CARBON STORAGE, SOIL CARBON DIOXIDE EFFLUX AND WATER QUALITY IN THREE WIDTHS OF PIEDMONT STREAMSIDE MANAGEMENT ZONES

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Abstract—Streamside management zones (SMZs) are used to protect water quality. Monitoring carbon pools and fluxes in SMZs may a good indicator of the SMZ's overall function and health. In this project we evaluated some of these pools and fluxes from three different SMZ widths (30.5, 15.3, and 7.6 m) in the Piedmont of Virginia. We quantified carbon storage in the soil (upper 10 cm), litter layer, and plant community, monitored soil carbon dioxide (CO_2) efflux and measured total organic carbon and benthic communities in stream water samples. The narrowest 7.6 m SMZ width did show changes in ecosystem function (litter decrease, soil moisture increase, soil CO_2 efflux increase) which could result in long-term impacts. At this point in time (3 years post harvest), no significant differences were found in the benthic community. The 15.3 m thinning treatment did consistently have the highest total organic carbon (TOC) which may be related to the disturbance from harvesting.

INTRODUCTION

Both agricultural and silvicultural activities may impair water quality due to the increased potential of sediment reaching either the streams or watersheds present near these activities. In recent years, forestry best management practices (BMPs) have been implemented in an attempt to improve or maintain water quality as required by the Federal Water Quality Control Act of 1972 (Aust and Blinn 2004). One of the BMP recommendations that specifically targets the protection of streams and other bodies of water is streamside management zones (SMZs). The Virginia Department of Forestry defines an SMZ as an "an area of reduced management activity on both sides of the banks of perennial and intermittent streams and bodies of open water where extra precaution is used in carrying out forest practices in order to protect bank edges and water quality" (Virginia Department of Forestry 2002). SMZs have many functions including the trapping of both sediments and nutrients; stream bank stabilization, temperature control, and protection of the forest floor (Governo and others 2004). This particular study focuses on the accumulation and cycling of carbon. A complete understanding of both carbon stocks and exchanges between vegetation, soil, and the atmosphere must be obtained in order to have a better understanding of the carbon cycle within terrestrial ecosystems (Cao and Woodward 1998). Knowing how the carbon cycle within SMZs is impacted is important to understanding their long-term effectiveness.

Carbon serves as a building block for most of nature. For this reason, carbon has been studied quite extensively and yet there is still much to be discovered. It is well know that carbon exists in many different forms and therefore in many different pools within the terrestrial ecosystem, including SMZs. Consequently, the presence of carbon drives many of the ecosystem functions within the riparian area and can be used as a determinant of both water quality and SMZ processes. Within the terrestrial ecosystem, carbon moves through the vegetation, soil, and litter layer and escapes back into the atmosphere through autotrophic and heterotrophic respiration (Cao and Woodward 1998). According to Giese and others (2003) riparian areas have high potential to store carbon due to their relatively high rates of productivity and the persistent soil water saturation. Studies have been developed to determine total carbon within an area (Giese and others 2003, Governo and others 2004, Trettin and others 1999) but little research has been conducted to determine how silvicultural management practices may impact the flow of carbon through SMZs.

The benthic macroinvertebrate community tends to be sensitive to any disturbance within the habitat. Due to this, macroinvertebrate sampling is done frequently to determine the health of a stream. Stone and Wallace (1998) found that logging might alter the site by changing the energy of the stream from allochthonous (outside of the system) to autochthonous (within the system). For this reason it is believed that any change in carbon pools would result in a change in the benthic macro invertebrate population. The objective of this project is to determine the influence various SMZ treatments (harvesting intensity; varying widths) have on either the components of the carbon cycle or accumulation of carbon within the stream water. Specifically we will identify the impact these treatments have on aboveground biomass, litter layer, soil carbon (10 cm depth), and total soil CO_2 efflux, examine the influence of these SMZ treatments on environmental drivers of carbon flux (soil moisture and temperature), and determine the effects of these treatments on benthic macro invertebrate populations present within the stream.

MATERIALS AND METHODS

Study Site Description

A field experiment was designed that would allow us to investigate the effects of different SMZ widths and thinning in SMZs upon the riparian carbon dynamics and stream benthic community. This experiment consisted of four SMZ treatments (30.5 m, 15.3 m, 15.3 m with thinning and 7.6 m wide SMZs) with three to six replications across sixteen

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watersheds. Treatment widths are per streamside, and thinning is defined as the removal of approximately 50 percent of the basal area. Not all treatments were installed properly when commercially harvested which resulted in an incomplete block design.

The watersheds consist of first order headwater streams that are ephemeral to intermittent in nature. They are all located on MeadWestvaco property within the Piedmont in Buckingham County, VA in 23 to 25 year old *Pinus taeda* L. (old loblolly pine) plantations (Walker-Easterbrook and others 2003). Overstory vegetation predominantly consists of planted loblolly pine and native hardwoods such as *Acer rubrum* (red maple)*, Quercus* spp. (oaks), and *Carya* spp. (hickory). This study was set up as a long-term study with pre-harvest data collected and analyzed in 2002. In 2003 the watersheds were clearcut and in 2004 post-harvest sampling commenced. In addition to the carbon and benthic study, erosion studies are also being conducted.

Field and Lab Techniques

A complete inventory was performed on the following strata: over story, shrubs, and groundcover. The center of the sampling plots was positioned in the middle of one side of the SMZ. For the 7.6 m-wide treatment, the center of the plot was placed in the stream to ensure that the plot did not extend outside of the SMZ. Overstory was defined as any vegetation with a diameter > 9.1 cm (3.6 inches) at 1.3 m above ground diameter breast height (d.b.h.). An 8.01 m radius circular plot (1/20-acre) was established and all vegetation meeting these requirements was measured for height and d.b.h. by species. Shrubs were defined as any vegetation with a diameter < 9.1cm at d.b.h. For shrubs, a circular plot with a 2.5 m radius (1/200 acre) was established along the same location within the transect and all species, number, and heights were recorded. A 1/1000 acre (1.1 m radius) ground cover plot was established and all vegetation within the plot was clipped to the ground line and transported to the lab for dry weight determination. The data collected in the field for both the over story and shrub strata was used in conjunction with existing biomass equations to estimate aboveground biomass within each treatment (Clark and others 1986, Hauser 1992). Carbon was assumed to account for about 50 percent of tree dry weight (Birdsey 1992). Consequently, biomass estimates were converted to carbon by multiplying by 50 percent. The groundcover samples were brought back to the lab and dried at 85 ˚C in an oven and then weighed.

In addition to biomass, the litter layer was sampled twice during the year once in late summer (September 2005) and again following leaf off in the winter (January 2006) at three locations (creek side, middle of SMZ and upper edge of SMZ). The two seasonal sub samples and locations in the SMZ were averaged for analysis. Litter sub samples were taken at the exact same time and location as a measure of total CO_2 efflux. A soil CO_2 efflux measurement was taken and the area (506.5 cm^2) underneath the efflux chamber was removed. Both the litter layer and the entire O horizon were collected. Samples were brought back to the lab and dried at 85 ºC in an oven to a constant weight and then weighed. These dry samples were then placed in muffle furnace at 380 ºC for 24 hours to correct for mineral soil contamination. Litter weight was calculated as oven dried weight minus ash weight obtained from the muffle furnace (Wiseman and Seiler 2004).

In November 2005, ten pushtube soil samples were taken at each of the three sub sample locations (creek side, middle and upper edge) along each transect. These 10 samples were taken along a 10 foot linear transect running perpendicular to the original sub sample location. Pushtube samples were taken to a depth of 10 cm. These samples were mixed together and a single composite sample was brought back to the lab for further analyses. In addition to pushtube samples, an undisturbed bulk density soil sample was taken to the depth of 10 cm using a double-cylinder bulk density corer. Bulk density cores were brought back to the lab and dried at 105 ºC for 24 hours and weighed in order to determine bulk density. These samples were subsequently ground using a mortar and pestle and passed through a 0.64 cm mesh to separate the coarse fragments (Chen and Xu 2004). These coarse fragments were then weighed in order to determine percent coarse fragment content. The separated soil was analyzed for percent carbon content using an Elmentar varioMax CNS analyzer (Elementar American Inc., Mt. Laurel, NJ).

Beginning in May 2005 and continuing through January 2006, total soil CO_2 efflux, soil temperature, and soil moisture was measured on five different dates in an attempt to capture seasonal variation. Measurements were taken along the same transects and locations as with the litter measurements. The order these three locations were measured within the transect was randomized each time. A 15 cm Digi-Sense® thermocouple thermometer (Cole-Parmer, Vernon Hills, IL) was utilized to determine soil temperature to a depth of 15 cm. Soil moisture was measured using a Trase® 6050X1 time domain reflectometer (Soil Moisture Equipment Corp., Golena, CA) to a depth of 13 cm. Total soil CO_2 efflux was measured using a Li-Cor 6200 infrared gas analyzer (Li-Cor Inc., Lincoln, Nebraska) with a dynamic closed cuvette chamber system. The system was constructed of PVC pipe walls, Plexiglas top, and a stainless steel edge on the bottom to ensure a tight seal once placed on top of the sampling location. The internal diameter of the chamber was 25.5 cm and the height was 13.5 cm creating a total volume of 6744 cm^3. Plastic tubing (0.32 cm diameter) was used to attach the cuvette chamber to the infrared gas analyzer. Air enters the cuvette chamber through an input hose on the side of the chamber. This air is then diffused through the chamber via a perforated hose that runs along the interior wall of the chamber. Air then leaves the system through a hose that is located at the top of the chamber through the Plexiglas top (Selig 2003). Before each sampling date, the system was calibrated in the lab by running a known CO_2 concentration through the system. Care was taken to be sure no living plant material was in the chamber and that CO_2 concentrations were at or near ambient levels near the ground line. After CO_2 concentrations were found to be steadily rising in the chamber, a measurement period of 30 seconds was used to estimate total soil CO_2 efflux.

Water samples were taken seasonally in order to estimate total organic carbon (TOC). Water grab samples were taken from a downstream portion of the stream to ensure the presence of water. Three 25 ml bottles were filled by placing them in the stream with the open end facing upstream to capture flowing water. These bottles were then placed on ice and brought back to the lab where they were placed in the freezer until further analysis could be performed. The water samples were then analyzed for TOC. The samples were analyzed using persulfate-ultraviolet oxidation. In order to remove any inorganic carbonates, the samples were purged prior to analysis using oxygen. The instrument used was a Seiver DC80 TOC analyzer with an autosampler.

Samples were also taken from the streams to determine the benthic macroinvertebrate populations. This sampling occurred in January 2006 two to three days after a rain to ensure the most amount of water present for sampling purposes. A D-frame macro invertebrate sampling net was utilized along a 50 m stretch of stream. Along this 50 m stretch a subsample was collected every 2 m. The benthic samples were then washed in a 500µm mesh bottom wash bucket and stored in 90 percent ethyl alcohol. The macroinvertebrate samples were sorted and separated from all gravel pieces and woody debris pieces that may have been collected. These samples were then stored in 95 percent ethanol (EtOH) and later identified to family by Stephen Hiner, an aquatic entomologist technician at Virginia Polytechnic Institute and State University. The results of these sample counts were then applied to various macroinvertebrate metrics.

Statistical Analyses

Data were analyzed as an Incomplete Block Design using an analysis of variance (ANOVA) to determine if differences between treatments existed (SAS v 9.1, Cary, NC). Differences in means were determined by using Tukey's Studentized range test (HSD) at the α= 0.1 significance level. The three different biomass strata were analyzed separately. For data that was not normally distributed a log transformation was performed and the back transformed means are reported. For the respiration data, the analysis was performed as a repeated measure with both soil moisture and soil temperature as covariates. In addition to a repeated measure analysis, each respiration measurement date was analyzed separately. A means separation analysis was performed on litter layer, soil moisture, and soil temperature (Number Cruncher Statistical Systems, Kaysville, UT) to detect significant differences between SMZ treatments and subplot location in these three independent variables.

RESULTS AND DISCUSSION

No differences in total standing biomass carbon were found between SMZ treatments (fig. 1, p=0.3061). The 15.3 m thinned treatment did have the least standing carbon. No differences in total groundcover carbon nor shrub carbon were found between the SMZ treatment (fig. 2, p=0.4304 for groundcover, p=0.2587 for shrubs). The 15.3 m thinned treatment did have the least groundcover and shrub carbon, while the 7.6 m no thin treatment had the most groundcover and shrub carbon. A study by Peterson and others (1997) demonstrated that during the six years following a thinning treatment regime, the trees responded with both increased crown dimensions and bole diameter increases. Our sampling occurred only two years following the harvest, therefore residual trees had not yet reoccupied the site fully.

The average litter layer in the 7.6 m SMZ was found to be significantly less than the 15.3 m treatments (fig. 3). As would be expected given the short time treatments have been installed, soil carbon showed no significant difference due to the SMZ treatment (p=0.2361) or subplot location (p=0.4775)

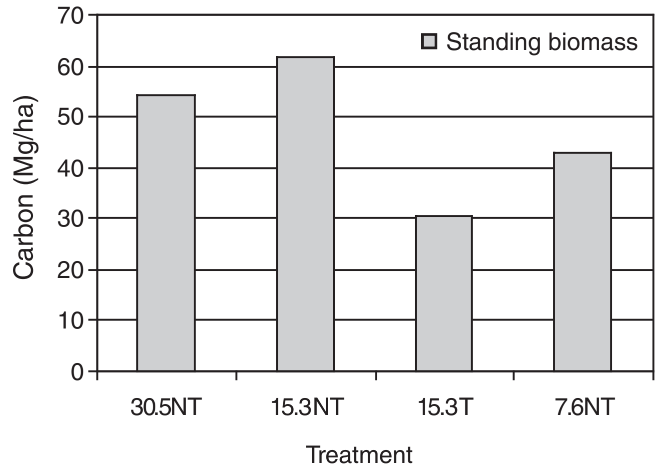

Figure 1—Aboveground standing biomass as influenced by streamside management treatment [numbers (e.g., 30.5) are SMZ width in meters, NT=no thinning, T=thinning] on the Piedmont of Virginia.

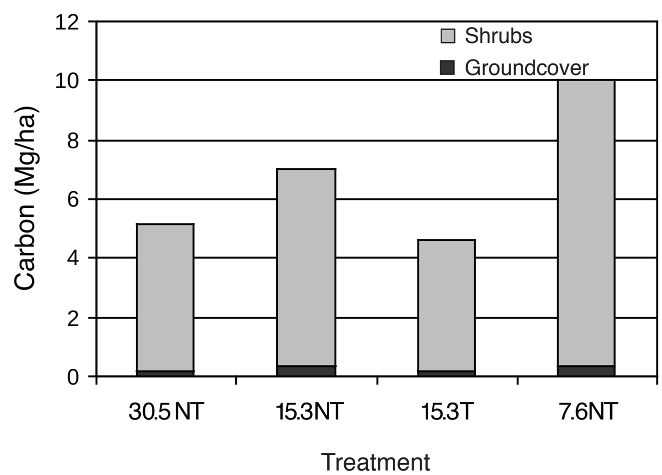

Figure 2—Aboveground groundcover and shrub biomass carbon as influenced by streamside management treatment [numbers (e.g., 30.5) are SMZ width in meters, NT=no thinning, T=thinning] on the Piedmont of Virginia.

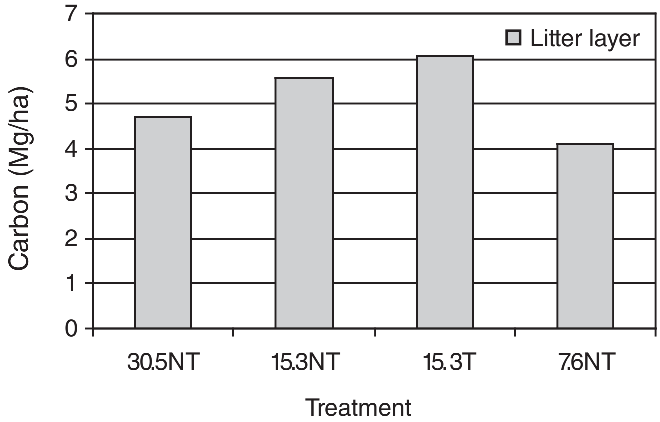

Figure 3—Litter layer carbon as influenced by streamside management treatment [numbers (e.g., 30.5) are SMZ width in meters, NT=no thinning, T=thinning] on the Piedmont of Virginia.

effect. The results did show a significant interaction between SMZ treatment and subplot location (p=0.0628). This was due to the 15.3 m thin treatment showing a large soil carbon concentration at the creek side subplot location. This high value appears to be due to prior high soil organic matter concentrations at a few locations.

Although the 7.6 m SMZ width did show a slight increase in temperature during the fall months (fig. 4A), soil temperature was not significantly impacted by the SMZ treatments (table 1). However, soil moisture did show a consistent and significant effect with the 7.6 m treatment having consistently the highest soil moisture (table 1 and fig. 4B). Soil CO_2 efflux did not demonstrate a large change due to SMZ treatment but the 7.6 m treatment generally had the greatest rates over the time of this study (table 1 and fig. 5). This is perhaps due to the effect of the higher soil moisture and the slightly higher temperature (Lloyd and Taylor 1994, Davidson and others 1998). A study conducted on similar sites on the Piedmont of Virginia by Wiseman and Seiler (2004) indicated both soil temperature and soil moisture as two of the main driving factors influencing soil CO_2 efflux.

Water sample collection was attempted at all 16 watersheds on 5 dates. Grab samples were never collected from one of the watersheds due to the absence of water. In addition, one other watershed was only collected from once and this collection occurred after remnants of a hurricane passed through the area. This one collection during high flow instead of base flow, resulted in a highly significant date effect (p=<0.0001). Thinning can increase the amount of large wood debris that is present within the riparian area therefore increasing the potential for introduction of carbon into the water system. The additional large woody debris can also form organic debris dams which assist in the control of exportation of particulate matter downstream (Bilby 1981). Samples that were taken from the 30.5 m no thin treatment had lower TOC than the other treatments during the hurricane season and consequently during high

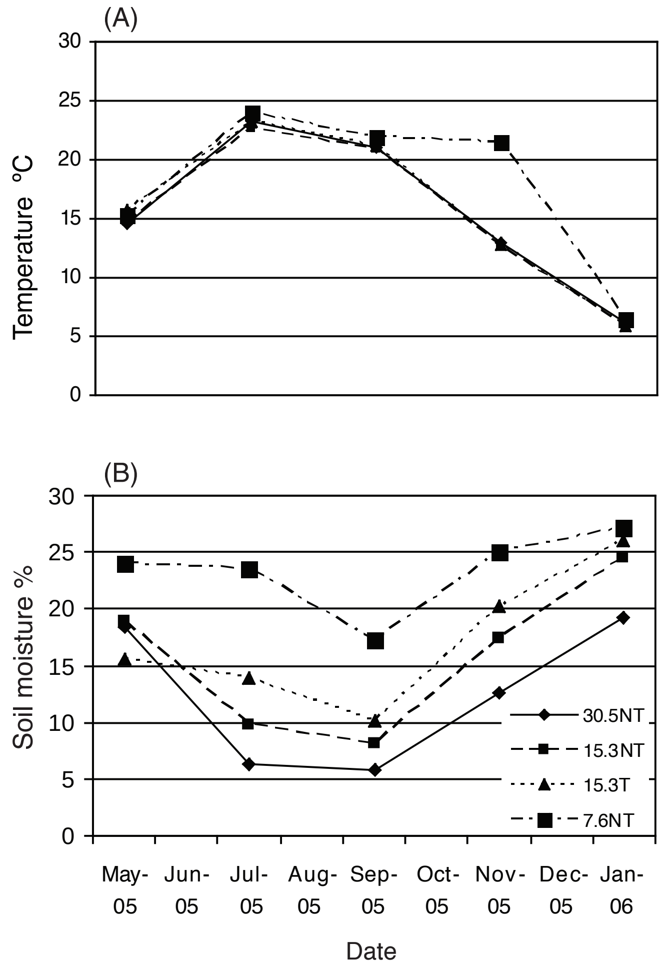

Figure 4—Seasonal trends in soil temperature (A) and soil moisture (B) as influenced by streamside management treatment [numbers (e.g., 30.5) are SMZ width in meters, NT=no thinning, T=thinning] on the Piedmont of Virginia.

Table 1—Seasonal means for soil temperature, soil moisture and soil CO_2 efflux as influenced by the streamside management zone treatments

Streamside management treatment	soil temperature (°C)	soil moisture (%)	soil CO_2 efflux (uMol/m^2 s)
30.5 m width	15.6 a	12.5 a	3.4 a
15.3 m width	15.4 a	15.8 a	4.2 ab
15.3 m width, thinned	15.8 a	17.2 ab	4.0 ab
7.6 m width	16.0 a	23.4 b	5.0 b

Means in a column followed by the same letter do not differ significantly (p=0.05).

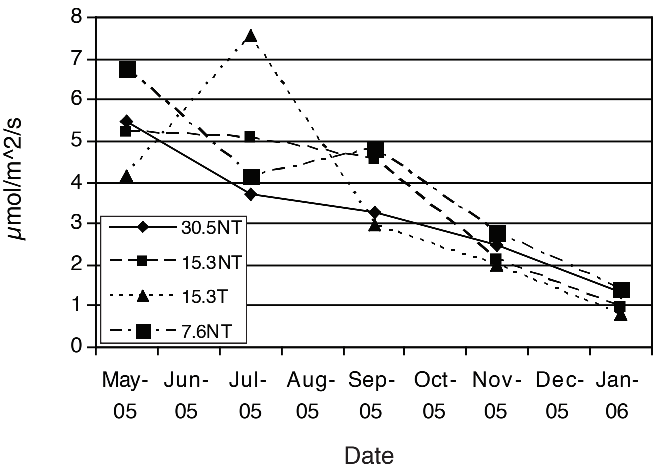

Figure 5—Seasonal trends in soil CO_2 efflux as influenced by streamside management treatment [numbers (e.g., 30.5) are SMZ width in meters, NT=no thinning, T=thinning] on the Piedmont of Virginia.

flow suggesting that the width of the SMZ may reduce the potential of carbon from entering the stream during storm events. No significance was detected among treatments (p=0.8396) and interaction between treatment and date (p=0.9876).

Only 13 of the 16 streams were sampled for benthics due to the absence of water. A total of 12 macro invertebrate orders and 31 families were identified within the 13 streams that were sampled. One genus that was found is rare, *Anisocentropus*. In addition, a few families were found in only one stream. Although no significant differences were found for any of the analysis for treatment differences, the 15.3 m no thin treatment had the better index value in 7 of the 10 tests performed. The same treatment also yielded the highest TOC present in the water samples. Studies have shown that the introduction of LWD to streams and consequently the habitat improvement, potentially shifting the benthic populations (Lemly and Hilderbrand 2000).

CONLCLUSION

The 7.6 m SMZ width did indicate some changes in ecosystem function (litter decrease, soil moisture increase, soil CO_2 efflux increase). With time, these initial changes we measured could result in changes in soil carbon concentration and water quality changes. Based on these measured variables a 15.3 m SMZ even with thinning appears adequate to prevent changes in water quality.

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