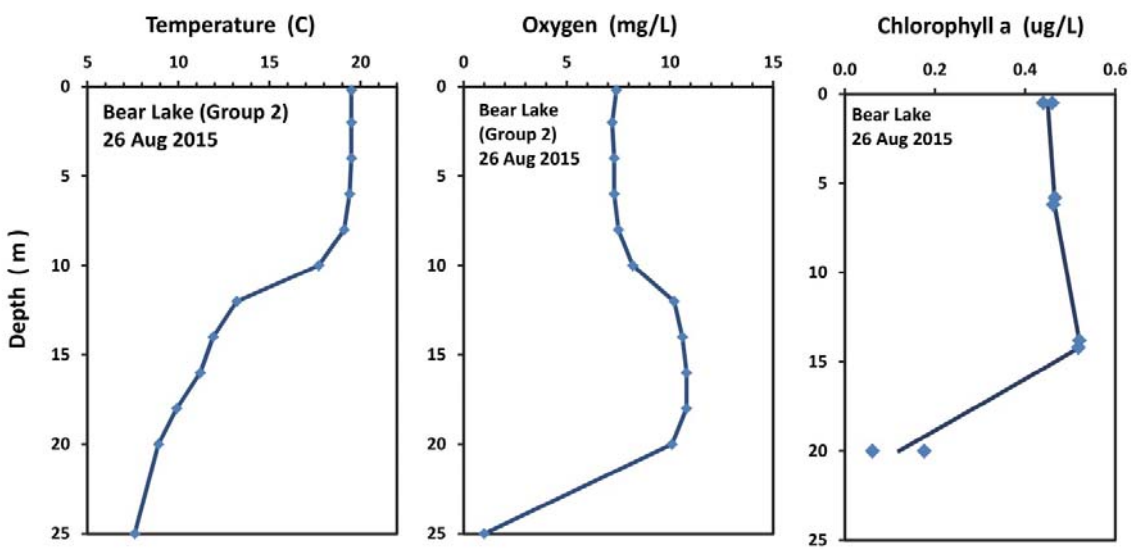

Figure 1. Left – Temperature profile. Center – Dissolved oxygen. Right – Chlorophyll a profile in Bear Lake on 26 October, 2015.

Bear Lake was strongly stratified with temperatures of 19.5° C in most of the epilimnion (Figure 1). The thermocline began between 8-10 m, and the temperature dropped to 11.9° C at a depth of 14 m and continued to decline to 7.6°C at 25 m. Oxygen concentrations were near 7 mg/L in the epilimnion, increased to over 10 m in the colder metalimnion (12-20 m) and then declined abruptly at 25 m. It is likely, however, that at 25 m the probe was in the sediments, as such a sharp decline would not be expected in the water column of an unproductive lake like Bear Lake.

Chlorophyll levels, a measure of algal biomass, were very low in the epilimnion of the lake, with concentrations near 0.45 ug/L. Concentrations increased slightly in the metalimnion (14 m) suggesting that there was a slight deep-chlorophyll layer, but concentrations nevertheless were low. At the deepest depth sampled (20 m) concentrations declined to near 0.10 ug/L. The low chlorophyll concentrations indicate that the lake is ultra-oligotrophic.

Secchi depths of 10.5 m (20 August) and 5.7 and >6.5 m (26 August) were less than expected based on the amount of chlorophyll in the phytoplankton. However, calcium carbonate precipitates (marl) are present in the water column, and this reduces water clarity and results in the milky-blue color of the water. The lower Secchi depths measured on the 26th may have been the result of wavy conditions and an overcast sky that causes high reflection on the lake surface and makes it difficult to accurately measure the depth the disk disappears from view.

Ponar dredge samples were collected at a depth of approximately 20 m and inshore near the Bear Lake Marina where the depth was ~2 m. The offshore sample was dominated by fine marl with a limited amount of sand, whereas the inshore sample had little fine marl, considerable sand, and snail and clam shells. The offshore dredge sample contained numerous red oligochaete worms, but only one worm was observed (by eye) in the inshore sample.

A vertical haul with a 30-cm, 153-µm zooplankton net done by each group. The sample was dominated by rotifers (probably *Conochilus* sp.), the copepod *Epischura sp.*, and the cladoceran *Bosmina* sp.. However, quantitative analyses with a microscope were not done.

Nutrient Addition Bioassay

Water was collected from 5 m in Bear Lake on August 20th at ca. 10:30 and 900 ml was placed into 15, 1000-ml acid-washed polycarbonate bottles (Coke bottles). Macro-zooplankton were removed with a 153-µm mesh net, except for 1 treatment where zooplankton collected with a net were added back to three replicates.
Nutrients were injected into the bottles as shown at the right.

Treatments (3 replicates each)	Form
Nutrient Control (no addition)	---
+ N (350 ug N/L)	NH_4NO_3
+ P (50 ug N/L)	$NaHPO_4$
+N + P (350/50 ug/L)	both
+N + P (350/50 ug/L) + Zooplankton	both

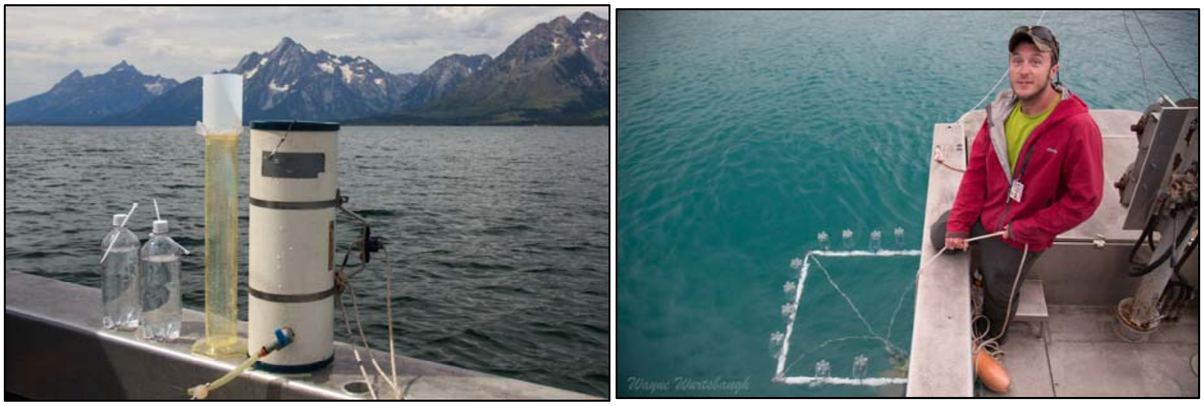

Figure 2. Left—apparatus used to collect bioassay water (Jackson Lake photo from 2014). Right—incubation frame used to incubate the 15 bioassay bottles.

The bottles were incubated at 5 m depth off SE corner of the Bear Lake Marina. During the first 5 days of the incubation there was little cloud cover but the sky was very hazy due to western wildfires. The bottles were retrieved at 9:00 AM on 26 August (day 6) at 8:30 AM and a 50-ml sample from each bottle was filtered on 1-µm glass fiber filters by the students, frozen on dry ice, placed in 95% ethanol in 15-ml centrifuge tubes for 3 hrs., and then read in an Turner Aquafluor fluorometer. The results were quite variable (Appendix 1), so the bottles were transported to USU and placed in a temperature controlled chamber (20 C) and 150 $\mu E/m^2$/second light intensity until the following day (day 7). 50-ml samples were again filtered using a Millipore filtration assembly. The filters were frozen in the laboratory freezer overnight, placed in 95% ethanol, and extracted for 22 hours before chlorophyll *a* was measured with a Turner 10 AU fluorometer using the Welschmeyer filter set (Welschmeyer 1994).

Bioassay Results--The results of the bioassay (Fig. 2) indicated that phosphorus was the nutrient limiting growth of phytoplankton at the time of the bioassay. Day-7 chlorophyll levels both the phosphorus (+P) and in the nitrogen plus phosphorus (NP) treatments were double those in the controls or +N treatments, and these differences were statistically significant.

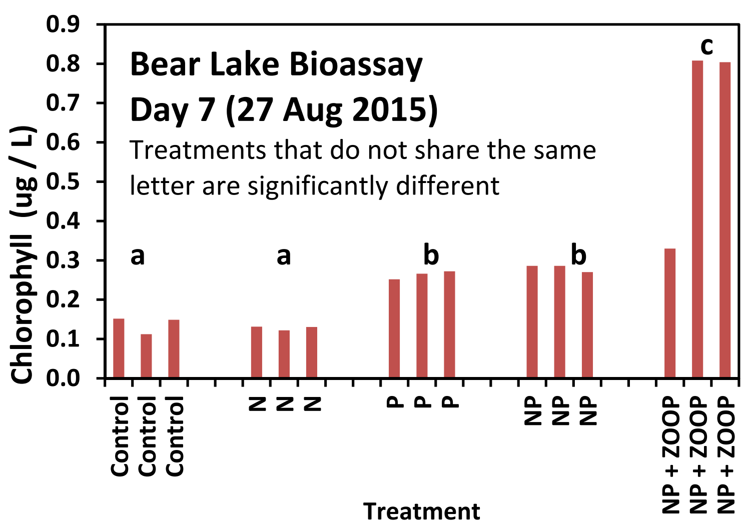

Figure 3. Chlorophyll *a* concentrations at the end of the bioassay (day 7). Groups of replicates with the same letter over them were not significantly different (ANOVA of log-transformed values followed by Tukey's test, $p < 0.05$; SYSTAT).

Surprisingly, the treatments receiving N+P+zooplankton had the highest chlorophyll levels, and although variability between the three replicates was high, these concentrations were significantly higher than any of the other treatment groups.

Discussion

The very low levels of chlorophyll in the lake indicated that it is ultra-oligotrophic. The epilimnetic concentrations measured averaged 0.46 µg/L. This is similar to the mean chlorophyll levels reported by Wurtsbaugh and Hawkins (1990) and Dean et al. (2009). The high oxygen levels, particularly in the metalimnion, are also indicative of the oligotrophic nature of the lake.

Algal nutrient limitation by phosphorus was somewhat unexpected, as Wurtsbaugh (1988) reported bioassay results showing that that nitrogen was limiting production during the mid-1980s. More bioassays would be needed to determine if there really has been a shift in the limiting nutrient. However, Goldman et al. (1993), attributed a shift from nitrogen to phosphorus limitation in Lake Tahoe to increased atmospheric deposition of nitrogen in the Tahoe Basin. Air pollution has increased considerably in the Wasatch Front west of Bear Lake, so it is possible that nutrient loading patterns have changed here as well. The extensive wildfires in the west prior to the experiment could also have contributed ammonia and nitrate to the lake. However, a much more thorough analysis of nutrient loading and the biological responses would be needed to test these hypotheses.

More surprising was the high chlorophyll levels in the N+P+Zooplankton treatment. This treatment was done to show the top-down effects of grazers on the phytoplankton, but the opposite result was found. It is possible that the concentrate used to inoculate the zooplankton treatment had filamentous phytoplankton that did not pass through the 153 µM mesh, or that excretion of viable phytoplankton from the guts of zooplankton (Porter 1976) produced the higher chlorophyll levels.

Figure 4. Bear Lake sunset on 25 August 2015 taken at Rendezvous Beach at the south end of the lake.

References

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Appendix 1. Concentrations of chlorophyll a measured in the lake, and in the bioassay initially, on day 6 (26-Aug) and on day 7 (27-Aug).

Flask	Nutrient	Replicate	Chl Concentration (ug / L)	Sample Date	Date Chl Analyzed	mL Filtered	mL Extractant
	Initial		**0.53**	**20-Aug-15**	26-Aug-15	**40**	**10**
	Initial		**0.61**	**20-Aug-15**	26-Aug-15	**40**	**10**
1	**Control**	1	**0.17**	26-Aug-15	26-Aug-15	50	**10**
2	**Control**	2	**0.29**	26-Aug-15	26-Aug-15	50	**10**
3	**Control**	3	**0.07**	26-Aug-15	26-Aug-15	50	**10**
4	**N**	1	**0.14**	26-Aug-15	26-Aug-15	50	**10**
5	**N**	2	**0.13**	26-Aug-15	26-Aug-15	50	**10**
6	**N**	3	**0.28**	26-Aug-15	26-Aug-15	50	**10**
7	**P**	1	**0.34**	26-Aug-15	26-Aug-15	50	**10**
8	**P**	2	**0.34**	26-Aug-15	26-Aug-15	50	**10**
9	**P**	3	**0.24**	26-Aug-15	26-Aug-15	50	**10**
10	**NP**	1	**0.21**	26-Aug-15	26-Aug-15	50	**10**
11	**NP**	2	**0.32**	26-Aug-15	26-Aug-15	50	**10**
12	**NP**	3	**0.27**	26-Aug-15	26-Aug-15	50	**10**
13	**NP + Zoo**		**0.43**	26-Aug-15	26-Aug-15	50	**10**
14	**NP + Zoo**		**0.80**	26-Aug-15	26-Aug-15	50	**10**
15	**NP + Zoo**		**0.56**	26-Aug-15	26-Aug-15	50	**10**
1	**Control**	1	**0.15**	27-Aug-15	28-Aug-15	50	**10**
2	**Control**	2	**0.11**	27-Aug-15	28-Aug-15	50	**10**
3	**Control**	3	**0.15**	27-Aug-15	28-Aug-15	50	**10**
4	**N**	1	**0.13**	27-Aug-15	28-Aug-15	50	**10**
5	**N**	2	**0.12**	27-Aug-15	28-Aug-15	50	**10**
6	**N**	3	**0.13**	27-Aug-15	28-Aug-15	50	**10**
7	**P**	1	**0.25**	27-Aug-15	28-Aug-15	50	**10**
8	**P**	2	**0.27**	27-Aug-15	28-Aug-15	50	**10**
9	**P**	3	**0.27**	27-Aug-15	28-Aug-15	50	**10**
10	**NP**	1	**0.29**	27-Aug-15	28-Aug-15	50	**10**
11	**NP**	2	**0.29**	27-Aug-15	28-Aug-15	50	**10**
12	**NP**	3	**0.27**	27-Aug-15	28-Aug-15	50	**10**
13	**NP + ZOOP**	1	**0.33**	27-Aug-15	28-Aug-15	50	**10**
14	**NP + ZOOP**	2	**0.81**	27-Aug-15	28-Aug-15	50	**10**
15	**NP + ZOOP**	3	**0.80**	27-Aug-15	28-Aug-15	50	**10**
	Pseuo-replicates						
0.5	**Lake (m)**	1	**0.46**	26-Aug-15	28-Aug-15	50	**10**
0.5	**Lake (m)**	2	**0.44**	26-Aug-15	28-Aug-15	50	**10**
5.8	**Lake (m)**	1	**0.47**	26-Aug-15	28-Aug-15	50	**10**
6.2	**Lake (m)**	2	**0.46**	26-Aug-15	28-Aug-15	50	**10**
13.8	**Lake (m)**	1	**0.52**	26-Aug-15	28-Aug-15	50	**10**
14.2	**Lake (m)**	2	**0.52**	26-Aug-15	28-Aug-15	50	**10**
20	**Lake (m)**	1	**0.18**	26-Aug-15	28-Aug-15	50	**10**
20	**Lake (m)**	2	**0.06**	26-Aug-15	28-Aug-15	50	**10**