

Relationships Between Biomass, Primary Productivity, and Environmental Heterogeneity  
in Wilderness Streams of Central Idaho

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## INTRODUCTION

Primary production in mountain streams provides basal energy resources that support higher trophic levels in aquatic food webs (Allan and Castillo 1995) and is related to variation in light, temperature and nutrients, as well as disturbance from streambed scour and removal by grazers (Odum 1956, Bott et al. 1985, Bott 1996). Intriguingly, rates of gross primary production may differ among streams with similar standing crop biomass of primary producer organisms. In fact, the relationship between biomass and production is often non-linear, and low to moderate levels of disturbance or grazing may actually stimulate productivity (much as mowing a lawn can cause faster rates of grass growth) over what would occur if biomass accumulated to high levels, whereas more severe disturbance or grazing could result in diminished productivity (Bott 1996).

Adaptation to changing climate may involve shifts of species assemblages to those that are adapted to disturbance and can capitalize on variability in ecosystem conditions (e.g., Lamberti et al. 1987, Minshall et al. 1998, Malison and Baxter 2010). Thus, there is a need to investigate the response of primary producers to factors that may change with altered disturbance regimes, and to do so in terms of production rather than biomass alone. Climate change is expected to lead to multiple ecological impacts for stream ecosystems in response to decreased winter snowpack, increases in snow line elevations, and increased frequency of natural disturbances like wildfire (Davis et al. in press). Rising global temperatures have been correlated with increased fire frequency and consequent changes in hillslope and riparian vegetation (Westerling et al. 2006). Collectively, effects could contribute to multiple influences on stream ecosystems such as changed flow regimes, highly responsive runoff events, earlier peak flows, a thinning or loss of riparian vegetation, increased mobility of streambed materials, and greater stream temperature variability (Larned 2010). In mountain streams, many hydrographs

previously dominated by snowpack may become more strongly governed by rainfall (Stewart 2009, Kunkel and Pierce 2010). Changes in peak flows may also alter streambed morphology, as late-winter or early spring flow disturbances may become more common. This trend may not only be accompanied by higher flow events triggered by hastened snow runoff, but winter rain events may be accompanied by more frequent scouring of the streambed and erratic peaks of sediment load and turbidity. Because biomass is often used as an index of productivity (e.g. Davis et al. 2012) due to relatively simple assessment, understanding the relationship between primary producer biomass and production is important for the understanding of primary producer response to these dynamic environmental controls.

Here, I report the results of a study that builds on past and on-going studies conducted in the Big Creek watershed of central Idaho and contributes new information and understanding regarding factors influencing variation in stream primary production. The overarching goal of this study was to provide basic information about the rates of primary production in wilderness streams, evaluation of factors potentially affecting this important ecosystem process, and insight into how it may occur under future conditions. Specifically, the goal of this study was [for a suite of mountain streams] to assess the relationships between gross primary productivity (GPP) and biomass, as well as to evaluate the relationships of these parameters to various environmental factors. More specifically, our aims were to 1) assess the relationships between primary producer biomass and rates of primary production on rocks from a suite of mountain streams and 2) to investigate potential interactions between primary production and a suite of environmental factors that vary along these streams.

## METHODS

### *Study Site*

Sampling was conducted in five tributaries within the Big Creek watershed in the Frank Church 'River of No Return' Wilderness, central Idaho. The area provides a unique opportunity to study stream ecosystems in a wilderness context, having been largely unaffected by anthropogenic impacts. Big Creek is a 6<sup>th</sup> order river with a mean elevation of 2117 m and a drainage area of approximately 1444 km<sup>2</sup> which flows into the Middle Fork Salmon River. The drainage is dominated by Ponderosa pine (*Pinus ponderosa*) and Douglas fir (*Pseudotsuga menziesii*) mosaic forest, sagebrush (*Artemisia*) and grass shrub-steppe, and felsic, intrusive rock outcroppings. The six tributaries sampled for this study ranged from 2<sup>nd</sup> to 5<sup>th</sup> order streams with drainage areas ranging from 7.9 to 243.4 km<sup>2</sup> (Davis et al. 2012). Rush Creek, the largest sampled tributary, flows through varying intrusive and extrusive igneous lithology, while other drainages share a common granitic bedrock. The study sites have been part of an extensive 20 year monitoring led by Drs. G. Wayne Minshall and Colden Baxter, and they encompass variation in aspect, drainage area, stream discharge, riparian vegetation, and past disturbance (particularly wildfire) though the drainages are linked by similar lithology (although there may be some potentially important differences e.g. Rush Creek) and regional climate.

### *Sampling and analyses*

We measured periphyton (a complex matrix of algae and heterotrophic microbes attached to submerged substrate), standing crop biomass, and rates of primary production in each of five tributaries of Big Creek in the vicinity of Taylor Wilderness Field Station (Rush, Cliff, Pioneer, Cougar, and Goat creeks) during three sample periods corresponding to early, mid, and late summer. In each stream, individual rocks were collected and placed in metabolism microcosms (e.g. Hoellein et al. 2009) for productivity and respiration measurements; these rocks were also utilized to measure periphyton and biomass. Thirty chambers, a combination of 32 oz. and 4 oz.,

were used to sample each stream; chamber size was assigned according to the size of rocks, based on surveys of particle sizes conducted annually in each stream (Davis et al, 2001). Four blanks filled with filtered stream water were utilized for each chamber size to account for any signals of production that might be suspended in the water column. Rocks randomly chosen for use in metabolism microcosms were placed in the chambers to establish isolation from atmospheric reaeration and submerged in the stream to preserve ambient temperature conditions. The dynamics of oxygen within the chambers were used to estimate rates of rock biota metabolism, as both GPP and community respiration (CR) are constituents of metabolism (Bott et al. 1996, Hoellein et al. 2009). Chamber measurements were conducted across the five sites in randomized order, during consistent periods of the day, typically from 9 a.m. to 1 p.m.) from July 7<sup>th</sup> to August 13<sup>th</sup> 2011. In the process of conducting chamber experiments, care was taken to minimize disturbance to the periphyton community.

Rocks selected for use in microcosms were chosen to represent the particle sizes found in the study streams and of sizes that are typically used to measure biomass of periphyton during annual monitoring of these streams conducted by Drs. Baxter and Minshall (Davis et al. 2001, 2012). Stream water used in microcosms was filtered through a 54 micrometer sieve in order to eliminate suspended fine sediment that might affect periphyton productivity. To fill each microcosm, selected rocks were carefully (to avoid disturbance of the periphyton) placed in microcosms and then submerged in a bucket of filtered stream water to rid the chamber of any air bubble inclusions. In order to eliminate the effect of dislodged periphyton in the chambers, fresh, filtered stream water was repeatedly added to the large container (bucket) used to submerge microcosms. Before carefully sealing each microcosm chamber, water in each chamber was systematically tested for initial temperature and dissolved oxygen near the rock

surface using an optical dissolved oxygen probe (YSI Inc. SonTek). After being tightly sealed, each chamber was removed from the bucket of filtered stream water, carefully inverted, and placed into the stream. Microcosms were placed in randomized locations within patches of the streambed with light input representative of the overall site (Fig.1). Microcosm chambers were left in the stream for a two-hour incubation period (Hoellein et al. 2009).

After incubation, temperature and dissolved oxygen were measured again in each microcosm to measure the change in oxygen in the light. The chambers were then filled with fresh, filtered stream water to prevent nutrient depletion from dislodged, suspended periphyton contamination, and the same rocks were incubated in a similar manner in the dark to obtain dissolved oxygen readings for an additional two hour period (Odum 1956, Bott 1996). To establish a dark condition, the sealed chambers were placed in opaque plastic bags. The plastic bags and chambers were submerged in the flowing stream water to maintain temperature representative of the ambient conditions of the stream.

After the second incubation was complete and final oxygen recordings had been collected, rocks were removed and periphyton was scrubbed from their entire surface. A subsample of the composited slurry from each rock was filtered through a 0.7  $\mu\text{m}$ , pre-ashed, glass-fiber filter. Filters were then wrapped in aluminum foil, labeled, and frozen to await lab processing at the end of the field season. Planar surface tracings were made of each rock for circumference estimates; rock surface area was then approximated by weighing individual cut outs and applying a paper weight-to-surface area regression. The rock surface area calculation allowed for biomass and productivity rates to be expressed on a per area basis.

Standing crop biomass of periphyton for each rock was then estimated after the field season was complete by using standard laboratory methods (Steinman et. al 1996, Davis et al.

2001) to quantify chlorophyll-*a* (chl-*a*) concentration and ash-free dry mass (AFDM). The filters were each extracted with 10 mL of methanol for 12 hours in individual centrifuge tubes. After extraction, the tubes were placed in a centrifuge for 20 minutes at 3000 rpm. Using a pipette, 3 mL of the homogeneous methanol mixture was then removed from each sample and placed in a 4 mL cuvette. The extract was then analyzed at 664 and 750 nm wavelengths pre-acidification and at 665 and 750 nm wavelengths post-acidification using a spectrophotometer. Samples were acidified to correct for pheophyton with two drops of a 0.1N HCl solution. After processing, filters and the remaining 7mL of methanol in the centrifuges were placed in ashed, pre-weighed crucibles and left in a drying oven for 12 hours at 60°C. The dried filters were then weighed in the crucible to obtain a dry weight reading then placed in a muffle furnace at 550°C for 4 hours. After ashing, a few drops of deionized water were added to each sample; the crucibles containing the samples were then placed in the drying oven for several hours before a final ashed weight was obtained for each sample. The chl-*a* analysis and AFDM measurements were utilized for the biomass and productivity assessment of each sample. AFDM provides a measurement of all organic matter, living or senesced, within the samples whereas chl-*a* measures living autotrophs contributing to productivity (Davis et al. 2012). Analysis was focused on comparison of GPP to biomass across all streams, as well as on an individual, stream-by-stream basis.

Additional parameters of the study included measurements of solar insolation, stream discharge and tributary hydrologic regimes, stream nutrient content. Tributary hydrologic regimes were monitored using pressure transducers which were installed on Rush, Pioneer, Cliff, Cougar, Goat, and Duncce Creeks at sites established by previous ISU DeVlieg graduate researcher N. Olson (Olson 2010). The pressure transducers recorded tributary water levels at fifteen-minute intervals and, when combined with stage-discharge relationships established for

each site, allowed for continual hydrologic monitoring. Monthly discharge measurements were used to update these relationships during the frame of this study. In addition to water level, these sensors also recorded stream temperature, used in calculation of degree-day values for each site.

Nutrient (N and P) concentrations were determined by collecting water samples from each site during each of the periods during which primary production is estimated. Samples were stored frozen and returned to the analytical chemistry laboratory of the Center for Ecological Research and Education (CERE) at Idaho State University for measurements of concentrations of total nitrogen (TN), nitrate-nitrite, and non-purgable organic carbon (NPOC).

Light input was monitored using a LI-COR handheld photosynthetically active radiation (PAR) meter. Light surveys were conducted at mid-day along 100-meter reaches of the study sites to generate estimates of light input to each of the stream reaches. These surveys included approximately 20 measurements encompassing the natural heterogeneity of riparian canopy influence within streams. PAR measurements were then processed using a weighted average to determine representative light input estimates of study sites.

In addition, Taylor Wilderness Field Station installed a RAWS (remote automated weather station) in 2008 that independently records climate measurements made available to the National Weather Service. This station measures hourly temperature, dew point, relative humidity, wind velocity, solar radiation, and accumulated precipitation. Data from the weather station were utilized to further monitor meteorological conditions (i.e. weather patterns, air temperature, and solar radiation) of the study area.

A comprehensive comparative framework utilizing GPP, CR, temperature, nutrients, drainage area, aspect, and flow regime were used for analyses. Drainage aspect and area calculations were obtained from Olson 2010. The processing of these data provided comparative



framework analyzing the combination of environmental variables and their mechanistic controls on the gradients of mountain stream primary production. Comparative matrices and stepwise regression were used to measure individual and synergistic relations of environmental factors. The assessment of these parameters, provide a greater collective understanding of the influence of these mechanisms on mountain stream primary productivity (e.g., Lamberti et al. 1987). As many of these gradients are likely to be influenced by climate change, understanding of the current controls on primary production may influence prescriptive awareness of how these environmental factors may influence future ecological responses. Rush Creek was approached as a possible outlier in these assessments as it has been shown to be P and N co-limited, linked to varying lithology, and levels of productivity may be more influenced by levels of phosphorus than by the levels nitrogen as anticipated by the remaining sample streams; for these reasons it was methodically omitted from some comparative analyses.

## RESULTS

For the relations of GPP to benthic biomass, we observed that AFDM was the strongest predictor of GPP ( $R^2=0.92$ ) followed by the AFDM to chl-*a* ratio ( $R^2=0.71$ ) and chl-*a* ( $R^2=0.65$ ). AFDM was also the strongest predictor of CR ( $R^2=0.70$ ) followed by the AFDM to chl-*a* ratio ( $R^2=0.30$ ) and chl-*a* ( $R^2=0.26$ ) (Fig. 2) Average GPP, average chl-*a*, average AFDM, and the average chl-*a* to AFDM ratio tended to increase throughout the summer. Linear trends for GPP vs. Average Chl-*a*, AFDM, and the Average Chl-*a* to AFDM ratio also strengthened as the summer progressed. Figure 3 shows the increasing linearity for GPP vs. chl-*a* throughout the sampling periods. Smaller Big Creek tributaries (i.e. Duncce Creek and Goat Creek) reached their peak values during the second of the three sample periods for average GPP, average chl-*a*, chl-*a* to AFDM ratio, whereas these values appeared to continually increase throughout the season for

the remaining larger streams. Average GPP exhibited stronger changes in time than CR. Overall, scale appeared to be influential within analyses as GPP to chl-*a*, AFDM, and chl-*a* to AFDM relationships proved to be stronger on a stream-by-stream basis. Stream productivity relationships tended to follow largely linear relations, though slight curvilinear associations were observable for the relationships of chl-*a* to GPP on a per-stream basis. Table one includes the season averages of all factors included in this study.

With Rush Creek as an outlier, GPP had a strong linear relationship with TN ( $R^2=0.89$ ), and  $\text{NO}_2/\text{NO}_3$  had a strong linear correlation with CR ( $R^2=0.93$ ). Cliff Creek and Pioneer Creek had the highest levels of  $\text{NO}_2/\text{NO}_3$ . Cliff Creek and Dunce Creek had the highest TN values. Rush Creek was the only stream with detectable levels of  $\text{PO}_4$  (0.01 mg/L detection limit). Dunce, Cliff, and Rush creeks had greater levels of PAR than Cougar, Goat, and Pioneer creeks (Table 1). GPP had a strong linear and power correlation with PAR ( $R^2=0.74$ , 0.80 respectively). Net Primary Productivity (NPP) increased as the summer progressed for all study streams except for Dunce, which had a peak NPP value during the second of three sample periods.

As derived from stepwise multiple regression of environmental parameters, PAR was the most influential factor (partial  $R^2=0.74$ ) on GPP. The model stepwise regression for all streams, excluding Rush Creek, also yielded PAR as the most influential parameter on GPP ( $R^2=0.67$ ) along with  $\text{NO}_2/\text{NO}_3$  ( $R^2=0.29$ ) and degree days ( $R^2=0.04$ ). Combined, the three factors established a model  $R^2$  value of 0.99. Figure 4 shows the relationship among sample period averages for GPP, PAR and  $\text{NO}_2/\text{NO}_3$ . The timing of peak flow also explained some of the variation of GPP; such that the combined model between PAR and peak flow timing explained 97% of variation. A comparative matrix of all study parameter averages for all streams yielded Pearson correlation coefficients of 0.84 for aspect and degree-days, 0.62 for aspect and TN, .61

for PAR and degree-days, and -0.63 for aspect and peak flow timing. When the outlier, Rush Creek, was excluded from the comparative matrix, degree days remained the most influential factor. A comparative matrix of all study parameter averages, for all streams except Rush Creek, yielded Pearson correlation coefficients of 0.97 for aspect to degree days, 0.95 for PAR to TN, 0.82 for GPP to PAR, 0.67 for PAR to aspect, and 0.55 for PAR to degree days.

## DISCUSSION

Our results suggest that the biomass of streambed periphyton, as commonly monitored in streams of this region, is closely related to estimated rates of primary production and community respiration on rocks during the summer months. These relationships are generally linear and appear to become more so as summer progresses. AFDM was the strongest predictor of both primary production and CR followed by the chl-*a* to AFDM ratio and chl-*a*. This may suggest that biomass, in contrast to chl-*a* alone, may actually be a better predictor of productivity than initially thought. Biomass is commonly used as a proxy for freshwater primary production, due to its ease of measurement, though its reliability of such has been contested (Bott et al., 1996). The comparison of GPP to AFDM provides a basis by which productivity can be compared against biomass. This analysis demonstrated that a general increase in GPP reflects an analogous increase in biomass. Overall, the linearity of P:B ratios was reflected in patterns across all study streams, and the linearity increased throughout the season.

This increasing linearity likely is influenced by drainage heterogeneity (i.e. area, aspect, canopy) influencing initial productivity early in the season. Smaller drainages, as well as south facing, burned drainages receiving large amounts on unobstructed solar radiation, reached their peak productivity earlier in the season. These drainages exhibited greater relative productivity earlier in the season as compared to their biomass. As the season progressed, biomass began to

increase at a rate to more closely mimic the rate of productivity. In large, north facing, or unburned drainages, the P:B ratio was tighter throughout the season, and the applicability of biomass as a measurement of productivity held true to a greater degree throughout all sample periods.

The weak curvilinear trends recognized in P:B ratios may reflect threshold relations between benthic biomass and stream discharge or invertebrate grazing. The linearity of the P:B ratios may also be a product of the level of spatial and temporal variability within the sample set as well as the size of the sample set itself. Although correlations were determined to be largely linear, weak curvilinear correlations can be discerned from the comparison of GPP to chl-*a* suggest that a threshold mechanism may be controlling increased levels of chl-*a* in which high levels of biomass can correlate to low levels of productivity. This non-linear correlation between production and biomass is consistent with vast literature regarding this relationship. Stream-by-stream evaluations produce more evident trends linking production and photosynthetically active biomass.

It is important to recognize that the rates of metabolism recorded on individual rocks may not correspond directly to whole ecosystem measures of metabolism. The productivity on individual rocks may not scale to whole ecosystem production as the productivity on a rock, or even the productivity averaged over a range of streambed rocks at a sample site, provides a highly oversimplified estimate of the benthic environment. The chamber experiments do not account for water flow variation, do not exactly mimic temperature conditions. As stream primary producers may account for much of the productivity in aquatic environments (Bott 1996), stream GPP may be more represented by chamber estimates; however, CR estimates may

to prove to deviate from chamber estimates because the influence of hyporheic exchange and some mosses will likely have a substantial effect on whole ecosystem rates of CR.

This study suggests that during the summertime, the strongest predictor of GPP of periphyton on rocks within study streams was light, with weaker contributions of nitrogen and temperature respectively. Light is likely such a limiting factor among the study streams due to its high variability among the sites. The level of solar radiation reaching study sites was influenced by multiple varying parameters including aspect, stream width, and burn history.

The lithology of the study drainages is predominately granitic Tertiary batholiths, and consequently nutrient poor and largely nitrogen limited, for all study sites excluding Rush Creek. The Rush Creek drainage is much larger than the other study sites and encompasses a greater spread of Proterozoic meta-sediments and Tertiary volcanics (Lund, 2004). Consequently, Rush Creek has a greater nutrient influence and the relationship between GPP and nutrients may not be straightforward. The stream may have a N and P co-limitation. Hence, rates of nutrient uptake may vary substantially between Rush Creek and the other study streams. Watershed area is another factor affecting nutrient dynamics in region, especially where catchment lithology is largely nutrient poor. Sources of nitrogen, however, are likely to be fairly consistent throughout all study streams. All of the study streams have evident cyanobacteria, predominately *Nostoc commune*, acting as nitrogen fixers (Marcarelli et al.) Atmospheric nitrogen deposition may prove to be an important source of nitrogen in this nutrient poor area. The impact of climate change on this parameter as well as on light regime (i.e. shifts in vegetation, fire regimes, beetle kill) may become a much more important for mountain stream ecosystem in the future (Davis et al., in press).

For this population of streams, the lack of synergistic influence between PAR and

temperature on GPP suggests that temperature is likely less of a limiting factor on GPP than other environmental variables. This is true for this set of streams as the temperature of the streams is more strongly controlled by stream width and riparian coverage than by sunlight alone. Here, drainage area and light availability drive temperature variation (Malison and Baxter, 2010). The strong correlation between temperature and aspect magnifies the influence of aspect in snow-dominated, mountains streams

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## LITERATURE CITED

- Allan, D. J. and M. M. Castillo. 1995. Stream ecology: structure and function of running waters. Chapman and Hall, New York.
- Bott, T. L. Primary productivity and community respiration. pp. 663-691 in *Methods in Stream Ecology*, F.R. Hauer and G.A. Lamberti (eds). Chapter 28. Academic Press, San Diego.
- Bott, T. L., J. T. Brock, A. Baattrup-Pedersen et al. 1996. An evaluation of techniques for measuring periphyton metabolism in chambers. *Canadian Journal of Fisheries and Aquatic Sciences* 54:715-725.
- Bott, T. L. 1985. Benthic community metabolism in four temperate stream systems: An inter-biome comparison and evaluation of the river continuum concept. *Hydrobiologia* 123:3-45.
- Davis, J. M., C.V. Baxter, G. W. Minshall, N.F. Olson, C. Tang, and B.T. Crosby. 2012. Climate-induced shift in hydrologic regime alters basal resource dynamics in a wilderness river ecosystem.
- Davis, J. M., C. V. Baxter, B. Crosby, E. Rosi-Marshall, J. Pierce. In press. Incorporating indirect effects into a conceptual model for predicting responses of stream-riparian ecosystems to global climate change.
- Davis, J. C., G. W. Minshall, C.T. Robinson, and P. Landres. 2001. Monitoring wilderness stream ecosystems. General Technical Report RMRS-GTR-70.
- Hoellein, T. J., J. L. Tank, E.J. Rosi-Marshall, and S.A. Entrekin. 2009. Temporal variation in substratum-specific rates of N uptake and metabolism and their

- contribution at the stream reach scale. *Journal of the North American Benthological Society* 28(2): 305-318.
- Kunkel M. L. and J. L. Pierce. 2010. Reconstructing snowmelt in Idaho's watershed using historic streamflow records. *Climatic Change* 98:155-176.
- Lamberti, G. A., L. R. Ashkenas, S.V. Gregory, and A.D. Steinman. 1987. Effects of three herbivores on periphyton communities in laboratory streams. *Journal of the North American Benthological Society* 6(2): 92-104.
- Larned, Scott T. 2010. A prospectus for periphyton: recent and future ecological research. *Journal of the North American Benthological Society*. 29(1): 172-206.
- Lund, K., 2004. Geology of the Payette National Forest and vicinity, west-central Idaho, U.S. Geological Survey Professional Paper 1666 89p.
- Malison, R. L. and C.V. Baxter. Effects of wildfire of varying severity on benthic stream insect assemblages and emergence. 2010. *Journal of North American Benthological Society* 29:1324-1338.
- Minshall G. W., Robinson CT, Lawrence DE, Andrews DA, Brock JT. 2001. Benthic macroinvertebrate assemblages in five central Idaho (USA) streams over a 10-year period following disturbance by wildfire. *Int. J. Wildland Fire* 10:201-213
- Odum, H. T. 1956. Primary production in flowing waters. *Limnology and Oceanography* 1:102-117.
- Olson, N. 2010. Hydrology of Big Creek, Idaho: A snow dominated wilderness mountain watershed. MS Thesis, Idaho State University.
- Steinman, A. D., G. A. Lamberti, and P.R. Leavitt. 1996. Biomass and Pigments of



Benthic Algae, pp. 357-379 in *Methods in Stream Ecology*, F.R. Hauer and G.A. Lamberti (eds), Academic Press, San Diego.

Stewart, I.T. 2009. Changes in snowpack and snowmelt runoff for key mountain regions. *Hydrological Processes* 23:78-94.

Westerling A. L., H. G. Hidalgo, D.R. Cayan, and T.W. Swetnam. 2006. Warming and earlier spring increase western US forest wildfire activity. *Science* 313:940-943.

## FIGURE LEDGENDS

Figure 1. The metabolism microcosms used in to gather primary production data in Cliff Creek during the 2011 summer .

Figure 2. The seasonal relationship between GPP and chl-*a*, AFDM, and the chl-*a* to AFDM ratio during the 2011 summer in the lower Big Creek watershed, Idaho.

Figure 3. Graphs showing the increasing linearity of the GPP to chl-*a* relationship throughout the sample season. This relationship showed the strongest pattern of increasing linearity with time. The top graph represents sampling conducted from July 7 to July 23, the middle graph from July 24 to August 4, and the bottom graph from August 6 to August 13.

Figure 4. This graph shows the relationship among the season averages of GPP, NO<sub>2</sub>/NO<sub>3</sub>, and PAR for the study streams.

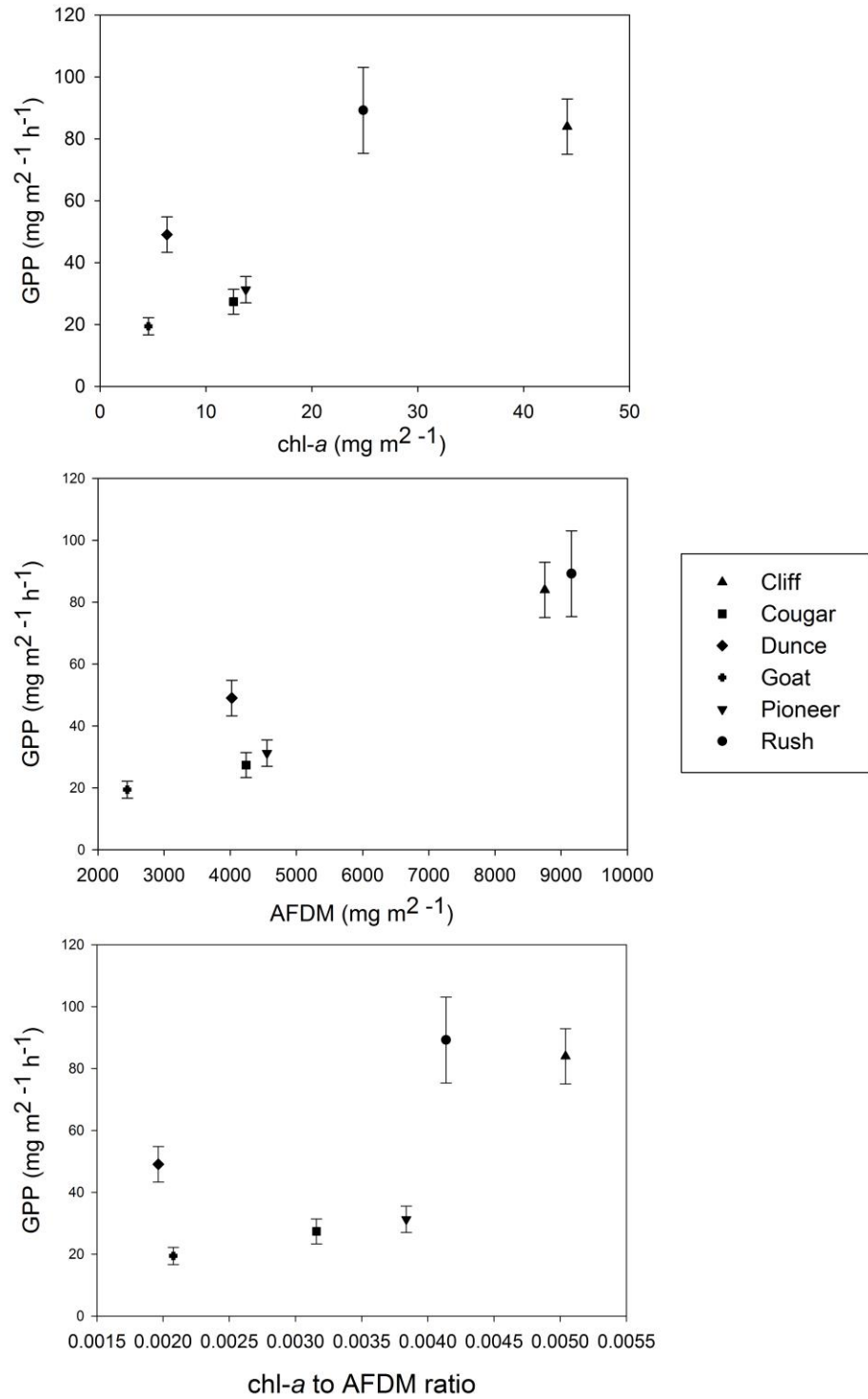
## TABLE LEGEND

Table 1. Measurements of environmental variables and ecosystem processes (season averages +/- 1SE for six tributaries in the lower Big Creek watershed, Idaho.

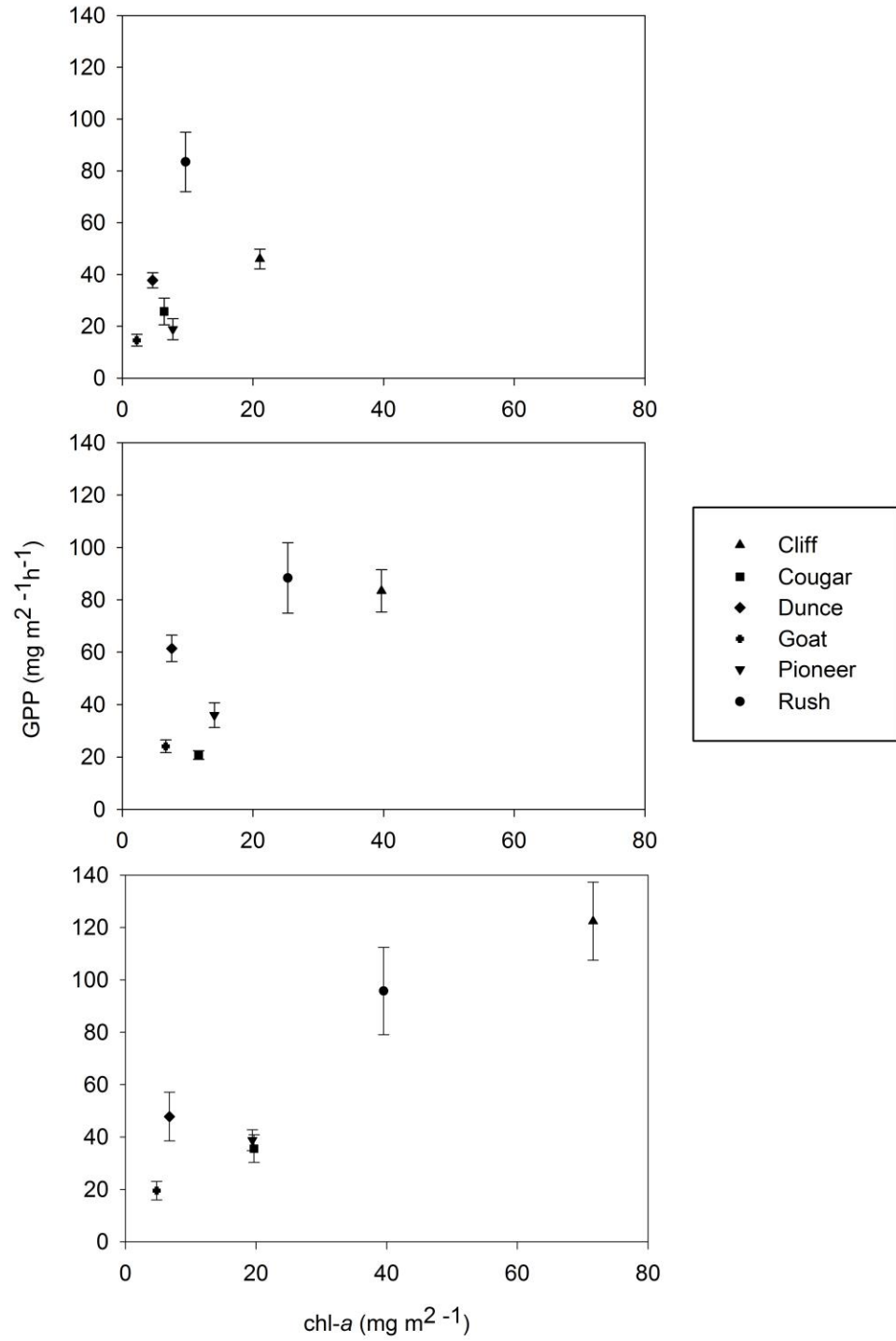
Gardner Figure 1



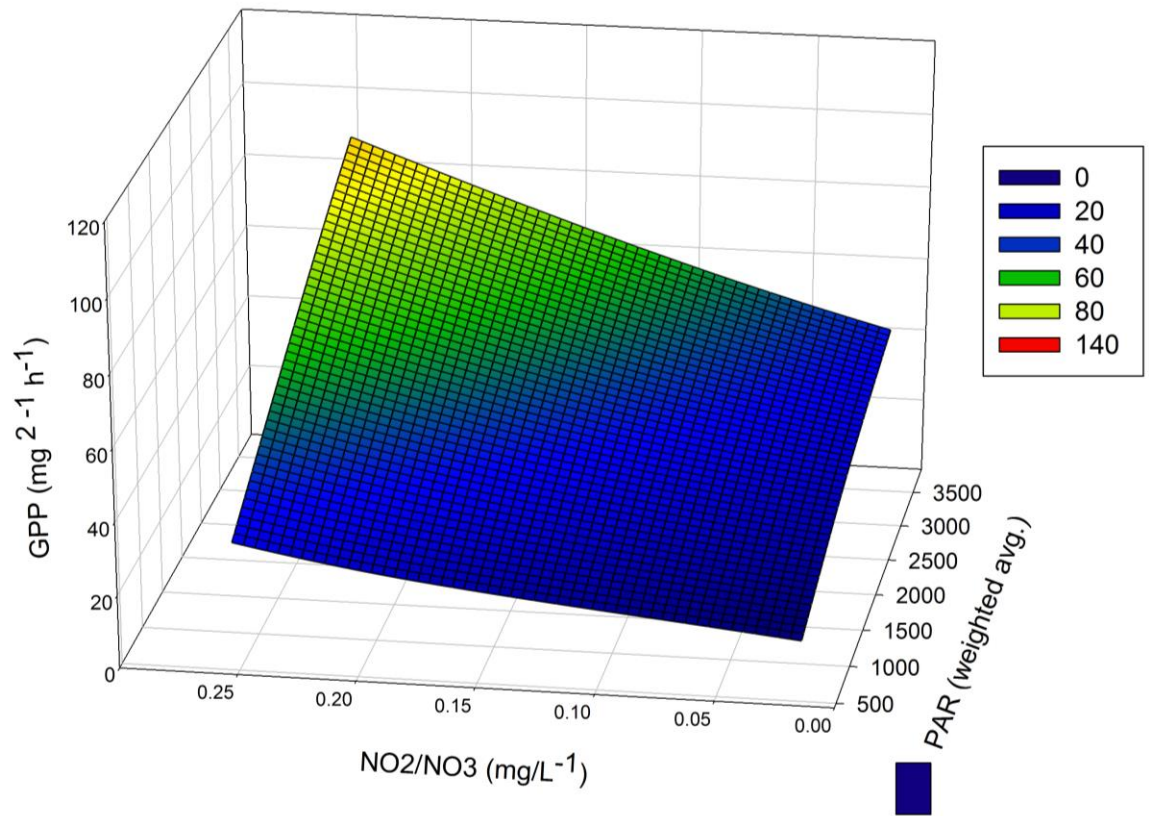
Gardner. Figure 2



Gardner. Figure 3



Gardner. Figure 4



Gardner. Table 1

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Stream Averages

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Stream	GPP (mg/m <sup>2</sup> /h)	CR (mg/m <sup>2</sup> /h)	NPOC (mg/L)	TN (mg/L)	Degree Days (°C)	PAR (μ mol)	Estimated Peak Flow Date	Aspect (%S)
Cliff	83.94 (8.93)	16.81 (2.57)	1.81 (.50)	0.33 (.04)	3.50 (.54)	3423.75(1240)	6/10/11	31.03
Cougar	27.35 (4.03)	10.03 (1.78)	4.55 (.50)	0.17 (.04)	4.09 (.54)	1480.40 (1145)	6/9/11	28.2
Dunce	48.00 (5.75)	12.50 (2.09)	1.88 (.50)	0.28 (.04)	4.25 (.54)	3730.64 (1403)	5/15/11	34.94
Goat	19.40 (2.76)	10.04 (1.32)	1.88 (.50)	0.13 (.04)	3.25 (.54)	439.35 (807)	6/10/11	26.58
Pioneer	31.23 (4.27)	13.34 (3.23)	1.35 (.50)	0.14 (.04)	0.81 (.54)	782.32 (733)	6/14/11	7.7
Rush	89.18 (13.86)	22.73 (4.34)	1.36 (.50)	0.11 (.04)	4.28 (.54)	3832.36 (1380)	6/15/11	21.64

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