Report for 2004PA30B: Nitrogen dynamics in the Spring Creek watershed (Pennsylvania, USA): Evaluating stream retention of point and non-point source loadings

There are no reported publications resulting from this project.

Report Follows

Abstract:

This project will assess the quantitative effect point and non-point watershed source loads (as estimated by stable isotope ratios and traditional wet chemistry) have on the retention of nutrients within the body of the Spring Creek ecosystem. Characterization of the sources of stream nitrate through analysis of stable isotopes and inorganic chemistry is expected to allow estimation of the relative magnitudes of various nitrogen sources at key locations with the streambed of the ecosystem. Finally, first order evaluation of the fate of N-loadings to Spring Creek will be accomplished by measuring the biomass, nutrient stoiciometry, and growth of resident biota. In this manner, I can evaluate the relative contribution of anthropogenic sources to the overall production of new (net) periphyton biomass within the streambed, and the transfer of this material to the next, step-wise trophic level in the food chain. The relative comparison of up and downstream sites can be used to, not only evaluate the addition of unique loads within the watershed, but the cumulative effect of loading on the stream ecosystems.

Statement of Critical Need:

The total maximum daily loads (TMDL's) to specific aquatic ecosystems are largely determined through modeling point and non-point land use practices of surrounding watersheds, as calibrated against limited water quality monitoring (e.g., Steinman et al. 2000). While this has proved to be an important and useful management construct, the actual influence of realized loads on the health (and therefore consequences of loads) is more difficult to ascertain. This project will assess the quantitative effect point and non-point watershed source loads (as estimated by stable isotope ratios and traditional wet chemistry) have on the retention of nutrients within the body of the Spring Creek ecosystem. The retention of material loads will be compared with variation in the biomass, production, and species composition of the resident biological community of periphyton.

Statement of Results of Benefits:

I expect to identify the retention of unique sources of nitrogen loading to spring Creek within the resident stream biota. The use of stable isotopes, in concert with traditional wet chemistry sampling is one of the only ways known to accomplish this task. While point sources are rather straight-forward to estimate, non-point sources can be very difficult to evaluate, and therefore require creative and new methods. I believe my approach will work, because, specific loads will likely have unique ^{15}N and ^{18}O signatures (fertilizers, animal manure, human wastes) that could not be distinguished by measuring gross quantities of nitrogen, as is the case with conventional wet chemistry techniques.

Finally, we can make a first order evaluation of the fate of N-loadings to Spring Creek by sampling biota among major trophic levels. Nitrogen signals in stream biota can be traced to specific watershed loads and variation in the trophic transfer of nitrogen can be tracked using ^{15}N (Adams and Sterner 2000). Our investigation of the resident periphyton assemblage and functional groups of macroinvertebrates from headwater and down-stream locations will allow us to determine if variations in nitrogen loading along the stream continuum causes differences in the trophic increase in ^{15}N, as well as N retention in the stream-bed in key reaches of the Spring Creek ecosystem. A simple trophic transfer model will be used to calculate efficiency (see Wetzel 2001) in affected and unaffected areas in order to evaluate the relative cost of N-loading on the local fishery. The model applied here will estimate retention from the difference between nutrient uptake by the biota (nutrient stoiciometry versus growth) and total available delivery of nutrients in that portion of the streambed.

This research will support several forms of scientific progress. First, the results from this project will be used to formulate a larger research proposal to retain more substantial support for this work (National Science Foundation or PA State Agency). Second, preliminary results from this project will constitute a research report that can be published in a referred scientific journal. Third, aspects of this information will be used to augment instruction in several courses through the further development of lab-field based exercises.

Nature, Scope and Objectives:

Given their size and position within watersheds, prominent lake and river ecosystems integrate conditions from the surrounding landscape, often serving as barometers of local, regional, and global-scale change (Wetzel 2001). Cultural eutrophication is a problem of epidemic proportion in the United States, and this issue is particularly pronounced in lakes and rivers that are in close proximity to the demands of a growing human population (Karr 1993). Elevated material loading from changing land-use (urban and agricultural practices) has had a measurable effect on aquatic ecosystems throughout the state of Pennsylvania, where more that 2,500 miles of native stream receive some degree of impact (see Landis 1995).

Spring Creek (4^{th} order stream) is an important tributary to the Susquehanna River, which in turn constitutes the major source of water (and nutrients) to the Chesapeake Bay. The stream serves as an important water resource for two urban centers in central Pennsylvania (St. College and Bellefonte, PA), and in the early part of the century it supported a productive native brook trout fishery that has been subsequently displaced through the stocking of brown trout (Wohl and Carline 1996). By the mid 1950's, water quality was impacted (weed growth, oxygen depletion) by the addition of sewage effluent (Landis 1995). Moreover, the introduction of toxic chemicals (e.g., Kepone, Mirex, and chlorine) into the stream was associated with major fish kills downstream (Landis 1995). By 1981, all stocking efforts ended and a no-kill policy was put into place, due to the high levels of Kepone and Mirex found in fish tissue, such that the stream again supports a premier brown trout fishery that is nationally recognized (Carline et al. 1991).

Having said this, water quality in Spring Creek has been an issue for over 30 years and recent declines are of particular concern. Point source nutrient loads can be attributed to three municipal wastewater treatment plants and two fish hatcheries within the watershed, all of which have been in violation of their pollution discharge permits (Bradley et al. 2002). Moreover, sediment loading from non-point sources appears to be responsible for compromised fish spawning habitat in stream reaches fed by portions of the watershed where agricultural activities (land drained by Slab Cabin and Cedar Runs) are widespread (Beard and Carline 1991). Finally, a survey of 17 sites in Spring Creek and its major tributaries showed that 8 of the sites supported impaired water quality and benthic macroinvertebrate species composition; the poorest sites were in proximity to known point and non-point sources (Hughey 2002). While references have been made to the development and growth of nuisance plants within the streambed (see Spring Creek Watershed Community, http://www.springcreekwatershed.org), few if any studies have been done to evaluate the cause of excessive plant growth, its growth relative to material loads, or their influence on the function of the stream.

Identification of the source of nitrate in streams can be facilitated by using 15N and 18O stable isotope signatures along with inorganic water chemistry. Nitrate from point sources such as fish hatcheries and sewage treatment plants and non-point sources such as septage, urban runoff, agricultural lands, and atmospheric deposition can be characterized using stable isotope signatures. I hypothesize that- *stable isotope signatures and inorganic water chemistry can be used to identify sources of nitrate in streams* (Williard et al.2001). As a first step in testing this hypothesis, I will characterize sources of nitrate at their origin and in streams within the Spring Creek basin. In addition, Spring Creek supports relatively simple food-web structure with few benthic macroinvertebrate taxa (see Hughey 2002) and an expansive coverage of attached algae (Carrick, unpublished data). This in turn allows for a clearly identification of a single trophic step in the food web. I plan to test the hypothesis- *variation in the nitrogen loading to a system affects the magnitude trophic transfer of resident biological community*. I will address this hypothesis by measuring the ^{15}N content within a single trophic step (algae to dominant invertebrate grazer) at up-stream and down-stream sites relative to known anthropogenic sources of nitrogenous inputs to Spring Creek. Spring Creek is an ideal *in situ* study site for this investigation, because it has several isolated point sources of anthropogenic nitrogenous inputs (three sewage plants and two fish hatcheries), which are known to contribute to downstream increases in ammonium and nitrate (Bradley et al. 2002; Hughey 2002). Last, the content of the stable isotope of nitrogen (^{15}N) in the tissue of living organisms increases in a stepwise fashion with increasing trophic position (from plants to herbivores to carnivores; Minawaga and Wada 1984). In this way, I plan to track unique source loads of N that are retained by stream biota, and thus predict the retention of loaded N in Spring Creek.

Methods, Procedures and Facilities:

<u>Watershed Sampling Design:</u>
We plan to estimate watershed-scale source loadings and stream retention of N in the Spring Creek ecosystem by sampling key in stream locations that reflect unique watershed loading scenarios (SPU- below Galbraith Gap, SPH-Spring Creek Park, Houserville; SPA-Fisherman's Paradise, Bellefonte). The first site will is located above the Cedar Creek inflow (denoted as SPU by SCWC), and is influenced by few point sources and several non-point sources loads (Galbraith Gap draining Tussey Mountain, municipal Golf course). The second site is located in Houserville (denoted SPH, at USGS gauging station) that integrates loads from Slab Cabin Run, Cedar Run, and two wastewater treatment plants. Lastly, the third site (denoted SPH, at USGS gauging station) receives loadings from one wastewater treatment plant and two fish hatcheries (Bellefonte and Benner Springs Fish Culture

stations). At all sites, stream samples will retrieved at one mid-stream location and for water analysis, and at left, mid, and right bank locations for tissue nutrient content of major stream organism (periphyton and macroinvertebrates).

All samples will be retrieved at five intervals throughout 2004-05 (same day collections) to characterize major flow periods throughout the year based on the annual hydrograph data (mid winter low-flow, winter/spring high-flow, early summer moderate-flow, mid summer/late low-flow, fall high-flow). Sampling of sites for stable isotopes signatures of dissolved nitrate will be limited by budget. Preliminary samples of nitrate in precipitation, sewage effluent, septage, agricultural runoff, fish hatchery discharge, Big Spring spring flow and urban storm runoff will be characterized for isotopes and inorganic chemistry. Several storm samples of streamflow at the mouth of Spring Creek basin at Milesburg will be used to test decision-tree models of nitrate origin.

Sample Processing and Analysis:

Biomass and Nutrient Stoiciometry of Resident Biota- At the three in-stream sites, we will sample across the streambed to characteristics the resident biological community. Algae will be collected from grab samples of natural substrata and placed in one zip-lock bag (see Steinman and Lamberti. 1996). Macroinvertebrates will be individual picked from the rocks sampled for periphyton (Hauer and Resh 1996). The nutrient content of algae and key macroinvertebrates (mainly *Lirceus* and *Gammarus*) will be evaluated by measuring concentrations of total phosphorus, nitrogen, and carbon using standard digestions and colorimetric reactions (Wetzel and Likens 2000). The 15-nitrogen stable isotope content of key food web components will be measured using a mass spectrometer (Minawaga and Wada 1984). Both algal and invertebrate samples will be concentrated in sample vials, and suspended in alcohol for subsequent stable isotope analysis (5 dates x 3 sites x 3 habitats x 2 replicates = 90 samples for both periphyton and invertebrates).

Growth of Stream Periphyton- Artificial substrata will be used to estimate the accumulation of nutrients in the tissue of the developing periphyton assemblages at all sites in the stream (Carrick and Lowe 1988). Eight artificial substrata (unglazed clay tiles) will be placed at all three sites and secured to the streambed using bricks during each of the 5 temporal periods. Preliminary analyses show that the flora that develops on the tiles is indistinguishable from the resident periphyton growing on nearby rocks in the stream (Carrick and Adams, unpublished data). Duplicate tiles will be retrieved at one week intervals for a total of four weeks to determine accumulation rates. Once collected, samples will be analyzed from chlorophyll (to estimate biomass), and nutrient stoiciometry (see above).

Nutrient Loads- Analysis for ^{18}O and ^{15}N in nitrate will also be analyzed using a mass spectrometer. Inorganic water chemistry will be analyzed at the Water Lab, Penn State Institutes of the Environment. Characterization of the sources of stream nitrate through analysis of stable isotopes and inorganic chemistry is expected to allow estimation of the relative magnitudes of various nitrogen sources in Spring Creek basin. A simple decision tree model will be developed to determine source of nitrate in stream water from isotope and inorganic chemical analysis. If perfected, this technique would allow identification of watershed nitrate sources and imply potential solutions without detailed watershed inventories and extensive water quality sampling.

At each site, I will characterize the habitat quality of the streambed and channel (five sampling periods x 3 sites x 2 samples per site = 30 total). The width of the stream will be measured with a forester's tape and condition within the bed will be summarized using a habitat assessment survey (DEP survey form). At 2 locations at each site, water temperature, dissolved oxygen concentration, and conductivity will be measured using an YSI meter. Whole water samples will be collected in clean bottles in order to determine a series of physical-chemical measurements (pH, alkalinity, nitrogen and phosphorus species) using standard wet chemistry techniques (Wetzel and Likens 2000). The N and P data will be compared with those collected by the Clear Water Conservancy (monthly data plus flow measurements) in order to calculate loadings.

Nitrogen Retention in Spring Creek- The retention of material loads will be compared with variation in the biomass, production, and species composition of the resident biological community of periphyton. The difference between the inputs of estimated sources versus uptake/storage of nutrients within resident biota will provide first-order estimates of retention (see Wetzel 2001). In this manner, I can evaluate the relative contribution of anthropogenic sources to the overall production of new (net) periphyton biomass within the streambed, and the transfer of this material to the next, step-wise trophic level in the food chain (see Minawaga and Wada 1984; Adams and Sterner 2000). The relative comparison of up and downstream sites can be used to not only evaluate the addition of unique loads within the watershed, but the cumulative effect of loading on the stream ecosystem.

Principal Findings and Significance:

Periphyton biomass (as chlorophyll concentration) in Spring Creek was measured at three-week intervals at five sites during the March 2004-2005 period (see Figure 1). Values for the downstream sites were very high, with average values being above the 90th percentile for more than 300 temperate streams. Biomass at sites 1 and 2 were modest and appear to reflect the relatively undisturbed nature of the stream reach (Figure 2 and 3). The chlorophyll densities vary significantly over time and across the sites. Two-way ANOVAs evaluating variation in chlorophyll densities among sites and seasons, revealed a significant interaction ($p=0.0001$) between the seasons and sites factors (Figures 2 and 3).

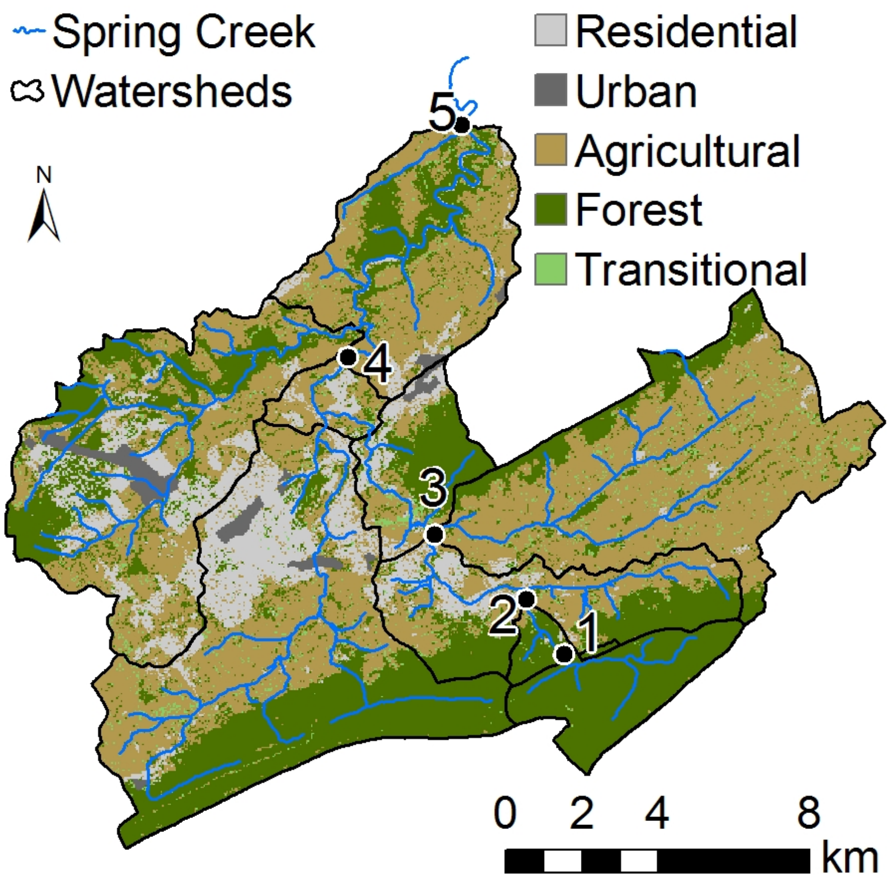
Periphyton in Spring Creek exhibited limited (less than expected) temporal variation. When the effects of season were analyzed at each site using a one-way ANOVA, the fall periods were significantly different than the other seasons at the downstream sites, but no significant differences existed upstream (Figure 2 and 3). Although some of the seasons were not significantly different, it suggests that there may be varying degrees of seasonality among the sites. Interestingly, our sampling period brackets the occurrence of a hurricane that passed through the area in September of 2004 (see Figure 2). The scouring associated with this climatic influence appears to out-weigh the seasonal variation throughout the year, underscoring the relative importance of episodic disturbances.

Average chlorophyll densities increase longitudinally downstream, although sites 4 and 5 supported the highest biomass and were not significantly different from one another (Figure 3). These data indicate that the downstream sites (sites 3, 4, and 5) are likely nutrient enriched from point and non-point sources influences in the watershed. This conclusion is supported further by the stable isotope data measured on periphyton tissue (delta N-15 values), which shows a large increase downstream (range 1-3 upstream to 5-6 downstream), that was analogue to shift typically seen over 1-2 trophic levels in studied food webs. Because we see the shift at one trophic level (algae), we believe this is strong evidence for the incorporation of changing watershed sources N downstream. Interestingly, average chlorophyll at the five sites was highly correlated with increasing conductivity downstream as well ($r=0.94$, $p<0.01$, $n=5$). These results are consistent with predictions made from the River Continuum Concept, where growing watershed loadings impinge on downstream sites relative to upstream, headwater locations.

Nitrogen concentrations in stream water increase significantly from up to downstream locations (range 0.20 to 4.4 mg/liter). Concentrations were low at sites 1 and 2, increase at site 3, and were highest at sites 4 and 5. At the same time, total phosphorus concentrations were low at all sites (<0.200 mg/liter). Having said this, concentrations of N and P were measured in periphyton tissues during all sampling intervals ($n=17$ for all sites). While these data are still being analyzed, preliminary analysis indicates that internal nutrients stores in the periphyton were many times greater compared with those in the overlying water. Moreover, periphyton nutrients concentrations in the periphyton also increase downstream in accord with N concentration in the overlying water.

Two experiments were conducted to evaluate the degree of nutrient limitation exhibited by the periphyton in Spring Creek using nutrient releasing substrata (Control, N, P and N+P additions) that were deployed in the stream at selected sites (Spring and Summer seasons). In April of 2005, no significant difference was noted among enrichment treatments at sites 2 and 4. The result at site-2 was likely due to disturbance and high flow (observation), while we suspect the lack of response at site 4 may reflect the nutrient sufficiency of the periphyton community there. Another experiment was conducted in the summer of 2004 at sites 3 and 5, which also showed no differences among nutrient additions. These preliminary results suggest that periphyton in Spring Creek are nutrient sufficient (not limited), particularly at the downstream sites.

Figure 1. The Spring Creek watershed with five sampling locations and landuse identified.



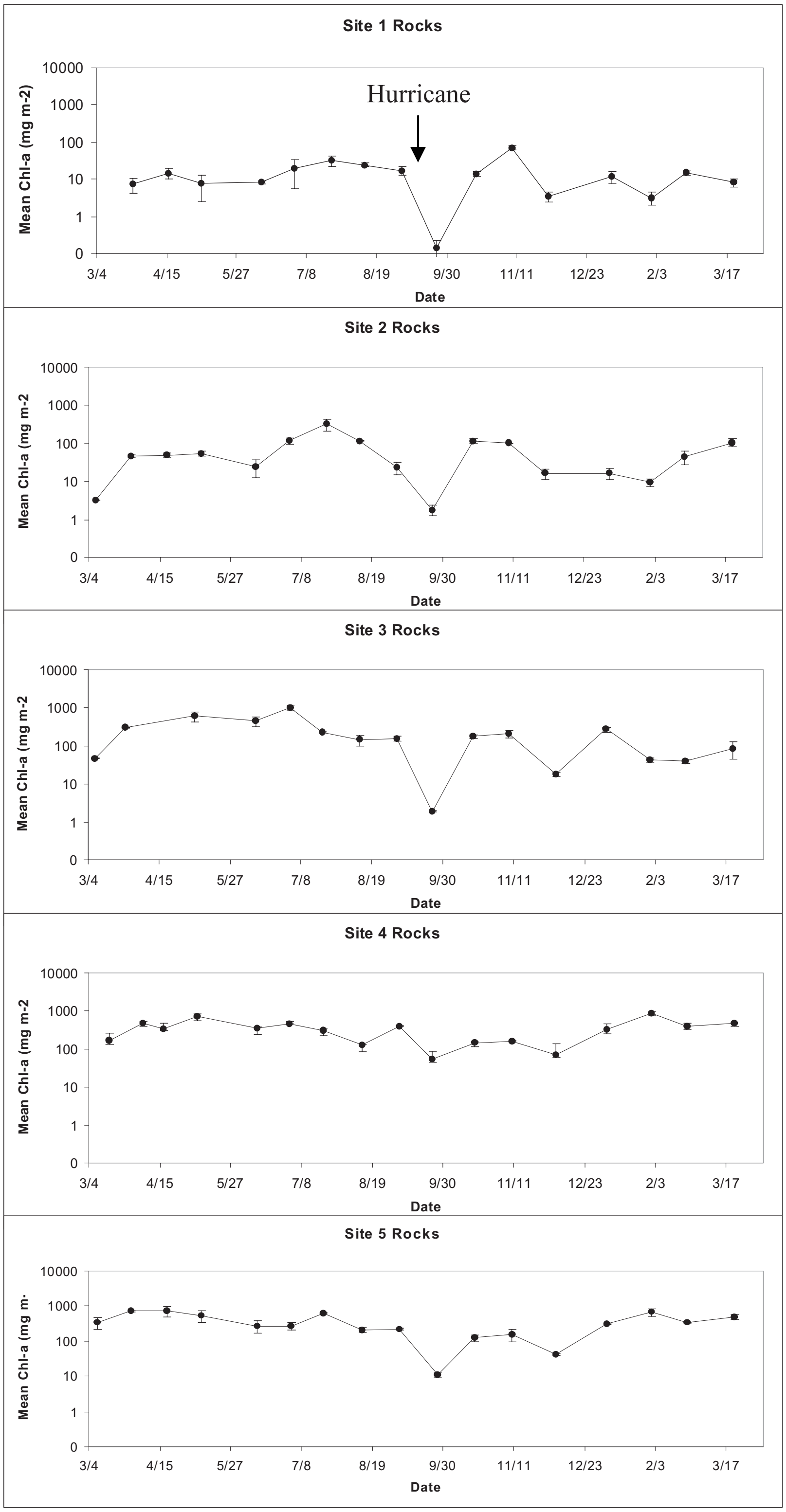


Figure 2. Log Chlorophyll-a concentrations (mg/m^2) for the five sampling sites (±1 standard error). Peak flows from the Hurricane occurred on 9/18/04.

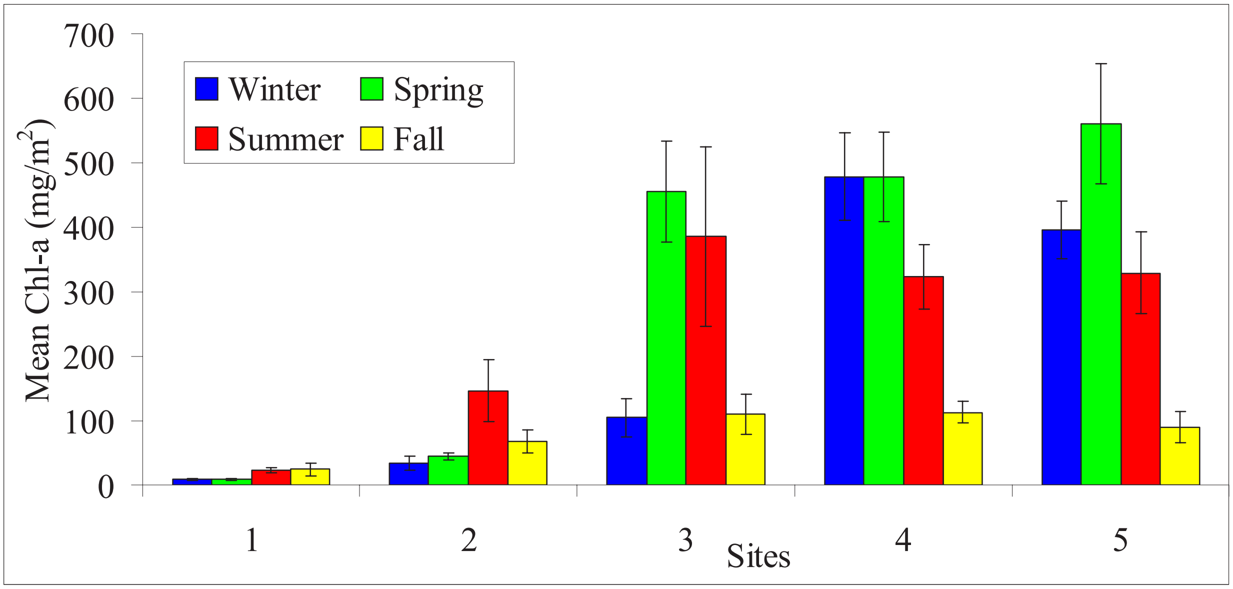


Figure 3. Mean chlorophyll densities (± 1 standard error) among four seasons at the five sites.

Publications: None published, but several in preparation including a student thesis.

Students Supported:

Student research has been supported on the Spring Creek project in the form of student financial support (wage employment), support of graduate research, and/or through undergraduate student involvement in independent research (completed credit hours 11).

Casey Godwin (M.S. Student, Ecology, PSU, thesis in progress)
Jessica B. Moon (Ph. D. Student, Ecology, PSU)
Morgan Johnston (Undergrad, Environmental Resources Management, PSU)
Joshua Jackson (Undergrad, Environmental Resources Management, PSU)
Lindsay Olinde **(**Undergrad, Environmental Engineering, Louisiana State University)
Corey L. Rilk (Undergrad, Environmental Resources Management, PSU)

Presentations and Other Information Transfer Activities:

Godwin, C.M. (presenter), H.J. Carrick, and M.E. Johnston. 2005. Temporal and spatial variation in periphyton growth in a temperate, cold water stream. 3rd Annual Northeast Ecology and Evolution Conference, ***Penn State University***, March 20.

Carrick, H.J. 2005. Use of periphyton to evaluate stream environmental quality. PA Dept. of Environ. Protection Regional Workshop on Periphyton Sampling. State College, PA (26 April).

Godwin, C.M. (presenter), H.J. Carrick, and M.J. Johnston-Greenwald. 2005. Temporal Patterns of Periphyton Accumulation in a Temperate, Cold-Water Stream. Joint Assembly of the American Geophysical Union and the North American Benthological Society, New Orleans, Louisiana (24 May)

Carrick co-hosted. Two-day workshop on periphyton sampling and identification (servicing 15 PA Dept. of Environ. Protect Agency employees). Pennsylvania State University and Fish and Boat Commission, University Park, PA (26-27 April).

Awards:

Support from this project supported the development (and eventual acquistion) of several research projects. These include the following:

2004 **PENNSYLVANIA DEPARTMENT OF ENVIRONMENTAL PROTECTION:** Water Quality Division. Entitled: Using periphyton to estimate TMDL endpoints and assess impairment in an urban-suburban stream (Skippack Creek, Pennsylvania). PI: H. Carrick ($40,242 over 1 year).

2004 **PENNSYLVANIA DEPARTMENT OF ENVIRONMENTAL PROTECTION:** Water Quality Division. Entitled: Assessing water quality conditions in an urban-suburban stream (Skippack Creek, Pennsylvania) based on BOD measurements. PI: H. Carrick ($28,700 over 1 year).

2005 **GROWING GREENER: Environmental Stewardship and Watershed Protection:** Use of periphyton to estimate TMDL end-points. PI: H. Carrick ($ 158,749 over 2 year, PENDING).

2005 **GROWING GREENER: Environmental Stewardship and Watershed Protection-** Determining Variation in TMDL Reduction Criteria. PI: H. Carrick ($ 144,333 over 2 year, PENDING).