The Effect of Suspended and Benthic Sediment on Primary Production

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Introduction

From headwaters to large rivers, energy flow is expected to vary with stream size and riparian vegetation according to the river continuum concept (Vannote et al. 1980). However, primary production and ecosystem respiration can also be modified by flow extremes. Periods of high flow can reduce primary production and shift the P/R ratio towards heterotrophy (Uehlinger 2000). The P/R depends on the frequency and magnitude of disturbance, light, and temperature (Uehlinger 2000). For example, Atkinson et al. (2008) found that instability of the stream bed is a major factor affecting stream metabolism because the transport of abrasive sand inhibits the growth of benthic primary producers. Erosion and runoff resulting from land use can be a major contributor to sediment accumulation and disturbances from high flow in streams.

Land use by humans changes the physical characteristics of aquatic ecosystem, ultimately altering stream structure and function (Von Schiller et al. 2008). During construction projects, contractors are usually required to create retention ponds to prevent runoff into streams (Suren 2005); however, many of these retention systems are inefficient or poorly regulated. Catchment characteristics effect the amount of sediment flowing into streams and influence stream processes (Houser et al. 2005). Human land use also affects organic matter input, and nutrient and light availability (Von Schiller et al. 2008). For example, agricultural and urban land use can increase stream nutrient concentrations which may increase algal biomass, increase trophic rates, and degrade the macroinvertebrate communities (Zheng et al. 2008). It is imperative to study the interaction between human land use and stream ecosystems because of the dangers imposed on stream ecological stability.
Increased turbidity from altered land use has shown negative correlation with algal biomass (Kies 1996). Primary producers are important in aquatic systems because they provide a high quality resource to higher trophic levels and can influence food web structure (Power 2006). Turbidity creates light-limiting conditions (Figueroa-Nieves et al. 2006), and abrasion by sediments can remove benthic algal biomass from substrata during floods, drastically altering benthic algal communities (Francoeur et al. 2006). The amount of scour varies with water velocity and suspended sediment concentrations (Francoeur et al. 2006). It is important to determine the effects of land use and total suspended solids on stream ecosystems to protect biodiversity and water quality (Von Schiller 2008).

Our goal is to understand the effects of suspended and benthic sediments on algal biomass and primary production. We addressed this through observations of algal biomass and suspended sediments in two streams of differing benthic sediment cover and by examining algal biomass accrual under varying concentrations of suspended sediments in laboratory microcosms. We predicted that streams with lower concentrations of inorganic sediments would have lower primary production due to inhibited light penetration. In addition, we expected to observe a lower rate of algal biomass accrual with greater amounts of suspended sediments in experimental microcosms.

**Methods**

**Sampling Locations**

Our study sites were two streams in Blacksburg, Virginia observed to differ in benthic sediment cover. One stream draining a retention pond on the Virginia Tech campus (Vet Med) was observed to contain a large amount of fine sediments. The second stream (Sinking Creek)
was located in Giles County Virginia, approximately 20 miles from the Vet Med stream. Sinking Creek ran through a more rural area than Vet Med, which was bordered mostly by farmland. We observed less fine sediment and more smooth rocks on the bottom of the stream, making it a good stream for comparison.

**General Stream Characteristics**

Each stream was visited once during the month of March, to determine a few standard observations about the water and physical appearance of each. The outside conditions and apparent tree cover were noted for each different location. At each site, a twenty meter reach was established and five sampling locations were designated 4, 8, 12, 16, and 20 meters. At each of these locations, we measured stream width, took chl-a samples, and measured corer depth (cm). Using a Flo-Mate velocity meter, the velocity was measured in three different locations at each stream: 0m, 10m, and 20m. The dissolved oxygen concentration of each stream was taken using a portable oxygen meter. Temperature and conductivity were measured using a YSI model 30 hand-held probe (YSI, Yellow Springs, Ohio, USA). LaMotte pH kits (Chestertown, Maryland, USA) were used to test the pH three times for each location. The total hardness and calcium hardness were measured using LaMotte field hardness kits (Chestertown, Maryland, USA). Water samples (n=3) were filtered (Whatman GF/F, pore size =0.7 µm) at each site. Concentrations of nitrate (NO₃-N), ammonium (NH₄-N), and phosphate (PO₄-P) were determined colorimetrically using a Lachat QuikChem 8500 auto analyzer (Lachat Instruments, Loveland, Colorado, USA).

*Benthic Inorganic Matter*
Benthic organic matter concentrations were determined for both streams in the five different locations using a benthic corer placed on the stream bottom. Using a meter stick, depth measurements were made inside the corer and benthic sediments were stirred into suspension and a subsample of the entire water volume in the corer was collected. Subsamples were then filtered, dried (50ºC), and ashed (550ºC) to determine quantities of both organic and inorganic materials. These quantities were then scaled up to the total water volume inside the corer to determine mass per unit area of the streambed.

Chlorophyll a Biomass

The chlorophyll a biomass was determined by scrubbing three rocks chosen from each of the five locations from both streams. The rocks were then scrubbed with a scrub brush and sprayed off into a pan. The contents of the pan were placed into bags, and the rocks were covered in tin foil to determine surface area. The materials were brought back to the lab where the tin foil was weighed and compared to a standardized curve. The slurry samples were measured for total volume and the standard chlorophyll-a extraction method was used to find the chlorophyll-a concentration of each sample. The samples were analyzed using a spectrophotometer.

Laboratory Study

A laboratory experiment was set up in order to determine how different suspended sediment concentrations affect chlorophyll-a. From the Vet Med stream, 15 rocks of similar size and about 25L of stream water were collected. Five 5L tanks were stationed with three rocks placed in each. The tanks were filled with 3L of stream water and tubes were connected to air faucets with one placed in each tank to continuously circulate the water, keeping the sediments
in suspension. A large quantity of sediment was also collected from the Vet Med stream. This sediment was dried and sifted so that only the fine sediment (<600µm) was used in the tanks. The fine sediment was used to create four different concentrations of suspended sediment (40, 100, 500, and 1,000 mg/L). A control tank containing no added sediment was also created. Light fixtures were hung over the tanks so that each tank would receive the same amount of light. The tanks were observed for two weeks, and the remaining stream water was used to refill tanks after evaporative loss. After two weeks, the algal biomass was derived for each tank using the same methods for the chlorophyll-a analysis. Water samples (250mL) were also taken from the tanks to determine the actual amount of sediment in suspension to account for any settling. These lab studies were then compared to the field results to determine the relationship between turbidity (benthic inorganic matter) and chlorophyll-a biomass. Finally, all data were analyzed using regression method of statistical analysis to determine how benthic inorganic matter affects chlorophyll-a biomass.

**Results**

**General Stream Characteristics**

The general stream characteristics at Sinking Creek (SC) and Vet Med (VM) streams were compared. Overall, SC is a wider, slightly deeper stream than VM, and has a higher velocity. The pH and temperature values for each stream were similar; however the hardness and conductivity were higher in the VM stream. The concentration of nitrate in VM (2133 µg/L) was over four times that of SC (481 µg/L; t-test, P=6.69E-09; Fig.1).


**Benthic Inorganic Matter and Chl-a Biomass**

A relatively strong negative correlation was found between benthic inorganic matter and chl-a biomass at the SC stream. As inorganic matter increases, chl-a biomass decreases (regression, \( y = -0.02x + 3.39, R^2 = 0.52, P = 0.279 \); Fig. 2). However, no relationship was found between inorganic matter and chl-a biomass at the VM stream (regression, \( y = 0.0072x + 1.57, R^2 = 0.12, P = 0.649 \); Fig. 3). Unlike SC, in the VM stream the chl-a biomass remained unchanged despite higher inorganic sediment.

**Laboratory Study**

In the lab experiment, there was also a relatively strong correlation between benthic inorganic matter and chl-a biomass. Chl-a biomass was significantly lower in the tanks with higher inorganic sediment concentrations (regression, \( y = -1.22x + 9.83, R^2 = 0.61, P = 0.220 \); Fig. 4). However, the p value indicates that the regression line is not significantly different from zero.

**Table 1.** Stream Characteristics at Sinking Creek (SC) and Vet Med (VM) streams

<table>
<thead>
<tr>
<th></th>
<th>SC</th>
<th>VM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width (m)</td>
<td>16.55</td>
<td>3</td>
</tr>
<tr>
<td>Depth (cm)</td>
<td>23.9</td>
<td>19.4</td>
</tr>
<tr>
<td>Velocity (m/s)</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>pH</td>
<td>8.5</td>
<td>7.93</td>
</tr>
<tr>
<td>Hardness (ppm)</td>
<td>106</td>
<td>247</td>
</tr>
<tr>
<td>Ca Hardness (ppm)</td>
<td>82</td>
<td>165.5</td>
</tr>
<tr>
<td>Dissolved Oxygen (mg/L)</td>
<td>10.67</td>
<td>9.47</td>
</tr>
<tr>
<td>Conductivity (µS)</td>
<td>212.7</td>
<td>599</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>11.8</td>
<td>12.2</td>
</tr>
<tr>
<td>PO4-P (µg/L)</td>
<td>5.93</td>
<td>6.93</td>
</tr>
<tr>
<td>NO3-N (µg/L)</td>
<td>480.67</td>
<td>2133.33</td>
</tr>
<tr>
<td>NH4-N (µg/L)</td>
<td>6.57</td>
<td>3.47</td>
</tr>
</tbody>
</table>
Figure 1. Nitrate-N concentrations in Sinking Creek (SC) and Vet Med (VM) streams.

Figure 2. Relationship between benthic inorganic matter and chl-a biomass at Sinking Creek (SC) stream.
In comparing the general traits of the Vet Med (VM) and Sinking Creek (SC) streams, nitrate concentrations were four times higher in VM (2133.33 µg/L) than in SC (480.67 µg/L; P=6.69E-09; Table 1, Fig.1). The overabundance of nitrate is probably the result of agricultural...
land use (Bernot et al., 2006). The VM stream is close to some of Virginia Tech’s agricultural facilities, including the Dairy Science Complex. Bernot et al, (2006) state that as agricultural land use increases, nitrogen and phosphorous levels increase in nearby streams. Specifically, Bernot et al. (2006) found that in each stream studied, NO3 concentrations were higher than any other types of phosphorous and nitrogen levels. The increased nitrate concentration is also consistent with Zheng et al.’s (2008) observation of agricultural land use and increased nutrient concentrations. The VM stream also contained higher conductivity levels than the SC stream. The higher conductivity levels can be explained by agricultural land use as well. Biggs (2006) found that conductivity increases with increased catchments in agricultural land use areas. Pasture applied manures and excreta from grazing animals contain organic matter and substantial amounts of trace elements such as Zn, Cu, Fe, Mn, and non-essential trace elements such as Al, Cd, and Pb (White et al., 2001). Agricultural land use usually takes place over large areas, and White et al. (2001) observed that the majority of the metal intake by livestock gets returned to the soil surface and enhances the risk of water pollution. Thus, large amounts of run off from the soil surface could lead to increased conductivity levels in a nearby stream.

The SC stream data indicated that as inorganic matter increases, chlorophyll-a biomass decreases (regression, $y = -0.0243x + 3.3852$, $R^2 = 0.5201$, $P = 0.279$; Fig. 2). The finding is consistent with Kies (2006) study that increased turbidity due to land use is negatively correlated with chlorophyll-a biomass. Conversely, the VM stream data indicated no relationship between inorganic matter and chlorophyll-a biomass (regression, $y = 0.0072x + 1.5689$, $R^2 = 0.123$, $P = 0.649$; Fig. 3). The steady amount of chlorophyll-a biomass with increasing inorganic sediment in the VM stream could be explained by the high concentration
of nitrate within the stream. Nitrogen pollution can cause increased eutrophication of an aquatic ecosystem (Von Schiller et al., 2009). In their experiment, Barker et al. (2008) discovered nitrate loading is positively correlated with chlorophyll-a biomass. As nitrate concentrations increase, chlorophyll-a biomass increases (Barker et al, 2008). Therefore, the high nitrate level in the VM stream could be causing the high chlorophyll-a biomass despite the increasing amount of inorganic matter. Since the VM stream contained higher levels of conductivity (599 µS) and hardness (247 ppm), further research could be conducted to indicate whether these were factors in the high chlorophyll-a biomass as well.

The laboratory experiment showed a reasonably strong correlation between benthic inorganic matter and chlorophyll-a biomass. The negative regression line indicates that higher amounts of inorganic matter are associated with lower amounts of chlorophyll-a biomass (regression, $y = -1.2191x + 9.8327$, $R^2 = 0.6088$, $P = 0.220$; Fig. 4). The lab results are consistent to the results from SC, indicating that the amount of inorganic matter does affect chlorophyll-a biomass in an aquatic environment.

We hypothesized that higher concentrations of benthic inorganic matter would decrease chlorophyll-a biomass due to inhibited light penetration. The hypothesis was correct in that higher concentrations of inorganic matter caused lower concentrations of chlorophyll-a biomass. The experiment failed to address the issue of light penetration. Both the streams visited and the tanks used in the experiment were too shallow to use the Licor light meter to measure light penetration. However, within our lab experiment, we observed that the majority of the inorganic matter did not stay suspended in the water; instead it settled on top of the rock surfaces. Conclusions can be drawn that the inorganic matter inhibited chlorophyll-a
biomass through the scouring of the biomass off the surface of the rocks rather than inhibiting light penetration. This idea is consistent with Atkinson et al.’s (2008) research that the instability of the sediment is a major influence on stream metabolism. Atkinson et al. (2008) determined that abrasive sands inhibit the growth of benthic primary producers. Furthermore, Francoeur et al. (2006) states abrasion can remove chlorophyll-a biomass from substrata, especially during times of flooding. Future research to specifically test whether or not the inorganic matter significantly scoured the chlorophyll-a biomass collected could provide further understanding of land use and its affect on aquatic environments.

In our study, the higher nutrient concentrations and the negative correlation between algal biomass and benthic inorganic sediments suggest that development can dramatically impact a stream ecosystem’s structure and function. Zheng et al. (2008) found that increased nutrient concentrations due to land use led to an increased trophic state and degradation of macroinvertebrate communities. Algal communities are an indicator of stream health, provide resources to higher trophic levels, and influence food web structure (Zheng et al., 2008). The regulation of land use is imperative to the preservation of biodiversity and water quality in stream ecosystems.
Literature cited


