A River Continuum Analysis of an Anthropogenically-Impacted System: The Little Bear River, Utah

Natural Resources and Environmental Issues

S.J. and Jessie E. Quinney Natural Resources Research Library
College of Natural Resources
Utah State University

Volume XVIII, 2013

A River Continuum Analysis of an Anthropogenically-Impacted System: The Little Bear River, Utah

Editors:
Wayne A. Wurtsbaugh
Nick Heredia

Managing Editor
Patsy Palacios

Natural Resources and Environmental Issues
Volume XVIII
2013

Watershed Sciences Aquatic Ecology Practicum (WATS 4510)
College of Natural Resources
Utah State University
Logan, Utah 84322-5210

Fall 2012 Class Report with Students
Jared Baker, Chance Broderius, Katie Fisher,
Jason Fuller, George Andy Pappas, Christian Smith, Marc Weston

Suggested Citation

Wurtsbaugh, Wayne A, Nick Heredia, Patsy Palacios, Jared Baker, Chance Broderius, Katie Fisher, Jason Fuller, G. Andy Pappas, Christian Smith and Marc Weston. 2013. A River continuum analysis of an anthropogenically-impacted system: the Little Bear River, Utah. Natural Resources and Environmental Issues, Volume XVIII. S.J. and Jessie E. Quinney Natural Resources Research Library, Logan, Utah, USA.

Series Forward

Natural Resources and Environmental Issues (NREI) is a series devoted primarily to research in natural resources and related fields. This series is published by the S.J. and Jessie E. Quinney Natural Resources Research Library, College of Natural Resources, Utah State University, Logan, Utah 84322-5260.

The Quinney Library recognizes its role in educating natural resources leaders who can then provide the guidance needed to increase the production of the earth's renewable resources while sustaining / enhancing the global environment. This publication, first published in 1993, is a monographic series that addresses relevant current topics. The journal is published in a series of volumes, each addressing a single topic and often associated with an organized symposium. Publication in NREI is by invitation only.

Volumes of this series will be sent upon request. Single issues are $25.00 in the United States and $30.00 elsewhere. Payment can be made by credit card, check, money order, or purchase order, payable in U.S. dollars to the Quinney Library. Order information is located in the back of this publication.

This is an open access journal which means that all content is freely available without charge to the user or his/her institution. Users are allowed to read, download, copy, distribute, print, search, or link to the full texts of the articles in this journal without asking prior permission from the publisher or the author. This is in accordance with the BOAI definition of open access. Visit us at http://digitalcommons.usu.edu/nrei/.

Contact Information:

Address: NREI, 5260 Old Main Hill,
Logan, UT 84322
Phone: 435.797.2464
Fax: 435.797.3798
E-mail: quinneylibrary@aggiemail.usu.edu

ISSN 1069-5370

TABLE OF CONTENTS

A River Continuum Analysis of an Anthropogenically-Impacted System: The Little Bear River, Utah

---

Executive Summary

In September 2012 the Aquatic Ecology Practicum class from Utah State University studied the 51km river continuum of the Little Bear River located in northern Utah (Figure 1). The relatively pristine headwaters of the river begin in the Wasatch Mountain Range at an altitude of 1800 m. The river flows northward into Cache Valley where it terminates in Cutler Reservoir (1345 m elevation). Agricultural development and urbanization have modified the natural terrain and chemical characteristics of the river, and Hyrum Reservoir, located midway along the gradient causes a discontinuity in river processes. The results from analyses of stream condition indicators from up to eleven stations along the gradient were interpreted within the context of the River Continuum Concept (Vannote et al. 1980) and the Serial Discontinuity Hypothesis (Ward and Stanford 1983).

Physical characteristics of the river were studied by Marc Weston (Chapter 1). The first order stream in the headwaters had a width near 1 m, increasing to a width of 8-16 m in the fourth order river at its terminus. In the mountainous region (kilometers 0-16) the river gradient decreased from 2.9 percent to 1.4 percent. In the lower valley below Hyrum Reservoir the gradient decreased from 0.6 percent to only 0.1 percent near Cutler Reservoir. Sediment sizes were near 60 mm in the headwaters, decreased to 16 mm above Hyrum Reservoir, and then showed a predictable increase immediately below the reservoir (Figure 2A). In the lowest reaches sands and silt dominated the low gradient river. Photos of each study station are shown below.

Temperatures and discharge were studied by Andy Pappas (Chapter 2). During fall, headwater base flow discharge was near 0.1 m^3 sec^{-1} and this increased to near 0.6 m^3 sec^{-1} above Hyrum Reservoir at kilometer 26 (Figure 2B). Water release from the reservoir was low with a discharge of 0.03 m^3 sec^{-1} at the station below the dam. Tributary inputs, agricultural return flows, and wastewater treatment plant inflows increased discharge to 0.81 m^3 sec^{-1} at the lowermost station. Thermistor data from four Utah State University monitoring stations indicated that mean temperatures in August were near 12.3°C in the headwaters, but increased to 18.6°C in the lowest reaches (Figure 2B). Thermistors deployed during the first 20 days of October at additional stations indicated relatively little temperature variation along the river, with 8°C water in the headwaters, a 12°C peak below Hyrum Reservoir, and then a decline to near 10°C in at the lowest stations.

Nutrient concentrations along the river gradient were analyzed by Jason Fuller (Chapter 3). Specific conductivity, a measure of natural weathering of the limestone rocks and soils in the region, increased nearly continuously downstream from a low of 395 µS cm^{-1} in the headwaters, to 680 µS cm^{-1} at the lowest station - an increase of 72 percent. In contrast, nitrate concentrations increased from a mean of 95 µg N L^{-1} at the three highest stations in the watershed to 1100 µg N L^{-1} at stations below the wastewater treatment inputs from the town of Wellsville and where non-point inputs from agriculture were likely high (Figure 2C). This represented an 1100 percent increase in nitrate along the gradient. However, nitrate concentrations dropped markedly at the station below Hyrum Reservoir, indicating marked retention in the reservoir. Total phosphorus increments were not as high as those of nitrogen, but increased from 16 µg P L^{-1} in the three headwater stations to 70 µg P L^{-1} at the lowermost stations - a 350 percent increase. The levels in the lower valley exceeded the State of Utah's threshold criteria of 50 µg P L^{-1}, and thus likely contribute to eutrophication problems in Cutler Reservoir. Ratios of total N to total P (TN:TP) indicated that phosphorus was likely the limiting nutrient at all stations, but the ratio of dissolved inorganic nitrogen to phosphorus (DIN:TP) suggested co-limitation by these nutrients at several stations.

Periphyton and phytoplankton chlorophyll levels along the river continuum were studied by Katie Fisher (Chapter 4). On an aerial basis, periphyton represented 98 percent or more of the chlorophyll in the river, suggesting that phytoplankton contributed little to autochthonous primary production. Phytoplankton chlorophyll levels did, however increase from 1.5 µg L^{-1} in the mountainous region to 5.0 µg L^{-1} at the lowermost station sampled (Figure 2D), and this increase was most closely correlated with increases in TP. Periphyton chlorophyll levels also increased relatively steadily from the headwaters (13.5 µg cm^{-2}) to 48 µg cm^{-2} at the next-to-last station in the valley. Periphyton chlorophyll then decreased markedly to 15 µg cm^{-2} at the lowest station, perhaps because of light limitation in this reach (Secchi depth – 0.64 m).

In vitro bioassays were used to study algal nutrient limitation at four sites along the river by Jared Baker (Chapter 5). Chlorophyll response after 2.5 days provided the most statistically consistent results (Figure 2E). In the headwaters (Station 1; kilometer 3.4), neither N nor P alone stimulated algal growth, but N+P additions increased chlorophyll concentrations 209 percent above the control treatments. At Stations 6 and 7, P or N+P stimulated algal growth in the bioassays, and at Station 10 in the lowlands, none of the nutrients stimulated chlorophyll production, likely because background dissolved inorganic nitrogen and soluble reactive phosphorus concentrations were high at this station (see Chapter 3).

The nitrogen isotopic enrichment of periphyton was studied by Chance Broderius (Chapter 6). Isotopic enrichment ($\delta^{15}N$) of periphyton increased from near +3 in the headwaters to near +13 below Hyrum Reservoir (Figure 2F), indicative of increasing proportions of anthropogenic nitrogen reaching the river. However, below the town of Wellsville and its wastewater discharge, isotopic enrichments decreased unexpectedly to between +6 to +9. GIS analysis indicated that ^{15}N enrichment at the different sites was significantly correlated with the proportion of the watershed with anthropogenic development ($p = 0.04$; $r^2 = 0.38$).

A preliminary analysis of the invertebrates collected by sweep nets from the river was done at four stations, and analyzed as part of a group project by the class (Chapter 7). Mayflies (Ephemeroptera, E), stoneflies (Plecoptera, P), and caddisflies (Tricoptera, T) were abundant in the upper reaches of the river, but decreased steadily. In the lower region the EPT taxa was replaced with an abundance in midges (Chironomidae) and Hemiptera. The relative abundance of EPT taxa consequently decreased from 51 percent at the headwater station to only 7 percent at the lowest station (Figure 2F), indicative of a decrease in water quality and/or because of changes in substrate size that were more conducive for midge larvae.

The fish community in the river was studied at four stations by Christian Smith using 2-pass backpack electroshocking (Chapter 8). Eleven species and 408 individuals were captured. With the exception of mottled sculpin (n= 241) native species were rare, with only three Bonneville cutthroat trout and eight white suckers captured. Introduced brown trout (n =129) represented the highest biomass of fish in the river with their biomass decreasing progressively from the headwaters to absent at the lowest station sampled (Figure 2G). At this lowest reach the fish community consisted entirely of introduced warm-water species (common carp, green sunfish, largemouth bass and sand shiners) but the overall biomass captured there was low (Figure 2G). One tiger trout and one rainbow trout were also captured at Station 7 below Hyrum Dam.

The combined data set provides support for many of the hypotheses presented in the River Continuum Concept, but in the case of the Little Bear River, anthropogenic increases in nutrients, channel modifications, and the presence of Hyrum Reservoir superimposed many changes in the systems characteristics. Although the study revealed many important changes along the river gradient, longer-term and more in-depth studies will be necessary to fully understand the relative importance of natural changes and those imposed by development in the river valley.

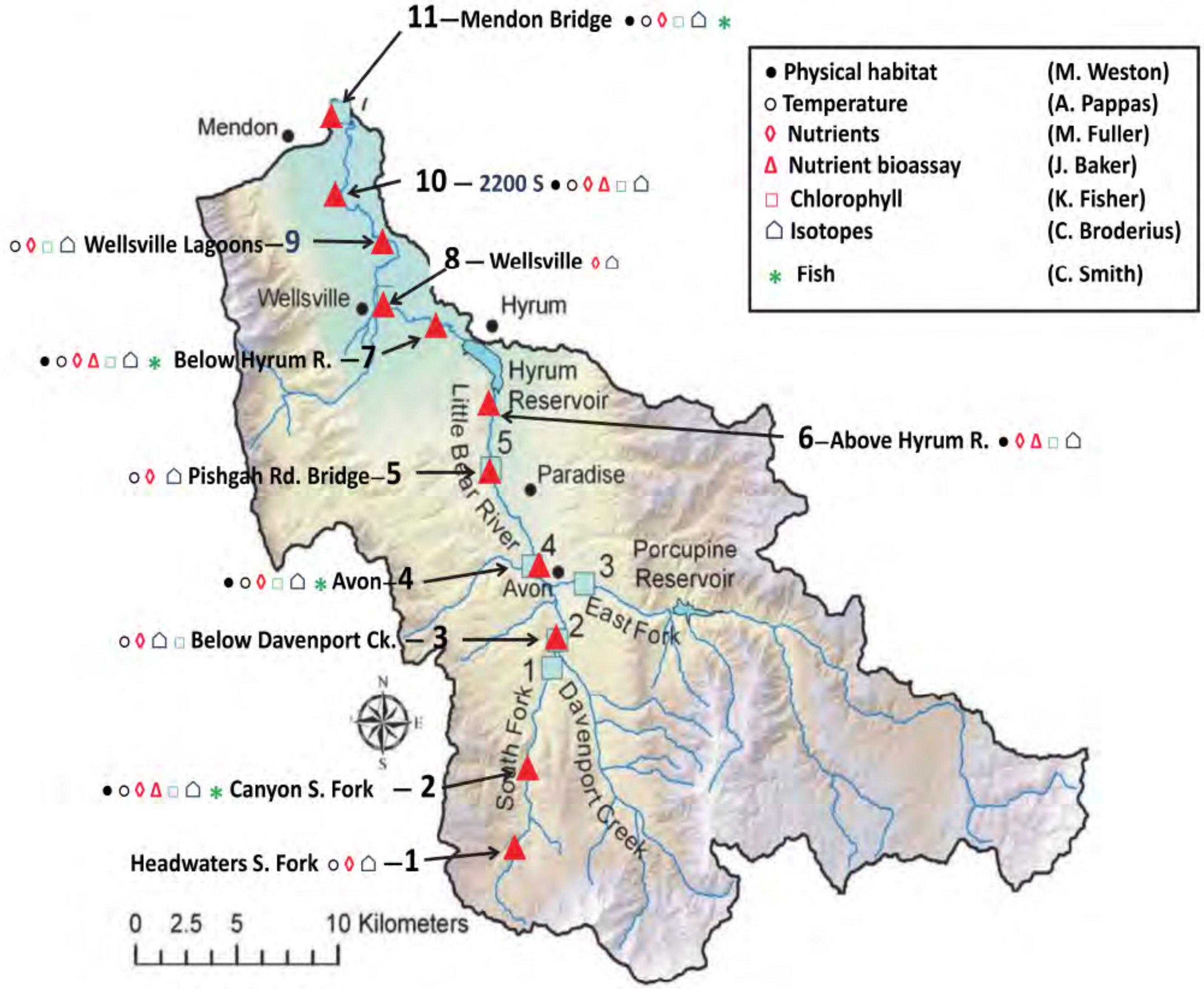


Figure 1. *Location of study sites (▲) along the Little Bear River. The inset table shows the sampling that was done at each station. Blue squares show the USU monitoring stations described in Horsburgh et al. (2010). Map derived from Horsburgh et al. (2010).*

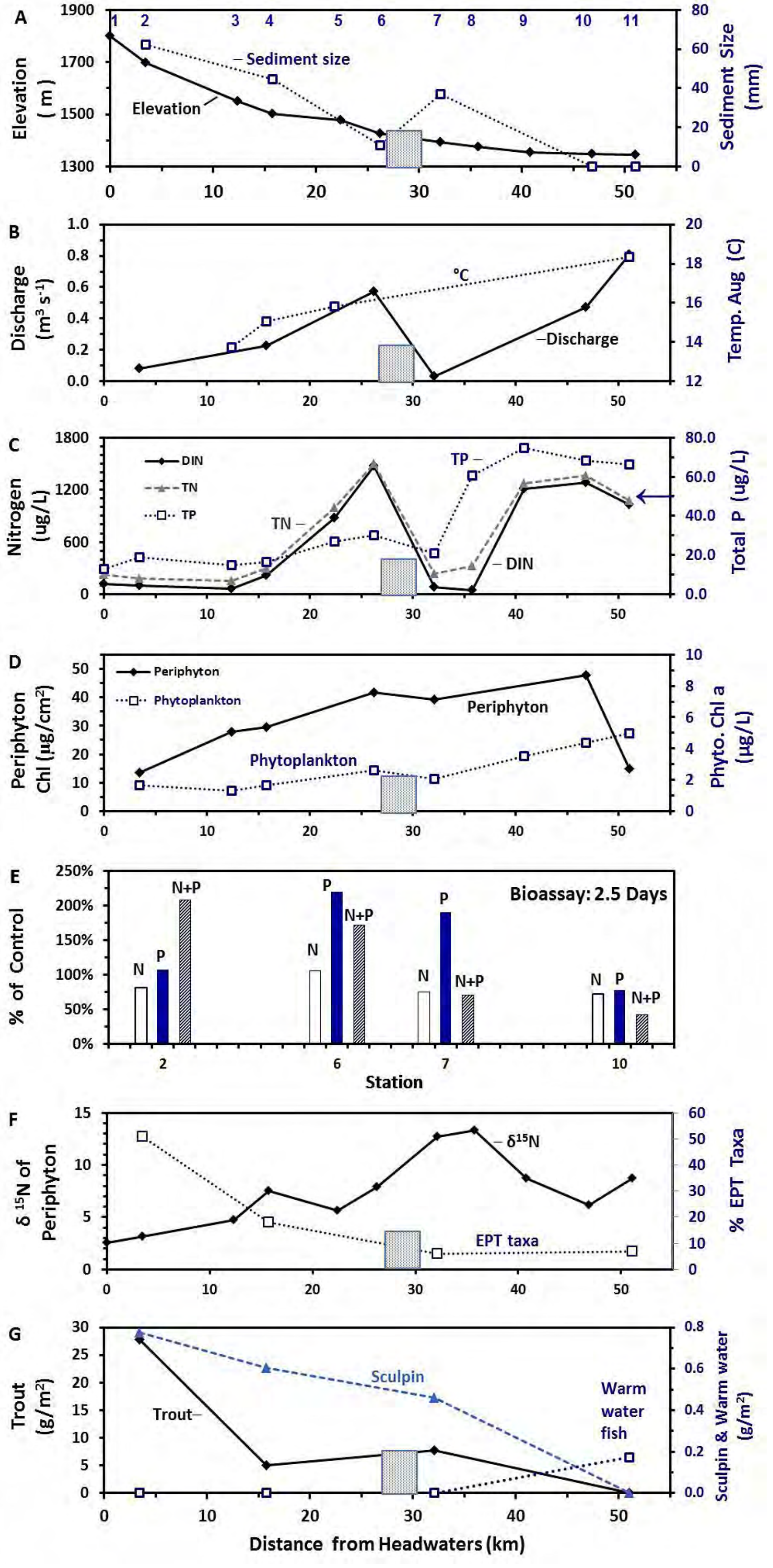


Figure 2. A. *Elevation and mean sediment size changes along the river gradient. Numbers at the top of the frame show sampling stations, and the shaded blue rectangle between 27 and 30 kilometers show the location of Hyrum Reservoir.*

B. *Discharge and temperature changes along the gradient.*

C. *Dissolved inorganic nitrogen (DIN), total nitrogen (TN) and total phosphorus (TP) concen- trations. The arrow on the left axis shows Utah's TP criteria.*

D. *Changes in chlorophyll concentrations in periphyton (left axis) and phytoplankton (right axis) along the river gradient.*

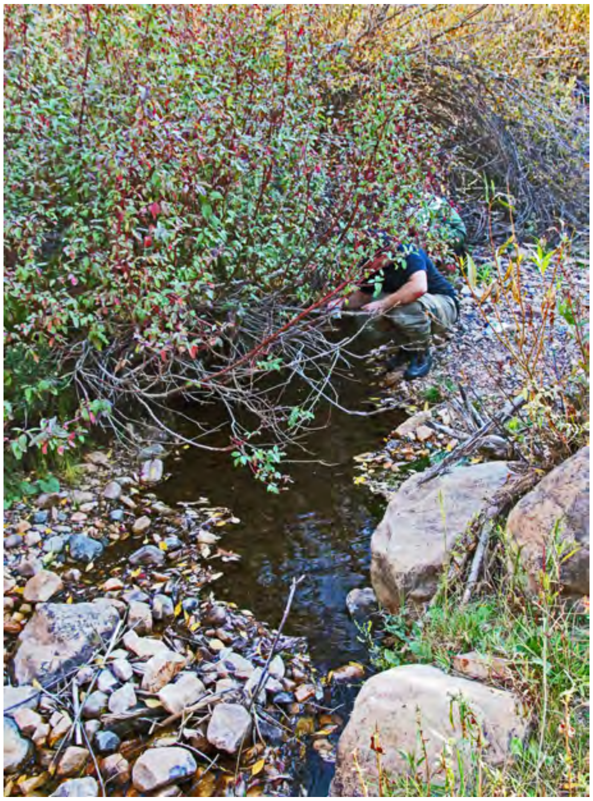
E. *Response of phytoplankton chlorophyll levels relative to controls (100 percent) after 2.5 days in a laboratory bioassay of water collected from four stations.*

F. *Changes in the isotopic enrichment of ^{15}N at eleven stations along the gradient (left axis). Changing percentage of Ephemeroptera, Plecoptera and Tricoptera (EPT) as a fraction of the total invertebrates sampled.*

G. *Changes in the biomass of trout (primarily brown trout; left axis), mottled sculpins and warm water fishes (right axis) along the gradient.*

Table 1. *Geographic information (latitude, longitude, elevation above sea level) for sites used in our analysis for the Little Bear River Continuum Study, WATS 4510, 2012.*

Station	Station Name	Distance Downstream (km)	Elevation (m)	Latitude	Longitude
1	Headwaters South Fork	00.0	1799	41°25.637′	-111°50.105′
2	Canyon South Fork	03.4	1699	41°27.136′	-111°49.864′
3	Below Davenport Creek	12.4	1549	41°30.872′	-111°48.758′
4	Avon	15.8	1501	41°32.098′	-111°49.828′
5	Pishgah Road Bridge	22.4	1479	41°34.534′	-111°51.321′
6	Above Hyrum Reservoir	26.2	1427	41°36.238′	-111°51.167′
7	Below Hyrum Reservoir	32.1	1392	41°38.005′	-111°53.190′
8	Wellsville	35.8	1376	41°38.612′	-111°55.038′
9	Wellsville Lagoons	40.8	1356	41°40.003′	-111°55.353′
10	2200 South	46.9	1348	41°41.556′	-111°56.501′
11	Mendon Bridge	51.0	1347	41°43.120′	-111°56.690′



Station 1: Headwaters South Fork

Station 2: Canyon South Fork

Station 3: Below Davenport Creek

Station 5: Pishgah Road Bridge, Paradise, Utah

Station 4: Near Avon, Utah, below the confluence with the East Fork

Station 6: Above Hyrum Reservoir – Electrofishing

Station 7: Below Hyrum Reservoir

Station 8: Bridge crossing on the eastern edge of Wellsville, Utah

Station 9: Below Wellsville Wastewater Treatment Lagoon

Station 10: Near 2200 South in Wellsville

Station 11: Just above Bridge, Mendon, Utah

Acknowledgements

We thank Tony Ward, Robert Lee, John Hardman, Roger Pulsipher, and C. Darley (below Hyrum) who provided access across their private lands to reach the river. Iva Sokolovska assisted with collection of field samples. Brett Roper of the US Forest Service loaned thermistors for the project. Lisa Ward and Michelle Baker in USU Aquatic Biogeochemistry Laboratory assisted with analysis of nutrients. The UC Davis Stable Isotope Laboratory analyzed ^{15}N isotopic ratios. Jeff Horshberg of the Utah Water Research Laboratory provided ling-term temperature data for the river. Finally, we appreciate the support of Chris Luecke and Charles Hawkins, Department of Watershed Sciences, Quinney College of Natural Resources for continued support of the course.

Chapter 1

A Profile of the Physical Attributes of the Little Bear River in the Context of the Serial Discontinuity Concept

[by] Marc Weston

SUMMARY

To study the Little Bear River's physical characteristics in the context of the serial discontinuity concept, sites were sampled along a continuum from the headwaters to 51 km downstream, near where the Little Bear River flows into Cutler Reservoir. Samples were collected in September 2012 at base flow. To estimate sediment sizes along the transect pebble counts were conducted at six sites and where possible pebble counts were done in both pools and riffles. Sediment sizes showed a decrease in median size (D_{50}) of 45 mm at the upper station to the lower station where the substrate was a mixture of sand and silt. An elevation gradient profile measured with ArcGIS demonstrated a significant positive correlation between elevation and substrate size. Sinuosity was measured using ArcGIS and showed an increasing trend from the upper reaches to the lower reaches, but the lower valley agricultural areas had remnants of levees, indicating that the river was not following its natural channel.

INTRODUCTION

The Little Bear River watershed, located in Cache Valley Utah, has been altered by anthropogenic development. Historically, the Little Bear River was a free flowing stream with two main drainages, the East Fork and the South Fork. For this study I focused on the South Fork and the effects of Hyrum Dam on the physical parameters of the Little Bear River within the contexts of the River Continuum Concept (RCC) (Vannote 1980) and the Serial Discontinuity Concept (SDC, Ward and Stanford 1983). The study included substrate size analysis, sinuosity measures, and a gradient profile analysis of the Little Bear River.

It is likely that channel morphology has been altered on the Little Bear River due to human influences. Hyrum Dam, agricultural practices, and some small communities along the river have all played a part in altering channel morphology. Sinuosity and gradient could be altered due to all three of these factors (Kang et al. 2006). Hyrum Dam has likely affected the lower reaches of the Little Bear River due to reduced upstream sediment supply, causing variations in the substrate character and channel geomorphology as shown elsewhere (Draut et al. 2011).

Expectations made from the Serial Discontinuity Concept (SDC) are that the average sediment size will decrease from the upper reaches to just above Hyrum Dam, where most of the fine sediments will be captured. Below the dam the average substrate size should sharply increase, then begin to decrease towards the lower reaches until the Little Bear River enters Cutler Reservoir (Ward and Standford 1983). Sinuosity should be higher in the lower reaches, also due to decreased elevation gradient. Hyrum Dam could affect sinuosity of the lower reaches due to altered flood regime (Draut et al. 2011). Gradient should be higher in the upper reaches due to the geography of the area and become much less in the lowlands, entering the valley floor. I also predicted that diking in the lower reaches, due to agriculture practices, would decrease sinuosity in the lower elevation areas of the Little Bear River.

METHODS

Study Area

Choosing sites for substrate analysis on the Little Bear River was difficult due to the minimal field time for this project. Six sites were chosen to best describe changes in the Little Bear River from the headwaters to the lower reaches, before entering Cutler Reservoir (Executive summary, Figure 1). Station 2 was selected to represent the higher gradient upper reaches of the Little Bear River. Station 4 was selected to show the effects of the East Fork of the Little Bear River on sediments. Stations 6 and 7 were above and below Hyrum Reservoir, respectively, thus allowing me to gain an idea of the effects of the dam on channel structure (Ward and Stanford 1983). Station 10 and Station 11 were representatives of the low gradient agricultural area of the lower Little Bear River.

Gradient Profile

The elevation gradient profile was extracted using ArcGIS. The channel digitization was used to generate a table with elevation data at various points along the river. Along the channel, there were 855 points, roughly every 60 m downstream from Station 1, plotted with elevation data for each point. With these elevation data a profile of the gradient was constructed against the downstream distances.

Pebble Counts

Pebble counts were conducted at six sites; Station 2 was located 3.4 km downstream of the uppermost site (Station 1), Station 4 was located 15.8 km downstream, where the gradient decreased near the town of Avon, Station 6 was located 26.2 km downstream, just above Hyrum Reservoir, Station 7 was approximately 2 km below Hyrum Dam and was 32.1 km downstream, Station 10 was located 46.9 km downstream, and lastly, Station 11 was located 51 km downstream near Mendon Utah. All of the downstream distance measurements are referenced to Station 1 studied by the WATS 4510 class. Three sites above Hyrum Reservoir were selected to represent changes in substrate prior to the influence of the reservoir. Station 6, directly above Hyrum Reservoir, and Station 7, directly below Hyrum Dam, were employed to potentially show the effects of the dam (See site map in executive summary). For most of the sites, there were 100 pebbles measured at both a representative riffle and pool habitat (Bunte et al. 2009). At Station 2, only 50 measurements were made due to a small cross section at the riffle. The pool habitat at this location was not measured. Once the representative pool or riffle was chosen, counts were conducted by choosing randomly the particle first touched by the index finger at the point of the toe, while walking heel to toe. After the particles were randomly chosen they were measured using a gravelometer, which had size classes from 4 mm to a maximum size of 128 mm.

A median substrate size (D_{50}), was then estimated. Note that this parameter is not a measure of the median size of particles in the bed, but rather is a measure of the areal coverage of particles of different sizes. At all sites very small particles would dominate numerically, but each of these tiny particles covers only a very small area. At Station 2 only 50 pebbles were measured due to the fact that the majority of the cross section at the riffle and pools were particle sizes above 128 mm, the upper limit of the gravelometer used, and thus, these values were recorded as a 128 mm. At Stations 10 and 11 there were no riffles present and the substrate at these sites consisted of uniformly small particle sizes. Station 11 differed slightly from Station 10, with Station 10 consisting of a mostly sand substrate and Station 11 consisting of smaller silts and clays. These differences were noted in the field. The gravelometer used for this sampling was only useful down to a diameter of 4 mm, which was too big for these sand and silt substrates. For analysis of this data these sites were given arbitrary numbers: Station 10's particles were classified as 0.2 mm and Stations 11's particles were classified as 0.1 mm, these numbers were assigned to show a difference in the composition of substrate between sites. A pebble count at Station 6 pool habitat revealed only fine sediments of sand and small pebbles: these were also smaller than 4 mm, the smallest size on the gravelometer. These were again assigned an arbitrary value (1 mm) representing a slightly larger average particle size than the lower sites.

Sinuosity

ArcGIS was used to measure the thalweg channel distance downstream and the straight-line distances between sites. Sinuosity was measured as a ratio of these two measures (Channel Length /Straight Line Distance). Using a base map from August 2011 the river was manually digitized. The margins of error due to the riparian cover occasionally obscuring the channel were relatively small comparatively across the entire 51 km length of the study area.

RESULTS

Gradient Profile and Channel Width

As expected, gradient in the upper reaches was higher than in the lower stretches (Figure 1). The section directly below the Hyrum Dam, had a severe drop in elevation (Figure 1). The channel width increased from approximately 1-m wide at Station 1 to 10-m at Station 4. It then decreased slightly at Station 6 and then markedly in the de-watered section below Hyrum Reservoir (Station 7). In the valley bottom the channel was 10 m wide in the levied section at Station 10, and increased to 16 m at the final Station (11) by Mendon Bridge.

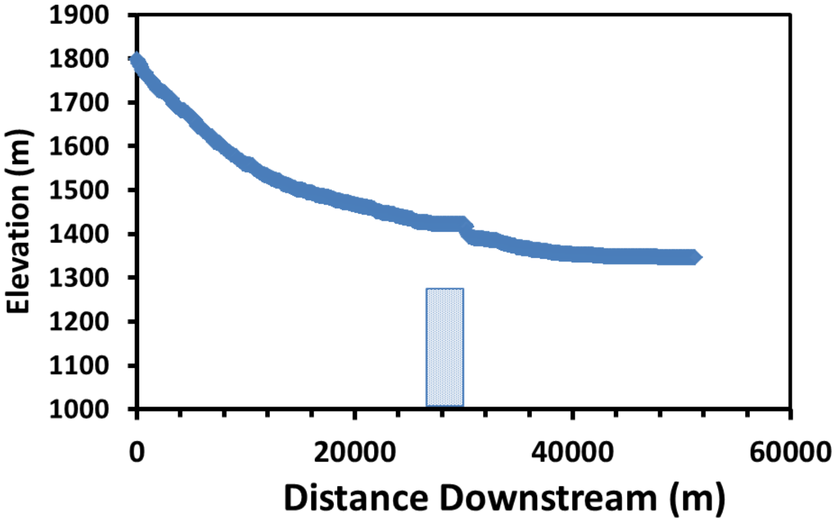


Figure 1. *Elevation profile of the Little Bear River along the study area of the WATS 4510 class. The shaded rectangle represents the location of Hyrum Reservoir.*

Pebble Counts

Pebble counts at the six sites revealed a trend of smaller particle size moving down the gradient of the Little Bear River (Figure 3a and 3b). Substrate size decreased significantly from high in the watershed to the lower valley sections (pool regression analysis; p= 0.014; riffle regression analysis; p= 0.057). The relationship between riffle particle size and stream distance was only marginally significant. There were slightly coarser particle sizes directly below Hyrum Reservoir compared to the site above the impoundment (Figure 3a and 3b). The pool at Station 6 was composed largely of sand and pebble substrate; a value of 1 mm was assigned to represent the substrate makeup. The pool substrate had a much smaller composition than the riffle habitat at the same site, which had a D_{50} value of 16 mm. At all other sites there were only small differences between riffle and pool substrate compositions (Figure 3b). Below Hyrum Dam there was an obvious trend of finer particle sizes moving downward (Figure 3a and 3b). At the bottom sites the entire character of the river had changed to a slow moving, finer sediment stream with no riffle habitat.

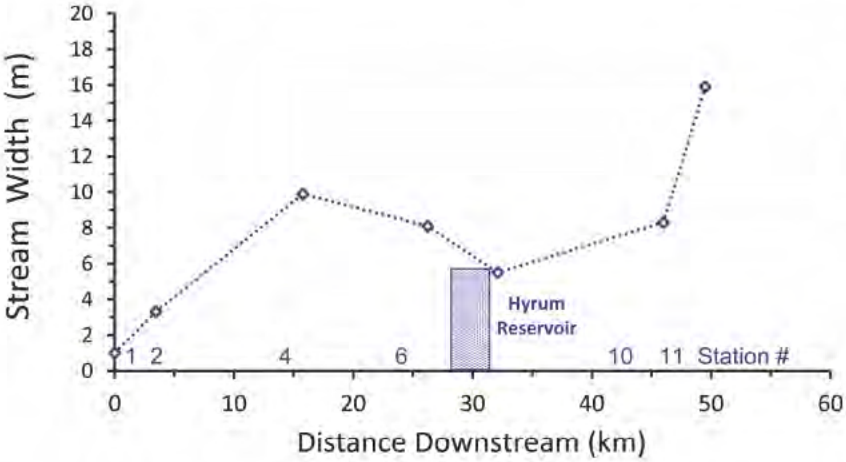


Figure 2. *Relationship between distance downstream and the width of the channel at our study sites. The channel width at Station 1 was estimated from photos.*

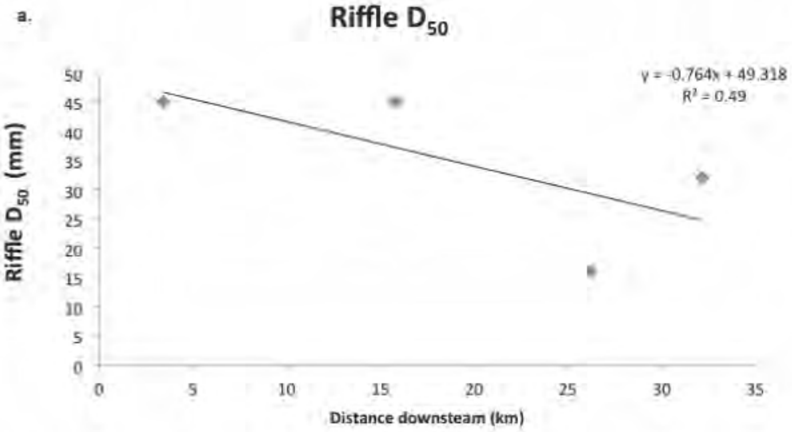


Figure 3. A. *D_{50} measurement of substrates at the 4 sites with riffle habitats showing decreasing particle size moving downward along the Little Bear River (regression analysis p-value= 0.058). There are only 4 sites with riffle habitat, Station 10 and Station 11 had only pools.*

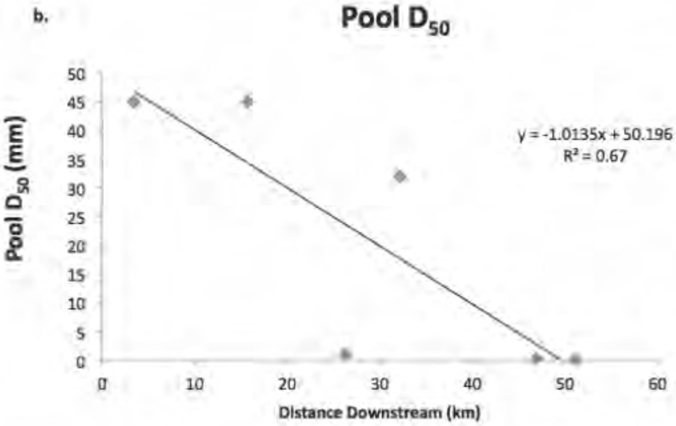


Figure 3. B. *D_{50} values at all six pool sites sampled September 2012. There was a strong statistical relationship of decreasing particle size moving downstream (regression analysis p-value= 0.014). Note, however, that the D_{50} at Station 6 was mostly sand and pebble composition and arbitrarily given value of 1 mm.*

Sinuosity

Sinuosity downstream from the upper site of the study to the lower site 51 km downstream, showed a significant (p= 0.00004) positive correlation with distance downstream (Figure 4). Sinuosity measurements in this study may not reflect the actual sinuosity measures at the time the study was conducted but as a comparative measure from the upper sites to the lower sites it is representative. In the upper reaches of the Little Bear River where the channel is confined by a canyon, sinuosity was 1.2 (Figure 4 and Photo 1 in Appendix). Below Station 7 there was a considerable increase in sinuosity from about 1.3 at 30 km downstream to 1.9 and 1.85 at 36 km and 40 km downstream, respectively (Figure 4 and Photo 2 in Appendix). Sinuosity trends increasing downstream could be explained by a decreasing elevation gradient (c.f. Figure 4 and Figure 1).

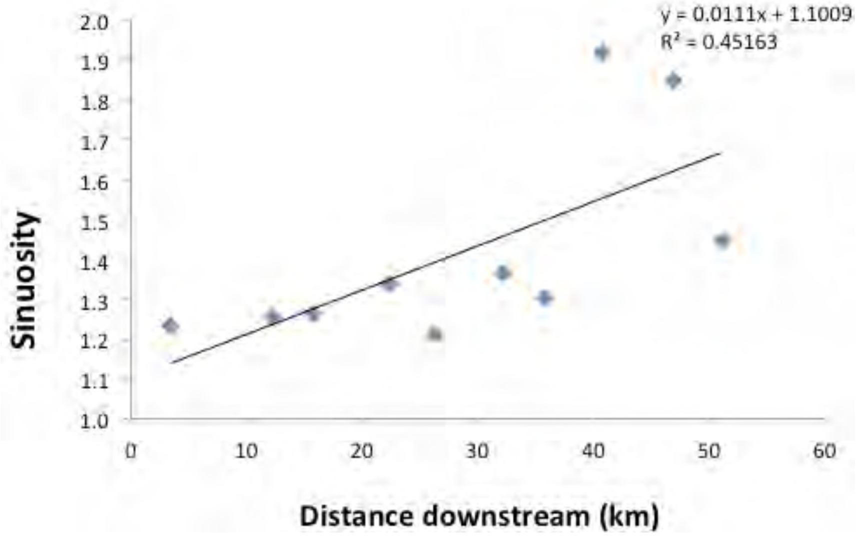


Figure 4. *Sinuosity at each Station, plotted as a function of distance downstream. There were ten sites. There is a strong relationship between increasing sinuosity from upper reaches to the bottom reaches in the valley floor (p-value = 0.0004).*

DISCUSSION

The elevation profile of the Little Bear River appeared to follow with the patterns of the River Continuum and Serial Discontinuity Concepts, with a high gradient upper watershed then moving into a lower gradient toward the valley floor (Ward and Stanford 1983). The high upper gradient would explain a larger particle substrate composition, as gradient is a key factor in what sediments are deposited. This same concept would explain increase in D_{50} measurements of sediment composition directly below Hyrum Dam. It appears that substrate composition is a function of the gradient on the Little Bear River. As seen elsewhere, elevation gradient is directly correlated to the size of sediment transported.

Substrate composition down the gradient of the Little Bear River behaved as described by the Serial Discontinuity Concept (Ward et al. 1983). D_{50} and D_{25} substrate measurements show a decreasing trend down the gradient of the Little Bear River from a D_{50} of 45 mm at Station 2, down to a pool D_{50} of ~1 mm and the riffle D_{50} of 16 mm, at Station 6. However, there were only small differences in the substrate values between Station 2 (3.4 km downstream) and Station 4 (15.8 km downstream), where the D_{50} value was identical. The elevation gradient of the Little Bear River was very similar in the areas of Station 2 and Station 4, which could explain the similar substrate composition. Station 6 (26.2 km downstream) was unique in that the riffle and pool substrate compositions were drastically different. It seems that Station 6 pool habitat was an outlier in the substrate composition of mostly sand and silt. There was a sharp increase in substrate size at the site below Hyrum Reservoir. This was followed by a continued decreasing trend to the bottom sites. The pebble counts from the pool habitats at Station 6 (26.2 km downstream), Station 10 (46.9 km downstream), and Station 11 (51 km downstream) were only approximate due to improper sampling device being used. A sieve would have produced an accurate measurement of the particle sizes at these sites; instead arbitrary values were given to represent substrate composition that was estimated visually.

Sinuosity measures for this study were subject to some degree of error but are useful for comparative analyses. Sinuosity trends increasing downstream could be explained by a decreasing elevation gradient (Figure 4 and Figure 1). There are several anthropogenic factors that could affect these measurements. The effects of Hyrum Reservoir on sinuosity are primarily due to an altered flood regime, lessening the effects of floods on channel morphology. Below Hyrum Reservoir there are several small communities and agricultural lands. These are possible causes of human influenced channelization, decreasing sinuosity (Kang et al. 2006). While I was digitizing the channel length of the Little Bear River I noticed some areas that had what appeared to be old dry river channels that may have been lost due to human-influenced channelization (Photo 3 in Appendix). The natural channel in the upper reaches was confined to a small canyon in a high gradient area. It then flows out of the canyon into the valley floor where the gradient decreases causing a natural shift to a higher sinuosity. Because I used a base map from 2011 (a very high water year) to digitize the channel of the Little Bear River this may have caused some variation from the channel that would we observed during September 2012. Although there may be differences in the sinuosity measured and actual sinuosity during the September 2012 sample period, these measures are representative for comparative analysis between the higher gradient upper reaches and the lower gradient reaches located in the valley floor.

In conclusion, the study of physical parameters of the Little Bear River shows a strong relationship with the Serial Discontinuity Concept (Ward et al. 1983) and the River Continuum Concept (Vannote et al. 1980). The elevation profile of the Little Bear River shows a steeper gradient in the upper stretches with a narrow channel, moving into a low gradient, and wider river in the lowest reaches. The substrate measures show higher median substrate size composition in the sections with higher gradients. Sinuosity of the Little Bear River increased the lower elevation areas, where there was an unexpected peak in sinuosity in the area between 36 km and 47 km downstream.

REFERENCES

Bunte, K.; Abt, S.R.; Potyondy, J.P.; Swingle, K.W. 2009. Comparison of three pebble count protocols (EMAP, PIBO, and SFT) in two mountain gravel-bed streams. Journal of the American Water Resources Association. 45:1209-1227. doi: 10.1111/j.1752-1688.2009.00355.

Draut, A.E.; Logan, J.B.; Mastin, M. 2011. Channel evolution on the dammed Elwha River, Washington, USA. Geomorphology. 127:71-87.

Kang, R.S.; Marston, R.A. 2006. Geomorphic effects for rural-to-urban land use conversion on three steams in the Central Redbed Plains of Oklahoma. Geomorphology. 79:488-506.

Vannote, R.L.; Minshall, G.W.; Cummins, K.W.; Sedell, J.R.; Cushing, C.E. 1980. The River Continuum Concept. Canadian Journal Fish and Aquatic Science. 39:130-137.

Ward J.V.; Stanford J.A. 1983. The serial discontinuity concept of lotic ecosystems. Pages 347-356 In Fontaine T.D. and Bartell S.M. (eds.). Dynamic of Lotic Ecosystems. Ann Arbor, MI.: Ann Arbor Science.

APPENDICES

Photo 1. *Screen shot of ArcGIS channel between Station 1 and 2.*

Photo 2. *This is the screen shot from ArcGIS of the channel between Station 8 an 9, an area of relatively high sinuosity (1.92).*

Photo 3. *Screen shot of the Little Bear River between Stations 9 and 10. This photo was included to show the many old channel beds.*

Chapter 2

Temperature and Discharge on a Highly Altered Stream in Utah's Cache Valley

[by] Andy Pappas

SUMMARY

To study the River Continuum Concept (RCC) and the Serial Discontinuity Hypothesis (SDH), I looked at temperature and discharge changes along 52 km of the Little Bear River in Cache Valley, Utah. The Little Bear River is a fourth order stream with one major reservoir, a number of irrigation diversions, and one major tributary, the East Fork of the Little Bear River. Discharge data was collected at six sites on 29 September 2012 and temperature data was collected hourly at eleven sites from 1 October to 20 October 2012. Discharge and temperature both increased as elevation declined to Hyrum Reservoir. After which point, temperature increased slightly and discharge dropped sharply for a period and then returned to similar patterns occurring above the reservoir. In addition to the data collected during our sampling efforts, a long-term temperature dataset available from the Internet was used to observe seasonal temperature changes. While seasonal temperature patterns were variable above the reservoir, the site below Hyrum Reservoir exhibited the strongest increase in temperature from winter lows to summer highs.

INTRODUCTION

Flowing from the southern edge of Cache Valley to Cutler Reservoir, the Little Bear River is a fourth order stream which has been modified for agriculture and to prevent flooding. Hyrum Reservoir is a 450 acre reservoir at 4,700 ft, located southwest of Hyrum, UT, and is the only major reservoir disrupting the flow of the Little Bear River (although another major reservoir lies upstream on the East Fork of the Little Bear River).

The River Continuum Concept (RCC, Vannote et al. 1980) is a framework for unmodified river systems (Statzner 1985) and the framework suggests that with downstream movement, rivers will increase in both discharge and temperature. Past work suggests that reduced riparian vegetation increases the amount of solar radiation penetrating the water column, and subsequently increases water temperature (Mohseni 1999). Additionally, stream discharge, also affected by downstream movement, can alter stream temperature (Beschta 1997). Along the Little Bear River, riparian vegetation has likely been reduced as agricultural use increased subsequent to settlement of the valley in the mid-1850s.

To test the predictions of the RCC, I looked at changes to water temperature and discharge along the longitudinal gradient of the Little Bear River. According to Statzner (1985), the changes predicted by the RCC might not fully explain the changes occurring along the longitudinal gradient of the Little Bear River because of the disruptions of Hyrum Reservoir and water diversions. To address this issue, another working hypothesis is often used, the Serial Discontinuity Hypothesis (SDH, Ward et al. 1983). The SDC specifically focuses on the effects of reservoirs and other disruptions to flow on temperature, discharge, pebble size, nutrients and others (Ward et al. 1995). The SDC suggests that reservoirs act to disrupt the otherwise normal changes to parameters as water moves downstream, and that after a transitional period (distance downstream form the disruption), rivers should return to follow the predictions of the RCC. I utilized both conceptualizations of river function to interpret the physical parameters of the Little Bear River.

STUDY AREA AND METHODS

Our study area of the Little Bear River starts on the boarder of U.S. Forest Service land, south of Avon, UT, and extended to a site located just above Cutler Reservoir, near Mendon, UT. Sites were chosen to best be able to describe the influences of tributaries, water diversions and Hyrum Reservoir.

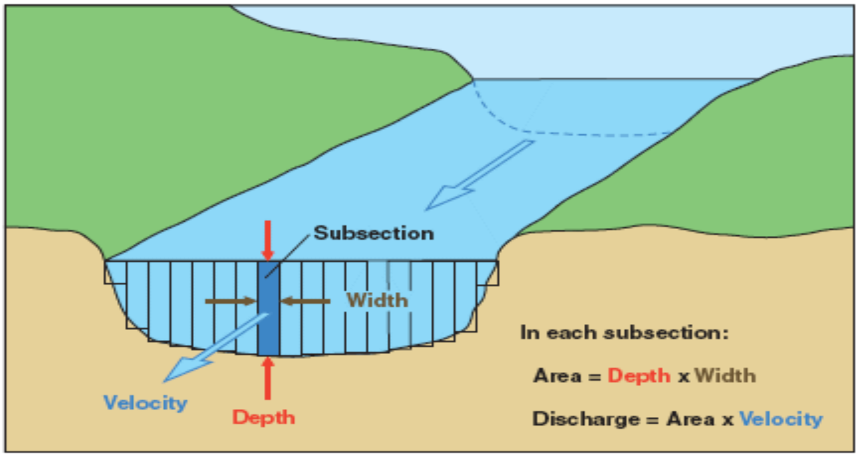
Temperature Analyses

I used both short-term and long-term temperature data to observe potential changes along the longitudinal gradient of the Little Bear River. To measure short-term temperature data, I used Onset's Hobo Pro v2 Data loggers with an accuracy of plus or minus 0.21°C, which proved very good for this study. I placed six temperature loggers in mid-stream using rebar and two zip ties. The remaining four sites have data loggers in place for a study conducted independently by Utah State University. These stations were installed by USU many years ago to record long-term changes in water chemistry, temperature and other parameters. The first day of October, I placed temperature loggers at all the sites without temperature sensors in place from the USU study. My temperature loggers were left in the river for 20 days. During this period, air temperatures ranged from -5 to 10 °C, which is typical October weather in Cache Valley. Data from all of the temperature loggers were then uploaded using Hoboware into an Excel Database. I then collected the remaining data from each of the USU stations (http://littlebearriver .usu.edu/current/Default.aspx) and found that these data had been collected at 30 minute intervals, opposed to the 1 hour time intervals set on the HOBO loggers I had used. I then removed all of the appropriate half hour intervals to form a matching dataset. Maximum, minimum, and average daily temperatures were calculated and distance downstream of each sample location was calculated (See Chapter 1). To see if the RCC is valid from Station 1 to Station 11, I did a two tailed t-test to see if they were statistically different. This was done using Excel's data analysis pack. I also repeated this process to see if Stations 6 and 7 were statistically different.

For the long-term temperature data from USU, I used Stations 3, 4, 5, and 11, as they were the only sites that had temperature data year round, for 2011. I used monthly average temperatures for these sites. Three of the four sites were located above Hyrum Reservoir while the forth site, the furthest downstream, was near the town of Mendon (see Figure 1 in Executive Summary). A two-tailed t-test was done to determine whether Stations 3 and 11 were similar in temperature. I then repeated this process to compare Station 3 to 4.

Discharge Measurements

Discharge in the Little Bear River varies from the headwaters to the entrance of Cutler Reservoir. I sampled six sites along the river: three sites above and three sites below Hyrum Reservoir. To measure flow I used the standard protocol of the USGS (Dickinson 1967). First I measured the wetted width of the steam. Depending on the width of the stream we took 25 to 10 velocity measurements at set intervals (Figure 1). Normally USGS uses a minimum of 15 velocity measurement but at Station 7 we were unable to take 15 velocity readings because the river was too narrow. When taking the velocity measurements, the probe was placed at 60 percent of the waters depth to obtain a representative reading. In other words, if the water depth was 100 cm we would take the velocity reading at 40 cm off the bottom. For calculating discharge, I first found the cross sectional area of each square we produced by doing multiple velocity measurements. Then I calculated discharge by multiplying the cross sectional area by the average velocity of that section. To get the total discharge I then summed the discharges for all the cross sections.



Current-meter discharge measurements are made by determining the discharge in each subsection of a channel cross section and summing the subsection discharges to obtain a total discharge.

Figure 1. *Descriptive diagram of how discharge measurements were collected (http://ga.water.usgs.gov /edu/streamflow2.html).*

RESULTS

The short-term temperature data increased from Station 1 to 2 (Figure 2). From Station 1 to 6, temperature increased consistently. At Station 7, the first site downstream of Hyrum Reservoir, the average and minimum temperatures increased while the maximum stayed relatively consistent with Station 6. From Station 7 to 8 all temperature parameters dropped sharply, and then increased from there to Station 11. Diel fluctuations in temperature were large (Figure 3), with 4-5°C day-night changes at Station 1, and 5-6 °C changes at Station 10.

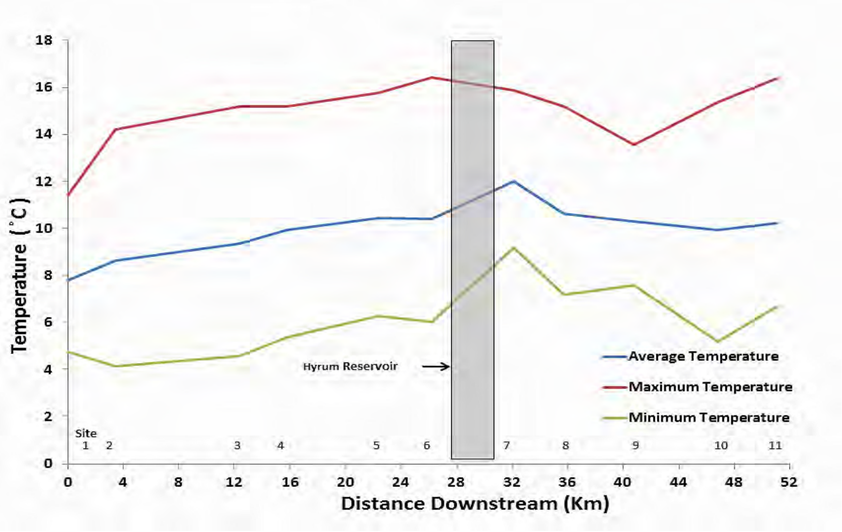
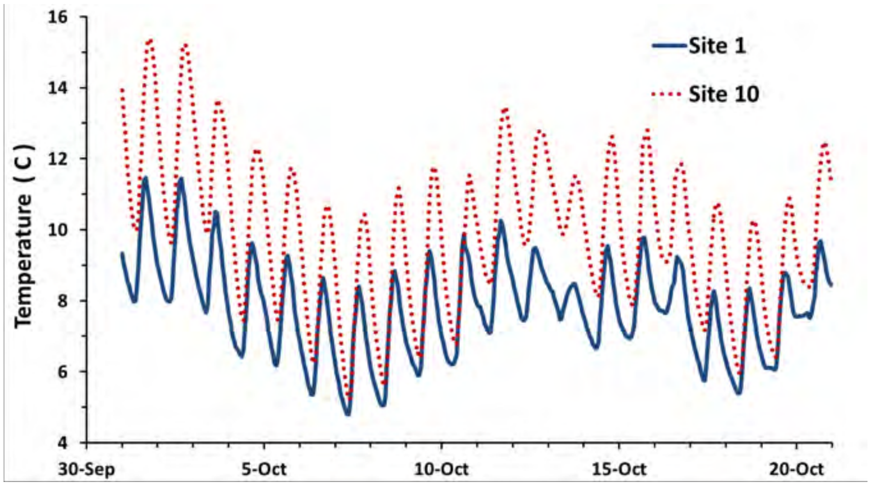


Figure 2. *Average, maximum and minimum daily temperature changes along the Little Bear River measured for a 20-day period from October 1 to 20, 2012. Station numbers are labeled above the X-axis. The grey bar shows the approximate location of Hyrum Reservoir along the gradient.*

Figure 3. *Diel temperature changes at the highest Station (10) and in the valley floor (Station 11) of the Little Bear River.*



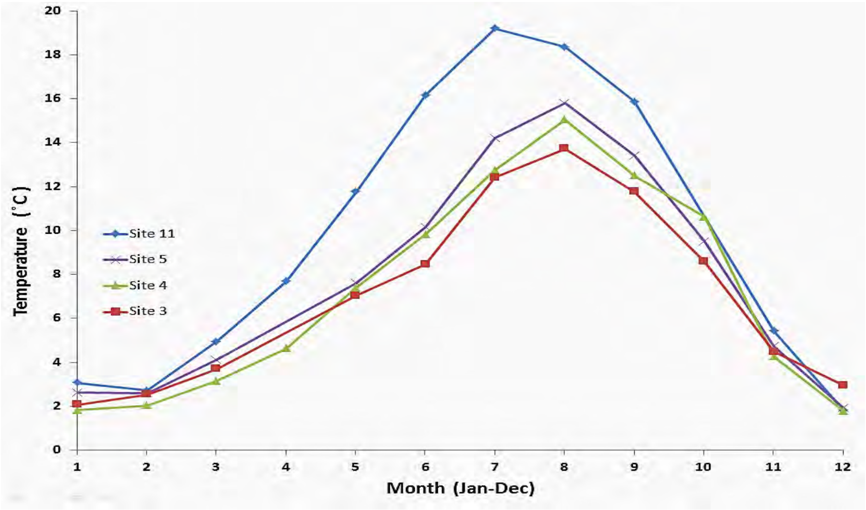


Figure 4. *Long term temperature data for Stations 3, 4, 5, and 11, depicting changes in temperature for each month. X-axis shows months from January to December. This temperature data was collected from the USU Little Bear River WATERS test bed.*

The long-term data showed a similar trend to that of the short-term data, in that temperature generally increased with downstream movement and increased most dramatically at Station 11 during summer months (Figure 4).

Discharge appeared to be negatively influenced by Hyrum Reservoir (Figure 5). From Station 6, the closest site upstream of Hyrum Reservoir, to Station 7, the first site below, discharge dropped from 0.58 to 0.03 cubic meters per second. Discharge then increased from Stations 7 to 11.

DISCUSSION

The short-term data from October suggest that both the RCC and SDH are appropriate theories for explaining trends in the Little Bear River. The increasing trend in temperature is typical of streams where there is a reduced ration of riparian cover to stream size. Additionally, the disruption of Hyrum Reservoir caused a sudden change in both temperature and discharge, followed by a slow reset period, and then these factors take on trends once seen above the reservoir. Other factors that could have played a part in temperature variation would be clear cutting of riparian vegetation for agricultural purposes, which causes the solar input into the stream to increase and temperatures to increase (Beschta 1997; Mohseni 1999). The maximum and minimum temperature below Hyrum Reservoir, at Station 7, were closer together then the rest of the sites, indicating less diel variability in temperature. This could be due to were the water is discharged from the reservoir which could cause the water temperature to not vary throughout a day. This section also had a good canopy, at least where we sampled (see photo in Executive Summary). Similar to temperature, discharge increased with distance downstream, was disrupted by Hyrum Reservoir inducing an alteration from the increasing trend then returned to similar trends taking place above the dam. The exact source of the river recharge is unknown, but a small tributary enters the river near the city of Wellsville, and agricultural return flows also likely contributed.

In the evaluation of the long-term temperature data I found that each Station followed normal seasonal trends. To see if RCC was valid for long- term temperature data I compared Stations 3 to 11. I got a p-value of 0.049, indicating a significant increase in temperature. I then wanted to see if Station 3 was similar to Station 4 and they were also significantly different (p-value 0.016). The long term data must have other influence such as a diversion dam or other water inputs that causes the temperature to vary per month and per station. Having less water in the stream influences the water temperature (Mohseni 1999). With less water there are higher water temperatures, but as stated earlier, 2011 had higher than normal flows. This causes the river to have more normal flows, which in turn causes temperatures to be lower than during low-water years. Also with more snow pack we get more runoff from areas that do not normally have overland flow (Gebert et al. 1987). This could cause the statistics to show no relation from site to site. For 2011 we show that the RCC was not valid for long-term dataset because it's a modified stream with many influences.

Some variability in these results may be attributed to inconsistencies in data collection. The online USU dataset was not consistent from month to month with the same number of readings. This could have been caused by errors with temperature readers, altered flows, or probes being fouled by debris. Working directly with the other researchers at USU would have helped to minimize some of these errors.

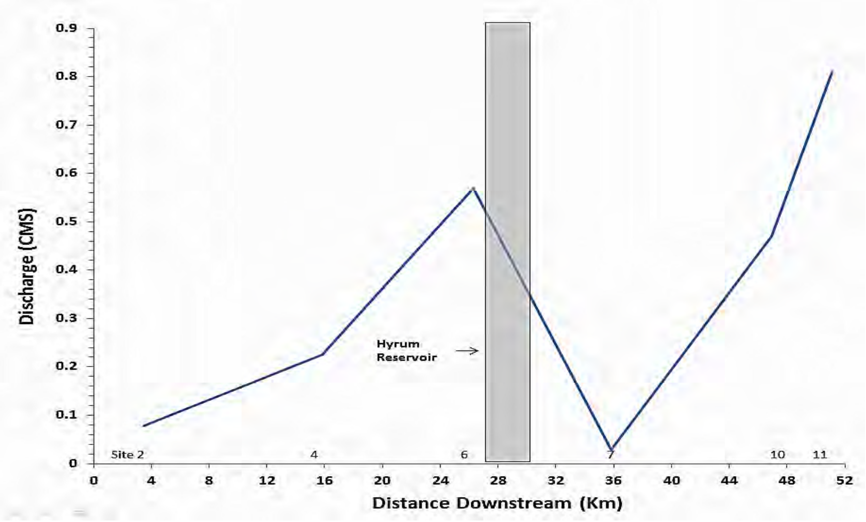


Figure 5. *Discharge along a longitudinal gradient of the Little Bear River measured on September 29, 2012. Station numbers are shown above the X-axis. Y-axis is discharge in cubic meters per second. The grey bar shows the location of Hyrum Reservoir.*

REFERENCES

Beschta, R.L. 1997. Riparian shade and stream temperature: an alternative perspective. Rangelands. 19(2):25-28.

Gebert, W.A.; Graczyk, D.J.; Krug, W.R. 1987. Average annual runoff in the United States, 1951-80 Hydrologic Investigations Atlas HA-710. Reston, Va.: U.S. Department of the Interior, U.S. Geological Survey.

Mohseni, O.; Stefan, H.G. 1999. Stream temperature/air temperature relationship: a physical interpretation. Journal of Hydrology. 218:128-141.

Statzner, B.; Higler, B. 1985. Questions and comments on the river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences. 42:1038-1044.

Vannote, R.L.; Minshall, G.W.; Cummins, K.W.; Sedell, J.R.; Cushing, C.E. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences. 37:130-137.

Ward, J.V.; Stanford, J.A. 1983. The serial discontinuity concept of lotic ecosystems. Pages 29-42 In . Fontaine, T.D. and Bartell, S.M. (editors) Dynamics of Lotic Ecosystems. Ann Arbor, MI.: Ann Arbor Sciences.

Ward, J.V.; Stanford, J.A. 1995. The serial discontinuity concept: extending the model to floodplain rivers. Regulated Rivers: Research and Management. 10:159-168.

Chapter 3

Anthropogenic Impacts on the Longitudinal Gradient of Nutrients in the Little Bear River

[by] Jason Fuller

SUMMARY

I measured the anthropogenic impacts from land use on nutrient concentrations along the Little Bear River in Cache Valley, Utah. Water samples from twelve stations along the Little Bear River were collected and analyzed using an auto analyzer in order to determine conductivity and concentrations of total nitrogen, total phosphorus, soluble reactive phosphorus (SRP), ammonia (NH_3), and nitrate (NO_3^-). Samples were collected at stations thought to reveal anthropogenically influenced nutrient loading. Some of the anthropogenic land usages that potentially impact the nutrient concentrations include agricultural land use, urban land use, Hyrum Reservoir, the Trout of Paradise fishing reserve located near the town of Paradise, and the Wellsville Wastewater Treatment Plant. Specific conductivity measurements indicated a 172 percent increase in ions from the headwaters to the lowest site sampled, near the confluence with Cutler Reservoir. My study indicated that total nitrogen was significantly increased by anthropogenic land use, with nitrate increasing from 115 µg N L^{-1} in the headwaters to 1260 µg N L^{-1} in the lowland agricultural areas. Total phosphorus (TP) did not appear to be influenced by anthropogenic land use above Hyrum Reservoir: However, below the reservoir concentrations reached 60-75 µg P L^{-1}, above Utah threshold criteria of 50 µg L^{-1}. Total nitrogen: total phosphorus ratios indicated that phosphorus was potentially the limiting nutrient at three of the twelve stations including the Trout of Paradise fishing reserve. The dissolved inorganic nitrogen (DIN): TP ratio indicated that phosphorus was the limiting nutrient at each of the stations except Station 8, which is located below Hyrum Reservoir. These findings highlight the influence of anthropogenic land use on the Little Bear River, within the framework of the Serial Discontinuity Hypothesis (Ward and Stanford, 1995).

INTRODUCTION

The Little Bear River (LBR), located in northern Utah, starts in the mountains south of Cache Valley (See site map in executive summary). Our study area ranged from a first order stream in the mountains a third order stream in Cache Valley. The river runs through the valley and has significant anthropogenic impacts including agricultural use, reservoirs, cities, water treatment plants, and Hyrum Reservoir which is located near Hyrum, UT. These human uses likely affect the physical and biological aspects of the river and may cause nutrient enrichment which can increase nutrient loads of a riverine system resulting in eutrophication; defined as extreme productivity (Dodds 2010). Eutrophic environments can provide a very displeasing site for many people in the valley and may also result in negative impacts to the water quality. My study helps determine how these anthropogenic land uses may be causing the nitrogen and phosphorus concentrations to change in the LBR. It will also help provide an understanding as to whether the River Continuum Concept (RCC), the Serial Discontinuity Hypothesis (SDH), or both apply to the behavior of the Little Bear River.

The RCC describes patterns of ecological processes that change as a result of the intrinsic alterations to rivers as they grow in size and move downstream (Urbaniak et al. 2012). These changes occur naturally in many rivers throughout the world. Specific conductivity, a measure primarily of major ions like calcium and carbonates, should increase with downstream movement caused by weathering of minerals in the watershed (Kratz et al. 1997). It is expected that as the stream order increases in the LBR, the amount of nutrients in the river will increase, perhaps exceeding the general increase in specific conductivity.

It is also possible that the amount of nutrients in the river could decrease between the inlet and the outlet of Hyrum Reservoir due to deposition of the nutrients (Urbaniak et al. 2012.). This process could have important implications for stream reaches below Hyrum Reservoir and is best described by the SDH (Ward and Stanford, 1995). The reservoir is yet another factor that could affect the nutrients within the LBR.

The ratio of nitrogen to phosphorus is an important index to measure, as these nutrients are major factors that control primary production and heterotrophic activity in many ecosystems (Dodds 2010). The Redfield Ratio is the ratio of carbon: nitrogen: phosphorous when a system has balanced growth. The molar ratio of N: P in phytoplankton (we did not measure carbon in this study) is typically 16:1 (Dodds 2010) and 7.3:1 in weight units. By understanding the ratio of nitrogen to phosphorus in a river one can predict which nutrients may be limited and will also be able to verify which anthropogenic factors may be impacting the nutrients within the river.

The nutrient load is subject to variation throughout different seasons of the year (Billen et al. 2007). In Cache Valley it is typical to have higher flows in the spring due to runoff from the mountains surrounding the valley. This runoff often provides a surge in the nutrient load and many of these nutrients are stored in soils. These stored nutrients are periodically released into the river throughout the year. A similar study showed that soluble reactive phosphorus (SRP) had the highest concentrations during the summer months while approximately 92 percent of total phosphorus (TP) was found in the river between fall and spring (Bowes et al. 2003). Obviously these concentrations may vary due to differences in locations but it is important to understand that these nutrient loads may vary throughout the year as well. For my project, I was very limited on time and was only able to observe the nutrient concentrations for one day of the year on September 29, 2012. Any observations from this experiment are subject to change throughout the year but these observations should, in fact, give us a good perspective on how the nutrient concentrations change longitudinally due to anthropogenic use of the land during the active growing period for the algae and other organisms in the river.

The main objective of my project was to determine if anthropogenic land use along the Little Bear River continuum was correlated with increasing gradient in the concentrations of phosphorus and nitrogen as stream order increases. The study also allowed me to determine if the ratio of N: P changed along the gradient. These ratios can ultimately help us decide if the change in nutrient load is due to natural causes explained by the river continuum concept, or if the anthropogenic land use is indeed a major factor in the source of nutrients found in the river (Harding et al. 1999).

FIELD STUDY AND METHODS

Samples were collected from twelve sample sites along a continuum of the Little Bear River (See site map in executive summary). Eleven of the stations were selected based on ease of accessibility and to adequately represent the different stream orders of the river. We wanted to represent many of the anthropogenic land uses that could possibly impact the nutrient concentrations in the LBR. One of these anthropogenic impacts included White's Ranch Fishing Preserve, which is located at river kilometer 22.4 and provides a large amount of water to the LBR. Water samples were consequently taken from White's water which enters the LBR just upstream from Station 5. Other notable anthropogenic impacts within the LBR watershed include agricultural land use, Hyrum Reservoir, urban land use, and the Wellsville Municipal Sewage Lagoons. Hyrum reservoir is located between Stations 6 and 7, the Wellsville sewage lagoons are located just upstream from Station 9, and a large portion of the land along the river below Hyrum Reservoir is utilized for agricultural use.

Before sampling water from each station, twenty-four Nalgene bottles were acid-washed to reduce contamination. Two replicate bottles were used to collect unfiltered water for "total nutrients" and two replicate bottles for "dissolved nutrients" for each station. Glass fiber filters (GF/F; 0.7 μm) were also rinsed with acid in preparation for the sample collection. An acid-washed syringe filtration apparatus and glass fiber filter was used to filter two replicates for dissolved nutrients at each station. Before collecting filtered samples from each station, the filtration apparatus was rinsed three times with river water to avoid contamination. Each of the Nalgene bottles for each station was also rinsed with river water before collecting samples. A YSI meter was also used at each station to record specific conductivity. All samples were collected on 29 September 2012 between 9:00 and 17:00, placed in a cooler with ice while in the field, and then stored in a lab freezer until lab processing was conducted.

The nutrient samples were analyzed in Dr. Michelle Baker's Biogeochemistry Laboratoy at Utah State University. The "total nutrient" samples were analyzed for total nitrogen (TN) and total phosphorus (TP) following persulfate digestion. The "dissolved nutrients" samples were analyzed for soluble reactive phosphorus (SRP) and dissolved inorganic nitrogen (DIN) which is comprised of ammonium (NH_3) and nitrate (NO_3^-). Reagents were prepared for each sample and each sample was analyzed using an auto analyzer. A spectrophotometer was also used in class to analyze prepared samples for total phosphorus. The results from the spectrophotometer showed signs of contamination. Contamination could have occurred due to a problem with the reagent or because of a lack of experience from the student analysts. The results from the spectrophotometer were consequently not used in the analysis of the data.

Ratios of nitrogen and phosphorus for the LBR were calculated using two different methods. First, I used the common TN:TP ratio (Redfield ratio). However, Morris and Lewis (1988) calculated the minimum relative error (MRE) between results from nutrient addition bioassays, and for various ratios including TN:TP and DIN:TP and they determined that DIN:TP was a better predictor of whether N or P would limit algal growth than the more commonly used TN:TP. This suggests that the DIN: TP ratio more accurately determines which nutrients are limiting within a body of water (Morris and Lewis 1988). The TN:TP ratio tends to overestimate nitrogen available for biotic uptake (Morris and Lewis 1988).

For the TN:TP ratios I used the MRE criteria outlined by Healey and Hendzel (1980) to determine nutrient deficiencies in phytoplankton. I converted the molar ratios that they used into weight ratios. These values were used to determine which nutrients were limiting along the LBR continuum. For the TN:TP ratios phosphorus limitation occurs when the weight ratio exceeds 9.0:1. Weight ratios between 4.5:1 and 9.03:1 indicate a combination of both nitrogen and phosphorus limitation, and a weight ratio smaller than 4.5:1 indicates nitrogen limitation (Healey and Hendzel 1980).

The MRE lines calculated by Morris and Lewis (1988) were used to analyze the DIN:TP ratios. Weight ratios greater than 4:1 indicate phosphorus limitation, weight ratios between 4:1 and 1:1 indicate co-limitation by both phosphorus and nitrogen limitation, and weight ratios below 1:1 indicate nitrogen limitation (Morris and Lewis 1988).

Anthropogenic land usage was calculated by Chance Broderius (2013; this report) using ArcGIS. The catchment area for each station was calculated and separated into different land use categories. Anthropogenic land use was categorized as urban land as well as irrigated, non-irrigated, and sub-irrigated agricultural land areas. Areas were calculated for each of the anthropogenic land use categories and then divided by the catchment areas for each station. This resulted in the percent of anthropogenic land use for each of the eleven stations.

RESULTS

Specific Conductivity

Figure 1 shows how specific conductivity increased longitudinally along the LBR continuum. There was a 172 percent increase in the specific conductivity from the headwaters (Station 1) to the lower reach (Station 11) of the LBR. This suggests that the concentration of major ions within the river increases downstream.

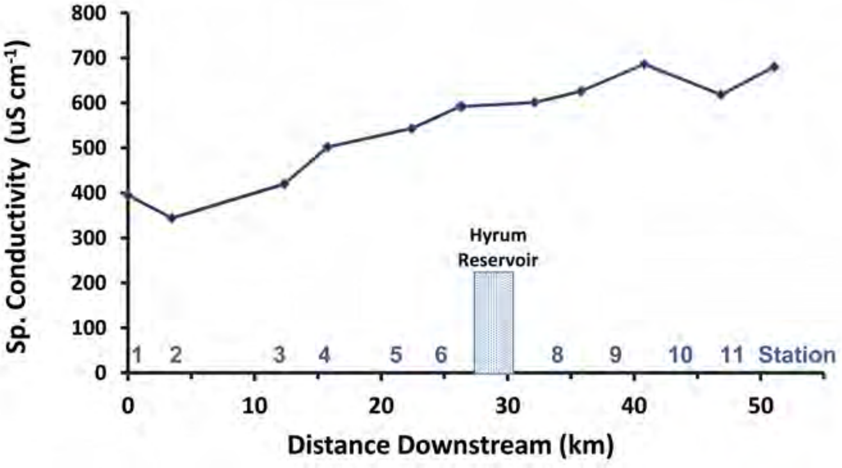


Figure 1. *Specific conductivity (µS cm^{-1}) of the Little Bear River continuum vs. distance in kilometers downstream on September 29, 2012. Station numbers are shown in blue above the x-axis. Specific conductivity is a measure of the concentration of ions within the river.*

Components of Total Nitrogen

Total nitrogen (TN) increased greatly down the Little Bear River continuum (Figure 2; Appendices). TN increased from 150-226 µg N L^{-1} in the mountainous sites (Stations 1-3) but reached over 1300 µg L^{-1} in the lowland agricultural areas. The main component of TN within the LBR was nitrate which reached a concentration of 1450 µg L^{-1} at Station 6. TN increased greatly first at the convergence of the White's Ranch Fishing Preserve, located at 22.4 km downstream from Station 1, and just upstream from Station 5. Mean nitrate and TN concentrations in the canal draining the fishing preserve were 946 and 1008 µg L^{-1}, respectively. Nitrate continued to increase until the river reached Hyrum Reservoir between Stations 6 and 7. It is possible that the collection at Station 5 (km 22.41) did not fully incorporate the nutrients entering from Whites, as the sample was taken on the west side of the river whereas the White's discharge enters the river only 30-m upstream on the east side. Mixing may therefore have not been complete within the river. The majority of the flow was coming out of the discharge canal, with little from the river itself.

There was a large decrease in nitrate below Hyrum Reservoir at Station 7. Although DIN decreased, there was a notable increase in organic nitrogen at Station 8 (Wellsville) the reservoir. Nitrate continued to increase rapidly in the lower reach of the LBR especially between Stations 8 and 9. The water treatment plant is located just upstream from Station 9 and is assumed to be the source of a large amount of this increase in nitrate. Nitrate showed the largest percentage increase of any nutrient from the headwaters to the lowlands (976 percent; Figure 3).

Ammonia wasn't affected as drastically by anthropogenic land use in the LBR watershed as the nitrate concentrations. Ammonia made up only a small portion of total nitrogen concentrations (Figure 2). Ammonia increased little as the river progressed downstream, and then increased significantly below the Wellsville Wastewater Lagoon discharge (Figure 2), but the overall increase from the headwaters (Stations 1 and 2) to the lowland river (Stations 10 and 11) was 578 percent (Figure 3).

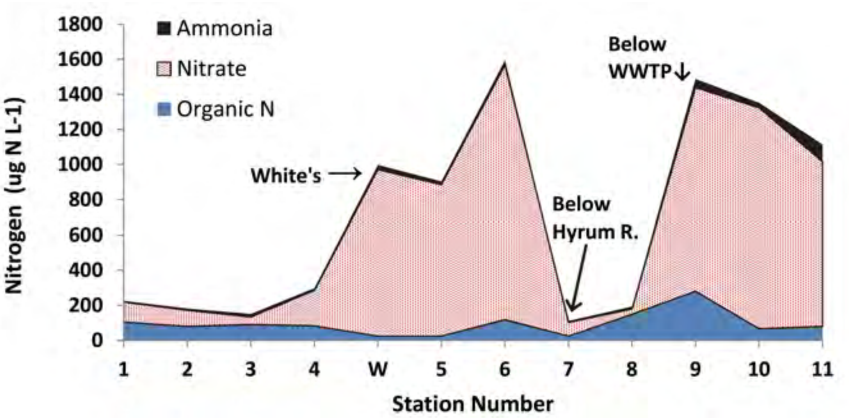


Figure 2. *Organic nitrogen (Particulate + dissolved organic N), nitrate and ammonia concentrations from the headwaters (Station 1) to the lowlands valley reaches of the Little Bear River. The samples were collected on September 29, 2012.*

Components of Total Phosphorus

Total phosphorus (TP) first increased gradually along the LBR continuum and then increased significantly between the fishing reserve and Station 6 (Figure 4). TP then decreased between Stations 6 and 7 below Hyrum Reservoir. TP is comprised of soluble reactive phosphorus (SRP), dissolved orgainic P, and particulate phosphorus. The "other forms" of phosphorus were derived by subtracting SRP from the TP (Figure 4). Both SRP and "other forms" of phosphorus increased greatly after Hyrum Reservoir at Station 8, and then peaked below the water treatment plant at Station 9.

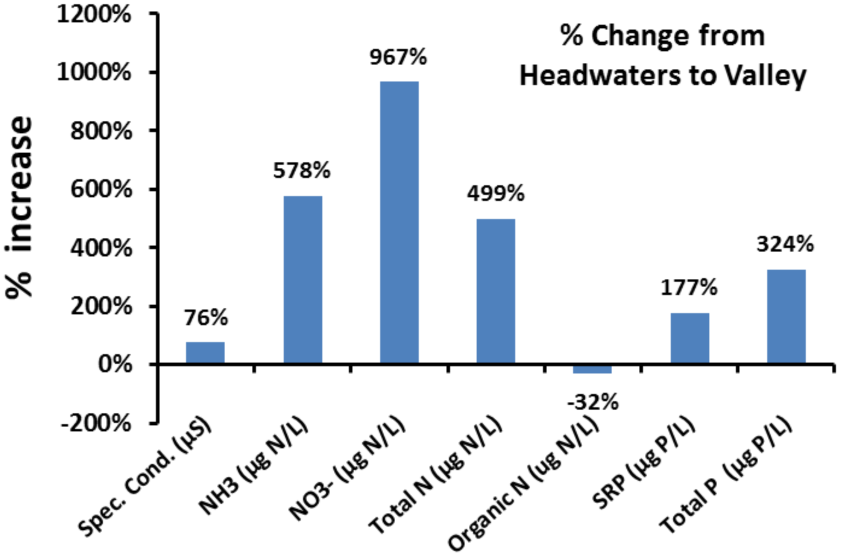


Figure 3. *The percent of change in different nutrients from the average of Stations 1 and 2 in the headwaters to the average of Stations 10 and 11 in the agricultural section (and below the wastewater treatment plant). This percentage shows how most nutrients demonstrated a positive increase in concentrations between the headwaters to the valley.*

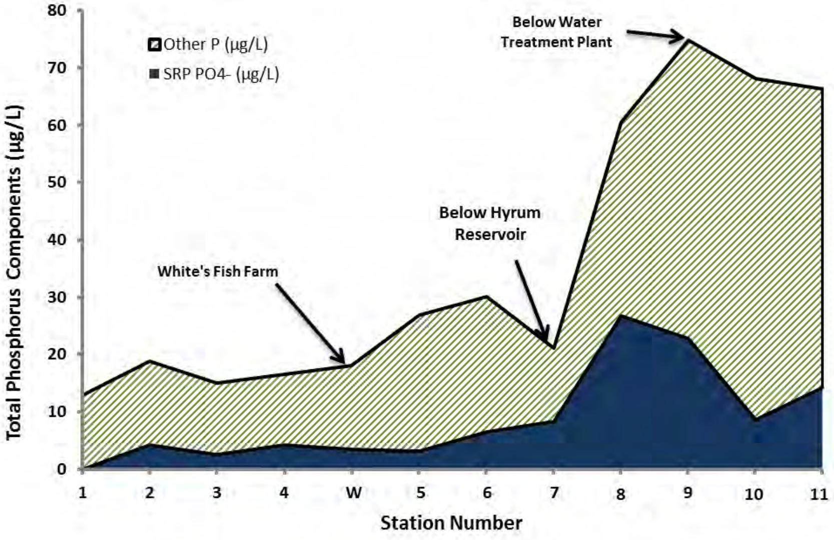


Figure 4. *Breakdown of total phosphorus (top black line) along the Little Bear River (LBR) continuum in Cache County, Utah on September 29, 2012. Total phosphorus is comprised of SRP (soluble reactive phosphorus) and other forms of phosphorus. Note the significant decrease in total phosphorus below Hyrum Reservoir (Station 7), followed by a large increase in the reach between Station 7 and the town of Wellsville (Station 8).*

Total phosphorus concentrations were correlated with the percent of anthropogenic land use surrounding the LBR (R^2 = 0.79; p = 0.0002; Figure 5). These statistics suggest that TP is significantly correlated with the percent anthropogenic land use though these results do not necessarily imply causation. Neither TN nor nitrate were significantly correlated with the percent anthropogenic land use of the land (TN: R^2 0.265; p = 0.087; NO_3^-: R^2 0.197; p = 0.148). The lack of correlation was likely due to the very large decrease in nitrate (and TN) below Hyrum Reservoir (Station 7).

N: P Ratios and Nutrient Limitation

Both the TN:TP ratio and the DIN:TP ratios indicated that algae would be phosphorus limited at most stations in the Little Bear River (Figure 6). The exception was Station 8 where the ratio suggested that N would be limiting: The mean TN:TP ratio there was 5.4:1 and the DIN:TP ratio was 0.72 . However, the DIN:TP ratio frequently approached levels suggesting co-limitation of N and P.

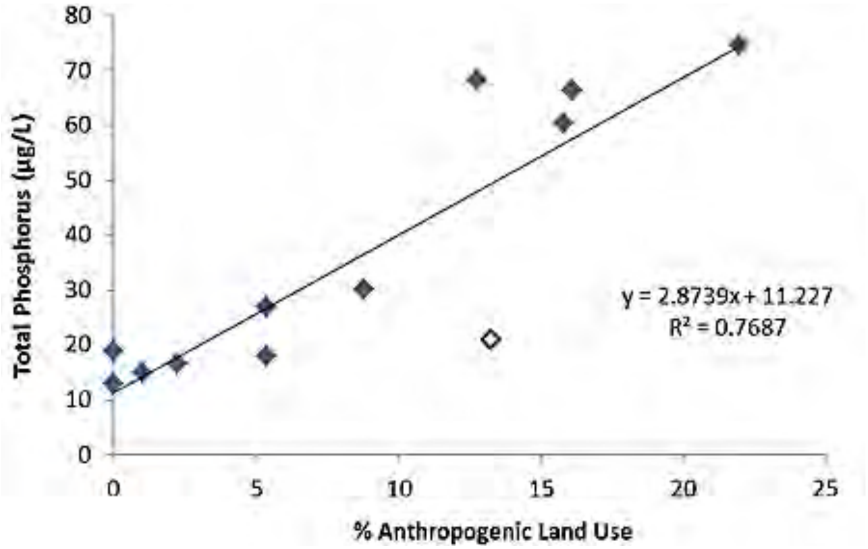


Figure 5. *Relationship between anthropogenic land use (largely agriculture) and total phosphorus concentrations along the Little Bear River on September 29, 2012. Land use in the watershed was derived from Broderius (Chapter 6 of this report). The hollow diamond is the Station below Hyrum Reservoir. Two replicates were taken at each station, but in some cases the variability was small and the points are superimposed on each other.*

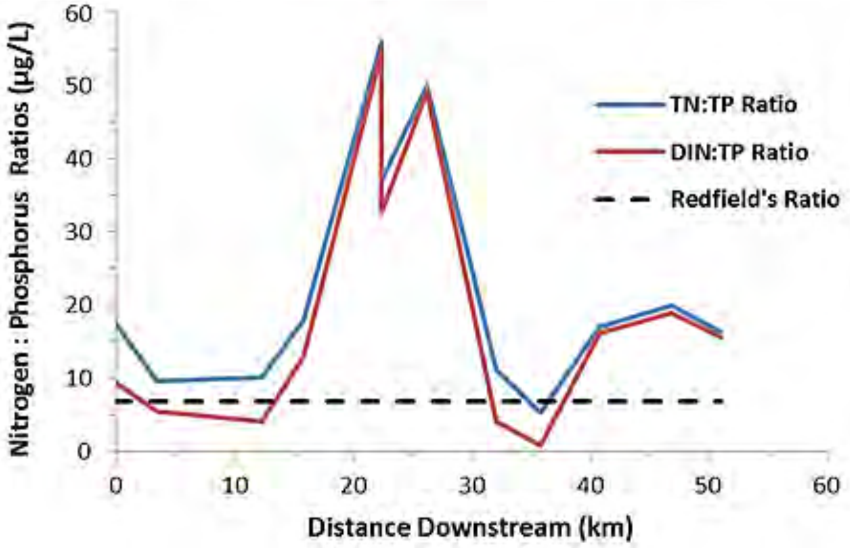


Figure 6. *TN:TP ratios (blue line) and the DIN:TP ratio (red line) along the Little Bear River continuum from the headwaters (0 km) to the lowlands. These ratios are helpful in determining which nutrient is limited within the water. Redfield's ratio (dotted line) defines the standard ratio of N:P which is approximately 6.8:1 µg/L. Ratios above the Redfield ratio suggests that phosphorus is the limiting nutrient. DIN:TP is a ratio preferred by Morris and Lewis (1988) because it excludes forms of nitrogen that aren't readily available for use to most organisms in the environment At DIN:TP ratios below 1:1 N likely limits algal growth and between 1:1 and 4:1 co-limitation of N and P is expected.*

DISCUSSION

Total nitrogen and total phosphorus both increased longitudinally along the LBR continuum. TN and TP were affected by the various anthropogenic land usages along the continuum. As expected the water draining White's Fishing Reserve and the Wellsville waste water treatment plant provided significant increases in TN. However, these results weren't as clear in the TP data. The increase in TN at Stations 5 and 9 indicated that anthropogenic land use does appear to impact the nutrient concentrations in the LBR. The state of Utah has a threshold criteria set for the concentration of phosphorus which helps define whether or not a body of water is considered eutrophic. The current threshold is a concentration of 50 µg L^{-1} for phosphorus (Rule R317-2, Utah.gov, 2012). This threshold is shown in Figure 7 for the LBR. Phosphorus concentrations exceeded the threshold at the four sites (Stations 8-11) below the town of Wellsville, suggesting that water downstream of Station 8 is eutrophic, according to Utah standards.

An in-depth bioassay was performed by Jared Baker (2013, this report) for the LBR continuum. He sampled water from Stations 2, 6, 7, and 10. I was able to compare my nutrient limitation results with Baker's bioassay experiment results and found that his results varied from mine. Baker found that a combination of both nitrogen and phosphorus were the limiting nutrients at Station 2. My results indicated that phosphorus should have been the only limiting nutrient at Station 2 suggesting that some of the TN measured was not bioavailable. The rest of the stations that Baker observed had similar results as mine, indicating that phosphorus was the limiting nutrient. Unfortunately, Baker didn't sample from Station 8 so a comparison of what happened below Hyrum Reservoir was not possible.

TN and TP concentrations along a continuum of the LBR suggest that hypotheses suggested by the SDH (Ward and Stanford, 1995) do hold true. Similar to the study by Urbaniak (2012) which took place in Central Poland, a significant decrease in TN and TP occurred below Hyrum Reservoir. We assume that this is due to many of the nutrients being deposited in the reservoir and trapped by Hyrum dam. Additionally, the very low discharges below Hyrum Dam allowed luxurious filamentous algae at the Station 7 reach (see photo in Executive Summary), and this periphyton may have also removed significant amounts of nitrogen and phosphorus from the water column.

Two factors in the research design confounded my analysis. First, on the day that we collected water samples we were notified by the waste water treatment plant that effluent wasn't being discharged into the LBR. Because of this we didn't expect a substantial increase in nutrients at Station 9. This wasn't the case, because a large increase in TN occurred between Stations 8 and 9. What caused this enormous increase in nitrogen? One hypothesis is that many of the nutrients from the waste water treatment plant infiltrate the hyporheic zone and in turn, have delayed releases of nutrients into the river. Comparing results of water samples taken when the wastewater treatment plant is releasing water to the LBR, with the results of water samples taken without an input from the plant would show how much of an increase in nutrient concentrations normally occurs at Station 9. Secondly, because of the restricted temporal analysis (one day!), I was unable to understand temporal changes in nutrient concentrations. I would suggest sampling the LBR during multiple time periods throughout the year to gain a better understanding of nutrient concentrations and loading.

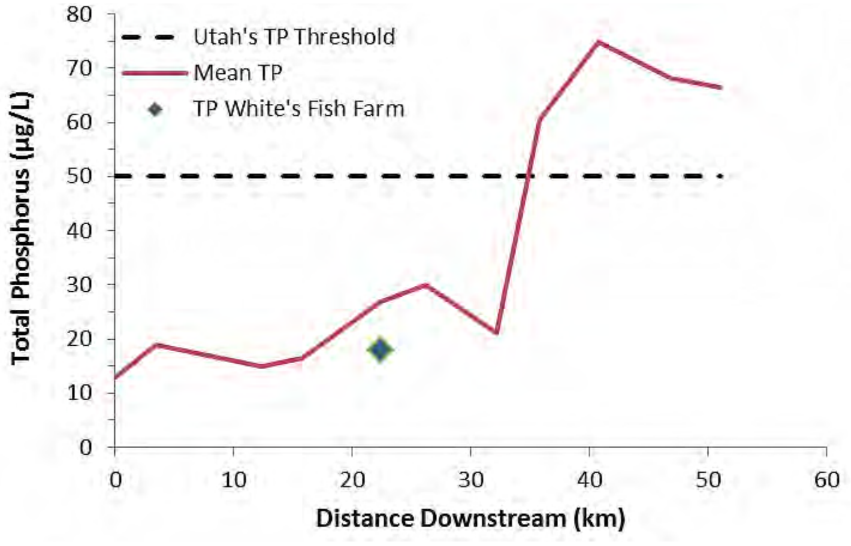


Figure 7. *Total phosphorus (TP) of the Little Bear River continuum vs. distance in kilometers downstream. Distance downstream begins with Station 1 at zero kilometers in the river headwaters. Utah's total phosphorus threshold of 50 µg/L is shown as the dashed line. Any measurement of TP greater than 50 µg/L is considered eutrophic and poor water quality.*

CONCLUSION

I feel that these results suggest that anthropogenic land use of the land along the LBR continuum indeed impacts the nutrient concentrations within the river. The serial discontinuity concept (Ward and Stanford, 1995) is adequately demonstrated along the LBR continuum, showing a disruption in nutrient trends caused by Hyrum Reservoir. It is unclear how much the hypotheses of the river continuum concept predict the nutrient concentrations along the LBR. However, conductivity concentrations may in fact fall in-line with its predictions.

REFERENCES

Bergstrom, A.K. 2010. The use of TN:TP and DIN:TP ratios as indicators for phytoplankton nutrient limitation in oligotrophic lakes affected by N deposition. Aquatic Sciences. 72:277-281.

Billen, G.; Garnier, J.; Nemery, J.; Sebilo, M. et al. 2007. A long-term view of nutrient transfers through the Seine river continuum. The Science of the Total Environment. 375:80–97.

Bowes, M.J.; House, W.A.; Hodgkinson, R.A. 2003. Phosphorus dynamics along a river continuum. The Science of the Total Environment. 313:199–212.

Dodds, W.; Whiles, M. 2010. Freshwater Ecology (Second ed.). Burlington, MA: Elsevier.

Harding, J.S.; Young, R.G.; Hayes, J.W.; Shearer, K.A.; Stark, J.D. 1999. Changes in agricultural intensity and river health along a river continuum. Freshwater Biology. 42:345–357.

Healey, F.P.; Hendzel, L.L. 1980. Physiological indicators of nutrient deficiency in lake phytoplankton. Canadian Journal of Fisheries and Aquatic Sciences. 37:442-453.

Hillbricht-Ilkowska, A. 1999. Shallow lakes in lowland river systems: Role in transport and transformations of nutrients and in biological diversity. Hydrobiologia. 408/409:349–358.

House, W.A.; Denison, F.H. 1997. Nutrient dynamics in a lowland stream impacted by sewage effluent: Great Ouse, England. The Science of the Total Environment. 205:25-49.

Kratz, T.K.; Webster, K.E.; Bowser, C.J.; Magnuson, J.J.; Benson, B.J. 1997. The influence of landscape position on lakes in northern Wisconsin. Freshwater Biology. 37:209-217.

Morris, D.P.; Lewis, W.M. 1988. Phytoplankton nutrient limitation in Colorado mountain lakes. Freshwater Biology. 20:315-327.

Urbaniak, M.; Kiedrzynska, E.; Zalewski, M. 2012. The role of a lowland reservoir in the transport of micropollutants, nutrients, and the suspended particulate matter along the river continuum. Hydrology Research. 43(4):400–411.

Utah Administrative Code. Rule R317-2 Standards of quality for waters of the state. http://www.rules.utah.gov/publicat/code/r317/r317-002.htm#T9. Accessed November 27, 2012.

Vannote, R.L.; Minshall, G.W.; Cummins, K.W.; Sedell, J.R.; Cushing, C.E. 1980. The River Continuum Concept. Canadian Journal of Fisheries and Aquatic Sciences. 37:130-137.

Ward, J.V.; Stanford, J.A. 1995. The serial discontinuity concept: Extending the model to floodplain rivers. Regulated Rivers: Research and Management. 10:159-168.

APPENDICES

Appendix 1. *Chemistry data along the Little Bear River Continuum Study, WATS 4510 2012 (Jason Fuller).*

Station	Replicate	D.O. (mg/L)	Temp (°C)	Specific Cond. (µS/cm)	Ammonia (µg/L)	Nitrate (µg/L)	Total N (µg/L)	SRP (µg/L)	Total P (µg/L)	N:P (weight)	DIN:TP
1	A	6.8	12.2	395	5.1	111	218	bdl	13.8	15.8	8.4
	B				8.9	119	234	bdl	12.0	19.5	10.6
2	A	7.6	14.8	344	12.6	93	194	3.6	20.7	9.4	5.1
	B				10.0	89	170	4.7	17.0	10.0	5.8
3	A	8.1	15.9	420	8.4	43	159	3.1	14.9	10.7	3.4
	B				28.3	44	144	1.9	15.1	9.5	4.8
4	A	10.5	16.4	502	12.3	205	307	4.5	17.3	17.7	12.5
	B				9.9	201	287	3.8	15.8	18.2	13.3
Whites Fish Farm	A	NA	NA	NA	16.8	947	1002	3.2	18.1	55.4	53.3
	B				56.9	945	1013	3.6	17.9	56.6	56.0
5	A	10.1	15.9	543	17.3	860	1007	3.9	24.6	40.9	35.6
	B				20.5	861	988	2.3	29.2	33.8	30.2
6	A	9.2	16.6	592	35.9	1456	1534	7.4	27.9	55.0	53.5
	B				18.5	1443	1470	5.7	32.2	45.6	45.4
7	A	10.3	16.0	601	11.2	78	236	8.2	22.3	10.6	4.0
	B				5.4	77	235	8.3	19.8	11.9	4.1
8	A	9.1	14.7	626	12.6	31	349	32.9	61.2	5.7	0.7
	B				13.2	30	297	20.5	59.9	5.0	0.7
9	A	8.4	12.6	686	56.1	1160	1296	30.1	70.7	18.3	17.2
	B				42.7	1158	1255	15.5	78.9	15.9	15.2
10	A	8.7	11.8	618	22.6	1257	1376	12.2	72.2	19.1	17.7
	B				30.8	1259	1354	5.1	64.1	21.1	20.1
11	A	7.9	13.5	680	110.2	934	1076	9.5	65.0	16.6	16.1
	B				84.7	939	1081	19.1	67.7	16.0	15.1

NA- Not Available bdl – below detection limits DIN=NO_{3-} + NO_{2-} + NH3

Appendix 2. *Site characteristics, del-15N values and areas and proportion of the watershed anthropogenically influenced (Broderius).*

Station	Replicate	del-15N	Catchment Area (km^2)	Anthropopogenically affected land use* (km^2)	Percent Anthropopogenically affected land use*	Total N (µg/L)
1	A	2.4	15.4	0.0	0.0	218
	B	2.6				234
2	A	3.2	45.8	0.0	0.0	194
	B	3.1				170
3	A	5.1	162	2.0	1.2	159
	B	4.3				144
4	A	7.4	343	8.9	2.6	307
	B	7.7				287
White's Fish Farm	A	5.5				1002
	B	7.6				1013
5	A	5.4	387	17.3	4.5	1007
	B	5.9				988
6	A	8.4	454	45.2	10.0	1534
	B	7.4				1470
7	A	12.5	480	67.8	14.1	236
	B	13.0				235
8	A	13.0	503	92.6	18.4	349
	B	13.7				297
9	A	9.1	584	129.0	22.1	1296
	B	8.3				1255
10	A	5.9	599	141.3	23.6	1376
	B	6.4				1354
11	A	8.5	625	156.8	25.1	1076
	B	9.0				1081

*Anthropopogenically affected land use includes: irrigated agricultural land, non-irrigated agricultural land, sub-irrigated agricultural land, and land in urban development

Chapter 4

Periphyton and Phytoplankton Chlorophyll *a* Levels in the Little Bear River and Hyrum Reservoir, Utah

[by] Katie Fisher

SUMMARY

This study was conducted to assess the applicability of the River Continuum and Serial Discontinuity Concepts to the Little Bear River, using chlorophyll *a* values along the gradient of the river and within Hyrum Reservoir. Periphyton was analyzed from seven sites and phytoplankton from nine sites (including Hyrum Reservoir) in September 2012. The lower parts of the Little Bear River is heavily influenced by agricultural and anthropogenic sources of nutrients and other pollution, creating poor water quality in its lower reaches. Periphyton levels in the river increased along the gradient, peaking just below Hyrum reservoir, and then decreased with distance downstream. Phytoplankton chlorophyll *a* concentrations increased significantly with distance downstream, with concentrations near 1.5 µg L^{-1} in the headwaters and 5 µg L^{-1} in the slow-moving valley sections. On an aerial basis, chlorophyll in the periphyton community overwhelmingly dominated (>98 percent) the total chlorophyll levels. Within the phytoplankton continuum, there was, however, a drop below Hyrum Reservoir. Furthermore, there was a significant positive relationship between the total phosphorous concentrations and phytoplankton levels. Periphyton levels, however, were not correlated with phosphorus concentrations. The chlorophyll *a* levels found suggest that high levels of phosphorus contribute to higher levels of algal chlorophyll *a*. Although these levels were not indicative of poor water quality, mitigation of nutrient sources in the valley would likely create more uniform chlorophyll *a* levels down the gradient of the LBR.

INTRODUCTION

The River Continuum Concept (Vannote et al. 1980) predicts that periphyton and phytoplankton communities in pristine systems should have predictable changes along the continuum from headwater streams to lowland rivers. However, most river systems in a developed landscape are not pristine, but rather, have been modified by damming, agricultural, and urban impacts (Ward and Stanford 1983; Caraco and Cole 1999). The Little Bear River located in northern Utah is an example of a system with both pristine and impacted reaches. The Serial Discontinuity Concept (SDC) of Ward and Stanford (1983) addresses this type of interruption, and consequently its precepts have helped interpret the findings of this project.

My study measured the chlorophyll *a* levels in periphyton and phytoplankton along the gradient of the Little Bear River (LBR). The South Fork of the LBR is relatively pristine with no discontinuities. These attributes make the upper LBR a good candidate for testing the RCC. However, due to the presence of Hyrum Reservoir, as well as the increasingly anthropogenic impacted landscape, the continuum of the LBR is disrupted.

Considering sources of nutrients, in a continuum, is important for developing hypotheses regarding chlorophyll abundances because nutrients within streams are shown to positively affect chlorophyll levels

(Dodds et al. 2006). Some rivers manifest community structure in "patches" as well as in continuous patterns—usually one more so than the other (Wright and Li 2002). Wright and Li (2002) found that the levels of periphyton were highly variable; however, this does not necessarily mean there was no continuity, because their study did not identify periphyton species within the community. Similarly, I did not identify specific periphyton taxa and my study was limited in the same manner as Wright and Li (2002). The presence of Hyrum Reservoir on the LBR was also a disruption to its predicted continuity. Jones (2007) noted that phytoplankton populations decreased below lakes, due to the destruction of fragile lake phytoplankton when exposed to turbulent river water. Furthermore, Acharyya, et al. (2012) found that phytoplankton blooms below a dam could be controlled through dam discharge—higher discharge led to less phytoplankton and lower discharge led to more phytoplankton. Myers et al. (2007) found that below-lake conditions favored periphyton growth due to an increase in sediment size and a decrease in scouring from small sediment.

Within the SDC, a gap in theory exists: "It is possible that limnological phenomena within reservoirs alter the food quality (as well as the amount and the chemical and size composition) of detritus, but no data are available (Ward and Stanford 1983)." Marcarelli and Wurtsbaugh (2007) found that alterations in the lake nutrients do not necessarily manifest as nutrient limitation of periphyton. This previous research leads to the prediction that periphyton levels should increase below Hyrum Reservoir. Nutrient data have also been used to predict chlorophyll *a*, since levels of nitrogen and phosphorus, as well as scour, effect presence and activity of periphyton and phytoplankton (Godwin et al., 2009).

Using the SDC and RCC framework I predicted that the chlorophyll *a* levels of the Little Bear River would gradually increase continuously downstream, shifting from periphyton to phytoplankton sources. Furthermore, just below Hyrum reservoir, I predicted that there will be a large increase in both periphyton and phytoplankton, creating a brief discontinuity of chlorophyll *a* in the Little Bear River. Overall, there should have been a shift from a periphyton dominant system to a phytoplankton dominated system (Ward and Stanford 1983).

STUDY AREA

Eight study sites along the LBR were selected to measure periphyton and phytoplankton chlorophyll *a* levels (See site map in Executive Summary). Phytoplankton chlorophyll levels were measured at one additional site (Station 9). Station 2 (Photo 1) was the uppermost site, being on the South Fork of the river in a relatively pristine area. The next two Stations sampled (4 and 6) were just below the confluence of the East and South forks of the LBR. Station 6 was just above Hyrum Reservoir and Station 7 was just below Hyrum Reservoir. Sampling at Station 6 and 7 allowed me to assess the effects of Hyrum Reservoir on chlorophyll levels. A phytoplankton sample was taken below the Wellsville Lagoons to see if its discharge had any effect on chlorophyll *a* levels. Station 11 (Photo 2) was channelized and full of sediment. These sites were selected to provide chlorophyll *a* levels at the very bottom of the LBR to see the compounded effects of the continuum and anthropogenic impacts on chlorophyll *a* levels. Additionally, 13 days prior to the river sampling, phytoplankton samples were taken as part of a class activity at three stations from varying depths on Hyrum Reservoir.

Photo 1. *Station 2, the uppermost site sampled on the Little Bear River.*

Photo 2. *Station 11, the lowermost site sampled on the Little Bear River. Note the turbidity in the river at this site.*

METHODS

Periphyton

At all the study sites, except Station 9, six 5-8 cm diameter rocks were selected from a horizontal cross section of the stream (US EPA 2012). At Stations 10 and 11, there were few rocks in the streambed, so rocks were selected from the side of the stream. Each rock was placed carefully into a plastic bag, sealed, and set on ice to prevent algae from dying. Each rock was handled carefully to minimize the loss of periphyton. Rocks were subsequently frozen at 20°C to preserve the chlorophyll cells for extraction on a later date. To extract chlorophyll *a*, rocks were placed in Mason jars containing 95 percent ethanol for 16-24 hours. (Lind 1985). Then, 0.10 ml of the extracted chlorophyll was diluted into 10 ml of the ethanol (Lind 1985). The chlorophyll in the diluted fluid was then read on a fluorometer utilizing the Welschmeyer (1994) non-acidification method. At Station 10, six sticks were collected in addition to the six rocks. The same extraction procedure and subsequent planar area estimation used for the rocks was used for the sticks.

In order to account for the planar area of periphyton on substrates, the surface area (in cm^2) of each rock or stick was measured by tracing each object's planar-surface-area outline on aluminum foil and cutting out and weighing this outline. The weight of each planar-surface-area cut-out (in grams) was then multiplied by the weight of a 100 cm^2 piece of aluminum foil. The mean and s.d. of rock size was 24 ± 10 cm^2. The product of the volume of extraction (ml), the fluorometer reading (converted to μg/ml), and the dilution factor, was then divided by the planar surface area (cm^2). This yielded the amount of chlorophyll *a* per unit of area (μg/cm^2).

Photo 3. *Convex spherical densitometer used for measuring overhead cover.*

Phytoplankton

Three water samples were taken from each site on the LBR and two samples from three sites on Hyrum Reservoir. 20 ml of each sample was filtered through a 25-mmGF/F filter with a nominal pore size of 0.7 μm. Each filter was folded, labeled in pencil, placed in tinfoil, and then put on ice. The samples were subsequently frozen at 20℃ to preserve the chlorophyll *a* trapped on each filter. These filters' chlorophyll *a* was then extracted and read using the same method as described in the periphyton chlorophyll *a* extraction. The corrected fluorometer readings (μg L^{-1}) were then multiplied by the extracted volume of ethanol (ml) and divided by the volume of water filtered (ml), to yield the amount of chlorophyll in each water sample (μg L^{-1}). In order to compare phytoplankton to periphyton, units of phytoplankton chlorophyll *a* were converted from μg L^{-1} to μg cm^{-2} using the available mean depths were measured on the same sample day.

Light Levels and Water Transparencies

To obtain quantitative information on how much light was penetrating the water column, I attempted to take Secchi depth readings at each site. However, only Stations 9, 10, and 11 were deep enough to obtain a reading. To obtain information on how much light was reaching the water surface, a convex spherical densiometer (Photo 3) was used to estimate canopy cover at each site. This densiometer had 24 squares on its surface. For each reading, the number of squares obscured by canopy cover was counted while the user faced north, east, south, and west. The densiometer was held level at waist height and read across a horizontal cross section of the stream. A densiometer reading was taken at each individual periphyton rock sample. The four readings for each compass direction were then averaged together (California Department of Pesticide Regulation Environmental Monitoring Branch, 2004). These averages were then applied to the following formula: *100 - (# of unfilled squares x 4.17) = percent overstory density (*California Department of Pesticide Regulation Environmental Monitoring Branch 2004). Then the values were averaged for an overall average canopy density for each site.

RESULTS

Chlorophyll **a** *in Periphyton and Phytoplankton*

Periphyton chlorophyll *a* levels dominated over phytoplankton chlorophyll *a* levels throughout the entire continuity of the LBR (Figure 1). However, they both had individual trends. In particular, there was a strong linear trend in increasing levels of phytoplankton down the continuum. Phytoplankton were low in the headwaters and gradually increased, dropped slightly below Hyrum Reservoir, and then increased rapidly to the lowest site. The trend in periphyton levels was less straightforward, having started out low and increasing, peaking just above Hyrum Reservoir, and then steadily decreasing to the lowest site.

The averaged chlorophyll *a* levels from periphyton in the LBR were low in the headwaters (13.5 μg/cm^2), and increased consistently to Station 6, peaking 41.7 μg/cm^2 just above Hyrum Reservoir, then decreased to Station 11 to 15.03 μg/cm^2 (Figure 2A). The humped nature of the longitudinal relationship resulted in a linear correlation that was insignificant ($p > 0.05$). Chlorophyll levels from the rocks at each site were highly variable, as shown by the large error bars in Figure 2B. No significant relationship was found between periphyton chlorophyll-a levels and total phosphorus or total nitrogen ($p > 0.05$).

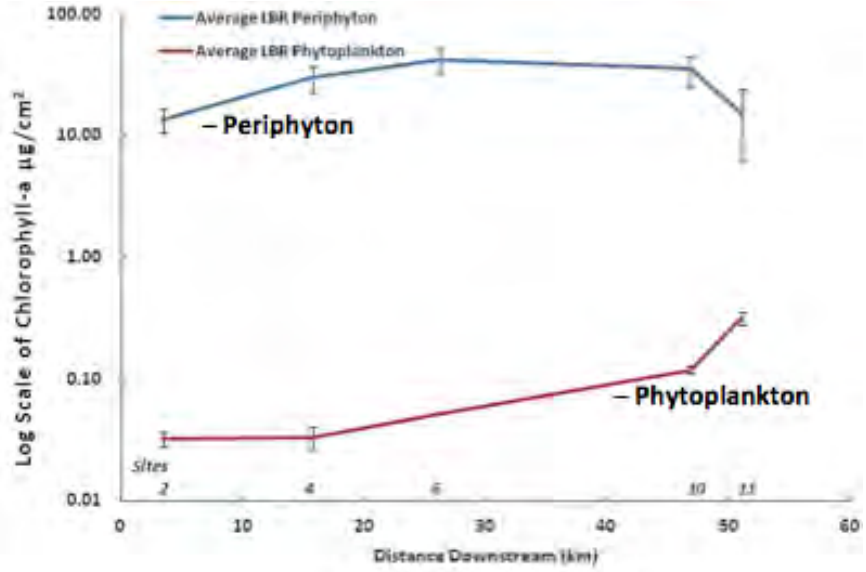


Figure 1. *Aerial chlorophyll a levels of periphyton and phytoplankton in μg/cm^2 in the Little Bear River, measured on 9 September 2012. Note log scale. Station numbers are shown above the X-axis.*

The averaged chlorophyll *a* levels from phytoplankton increased linearly (Figure 2B), demonstrating a large increase from the highest site to the lowest site. The chlorophyll *a* levels were low in the upper reaches, 1.6 μg L^{-1} at Station 2, reaching 2.6 μg L^{-1} just above Hyrum Reservoir. Within the reservoir, chlorophyll *a* levels reached as high as 5.81 μg L^{-1}. After Hyrum Reservoir, they dropped slightly to 2.0 μg L^{-1}, but then increased downstream, reaching the highest chlorophyll *a* level of 5.0 μg L^{-1} at the very bottom site, Station 11. There was a clear correlation between the rises in chlorophyll *a* levels of phytoplankton as the distance downstream increases (p = 0.006), which more than doubled from the top of the LBR to the bottom.

In comparing phytoplankton chlorophyll *a* levels to nutrient levels, I found that there was a significant relationship and linear trend between chlorophyll *a* and total nitrogen (Figure 3A; $R^2 = 0.58$; p = 0.027). As levels of total nitrogen increased from 151 µg L^{-1} to 1365 µg L^{-1}, chlorophyll *a* levels increased from 1.3 µg L^{-1} to 4.4 µg L^{-1}. There was an even more significant linear relationship between chlorophyll *a* and total phosphorus (Figure 3B; $R^2 = 0.93$; p = 0.001). As levels of total phosphorus increased from 15 µg L^{-1} to 75 µg L^{-1}, chlorophyll *a* increased from 1.3 µg L^{-1} to 5 µg L^{-1}.

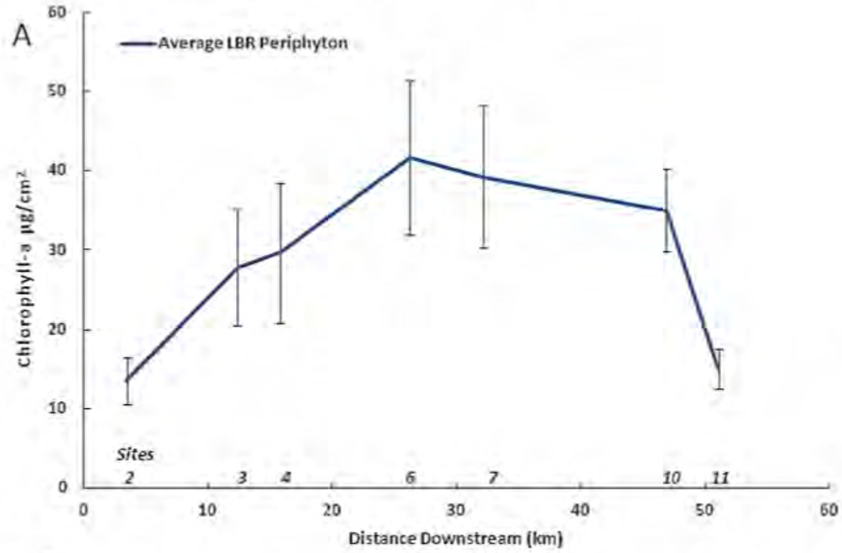


Figure 2. A. *The average level of chlorophyll a from periphyton, in µg/cm², along the distance downstream of the Little Bear River measured on 29-Sep-2012. The error bars indicate the standard error of the averaged values.*

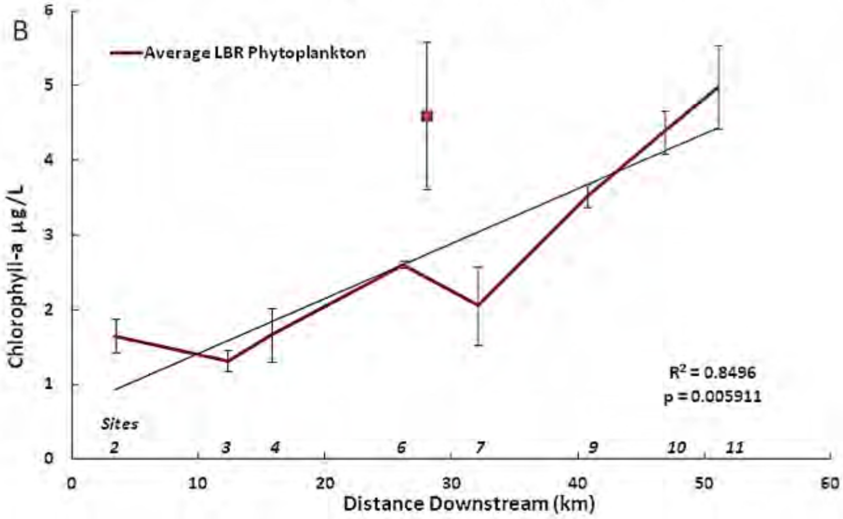


Figure 2. B. *Average levels of chlorophyll a from phytoplankton in µg L⁻¹, plotted against the distance downstream in the Little Bear River measured on 29-Sep-2012. Average surface values of phytoplankton from three stations in Hyrum Reservoir are also shown, measured on 11-Sept-2012. The error bars indicate the standard error of the averaged values.*

Light Levels and Water Transparencies

For the lower sites, the Secchi depths were low. At Station 11, where the average depth was 0.64 meters and the maximum depth was 1.2 meters, the Secchi depth was 0.40 meters. At Station 10, where the average depth was 0.27 meters and the maximum depth was 0.68 meters, the Secchi depth was 0.41

meters. At Station 9, depths were not measured, although there was a Secchi depth measurement taken of >1.2 meters deep. At all of the other sites visibility extended to the bottom of the channel.

As a general linear trend, the canopy cover increased going downstream (Figure 4). Canopy cover was not significantly correlated with periphyton chlorophyll *a* ($p = .70$). However, there was a significant positive linear correlation between canopy cover and phytoplankton chlorophyll *a* (Figure 5; $R^2 = .90$; $p = .006$); however, this relationship does not seem to be causal. In fact, this relationship is contrary to the RCC, which indicates denser canopy cover prevents sunlight from penetrating to the water, which does not support phytoplankton—or periphyton—growth (Vannote et al. 1980).

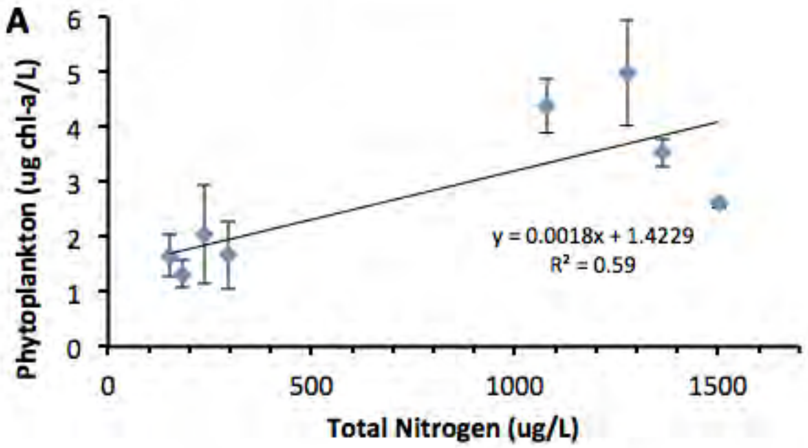


Figure 3. A. *Relationship between average values of phytoplankton chlorophyll a levels (µg L^{-1}) and average values of total nitrogen in the Little Bear River, measured on 29-Sep-2011.*

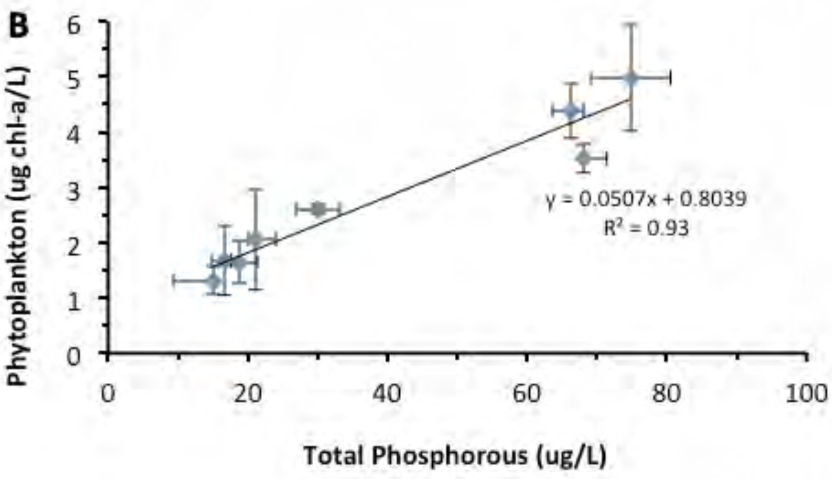


Figure 3. B. *Phytoplankton chlorophyll concentrations relative to total phosphorus concentrations. Error bars the standard error of the average. Nutrient concentrations were derived from Fuller (this report).*

DISCUSSION

Near the top of the LBR (Station 2), the chlorophyll *a* levels for both periphyton and phytoplankton were low. Periphyton chlorophyll *a* levels rose rapidly and peaked just above Hyrum Reservoir at Station 7. The periphyton levels above and below Hyrum Reservoir were nearly identical (42 vs. 39 µg/cm2). This outcome is contrary to the prediction of periphyton chlorophyll *a* levels increasing below the dam (Myers et al. 2007). Beyond the reservoir, periphyton levels continued to decrease, as expected. It should be noted that these average values for periphyton had high standard errors at most sites.

The low levels of periphyton at the bottom of the LBR, Station 11, could be attributed to many things: an increase in suspended sediment at Stations 10 and 11 from agricultural runoff, or perhaps a fining of substrate. Secchi depths (Appendix 1) at Stations 10 and 11 indicate low transparency in the water, thus high turbidity. This higher amount of suspended sediment could prevent sunlight from penetrating to the bottom substrates, thus creating scour during high-flow events and reducing the ability of periphyton to grow on substrate in the river. Furthermore, the substrate size in the stream at Stations 10 and 11 was silt/sand sized, with no apparent riffles at either site. Consequently, the rocks sampled for periphyton at Stations 10 and 11 were taken from one edge of the river in a shaded area. This restraint on the sampling was due to inadequate substrate sizes for periphyton sampling across the river. It was not determined whether or not there was algal growth in the finer substrates at Stations 10 and 11. Despite the decreases in the lower part of the river, periphyton remained dominant throughout the LBR. Furthermore, the sampling below Hyrum Reservoir, at Station 7, indicated a slight drop in periphyton levels. However, periphyton was only sampled in riffles—not pools, which had a substantial amount of periphyton growth at Station 7 (see photo in Executive Summary).

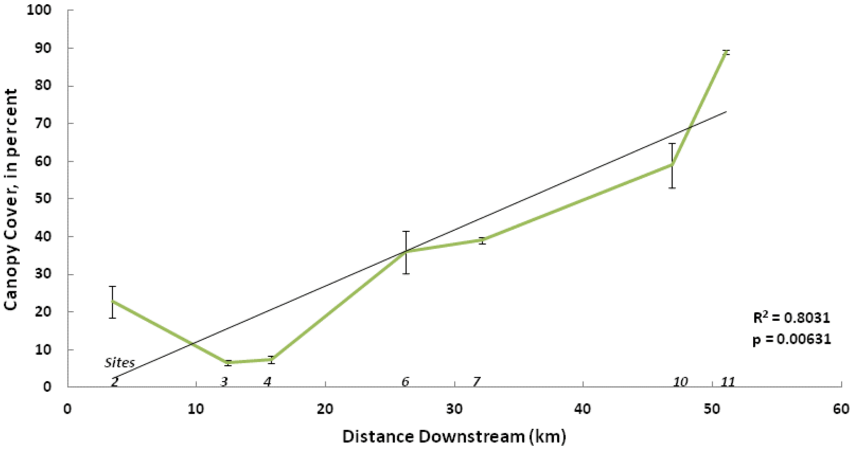


Figure 4. *Percent canopy cover against distance downstream (km) of the Little Bear River, measured on 29-Sep-2012. Error bars show standard error at each Stations. P value calculated using a linear regression analysis.*

As predicted, phytoplankton levels (Figure 2A) steadily increased from 1.6 µg L^{-1} at the top of the LBR (Station 2) to 5.0 µg L^{-1}at the bottom of the LBR (Station 11). The increase in phytoplankton is interrupted by a drop (from 2.6 µg L^{-1}, at Station 6, to 2.0 µg L^{-1}, at Station 7) below Hyrum Reservoir. This drop is contrary to the prediction that it would increase due to the outflow of the reservoir's water which was thought to have higher levels of phytoplankton. While Station 11 had increased phytoplankton chlorophyll *a* concentrations, this chlorophyll level was still two orders of magnitude below those of the periphyton. This indicates that there was not a shift between chlorophyll *a* sources in the LBR, as hypothesized.

The strong correlations between levels of phytoplankton and levels of both phosphorous and nitrogen suggest that nutrients do, indeed, influence phytoplankton chlorophyll *a* levels. The increase below Station 7 was probably because the water had more nutrient inputs from agricultural—among other anthropogenic sources—runoff. This trend is similar to what Dodds, et al. (2006) found in their study on temperate streams, although their study focused on benthic chlorophyll *a* levels. In my study, the periphyton chlorophyll *a* levels did not follow the trend found by Dodds, et al. (2006).

Following the RCC framework, we would expect to see a rise in phytoplankton-derived chlorophyll *a* levels from the top of the LBR to the bottom. The EPA has generalized northern Utah into a classification of "western forested mountains" (Ecoregion II). Based on the EPA's recommendation, chlorophyll *a* levels of phytoplankton for the LBR's location is 1.1 µg L^{-1} for rivers and streams (US EPA, 2007). With this in mind, it is clear that the upper, forested sites of the LBR are above 1.1 µg L^{-1}. It should be noted that the designation of "phytoplankton" also includes periphyton that had sloughed from the benthic substrate. In the upper reaches, in fact, it is likely that that algae derived from the benthos may have dominated the chlorophyll in the water column. However, the lower sites are in an agricultural valley, where the previous classification of "western forested mountains" does not apply. In the LBR's TMDL report, total phosphorous was identified as the pollutant of concern in the impairment, causing the LBR to on Utah's 303(d) list of water quality impaired water bodies (Utah Department of Environmental Quality). The level of total phosphorous should not exceed 0.05 mg L^{-1} (Utah Department of Environmental Quality). In the LBR, Stations 8 through 11 are above 0.05 mg L^{-1} (Appendix 2).

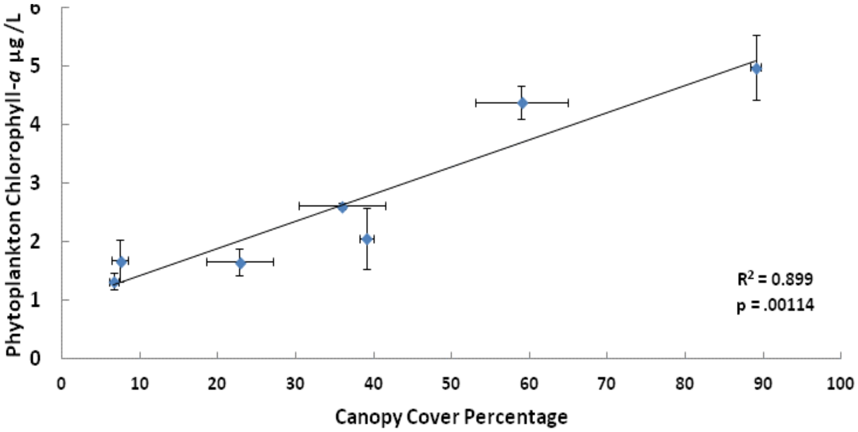


Figure 5. *Levels of phytoplankton chlorophyll a (µg $L^{-}1$) plotted against canopy cover (percent) on the Little Bear River, measured 29-Sept-2012.*

The Utah Division of Water Quality identifies the total phosphorous pollution as being "[linked] to plant production…and more tightly associated with animal waste and fertilizer" (Utah Department of Environmental Quality). Because the levels of phytoplankton chlorophyll *a* are correlated with the levels of total phosphorous, as seen in Dodds, et al. (2006), they are likely too high at the lower reaches of the LBR— Stations 9 through 11.

In conclusion, the levels of phytoplankton chlorophyll *a* exceed the TMDL recommendations. Since there is a positive relationship of phytoplankton chlorophyll *a* to levels of both total phosphorus and total nitrogen, it is assumed that anthropogenic sources of these nutrients are the cause of the excess chlorophyll. Therefore, anthropogenic nutrient sources need to be mitigated to decrease these levels of phytoplankton chlorophyll *a*. Identifying trophic states in streams is not as common or as straightforward as it is in lakes (Dodds 2007), but the few studies available—like this one—has also identified strong correlations between nutrient levels and chlorophyll *a* levels. Therefore, identifying a threshold for nutrients designed around chlorophyll *a* in the LBR would be a step in the right direction. Even though there appears to be no relationship between nutrient levels and periphyton, changes in LBR management should proceed with caution, due to the possible limitations in the collection of periphyton.

REFERENCES

Acharyya, T.; Sarma, V.V.S.S.; Sridevi, B.; Venkataramana, V. et al. 2012. Reduced river discharge intensifies phytoplankton bloom in Godavari estuary, India. Marine Chemistry. 132–133:15-22.

California Department of Pesticide Regulation Environmental Monitoring Branch. Instructions for the Calibration and Use of a Spherical Densiometer. Sacramento, 2004. http://www.cdpr.ca.gov/docs/emon/pubs/sops/fsot00201.pdf>.

Caraco, N.; Cole, J. 1999. Regional-scale export of C, N, P, and sediment: what river data tell us about key controlling variables. Pages 239-254 In Tenhunen, J.D and Kabat, P. (eds.) Integrating hydrology, ecosystem dynamics and biogeochemistry in complex landscapes. New York: John Wiley and Sons Ltd.

Dodds, W.K. 2007. Trophic state, eutrophication and nutrient criteria in streams. Trends in Ecology and Evolution. 22:669-676.

Dodds, W.K.; Smith, V.H.; Lohman, K. 2006. Nitrogen and phosphorus relationships to benthic algal biomass in temperate streams. Canadian Journal of Fisheries and Aquatic Sciences. 63:1190-1191.

Godwin, C.; Arthur, M.; Carrick, H. 2009. Periphyton nutrient status in a temperate stream with mixed land-uses: implications for watershed nitrogen storage. Hydrobiologia. 623:141-152.

Jones, N.E. 2010. Incorporating lakes within the river discontinuity: longitudinal changes in ecological characteristics in stream-lake networks. Canadian Journal of Fisheries and Aquatic Sciences. 67:1350-1362.

Lind, O.T. 1985. Handbook of common methods in limnology, 2nd ed. Dubuque, Iowa: Kendall/Hunt Pub Co. 199 pp.

Marcarelli, A.M.; Wurtsbaugh, W.A. 2007. Effects of upstream lakes and nutrient limitation on periphytic biomass and nitrogen fixation in oligotrophic, subalpine streams. Freshwater Biology. 52(11):2211-2225.

Myers, A.K.; Marcarelli, A.M.; Arp, C.D.; Baker, M.A.; Wurtsbaugh, W.A. 2007. Disruptions of stream sediment size and stability by lakes in mountain watersheds: potential effects on periphyton biomass. Journal of the North American Benthological Society. 26:390-400.

Strevenson, R.J.; Bahls, L.L. 1999. Periphyton Protocols. Chapter 6 in Barbour, M.T. et al. (eds.) Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

U.S. Environmental Protection Agency (EPA). 2007. Summary table for the nutrient criteria documents. Retrieved Sept. 20, 2012 from http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/upload/2007_09_27_criteria_nutrient_ecoregions_sumtable.pdf.

Utah Department of Environmental Quality, Division of Water Quality TMDL Section. (n.d.). Little bear river watershed TMDL. Retrieved Dec. 6, 2012 from http://www.waterquality.utah.gov/TMDL/Little_Bear_River_TMDL.pdf.

Vannote, R.L.; Minshall, G W.; Cummins, K W.; Sedell, J R.; Cushing, C.E. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences. 37:130-137.

Ward, J.V.; Stanford, J.A. 1983. The serial discontinuity concept of lotic ecosystems. Pages 29-24 In T.D.I. Fontaine and S.M. Bartell (Eds.), Dynamics of lotic ecosystems. Ann Arbor, MI: Ann Arbor Science Publishers.

Welschmeyer, N.A. 1994. Fluorometric analysis of chlorophyll a in the presence of chlorophyll b and pheopigments. Limnology and Oceanography. 39:1985-1992.

Wright, K.K.; Li, J.L. 2002. From continua to patches: examining stream community structure over large environmental gradients. Canadian Journal of Fisheries and Aquatic Sciences. 59:1404.

APPENDICES

Appendix 1. *Secchi depths, average channel depths (m) and maximum channel depths (m).*

Station	Distance Downstream (km)	Secchi Depth (m)	Statopm Average Depth (m)	Max Depth (m)
9	40.79	>1.2	N/A	N/A
10	46.86	0.40	0.27	0.68
11	51.07	0.41	0.64	1.20

Appendix 2. *Average levels of phosphorus and nitrogen along the river gradient (from Fuller, this report).*

Station	Average of Total Phosphorus (µg/L)	Average of Total Nitrogen (µg/L)
1	12.9	226
2	18.9	182
3	15.0	151
4	16.6	297
4.9	18.0	1008
5	26.9	997
6	30.1	1502
7	21.1	235
8	60.6	323
9	74.8	1276
10	68.2	1365
11	66.4	1079

Chapter 5

Algal Nutrient Limitation throughout the Little Bear River Watershed

[by] Jared Baker

SUMMARY

The objective of this study was to use a 5 day bioassay experiment to assess whether nitrogen or phosphorus limited the growth of algae in the Little Bear River watershed. Four sites were sampled along the river in September 2012. The locations of the sites were south of Avon (Station 2), near Paradise, UT (Station 6), downstream of Hyrum Reservoir (Station 7), and downstream of the Waste Water Treatment Facility in Wellsville (Station 10). Chlorophyll *a* analysis was conducted prior to, after 2.5 days, and at the conclusion of the 5 days. Varying combinations of nitrogen and phosphorus were added to water samples from each site and these were incubated in 125-ml flasks with 150 uM m^{-2} lighting and at 15°C. ANOVA was used to determine nutrient limitations within samples. Chlorophyll concentrations measured at the conclusion of the experiment indicated that both nitrogen and phosphorus limited algal growth at Stations 2 and 10 while phosphorus alone was limiting at Stations 6 and 7.

INTRODUCTION

The Little Bear River is located near Logan Utah and is a 58.6 km long tributary of the Bear River. Before entering the Bear River, the Little Bear River travels through moderately pristine areas, then through agricultural land, into Hyrum Reservoir, and then to Cutler Marsh. This ecosystem is impacted by anthropogenic influences consisting of about 182,000 acres, including rangeland, pasture, and cropland. In this watershed there is approximately 21,024 acres of irrigated land. The area supports wildlife, but the majority of the animals are domesticated. The river also receives effluent from the Waste Water Treatment Facility in Wellsville. These are all a part of human effects on the Little Bear River watershed (Little 2012). There has been limited research on the many chemical, biological, and physical factors that impact this ecosystem. However, past studies suggest highly variable levels of these factors throughout the river. This is likely due to the varying degrees of pollution and agriculture.

In managing the water quality, it is very useful to identify what nutrient(s) limit algal growth (Holmboe et al. 1999). If managers are aware of what nutrients are already present, one can adjust land use practices to potentially alter stream productivity. As a result, one could influence the amount and types of fish within the watershed. Another more common use would be to reduce the amount of the limiting nutrient going into a system to reduce eutrophication. Thus, understanding the nutrient limitations of the Little Bear River is essential to management and preservation.

Based on the above reasons, I studied the potential nutrient limitations of phytoplankton production in the Little Bear River. I conducted a bioassay experiment in order to determine the nutrient limitations at four locations. In-stream nutrient measurements were recorded by Jason Fuller and compared against my results. This data was essential for compiling the results I gathered through chlorophyll *a* analysis.

According to the Utah Department of Environmental Quality Division of Water Quality TMDL (Total Maximum Daily Load) Section, the "Little Bear drainage shows signs of water quality deterioration both above and below Hyrum Reservoir" (Little 2012). Although phosphorus is the nutrient most frequently addressed in Utah and other States, both phosphorus and nitrogen frequently limit algal growth in lakes (Lewis and Wurtsbaugh 2008).

STUDY AREA AND METHODS

Bioassay experiments were done to determine which nutrient or nutrients limited phytoplankton growth. The bioassays were completed within "1 week to minimize the effects of temporal changes on the bioassay responses" (Marcarelli and Wurtsbaugh 2007). I conducted a 5 day bioassay experiment and used water samples from four sites along the Little Bear River.

I chose to use Stations 2, 6, 7, and 10 to get a good representation of the longitudinal gradient of the Little Bear River (See site map in Executive Summary). Water samples were gathered from four locations: south of Avon (Station 2), in the middle near the town of Paradise (Station 6), downstream of Hyrum Reservoir (Station 7), and downstream of the Waste Water Treatment Facility in Wellsville (Station 10).

The first location, just south of Avon, was chosen based on both its accessibility and the fact that it is fairly pristine and has less anthropogenic impact than the other sites. The next sample was taken near Paradise where there is a higher anthropogenic influence. A sample just downstream of Hyrum Reservoir was selected to potentially show the effects of the reservoir on the nutrient regime. Lastly, the fourth sample was collected downstream of the Waste Water Treatment Facility in Wellsville where nutrients, and in particular phosphorus were expected to be high.

At each site, a 2 L Nalgene bottle was used to collect samples. In the laboratory, 17.5 ml of water from Hyrum Reservoir was added to each sample in order to ensure that there was phytoplankton present. These samples were then divided into 125-ml Erlenmeyer flasks. These flasks were each filled with 100 ml of water from the various sampling locations. I used 12 Erlenmeyer flasks for each site: three flasks as the control, three had phosphorus introduced, three had nitrogen introduced, and the last three had both phosphorus and nitrogen introduced. I used three replicates because I modeled this part of my experiment after a bioassay of phytoplankton with sockeye salmon lakes of Idaho (Wurtsbaugh et al. 1997).

The concentrations of nutrients that were added were based on those found by Abbott et al. (2008) in Cutler Reservoir: 0.82 mg/L phosphorus and 1.27 mg/L nitrogen. From these measurements, I added 0.5 mg/L phosphorus and 4.0 mg/L nitrogen to the appropriate treatments (Figure 1). The flasks were put in a climate controlled room at 15 °C with 150 $\mu M/m^2$ light intensity and a 12:12 light: dark cycle. The samples were labeled and randomly placed on a shaker table to agitate the water. This was done to emulate water movement. The algae needed to remain suspended, as they would be in a natural setting.

Chlorophyll concentrations were measured initially, after 2.5 days, and on day 5. Each day, 10-ml aliquots from each of the 48 flasks was filtered on Gelman A/E filters with a nominal pore size of 1.0 µm. The filters were frozen and then extracted for 24 hours in 95 percent ethanol in the dark. The concentration of extracted chlorophyll was measured with a Turner 10AU fluorometer equipped with a

Welschmeyer filter set that does not require acidification (Welschmeyer 1994).

ANOVA was used to determine significant differences in phytoplankton production between treatments, for each site. A p-value of 0.05 or less was considered significant. Microsoft Excel was used for this analysis.

RESULTS

Although each sample was kept at the same temperature, the chlorophyll *a* responded differently in each treatment. Changes in phytoplankton production at Station 2 did not appear to be significant between treatments for either two 2.5 or 5 day assay periods. At Stations 6, 7 and 10 there were significant differences between treatments after 2.5 days, however, at 5 days only Station 7 produced significantly different results.

In the treatment utilizing water from high in the watershed (Station 2) chlorophyll concentrations increased the most in the N+P treatment after both 2.5 and 5 days, but these results were not significant (Figure 1; ANOVA, p = 0.49, 0.27 for 2.5 and 5 days, respectively). Chlorophyll *a* concentrations in the phosphorus treatment were also statistically insignificant. Also note that mean chlorophyll concentrations in the Control treatment increased nearly 2.5 fold by the end of the 5 day bioassay. At Station 2, N and P appear to be co-limiting, but the lack of statistical significance warrants caution in this interpretation.

In water from Station 6 chlorophyll *a* concentrations in the control, nitrogen, phosphorus, and N+P samples all extended upwards over time (Figure 2). The chlorophyll *a* concentrations at Station 6 increased the most in the phosphorus treatment after both 2.5 days and 5 days, but treatments were only significantly different on day 2.5 (Figure 2; ANOVA, p = 0.01, and 0.26 for 2.5 and 5 days, respectively). At Station 6 phosphorus appeared to be the primary limiting nutrient for algal growth.

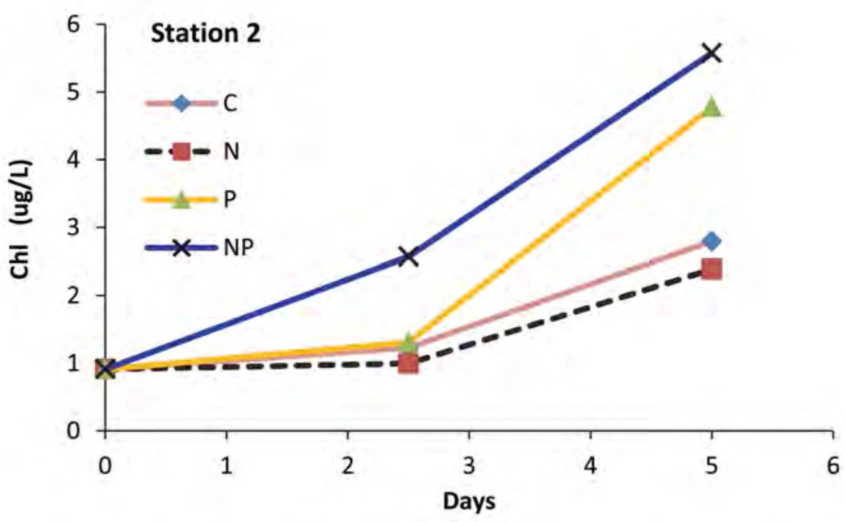


Figure 1. *Chlorophyll a concentrations in four nutrient treatments of the laboratory bioassay, utilizing Little Bear River water from Station 2 located south of the town of Avon, Utah. The location is 3.45 km downstream. Chlorophyll a concentrations increased the most in the N + P treatment after both 2.5 and 5 days, but these results were not significant.*

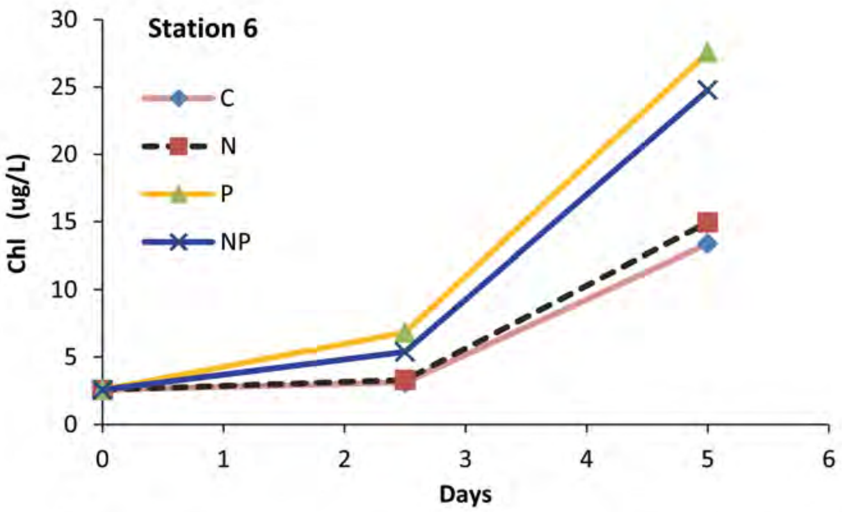


Figure 2. *The chlorophyll a concentration in the control, nitrogen, phosphorus, and N + P samples for bioassays of Station 6 water. By day 2.5 the chlorophyll a appears to have increased the most with phosphorus added. After 5 days this is still the case and is reiterated in the above graph.*

In the assay with water below Hyrum Reservoir (Station 7) the chlorophyll *a* concentration in the control, nitrogen, phosphorus, and N+P samples all rose. By day 2.5 the chlorophyll *a* increased the most in the P treatment. The P treatment still produced the best phytoplankton growth on day 5. These results were significant for both days 2.5 and day 5 (Figure 3; ANOVA, p = 0.001, 0.004 for 2.5 and 5 days respectively). At Station 7, P appeared to be the limiting nutrient.

Lastly, in the water from Station 10 the chlorophyll *a* concentration in the control, nitrogen, phosphorus, and N+P samples all increased. However, by day 2.5 chlorophyll levels had changed little from the initial condition and mean levels in the nutrient treatment were all below the mean control level. After 5 days the phosphorus + nitrogen, and the phosphorus treatments increased markedly. However, results were only significant at 2.5 days (Figure 4; ANOVA, p = 0.02, 0.07 for 2.5 and 5 days, respectively). The marginally significant response on day 5 suggests that both N and P may have been limiting nutrients for the phytoplankton.

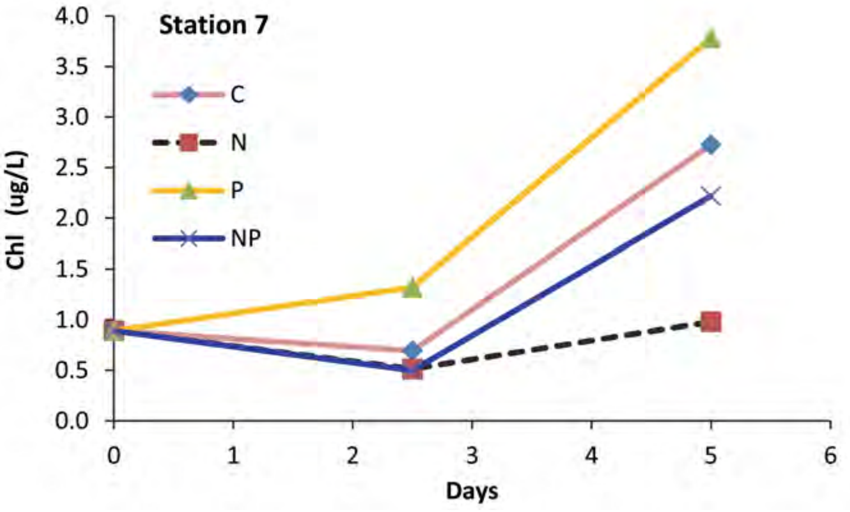


Figure 3. *Chlorophyll a concentrations in the control, nitrogen, phosphorous, and N + P bioassays using water from Station 7. By day 2.5 the chlorophyll a thrived the most with phosphorous added. After 5 days this is still the case and is reiterated in the above graph.*

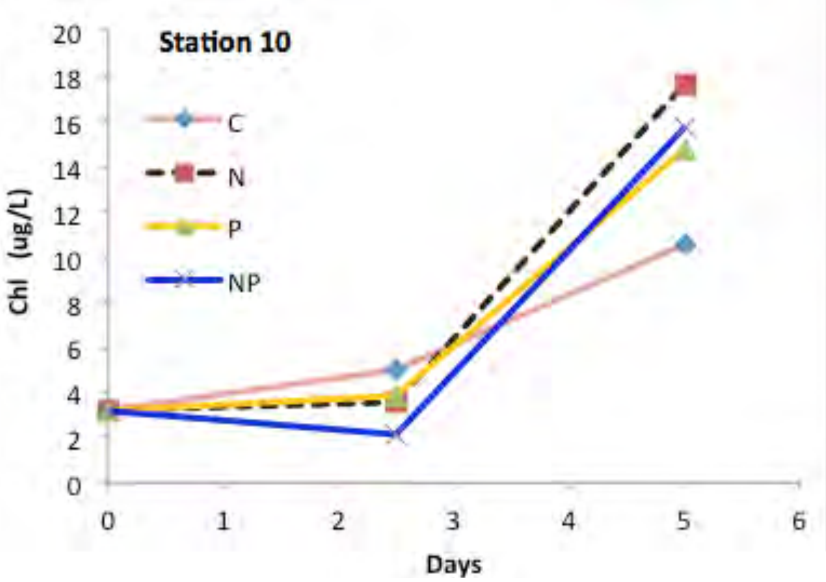


Figure 4. *Chlorophyll a concentrations in the control, nitrogen, phosphorus, and N + P bioassay treatments using Station 10 water.*

Figure 5 summarizes the results from all of the treatments on day 2.5. Phosphorus appears to most commonly stimulate chlorophyll production, with the exception of Station 2 where both N and P were the only stimulatory treatment. Station 10 is interesting because the control had the highest levels of chlorophyll *a*. This may be as a result of toxic levels of phosphorus and nitrogen.

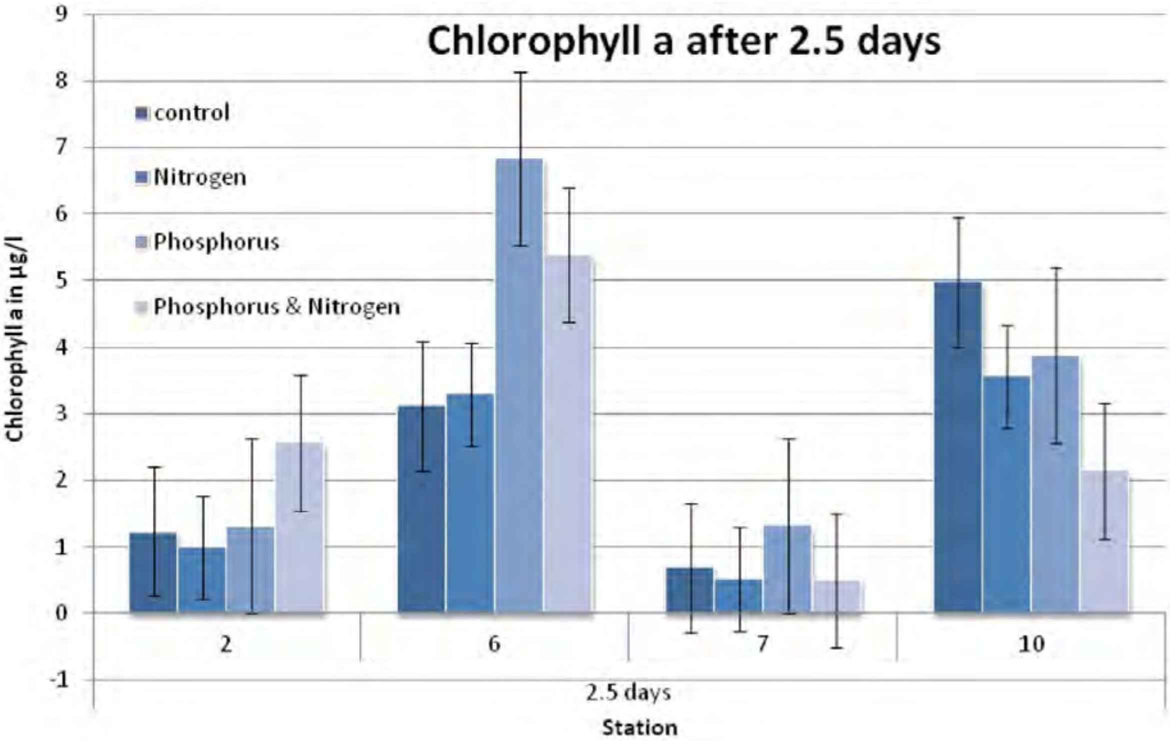


Figure 5. *Chlorophyll a concentrations after 2.5 days of incubation for Stations 2, 6, 7, and 10.*

DISCUSSION

The Marcarelli et al. (2002) study did not include multiple stations along a river. My study is unique in that aspect. Most nutrient level studies are in regard to lakes and/or large bodies of water (e.g. Abbott et al. 2008, Lewis and Wurtsbaugh 2008, Lewis and Wurtsbaugh 2011, Holmboe et al. 1999, Morris and Lewis 1988, and Wurtsbaugh et al. 1997).

According to the nutrient data from Jason Fuller, Hyrum Reservoir acts as a nutrient sink where nitrate flowing down the Little Bear River was trapped. The bioassay design I used is not useful for determining sinks or sources of nutrients, but rather just the relative response to different nutrient additions.

Due to the impact of humans on this watershed, I hypothesized that nutrient limitation would decrease with downstream movement. This did not appear to be true. At Stations 2, 6, and 7 chlorophyll levels in the most response treatments were approximately double those of the controls, suggesting relatively constant nutrient limitation at these sites (Figure 5). Only at Station 10 where nutrient levels were very high was there a lack of significant response to any nutrient addition. In fact, the nutrient-amended treatments all had lower levels than the controls, albeit not significantly below the controls (Figure 5)

Given the lack of studies done on the Little Bear River another bioassay experiment could be done to test whether or not seasonal variations in nutrient limitation exist, and whether my results can be replicated. Variability between replicates was high in the treatments and this made it difficult to determine if there were responses or not. An analysis of seasonal variation could be insightful for understanding the composition, biomass, and production of phytoplankton (Morris et al. 1988). Finally, since periphyton dominates chlorophyll levels in the Little Bear River (see Fisher (this report)) it would be useful in future studies to analyze nutrient limitation of these benthic algae.

REFERENCES

Abbott, B.; Braithwaite, N.; Eisner, J.; Mason, P.; Randal, J.; Epstein, D. 2009. Comparative limnological analysis of Cutler Reservoir and Dingle Marsh with respect to eutrophication. Aquatic Ecology Practicum Class Report. Logan, Utah: Watershed Sciences Department, College of Natural Resources.

Holmboe, N.; Jensen, H.S.; Andersen, F.O. 1999. Nutrient addition bioassays as indicators of nutrient limitation of phytoplankton in a eutrophic estuary. Marine Ecology Progress Series. 186:95-104.

Horsburgh, J.S.; Jones, A.S.; Stevens, D.K.; Tarboton, D.G.; Mesner, N.O. 2010. A sensor network for high frequency estimation of water quality constituent fluxes using surrogates. Environmental Modeling and Software. 25:1031–1044.

Lewis, W.M.; Wurtsbaugh, W.A. 2008. Control of lacustrine phytoplankton by nutrients: erosion of the phosphorus paradigm. International Review of Hydrobiology. 93:446465. doi: 10.1002/iroh. 200811065.

Lewis, W.M.; Wurtsbaugh, W.A.; Pearl, H.W. 2011. Rationale for control of anthropogenic nitrogen and phosphorus to reduce eutrophication of inland waters. Environmental Science and Technology. 45:10300–10305. doi: 10.1021/es202401p.

Utah Department of Environmental Quality, Division of Water Quality TMDL Section. (n.d.). Little bear river watershed TMDL. Retrieved Dec. 6, 2012 from http://www.waterquality.utah.gov/TMDL/Little_Bear_River_TMDL.pdf.

Marcarelli, A.M.; Wurtsbaugh, W.A. 2007. Effects of upstream lakes and nutrient limitation on periphytic biomass and nitrogen fixation in oligotrophic subalpine streams. Freshwater Biology. 52:22112225. doi:10.1111/j.13652427.2007.01851.x.

Morris, D.P.; Lewis, W.M.J. 1988. Phytoplankton nutrient limitation in Colorado mountain lakes. Freshwater Biology. 20: 315-327.

Wurtsbaugh, W.A.; Gross, H.P.; Luecke, C.; Budy, P. 1997. Nutrient limitation of oligotrophic sockeye salmon lakes of Idaho (USA). Verhandlungen Internationale Vereinigung für Theoretische und Angewandte Limnologie. 26:413-419.

Chapter 6

Anthropogenically Altered Land and its Effect on δ¹⁵N Values in Periphyton on a Fourth Order Stream in Utah's Cache Valley

[by] Chance Broderius

SUMMARY

The Little Bear River is a tributary to the Bear River that drains the south end of the Cache Valley in Northern Utah. The upper elevations are more pristine and are made up of mostly forested mountainous terrain with some grazing activity. The lower elevations are comprised of low gradient agricultural and urban parcels. Anthropogenically influenced landscapes can result in higher nitrogen inputs to streams, and these increases are often marked by an increase in the heavy-nitrogen isotope, δ^{15}N. This study looked at the concentration of δ^{15}N in periphyton on the river bed. These concentrations were then compared to anthropogenic land use in the surrounding watershed. δ^{15}N values in the periphyton were significantly correlated with increasing percentages of anthropogenically affected land use in the Little Bear River watershed. It is likely that anthropogenic land uses (manure fertilization and wastewater treatment) caused the enrichment in δ^{15}N concentrations.

INTRODUCTION

Increases in nitrogen levels in rivers and streams can cause eutrophication since nitrogen is frequently a limiting nutrient in aquatic ecosystems (Dodds 2010). Eutrophication can have dramatic effects on aquatic ecosystems including but not limited to excessive algal growth and alteration of food webs.

Land use has been tied to increases in nitrogen levels in rivers and streams. It is estimated that anthropogenic nitrogen sources produce as much nitrogen as natural sources (Vitousek 1997). Examples of land uses that increase nitrogen levels include livestock grazing, crop growth, livestock feed lots, and human waste treatment. Comparing the percentage of land used for these nitrogen-increasing activities within a watershed to the values of excess nitrogen within rivers and streams is important for water quality mangers to pinpoint problematic land use practices. The nitrogen coming from the aforementioned sources is rich in the heavy isotope form of nitrogen, δ^{15}N.

Several studies have documented how anthropogenic land use increases the heavy isotope concentration of nitrogen in watersheds. Harrington et al. (1998) studied the White River in Vermont and compared δ^{15}N values from different drainages on a fourth order stream and concluded that drainages that were comprised of forested land had lower δ^{15}N values than the drainages that were primarily made up of agricultural land. Additionally, Steffy et al. (2004) found significantly increased δ^{15}N values in the biota of areas downstream from septic tank use. From this, it can be expected that increased δ^{15}N values will correlate with increased anthropogenic uses such as wastewater treatment facilities and areas with septic tank usage. Finally, Luecke and Mesner (unpublished) demonstrated that δ^{15}N values among periphyton and macroinvertebrates in the Little Bear River correlated positively with percent agricultural land use within the drainage. For this study, I also compared periphyton-derived δ^{15}N values with percent anthropogenically-altered land along a continuum of the Little Bear River.

STUDY AREA AND METHODS

Study Area

As described in the Utah Department of Water Quality's Little Bear River TMDL, (Utah DWC 2000) the Little Bear River is located in Cache County, Northern Utah. The river's watershed is made up of 88 percent private land, 10 percent National Forest land, and 2 percent State land. The Little Bear River is a tributary to the Bear River and consists of two main drainages. "The South Fork originates in the low elevation foothills of the Wellsville Mountains and the Bear River Range." according to the TMDL. The East Fork drains National Forest land stored behind Porcupine Dam. There is an impoundment (Hyrum Reservoir) on the main stem as well. The Little Bear drains into Cutler Marsh/ Reservoir NE of the town of Mendon, Utah.

This project's study sites occurred entirely on the South Fork and main stem Little Bear River. A map of the study area can be viewed in Figure 1 of the Executive Summary. Stations 1 and 2 were on the South Fork above all major tributaries. Station 3 was located below the confluence of the South Fork and Davenport Creek. Station 4 was located near the town of Avon, UT and below the confluence with the East Fork. Station 5 was located in an agricultural valley with dispersed housing, and just 30 m downstream from a point source that use to be a trout hatchery and is now a stocked fishing and hunting preserve. Station 6 was located just above Hyrum Reservoir. Station 7 was 1.7 river kilometers downstream of Hyrum Reservoir. Station 8 was located at a bridge crossing on the eastern edge of the town of Wellsville, UT. Station 9 occurs a few hundred meters below the discharge of Wellsville's Wastewater Treatment facility. The facility was not discharging into the river on the day that it was sampled. However, the facility does discharge into the river regularly. Stations 10 and 11 were in low gradient agricultural areas just upstream of the river's entrance into Cutler Reservoir. The shapes and sizes of each site's contributing watershed is shown in Figure 1.

Field Sampling

Periphyton samples were taken at eleven sites along the Little Bear River gradient and at a possible point source site between Stations 4 and 5 on 29 September 2012. Samples were collected between the times of 10:30 and 17:30 starting at Station 11 and primarily at Mendon Road and progressing upstream to Station 1 (Headwaters S. Fork). The possible point source site (White's Trout Farm) that was also sampled is located 30 meters upstream of Station 5: Pishgah Road Bridge. Two replicate samples were taken at each site.

Samples were collected by scraping a representative sample of periphyton from rocks collected from the river bottom and placing the scrapings into pre-labeled scintillation vials. Care was taken to exclude macroinvertebrates so as to not contaminate samples. Once collected, the vials were put on ice to ensure preservation in the field.

Cobble sized rocks were scraped at all Stations except 10, 11, and the point source site. At Stations 10 and 11 there was an abundance of fine sediments making it difficult to find representative samples of periphyton from cobbles. Consequently, I collected samples from a farmer's pump intake and a road-bridge support (Photo 1) at Stations 10 and 11, respectively. At both sites the samples were taken from their respective structures approximately 3 centimeters below the surface of the water. The White's discharge site sample was scraped from the cement surface of the effluent channel shown in Photo 2.

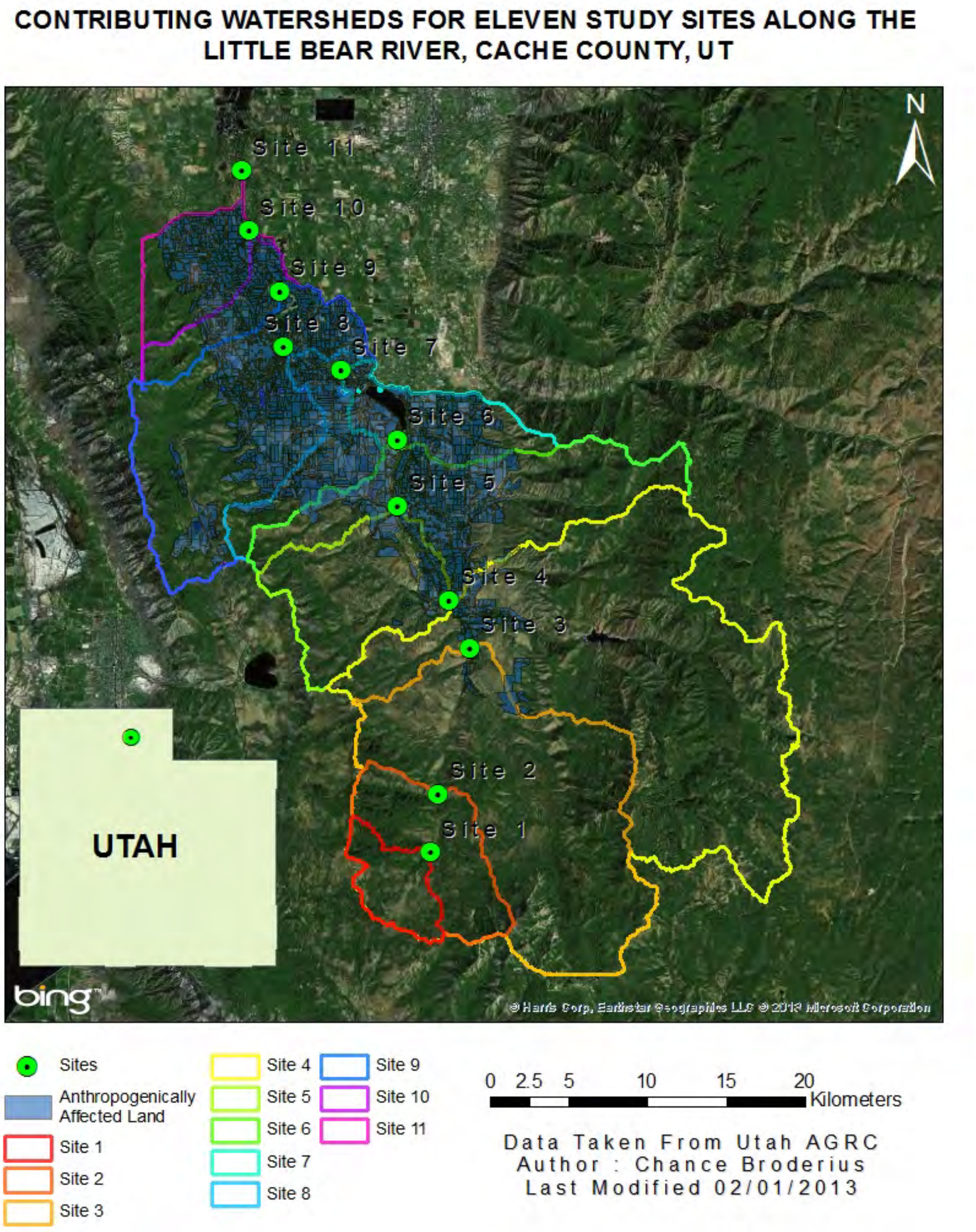


Figure 1. *Map showing contributing watersheds and anthropogenically affected land for each site. Anthropogenically affected land was placed using ArcMap 10.1 and water related land use data was taken from the Utah AGRC (http://gis.utah.gov/data/planning/water-related-land/). Contributing watersheds were calculated using GPS data collected at the time of sample collection and manipulated in ArcMap 10.1.*

Photo 1. *Road bridge support where sample for Station 11: Mendon Rd. was taken. A representative sample of periphyton was scraped off of the metal walls of the support approximately one inch below the surface of the water.*

Photo 2. *J. Fuller filtering water samples from the effluent of the possible point source (White's Trout Farm). The periphyton sample was scraped from the cement surface of the effluent channel. This site is located ca. 20 meters above Station 5.*

All samples were frozen at the end of the sampling day for preservation purposes. They were subsequently placed in a drying oven for 24 hours. After drying, each sample was homogenized within its original scintillation vial. A weighed subsample was then place into a tin capsule and sent to the University of California at Davis, where $\delta^{15}N$ values were measured using mass spectrometry. The isotopic concentration is reported as $\delta^{15}N$ = x.xx and represents a ratio of ^{15}N to ^{14}N isotopes on a ‰ basis.

It should be noted that one vial of periphyton from Station 2 was accidentally left out on the lab counter overnight while the other vials were in the drying oven. The following day the sample was placed in the drying oven for 24 hours, homogenized and encapsulated. The $\delta^{15}N$ value reported by the mass spectrometry lab for this sample was not deemed abnormal and was included in the analysis.

GIS Analysis of Catchment Area and Land Use Type

GPS coordinates and elevation were taken at each sample site. Using these coordinates and a 30 meter Digital Elevation Model (DEM) taken from the Utah Automated Geographic Reference Center (AGRC) website, the contributing watershed for each site was delineated using the watershed tool in ArcMap 10.1 (Figure 1).

Water-related land use data was also taken from the Utah AGRC and applied to the study area. Land use parcels labeled as irrigated agricultural land (IR), non-irrigated agricultural land (NI), sub-irrigated agricultural land (Sub), and urban development (URB) were selected from the total data set as anthropogenically-affected land. The amount of anthropogenically-affected land within each contributing watershed was calculated using ArcMap10.1 and is shown in Figure 1. These values were compared with the contributing watershed for each site. A percentage of area from each contributing watershed that was made up of anthropogenically-affected land was calculated from the values calculated in the GIS.

Statistical Analysis

The significance of each comparable relationship was determined using the regression function in Microsoft Excel. Each comparable relationship was also graphed in a scatterplot, given an appropriate trend line, and R^2 value.

RESULTS

Changes in δ^{15}N *Along the River*

δ^{15}N values of periphyton generally increased with distance downstream (Figure 2; Appendix 1). δ^{15}N from Station 1 through Station 4 increased steadily. δ^{15}N values at Station 5 dipped back down to the level of Station 3 but increased again at Station 6. I found it peculiar to see a dip in δ^{15}N values at Station 5 because Station 5 was only 30 meters downstream from the effluent of a private fishing reserve. There may be springs on the property that may have a resetting effect of the δ^{15}N values in their effluent. The mean value of δ^{15}N taken from the discharge canal of the private fishing reserve was 6.6. Upstream, at Station 4, the δ^{15}N value was 7.6 and downstream, at Station 5, δ^{15}N value was 5.6. This shows an unexplainable loss of δ^{15}N enrichment in the periphyton at the site I expected to be a point source of enriched anthropogenic nitrogen. There was an increase of total nitrogen at Station 5 (Figure 3).

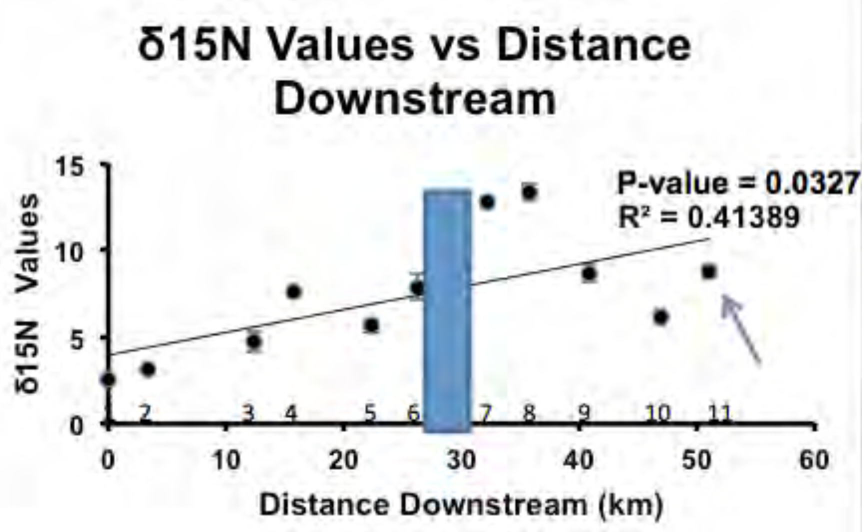
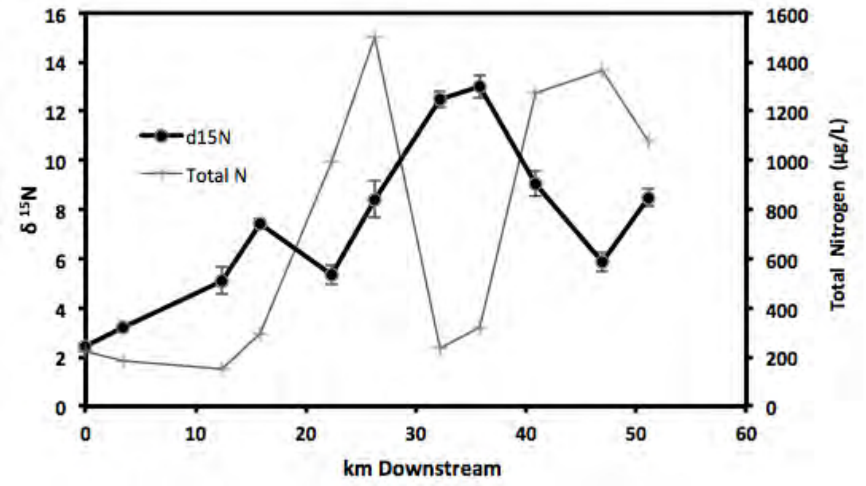


Figure 2. *The figure shows the relationship between distance downstream and delta 15N values of periphyton samples taken from the Little Bear River. Station numbers are shown above the X-axis. Each point represents a mean value for* δ^{15}N *values from two replicates. Error bars show ± one standard deviation from the mean. The blue rectangle represents Hyrum Reservoir. The blue arrow notes Station 11.*

Periphyton-derived δ^{15}N trends generally opposed those exhibited by total nitrogen (Figure 3). Approximately 27 kilometers downstream from Station 1, the river flows into Hyrum Reservoir. This occurs just downstream from Station 6. Station 7 was the site directly downstream from Hyrum Reservoir and it had a marked increase in δ^{15}N values. Station 7 also had very low levels of total nitrogen in the water column (Figure 3; also see chapter by J. Fuller). This is in opposition to the levels of δ^{15}N found in the benthic periphyton samples. Similarly, Stations 7 and 8 had high δ^{15}N values and relatively low total nitrogen. Stations 9 and 11 returned to δ^{15}N values more in line with the overall increasing downstream trend. Station 10, however, had lower δ^{15}N values than would be expected given the overall watershed trend. These three sites also followed an opposing pattern of the total nitrogen values (Figure 3). As expected, nitrogen levels increased at Stations 9 and 10 below the discharge point of the Wellsville wastewater treatment facility (Figure 3). One would also expect an increase in δ^{15}N values due to the sewage effluent. However, δ^{15}N values opposed that of total nitrogen at these locations.



3. *The relationship between total nitrogen values (from J. Fuller) and δ^{15}N values compared on the same x-axis (kilometers downstream). Data was taken from eleven sample sites along the Little Bear River. A pattern of opposing peaks and valleys is seen. Error Bars show ± one standard deviation from the mean.*

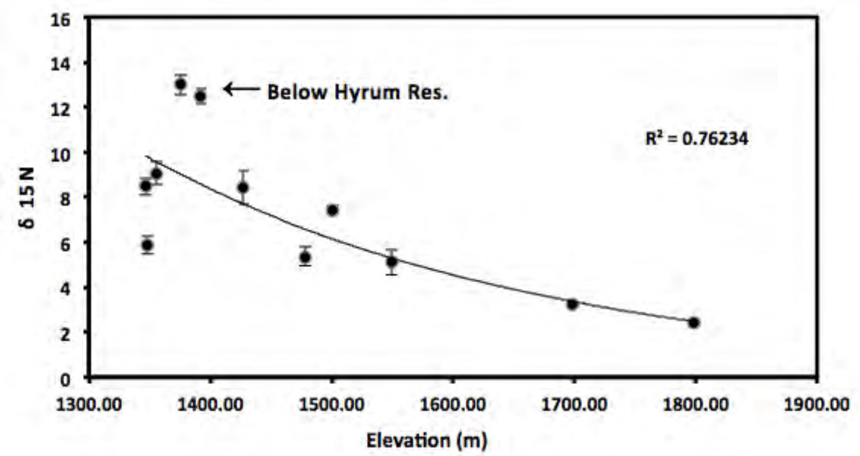


Figure 4. *The relationship between δ^{15}N value and the elevation of each site sampled along the Little Bear River. Error bars show ± one standard deviation from the mean.*

Elevation

Elevation was a highly significant (P = 0.004) predictive factor for δ^{15}N values in the periphyton along the river's gradient. As elevation increased, δ^{15}N values declined (Figure 4). However, outliers were observed at the two sites immediately below Hyrum Reservoir. Additionally, an outlier at Station 10 (δ^{15}N 6.1) had a lower δ^{15}N value than would be expected with the trend line that is shown in Figure 4. It could be that this site is not an outlier at all but only seems that way due to the shift in the trend line caused by the outliers at the two sites below Hyrum. This could also be due to the nature of the surrounding land. Station 1 is considered the most pristine, as it is the highest in elevation, boarders U.S. Forest Service land, and has little surrounding anthropogenically-influenced land.

There was a highly significant relationship between elevation and the percent anthropogenic land use within a sites catchment area (Figure 5; $p = 0.001$, $R^2 = 0.98$). This correlation could explain the significance of the relationship between elevation and $\delta^{15}N$ values.

Anthropogenically Affected Land

The $\delta^{15}N$ values of the periphyton samples can be explained most effectively by the percent of anthropogenically-affected land within the sample site's contributing watershed (Figure 6). The relationship between $\delta^{15}N$ values and the percent of anthropogenically-affected land shows a significant positive correlation (P=0.043) The only relationship with a higher P-value is that of the relationship between elevation and $\delta^{15}N$ values which can be explained by the fact that lower elevations in this watershed, as with most watersheds, generally have more anthropogenically-affected land. However, the relationship between the two factors was not as tight ($R^2 = 0.38$) indicating that additional factors contribute to the relationship. However, the variance around the trend line is generally similar.

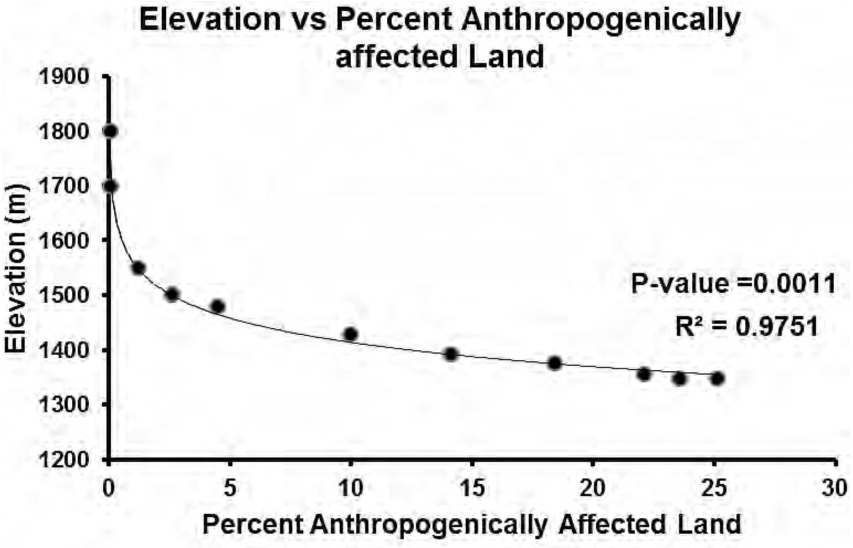


Figure 5. *Figure shows the correlation between percent anthropogenically affected land uses within the catchment area of a site and elevation for eleven sites along the Little Bear River. Anthropogenic land uses included: "irrigated", "non-irrigated", and "sub-irrigated" agricultural land, as well as land classified as "urban". Land use types and area were calculated using ArcMap 10.1 and water related land use data was taken from the Utah AGRC (http://gis.utah.gov/data/planning/water-related-land/).*

DISCUSSION

The percent of anthropogenically-affected land within a study site's contributing watershed can have a significant effect on the $\delta^{15}N$ values within the periphyton (Anderson and Cabana 2005, Harrington et. al. 1998, Steffy et. al. 2004). The percent of anthropogenically-affected land in a sample site's contributing watershed had a positive significant effect ($p= 0.043$) on $\delta^{15}N$ values in periphyton samples along the gradient of the Little Bear River (Figure 6). $\delta^{15}N$ enrichments in periphyton where generally higher when the contributing watershed had higher percentages of anthropogenically affected land. This effect can also be seen in upper levels of the food chain. Anderson and Cabana's (2005) study of 82 river sites on the St. Lawrence Lowlands of Quebec showed a significant correlation ($p< 0.0001$) between percent agricultural land in the catchment and $\delta^{15}N$ values of primary consumers, predatory invertebrates, and fish.

The distance downstream correlation with δ¹⁵N values could be caused by two possibilities. One factor could be that as distance downstream increases, so too does the opportunity for periphyton to accumulate heavy nitrogen isotopes. The heavy isotopes are more frequently accumulated than are the light isotopes of ^{14}N. The other factor which is most likely the main contributing factor to the correlation of δ¹⁵N values and distance downstream is that as distance downs stream increases so too does the amount of the contributing watershed that is made up of anthropogenically-affected land. Both of these factors are likely contributors to the significance of the correlation.

The only predictor of δ¹⁵N values that was more significant than percent anthropogenic land use was site elevation. As elevation decreased δ¹⁵N values increased. This could also be caused by the fact that anthropogenic land uses are more common at lower elevations.

In conclusion, the percent of a watersheds area that is being used by anthropogenically-affected land uses, which in this study included agricultural land and land classified as urban, can be an indicator of the level δ¹⁵N values in stream biota.

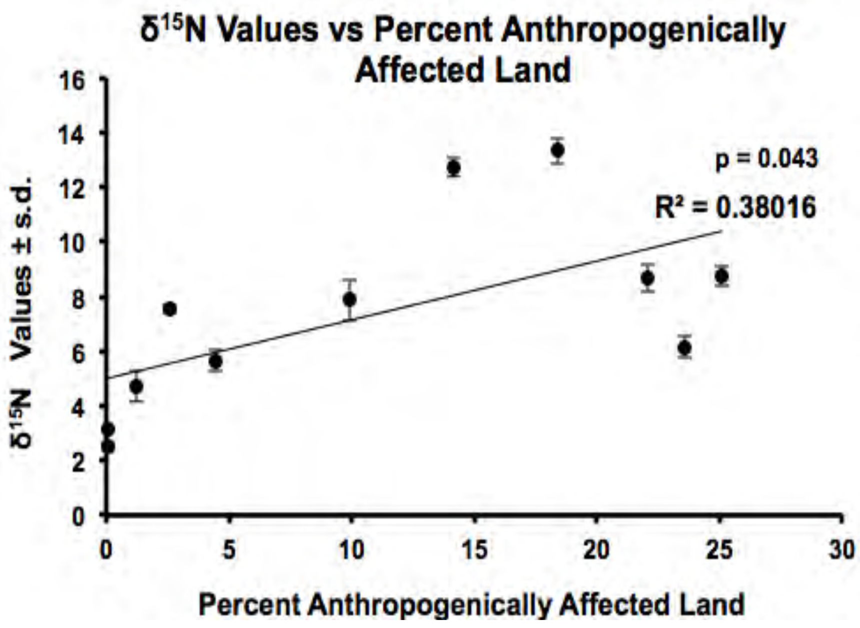


Figure 6. *The relationship between δ¹⁵N values and percent of the Little Bear River catchment area that was made up of anthropogenically-affected land uses. Anthropogenic land uses included: "irrigated", "non-irrigated", and "sub-irrigated" agricultural land, as well as land classified as "urban". Land use types and area were calculated using ArcMap 10.1 and water related land use data was taken from the Utah AGRC (http://gis.utah.gov/data/planning/water-related-land/). Each point represents one of eleven sites along the Little Bear River. Error bars show standard deviations.*

REFERENCES

Anderson, C.; Cabana, G. 2005. δ15N in riverine food webs: effects of N inputs from agricultural watersheds. Canadian Journal of Fisheries and Aquatic Sciences. 62:333-340. doi:10.1139/F04-191

Dodds, W.; Whiles, M. 2010. Freshwater Ecology: Concepts and Environmental Applications of Limnology. Burlington, MA : Academic Press.

Harrington, R.R.; Kennedy, B.P.; Chamberlain, C.P.; Blum, J.D.; Folt, C.L. 1998. 15N enrichment in agricultural catchments: field patterns and applications to tracking Atlantic salmon (*Salmo salar*). Chemical Geology. 147:281-294.

Luecke, C.; Mesner, N. Use of nitrogen stable isotopes to assess effects of land use on nitrogen availability in freshwater ecosystems. Unpublished manuscript, Utah State University, Logan, UT.

Steffy, L.Y.; Kilham, S.S. 2004. Elevated $\delta^{15}N$ in stream biota in areas with septic tank systems in an urban watershed. Ecological Applications. 14:637-641.

Utah Department of Environmental Quality, Division of Water Quality TMDL Section. (n.d.). Little Bear River watershed TMDL. Retrieved Dec. 6, 2012 from http://www.waterquality.utah.gov/TMDL/Little_Bear_River_TMDL.pdf.

Vitousek, P.M.; Mooney, H.A.; Lubchenco, J.; Melillo, J. 1997. Human domination of Earth's ecosystems. Science. 277: 494–499.

Utah AGRC. www.gis.utah.gov. SGID Data Sets.(2012) Utah AGRC. http://gis.utah.gov/data/. 10/17/2012

Chapter 7

Benthic Invertebrate Composition along the Little Bear River Continuum (Group Project)

SUMMARY

Benthic invertebrates were sampled at four stations along the Little Bear River continuum: Station 2 in the mountainous headwaters, at Station 4 in the transition area to the lowland valley, at Station 7 below Hyrum Reservoir, and at Station 11 in the low-gradient agricultural area near where the river flows into Cutler Reservoir wetland. At each station samples were collected with sweep nets in each of the habitats, with an effort made to sample each type of habitat in proportion to its abundance. Ethanol-preserved samples were counted utilizing 30X compound microscopes, with 2 or more students providing counts and taxa identifications for the invertebrates from each Station. The invertebrates identified from each station are shown in Table 1. A ratio of the combined counts of clean-water taxa (*Ephemeroptera*, *Plecoptera* and *Tricoptera*) and all other taxa was calculated for each station. This ratio can provide insight on water quality, but with the level of taxonomy used in the class exercise, should be interpreted cautiously.

Table 1. *Numbers of taxa counted in subsamples from each station on the Little Bear River, Utah.*

	Station 2	Station 4	Station 7	Station 11
Ephemeroptera	36	16	3	5
Plecoptera	18		1	
Tricoptera	76	30	12	12
Amphipoda		1	17	
Chironomidae	86	88	6	80
Other *Diptera*	12	27	4	4
Coleoptera	25	33	11	4
Crust. Zooplankton			3	
Hemiptera		9	1	24
Hirudinea			23	
Isopoda			150	2
Moliusca	6	2	1	7
Odonata		1	5	
Oligochaeta		11		11
Total	254	218	237	149
			Grand Total	**858**

Chapter 8

A Fisheries Investigation of the Previously Un-Surveyed Little Bear River

[by] Christian Smith

SUMMARY

To evaluate the effects of human impacts on the composition and abundances of fishes on the Little Bear River, the 2012 Aquatic Ecology Practicum class conducted backpack electrofishing surveys in four sites of the river on 29 September and 4 October 2012. At these sites, species composition, biomass, and abundances were documented utilizing 2-pass electrofishing. In total, ten species were captured, with native species being represented by Bonneville cutthroat trout (*Oncoryhnchus clarki Utah)* and mottled sculpin (*Cottus* bairdii). Mottled sculpin comprised the majority of native fish captured (n= 241), while brown trout accounted for the majority of nonnatives (n= 129). Brown trout abundance was highest at the most upstream site (Station 2) and decreased going down the longitudinal gradient. Regression analysis revealed that larger average pebble size at Station 2 could be a factor in determining the observed higher brown trout abundance at this site, although the small sample size warrants further investigation. At the lowest site (Station 11) with poor water quality, only introduced species were present: green sunfish (*Lepomis cyanellus*), common carp (*Cyprinus carpio*), largemouth bass (*Micropterus salmoides*) and sand shiner (*Notropis stramineus*). Recommendations for future fisheries investigations on the Little Bear River include the sampling of additional sites, inclusion of more passes per site, and additional invertebrate and pebble sampling. Management recommendations include assessment of the potential value of a fisheries management program on the Little Bear River.

INTRODUCTION

The Little Bear River drains the southern portion of Cache Valley, which is located in northern Utah. Similar to most streams in populated regions, the Little Bear River has been altered by anthropogenic influences, including diminished water quality, impoundment, and channel modifications. The Utah Department of Water Quality (UDWQ) investigated some of these impacts in an effort to determine the Total Maximum Daily Load (TMDL) of nutrients. Data analyzed in that study were compiled from water quality monitoring in the Little Bear River from 1976 through 1999. After determining that total phosphorous (TP) levels exceeded UDWQ criteria at five of the ten sites sampled on the Little Bear River, remediation efforts were suggested and outlined (UDWQ 2000).

Subsequent studies conducted by Utah State University scientists further investigated sediment loading and biological isotope indicators of heightened nutrient loads (Jones et al. 2011; Luecke and Messner Unpublished). Additional investigation of the Little Bear River and its watershed include studies performed by two upper-level undergraduate courses in the Watershed Sciences department at Utah State University during Fall semester of 2012.

Fisheries monitoring can provide much insight to the status of a stream's ecological integrity (Schmutz et al. 2000). Except for some Utah DWR data on the East Fork of the Little Bear River, there appears to be little information regarding fish abundance and taxonomic composition in the Little Bear River. This eliminates the possibility of comparing data collected in this study to those in the past, yet underscores the importance of developing some form of baseline study which could be referenced in the future.

METHODS

Study Area

Fish sampling at four sites along the Little Bear River conducted by the 2012 Aquatic Ecology Practicum class occurred on 29 September and 4 October and was initiated at the furthest downstream site (See site map in Executive Summary). Sampling locations were selected relatively evenly along the longitudinal gradient, but only four stations could be sampled due to time constraints. Reaches were 100 meters in length, as this maintained consistency with previous local depletion estimates and promoted the benefits of regional standardization (Bonar et al. 2009). Two elsctrofishing passes were conducted at each reach. A class member, Chance Broderius, collected GPS information at the bottom of each reach, which included station waypoints and elevation.

Station elevation where fish sampling occurred ranged from 1699 meters at the uppermost site (Station 2) to 1347 meters at Station 11 near Cutler Reservoir. The character of the river valley changed from a relatively narrow canyon at Station 2 to a somewhat typical mid- to lower-order stream of the intermountain west at Station 11. Hyrum reservoir is located between Station 4 and 11 and can be viewed as a discontinuity within the Little Bear River continuum and an assumed barrier to fish migration (Ward and Stanford 1983). Selecting two sampling locations above Hyrum Reservoir and two below allowed investigation of the possible influence of Hyrum reservoir on the Little Bear River fish assemblage.

Fish Collection

A Smith Root LR 24 backpack electrofisher was used to collect fish, and settings were calibrated with the automatic setup feature (Photo 1). Fish sampling occurring on 4 October 2012 at Station 2 was done by three students with dip nets, while sampling on 29 September 2012 at Stations 4, 7, and 11 required an additional netter due to higher average surface area. Electrofishing seconds were monitored to achieve consistency between the individual passes within a reach. Fish-abundance estimates were performed by the depletion method, with the upper and lower boundaries of the reach blocked by seines to prevent fish from escaping (Li and Li 2006). Captive fish were placed in a holding bucket and taxanomic identification, total length (mm), and total wet weight (g) were recorded on data sheets. Additional information was provided by photographs of different taxa, which were taken at Stations 7 and 11 as noted in Photos 1 and 2 in the Appendix. Species not photographed include Bonneville cutthroat trout and green sunfish.

Average Width, Biomass, Catch per Unit Effort, and Abundance Estimate Calculation

Average width of Stations 2, 4, and 7 were calculated by measuring five wetted-widths with a surveying tape. Average width of Station 11 was determined by the Google Earth® measuring tool, which was possible due to the channelized character and relative lack of riparian canopy at this site. Calculation of average width allowed for determination of reach surface area, which was subsequently used to quantify biomass of fish species captured and comparison of reach spatial characteristics.

Abundance estimates in this study were performed with the same approach utilized in an investigation on the Logan River which calculated abundance estimates with the simple linear regression method and the modified Zippin method for comparative purposes (Budy et al. 2002, Zippin 1958). The modified Zippin method was also used by Utah Department of Wildlife Resources (UDWR) surveys on the Logan River (Budy et al. 2002). The modified Zippin estimate of fish abundance is calculated as follows:

$$\boldsymbol{N = \frac{C_1^2}{C_1 - C_2}}$$

Where,
N = estimated fish population reported in units of fish per 100 meters, C_1 = number of fish captured on the first pass, and C_2 = number of fish captured on the second pass.

Additionally, standard error can be calculated with the modified Zippin method as:

$$\textit{Standard Error: } S.E.(N) = [\frac{C_1 - C_2}{(C_1 - C_2)^2}]^* \sqrt{C_1 + C_2}$$

The value of fish abundance estimates arguably supercedes other fisheries research results. Abundance estimates can provide managers with quantifiable results, which include biomass and population estimates, both of which are highly beneficial in determining resource allocation and measures of ecological integrity. As with most estimates, an increased sample size typically results in greater precision.

Statistical Analysis

Statistical analyses were conducted with Microsoft Excel 2010. Statistical analyses consisted of simple regression between variables of fish abundance, observed fish biomass, and catch per unit effort (CPUE), with each fish-related variable pertaining to an individual taxa. Small sample sizes of the majority of species captured precluded statistical analyses, particularly noticeable at Station 11. Variables analysed included location (river kilometer), monthly and annual temperature, monthly and annual dissolved oxygen concentration (percent of saturation), average pebble size (millimeters), turbidity (nephelometric turbity units), and EPT (*Ephemeroptera, Plecoptera, and Trichoptera*) to Chironomid ratios. Annual temperature, dissolved oxygen concentration, and turbidity data were obtained from the Utah State University "Little Bear River WATERS Test Bed" website (http://littlebearriver.usu.edu/sites/ Default.aspx 15 November 2012), which provides access to automated water quality monitoring stations. Information from these automated stations directly pertained to five of the eleven stations sampled by the Aquatic Ecology Practicum class, with two out of four being present at fish sampling reaches. Additionally, a two-sample t-test was used to compare length-frequency distributions between reaches for brown trout and mottled sculpin.

RESULTS

Ten species and a total of 408 fish were caught in the Little Bear River, with 80 percent of the total catch occurring at the two sites above Hyrum Reservoir (Table 1). As predicted, a cold-water fish assemblage was found in reaches further upstream, whereas the lowest reach sampled revealed a warm water assemblage. Mottled sculpin constituted 59 percent of fish captured in the Little Bear River, and brown trout comprised the largest proportion of fish biomass (Figure 2A) among our sample. Specific catch results at the four stations are provided below.

Common name & Abbreviation	Latin name	Station 2	4	7	11	Total
Bonneville cutthroat trout (BCT)	*Oncorhynchus clarki utah*	2	1			3
Brown trout (BNT)	*Salmo trutta*	64	34	31		129
Common carp (CC)	*Cyprinus carpio*				7	7
Green sunfish (GS)	*Lepomis cyanellus*				15	15
Largemouth bass (LM)	*Micropterus salmoides*				2	2
Mottled sculpin (MS)	*Cottus bairdii*	63	164	14		241
Rainbow trout (RBT)	*Oncorhynchus mykiss*			1		1
Sand shiner (SS)	*Notropis stramineus*				1	1
Tiger trout (TT)	*Salmo trutta* ♀ × *Salvelinus fontinalis* ♂			1		1
White sucker (WS)	*Catostomus commersoni*			8		8
	Total Fish	129	199	55	25	408

Table 1. *Fish taxa identified and corresponding total catch in the Little Bear River, Utah, 29 September 2012 and 4 October 2012.*

Station 2: In the Headwaters

Two Bonneville cutthroat trout, 64 brown trout, and 63 mottled sculpin were captured at Station 2, which produced the highest trout densities (individuals per 100 meters) and biomass among the reaches sampled (Figure 1). Although brown trout only outnumbered mottled sculpin by one fish, brown trout biomass at Station 2 vastly exceeded the other two taxa observed (Figure 1). Overall fish biomass at Station 2, which was 28.8 g m^{-2}, was markedly higher than any other reach. Depletion of brown trout and mottled sculpin was achieved by catching fewer individuals of each taxa during the second pass, which allowed for estimation of abundance. Brown trout abundance at Station 2 was estimated to be 100 individuals per 100 meters, with an estimated standard error of +/- 30. Estimated mottled sculpin abundance was 124 individuals per 100 meters with an estimated standard error of +/- 63. Although total fish biomass and estimated brown trout abundance were higher at Station 2 than any of the other reaches sampled on the Little Bear River, total fish catch per unit effort was highest at Station 4 (Figure 2).

Station 4: Near Avon

At Station 4 we captured one Bonneville cutthroat trout, 34 brown trout, and 163 mottled sculpin. More mottled sculpin were caught on the second pass than the first at Station 4, which eliminated the possibility of producing an abundance estimate for this species in this reach. Brown trout biomass decreased markedly from 27.6 grams per square meter at Station 2 to 5.0 grams per square meter at Station 4, despite maintaining the highest relative biomass (cf. Figure 1 and 2). Mottled sculpin biomass (g/m^2) decreased as well despite the increased catch. This reduction in fish biomass resulted from the increased surface area at Station 4, not from the total catch for the site. Estimated brown trout abundance in Station 4 was 67 fish, with a standard error of +/- 45 (Figure 3).

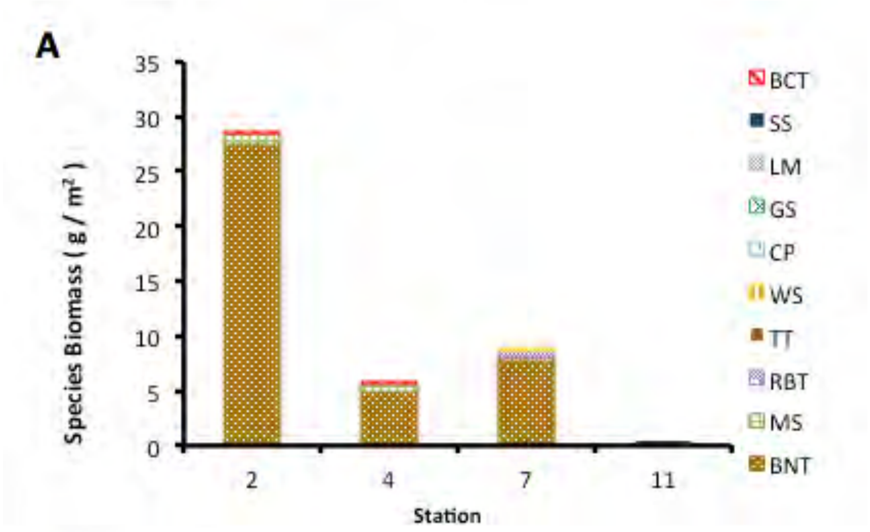


Figure 1. A. *Biomass (g / m2) of all fish species collected in the Little Bear River. Note the general decrease in total fish biomass observed from Station 2 to Station 11. Total biomass at Station 11 was 0.17 g / m^2.*

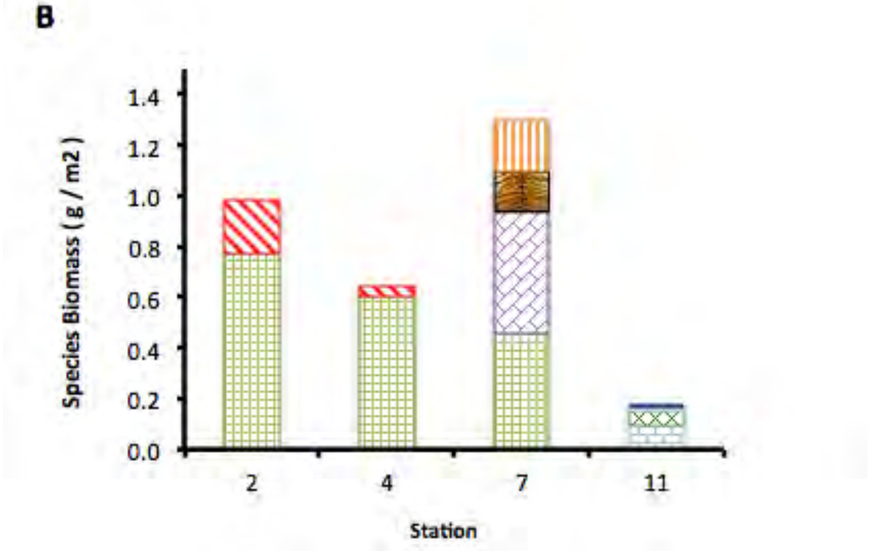


Figure 1. B. *Biomass of fishes other than brown trout (Salmo trutta). Coldwater species dominated the assemblage at Stations 2 through 7, while at Station 11 the fish assemblage shifted to warm water species. Species codes are shown in Table 1.*

Station 7: Below Hyrum Reservoir

The fish assemblage at Station 4 displayed the highest species diversity (five species) of any reach electrofished on the Little Bear River. However, the only native species captured at Station 7 was the mottled sculpin. Thirty-one brown trout and fourteen mottled sculpin were caught. The remainder of species captured were only observed at Station 7. These include tiger trout, rainbow trout, and white suckers (Table 1). Similar to Station 2, brown trout dominated the observed fish assemblage at Station 7 (Figures 2 and 3). Brown trout abundance in Station 7 was estimated as 33 individuals per 100 meters, with an estimated standard error of +/- 2.31, which was a reduction from densities in Station 4 (Figure 3). Station 7 was, however, considerably narrower than Station 4 (see Physical chapter), and consequently had less surface area.

Station 11: Mendon Bridge

An evident shift in the fish assemblage occurred at Station 11, wherein the cold-water species observed in upstream sites were no longer present (Table 1; Figure 2). Fish taxa captured in Station 11 were common carp, green sunfish, largemouth bass, and one sand shiner, and these were only present at this site.

Station 11 had the lowest observed fish biomass and densities of the four sites sampled. However, the backpack electrofisher did not appear to be stunning larger (> 200 mm) carp that were spotted by netters. Consequently, fish biomass may have been underestimated at this site.

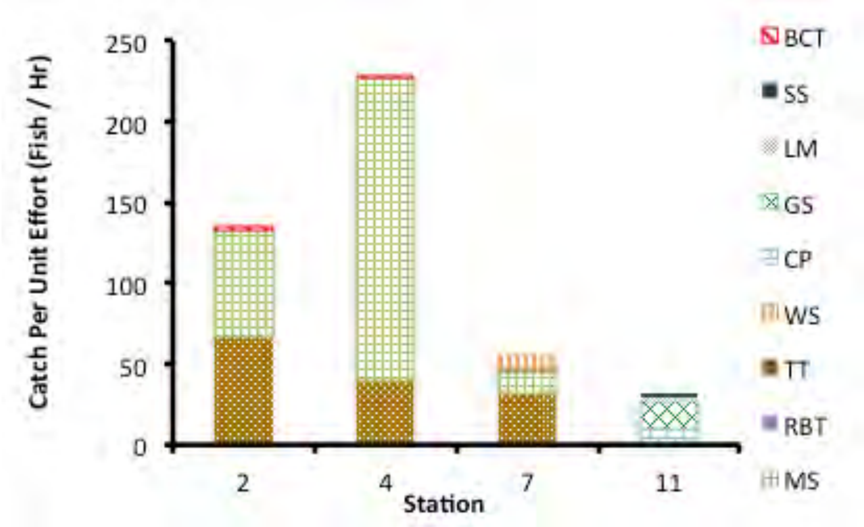


Figure 2. *Catch per unit effort (fish/hour) of each fish species captured at each station sampled during a backpack electrofishing survey of the Little Bear River, 29 September 2012 and 4 October 2012.*

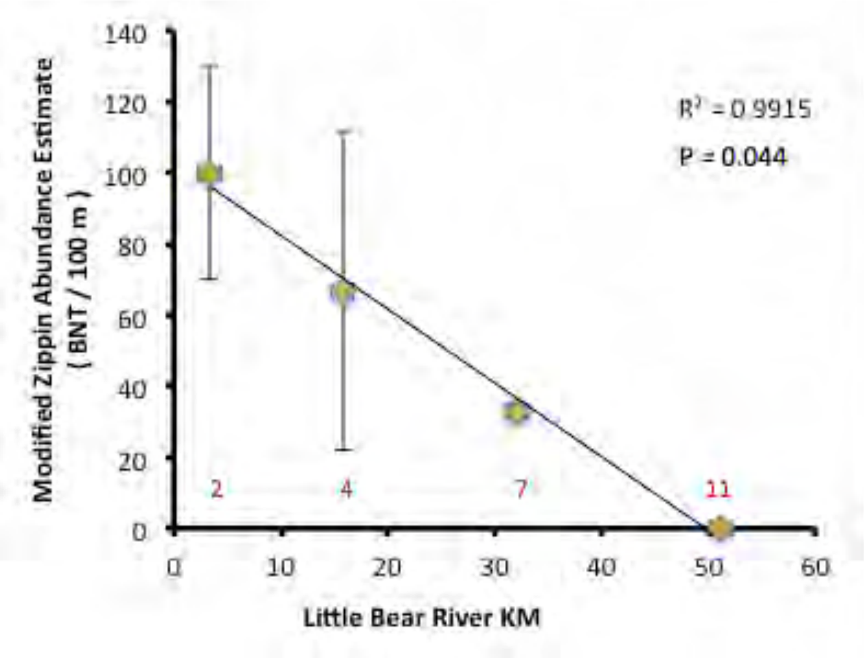


Figure 3. *Brown trout (Salmo trutta) abundance estimates at four sites along the Little Bear River longitudinal gradient. Abundance estimates were determined with the modified Zippin estimate. Station numbers are represented in red text above the horizontal axis. Location data courtesy of Marc Weston.*

Larger Scale Results

The Little Bear River fish assemblage was observed to undergo a shift from species that preferred cold water at Stations 2 through 7, to a warm water species composition at Stations 11. Identification of statistically significant relationships between habitat limiting factors, location, estimated fish abundance (fish 100 m^{-1}), and observed fish abundance ($hour^{-1}$) was limited to brown trout and mottled sculpin due to the higher observed abundance of these species. Linear regression of estimated brown trout abundance and position along the Little Bear River longitudinal gradient provided a statistically significant relationship ($R^2 = 0.99$, $p = 0.04$, Figure 3). This significant decline in trout density is consistent with the River Continuum Concept (RCC), which states that as rivers transition from low order headwater streams to higher order streams, the fish community is expected to change from "cool water species low in diversity to more diverse warm water communities" (Vannote et al. 1980). The presence of Hyrum Reservoir presents a discontinuity (*sensu* Ward and Stanford 1983) along the Little Bear River system, but its thermal influences to the river were not particularly evident (see chapter by A. Pappas). However, even at Station 11 mean July temperatures were <20°C, suggesting that trout could have inhabited the lowest reaches of the river. Consequently I attempted to determine other factors that might be influencing brown trout abundance in the Little Bear River.

Brown trout CPUEs at the four stations were negatively correlated with pebble sizes (Figure 4; $R^2 = 0.97$, $p = 0.014$). Corresponding average pebble size at each reach was 62, 45, 37, and 0.1 mm. The presence of spawning gravels is essential to the success of all salmonids (Spence and Hughes 1996), and gravels typically used for spawning range from 0.6 to 10.2 centimeters in size (Bjornn and Reiser 1991). The error bars displayed in Figure 5 indicate an increasing amount of variance that correlates higher CPUE with average pebble size, and suggest that while average pebble size is increasing at higher elevations in the watershed, there were many different sized pebbles within the sample.

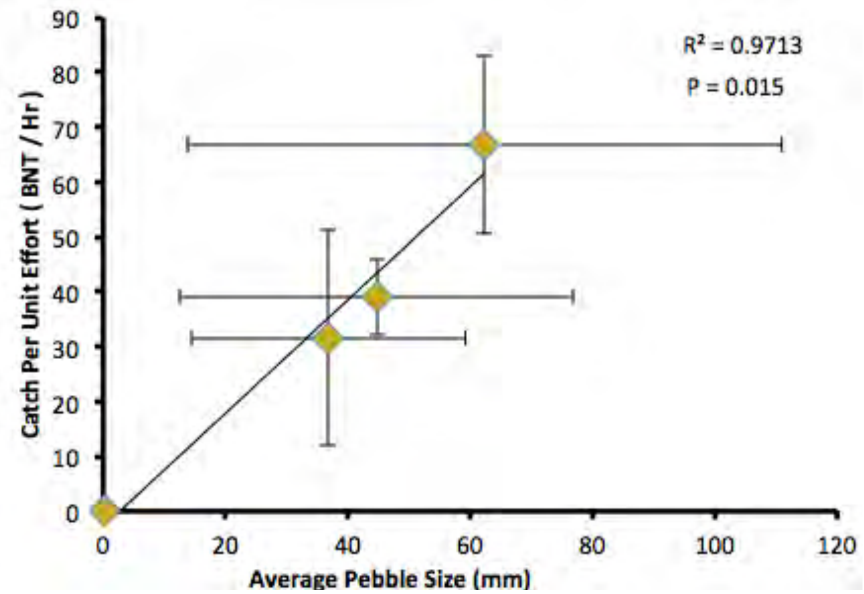


Figure 4. *Relationship between average pebble size and Brown trout (Salmo trutta) catch per unit effort. Pebbles were randomly collected then measured by Marc Weston at Stations 2, 4, 7, and 11. Corresponding average pebble size at each reach was 63, 45, 37, and 0.1 millimeters.*

DISCUSSION

The high proportion of nonnative fish observed in our sampling effort is a direct result of anthropogenic impact to the Little Bear River system, with only two of the ten species collected existing within their native range (Sigler and Sigler 1996). The 241 mottled sculpin caught comprised the majority of native fish observed in the Little Bear River, and neither native species captured in this study were observed at Station 11.

Brown trout are native to Europe and were introduced to the intermountain region in the late 1800s (Varley and Schullery 1998), however the source of introduction to the Little Bear River is unknown. If fisheries monitoring of the Little Bear River continues, the determination of source populations of nonnative fishes would help researchers determine important information pertaining to aquatic ecology, such as resource allocation and food web dynamics. Given the observed abundance, it could be assumed that brown trout are well established in the Little Bear River; however other sources could include the East Fork of the Little Bear River (http://www/ waterquality.utah.gov/watersheds/lakes/PORCUPIN.pdf).

Despite the observed low native trout densities, the brown trout abundances at Station 2 to Station 7 could indicate that the Little Bear River is not overly polluted (Elliot 1994). Additionally, the Little Bear River from Station 2 to Station 7 is an example of an unmanaged trout fishery that could be viewed as a reference for other streams where management has been intensive. Regional efforts to recover declining populations of native Bonneville cutthroat trout could benefit from information regarding this fish's presence in what appears to be a brown trout-dominated system.

Tiger trout, rainbow trout, and white suckers were only observed at Station 7 (Table 1), which as mentioned earlier, displayed the highest fish species diversity of any site on the Little Bear River. While the source of these species is unknown, the presence of white suckers is a possible sign of a transition to a warm water fish assemblage given this fish's wide range of thermal tolerance (Sigler and Sigler 1996). If deemed necessary and appropriate to future management, digging deeper into Utah Division of Wildlife Resources fish stocking report archives and possibly interviewing local fishermen and landowners might aid the determination of sources of nonnative trout introductions to the Little Bear River.

As with nonnative species at other sites investigated in the Little Bear River, the sources of introduction to Station 11 are unknown at this point in time. However, relatively extensive documentation of other warm water species in Cutler Reservoir suggest that fish may have moved upstream from this impoundment into Station 11 (Budy et al. 2011). Along with warm water fishes, cool water species such as walleye (*Sander vitreus*) are established in Cutler Reservoir and brown trout have also been collected there (Budy et al. 2011).

A notable absence in the observed fish assemblage was that of mountain whitefish (*Prosopium williamsoni*), which are commonly found in trout streams throughout the intermountain west. This might have been a result of our relatively small sample size. Other limitations that affected this study appear to be related to the backpack electrofisher. Multiple large common carp were missed at Station 11, with some spotted in congregations at the block nets by non-fishing students. If these fish were visible in the turbid water at this site, it seems likely that the electrofishing equipment might have missed more. I assume this reduction in gear efficiency was a result of the increased surface area, moderately high depth, and sandy substrate at Station 11.

Time limitations to this study allowed only two electrofishing passes per reach, which allowed us to sample more reaches. The consequence of this approach was the inability to estimate abundances for most species. However, sampling more reaches was assumed to provide a better indication of taxonomic presence or absence, wherein sampling the two sites below Hyrum Reservoir revealed seven additional taxa that had not been observed at Stations 2 and 4. If the goals of future research include quantification of these different species, I would recommend conducting at least three passes per reach, and sampling as many reaches as possible.

If fisheries investigation of the Little Bear River continues in the future, the sampling of stream macroinvertebrates to identify potential type and abundance of food sources for fish should be viewed as an important component. The positive relationship between larger average pebble size and higher brown trout abundance that I determined has also been observed with increased numbers of invertebrates in a Colorado stream (Allan 1975). Additionally, the increased assessment and quantification of stream macroinvertebrate communities in the Little Bear River would provide another biological indicator of overall stream health (Rosenberg et al. 1986). Future researchers are also encouraged to further investigate pebble size and other stream morphology parameters, including pool and riffle frequency. If the influence of pebble size and other morphological factors upon fish and macroinvertebrate abundance and species diversity in the Little Bear River could be determined and isolated, assessment of the potential effects of perturbations to fish and invertebrate communities in the Little Bear River by other sources such as increased nutrients would likely become more evident.

These findings also suggest that the Little Bear River has the potential to be viewed and managed as a trout fishing stream. Although the high proportion of private land along the river might limit the possibility of public access, the benefit of a healthy and productive trout stream to landowners and their property values could promote cooperative efforts with aquatic resource managers. Perhaps more important than the potential for recreational fishing, the close proximity of the Little Bear River to the Utah State University campus provides students and educators an ideal opportunity to apply science and sampling methods learned in the classroom to a stream ecosystem with a preexisting network of water quality monitoring stations and a noticeable level of human impact.

REFERENCES

Allan, J.D. 1975. The distributional ecology and diversity of benthic insects in Cement Creek, Colorado. Ecology. 56:1040–1053.

Bjornn, T.C.; Reiser, D.W. 1991. Habitat requirements of salmonids in streams. American Fisheries Society Special Publication. 19:83–138.

Bonar, S.A.; Hubert, W.A.; Willis, D.W. 2009. Standard methods for sampling North American freshwater fishes. American Fisheries Society Bethesda, Maryland. Available from http://scafs.org/ Events/2009-StandardMethods.pdf.

Budy, P.; Baker, M.; Dahle, S.K. 2011. Predicting fish growth potential and identifying water quality constraints: A spatially-explicit bioenergetics approach. Environmental Management. 48:691–709.

Budy, P.; McHugh, P.; Thiede, G.P.; VanDyke, E. 2003. Logan River whirling disease study: factors affecting trout population dynamics, abundance, and distribution in the Logan River, Utah. Annual Report to Utah Division of Wildlife Resources. Utah Cooperative Fish and Wildlife Research Unit, Logan, Utah.

Jones, A.S.; Stevens, D.K.; Horsburgh, J.S.; Mesner, N.O. 2011. Surrogate measures for providing high frequency estimates of total suspended solids and total phosphorus concentrations. Journal of the American Water Resources Association. 47:239–253. doi: 10.1111/j.1752-1688.2010.00505.x.

Li., H.W.; Li, J.L. 2007. Role of fish assemblages in stream communities. Pages 489-514 (chapter 22) In Hauer, F.R. and Lamberti, G.A. (eds.) Methods in Stream Ecology (Second Edition). Academic Press, San Diego. Doi: 10.1016/B978-012332908-0.50031-0.

Muhar, S.; Schwarz, M.; Schmutz, S.; Jungwirth, M. 2000. Identification of rivers with high and good habitat quality: methodological approach and applications in Austria. Hydrobiologia. 422:343–358.

Rosenberg, D.M.; Danks, H.V.; Lehmkuhl, D.M. 1986. Importance of insects in environmental impact assessment. Environmental Management. 10:773–783.

Schmutz, S.; Kaufmann, M.; Vogel, B.; Jungwirth, M.; Muhar, S. 2000. A multi-level concept for fish-based, river-type-specific assessment of ecological integrity. Hydrobiologia. 422:279–289.

Sigler, W.F.; Sigler, J.W. 1996. Fishes of Utah: a Natural History. Salt Lake City, Utah: University of Utah Press.

Spence, B.C.; Hughes, R.M. 1996. An ecosystem approach to salmonid conservation. ManTech Report 21TR-4501-96-6057. Northwest Regional Office, NOAA Fisheries. Available at http://www.nwr.noaa.gov/publications/reference_documents/the_mantech_report.html.

Utah Department of Environmental Quality, Division of Water Quality TMDL Section. (n.d.). Little Bear River watershed TMDL. Retrieved Dec. 6, 2012 from http://www.waterquality.utah.gov/TMDL/Little_Bear_River_TMDL.pdf.

Vannote, R.L.; Minshall, G.W.; Cummins, K.W.; Sedell, J.R.; Cushing, C.E. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences. 37:130–137.

Varley, J.D.; Schullery, P. 1998. Yellowstone Fishes: Ecology, History, and Angling in the Park. Mechanicsburg, PA.: Stackpole Books.

Ward, J.V.; Stanford, J. 1983. The serial discontinuity concept of lotic ecosystems. Pages 29-42 In Fontaine, T.D. and Bartell, S.M. (eds) Dynamics of Lotic Eecosystems. Ann Arbor, Mich.: Ann Arbor Science.

Zippin, C. 1958. The removal method of population estimation. The Journal of Wildlife Management. 22:82–90.

APPENDICES

Photo 1. *Fish species captured at Station 11 on the Little Bear River. Starting at the top and moving counterclockwise the species are largemouth bass (Micropterus salmoides, common carp (Cyprinus carpio), and Sand shiner (Notropis stramenius).*

Photo 2. *Fish species captured at Station 7 on the Little Bear River. Clockwise from top-left: brown trout (Salmo trutta); mottled sculpin (Cottus bairdii); white sucker (Catostomus commersoni), and; rainbow trout (Oncorhynchus mykiss).*