Structural and Functional Characteristics of Mining-impacted Reconstructed Streams

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Project Summary

The Clean Water Act [section 404; stream mitigation rule] mandates that mining operations permitted by the U.S. Army Corps of Engineers (COE) to impact streams by valley fill or other activities must employ compensatory mitigation (Register April 10, 2008). Reconstructed streams are one means of mitigation and are meant to replace ecosystem structure and function lost due to impacts. With the goal of restoring ecosystem processes and patterns in these headwater streams, reconstruction efforts can serve as an important environmental protection measure. Additionally, in 2012 EPA released *A Function-Based Framework for Stream Assessments and Restoration Projects*, a document aimed at those constructing and assessing restorations, which states that it would benefit "from review, comments, and example experiences and applications" (Harman et al. 2012). The research we present in this report is addressing these needs by directly measuring specific ecosystem functions of reconstructed streams as mitigation efforts on coal mine sites in southwestern Virginia, and can contribute to the knowledge of stream restoration practices and assessment.

Organic matter (OM), primarily as leaf litter and detrital input, serves as an essential energy source and habitat for benthic macroinvertebrates within headwater and larger stream ecosystems. Alteration of the sources, production rates, or processing rates of OM due to disturbance could have cascading effects throughout these ecosystems. As a result, we see the assessment of OM dynamics as important when characterizing and evaluating the overall functional condition of streams, and when identifying restoration practices that improve stream functions. To address these needs we have measured litterfall input, leaf breakdown, and periphyton biomass accrual for eight low-order mining-impacted reconstructed streams, and evaluated them via comparison to four minimally impacted reference streams. Relationships of these functional measures with physical, chemical, and biological structural measures are also being investigated.

Introduction:

Coal extraction is both an integral economic activity in Central Appalachia and a large- scale disturbance known to affect aquatic ecosystems in the region. The Surface Mining Control and Reclamation Act (SMCRA) of 1977, aims to strike a balance among economic prosperity, social well-being, environmental protection, and the nation's need for coal as an energy source. The overarching purpose of the Clean Water Act (CWA) is to restore and maintain the integrity of the waters of the U.S. [section 101]. Furthermore, the CWA compensatory mitigation rule [section 404] requires mitigation when all appropriate and practicable measures to avoid and minimize stream impacts have been exhausted (Federal Register April 10, 2008). Stream reconstruction is a standard means of compensatory mitigation and is intended to produce ecological benefits to offset those lost due to environmental impacts, such as stream filling by mining activities.

Although post-restoration monitoring is required in these reconstructed streams, until recently assessment of these streams has focused primarily on evaluating ecosystem structural measures (e.g., *point-in-time* measures of water chemistry, channel stability, and/or biotic community). Direct measurements of ecosystem function (e.g., *performance-through-time* measures of processes such as litter decomposition rates, growth rates of stream fauna or flora, stream metabolism, etc.) have rarely been implemented in assessment frameworks, which have instead relied upon structural measures to infer functional performance. Clearly, streams in mining areas perform important ecosystem functions, and mining affects those functions. Hence, restoration of both stream structure and function is an important component of the environmental restoration activities that are conducted by the mining industry. Also, recent regulatory guidance requires direct assessment and replacement of functional attributes and states that continued permitting of Appalachian coal mining operations is contingent upon maintaining or restoring ecosystem structure *and* function in streams affected by coal mining (USEPA and USACoE 2010).

Research reported here is addressing the needs of industry and regulators for functional assessment tools by directly measuring three OM processes that affect stream condition: litterfall input, leaf litter decomposition, and periphyton biomass accrual. We chose to study OM processes because they are important to environmental protection and restoration. OM dynamics in headwater streams influence fish communities, other biota, and ecosystem processes in larger streams and rivers below. Furthermore, many studies have shown Appalachian headwater streams to be predominantly open ecosystems, energetically regulated by inputs of OM from riparian areas (e.g., Fisher and Likens 1973; Cummins 1974; Vannote et al. 1980; Hall et al. 2000). Moreover, OM processes are coupled to in-stream physicochemical processes, as well as benthic macroinvertebrate communities, which are currently used in established structural assessment protocols. Because of this network of linkages we are attempting to determine those factors that exert control on OM processes and to understand if and how restoration practitioners can best direct stream function along a pattern of recovery toward reference condition.

The overall purpose of this project is to characterize selected OM dynamics, and environmental factors influencing them, in reconstructed coalfield streams of southwestern Virginia. Measures of litterfall input and periphyton biomass accrual address the sources of OM and the variability among these sources within and between stream types (e.g., mining-impacted reconstructed streams vs. forested reference). Leaf litter decomposition measures are meant to reflect how OM is processed within these streams. These measures are integrative, economical, and relatively simple to implement within the context of a monitoring/assessment framework. We anticipate that our results will provide new information to enhance assessment techniques currently in use, and guide functional assessment of stream restoration efforts in this region.

Objectives:

1. Assess selected OM processes in coalfield reconstructed streams relative to forested reference streams.
2. Evaluate factors affecting selected OM dynamics in Central Appalachian reconstructed streams
3. Examine relationships between established assessments based on biotic structure and those based on selected OM dynamics.
4. Determine whether selected measures of OM processes reflect unique information about these stream ecosystems not accounted for by structural measures.

Methods:

Site Selection and Description. We completed field sampling of eight reconstructed and four reference streams in four counties (Wise, Dickenson, Russell, and Buchanan) of southwestern Virginia (Table 1) in September 2012. All study streams are located within ecoregion 69 (Central Appalachian; level III), the Appalachian Plateau physiographic region, and the Pocahontas coal bed formation. In each stream, a sixty-meter reach of contiguous channel morphology and riparian structure was delineated and subdivided into two reaches of 30 m for different components of the study. Streams were classified into two major categories: un-mined forested riparian reference (REF), and mining-impacted reconstructed streams (MINE). The latter group is comprised of streams constructed on lands that have been influenced by coal mining (including reclaimed mine sites, reclaimed sediment ponds, and similar features) and receiving a variety of stream-restoration treatments, ranging from channel construction alone to Natural Channel Design (NCD) efforts and riparian plantings.

Table 1. Location, type, and order of streams selected for study.

Stream Name	Location	Stream Type[1]	Stream Order[2]
Sewing Creek	Buchanan County, VA	MINE	1
Shooting Range Creek	Buchanan County, VA	MINE	1
Chaney Creek	Russell County, VA	MINE	2
Laurel Branch	Russell County, VA	MINE	1
Stonecoal Creek	Russell County, VA	MINE	1
Callahan Creek	Wise County, VA	MINE	1
Critical Fork	Wise County, VA	MINE	2
Guest Mountain #3	Wise County, VA	MINE	2
Copperhead Branch	Buchanan County, VA	REF	1
Big Branch	Dickenson County, VA	REF	1
Crooked Branch	Dickenson County, VA	REF	2
Middle Camp Branch	Dickenson County, VA	REF	1

[1] Streams were separated into two categories, mining-impacted reconstructed streams (MINE) and un-mined forested reference (REF).

[2] Stream order was determined using a combination of 7.5' USGS quadrangles, the National Hydrographic Dataset (NHD), and aerial photography (NAIP and VBMP).

Most mining-impacted streams selected were constructed between 2005 and 2008, although some reconstructed streams are much older (e.g., Critical Fork > 20 years old). However, riparian canopy cover is highly variable even among streams younger than 8 years old. The variability of canopy cover is due to the nature of stream construction (e.g., some streams were constructed adjacent to mature forest) as well as some efforts to re-establish woody vegetation in riparian areas. Reference streams drain relatively undisturbed forested watersheds and feature intact riparian forest canopies. Efforts to locate reference-quality streams within Virginia's coalfield with riparian vegetation similar to that which occurs on reclaimed mine sites, such as streams flowing through unmanaged meadows, were unsuccessful. Comparative analysis of OM dynamics between the two stream groups provides information regarding the outcomes of restoration efforts and a goal for desired functional levels as these reconstructed streams develop through time.

Functional Measures. We evaluated leaf breakdown rates (k) by measuring mass loss from 6.5 g of dry *Quercus alba* (white oak) leaves, contained in coarse (C) and fine (F) mesh bags, through serial collections spanning two ~300 day periods. Coarse-mesh leaf bags allow access to leaves by benthic macroinvertebrates, while fine-mesh bags exclude macroinvertebrates and indicate breakdown due to all other factors. We initially collected leaves from a single location, uniformly mixed, dried (65° C for 5 days), weighed and placed them in mesh bags. During the first year of the study (2010-2011), we placed and secured twenty-four bags of each type during early December in pool glides using paracord, and retrieved in triplicate monthly for three months and bimonthly thereafter. We returned leaf bags to the lab on ice; rinsed the remnants of non-leaf material; dried them at 65° C for five days; weighed, ground, sub-sampled, ignited the material at 550° C for 40 minutes; and weighed the resulting ash to determine the percent OM.

These data were used to convert dry mass to ash-free dry mass (AFDM) and calculate the percent AFDM remaining from the initial deployment (~6.5 g *Q. alba*). We determined leaf breakdown as the slope of the regression of natural logarithm of mean percent AFDM remaining versus days of in-stream incubation, as well as a temperature corrected figure using degree-days; the slope of the regression line was used as the leaf-breakdown rate coefficient. Most procedures for the second year (2011-2012) repeated those of the first, except that we augmented the number of bags incubated per stream to 30 to account for losses due to extreme flows and we deployed in late November.

To characterize aerial OM inputs to each stream channel, we measured litterfall using 10 direct-fall traps (five on each bank) spaced equidistant along a 30 m sub-reach of the stream. Traps were constructed using perforated 5-gallon buckets of known dimensions with aluminum mesh cones lining the bottom to allow drainage. We deployed traps in December 2010, collected accumulated material from them approximately monthly through September 2012, and separated the samples into five OM fractions: wood, leaves/needles of woody taxa, reproductive parts of woody taxa (i.e., fruits, seeds, nuts, flowers), all herbaceous material, and unidentifiable detrital material. In similar fashion to leaf breakdown, we dried, weighed, ground, subsampled, ashed, and weighed the ash to determine the contribution of each of these fractions to aerial OM inputs for each collection date. Measurements from each collection were summed to determine the overall and yearly litterfall input as well as peak litterfall input rates during the study period.

Periphyton biomass was sampled by placing tile arrays consisting of 25 unglazed, 5.08 cm square ceramic tiles affixed to 30.5 cm square concrete pavers using microbially inert aquarium silicon. Avoiding areas of extreme scour and deposition, we placed three arrays in each stream during early December 2010 and October 2011 for the first and second year of the study respectively. Pavers elevated the tiles ~5 cm above sediment surface to limit grazing and scraping by benthic macroinvertebrates. By limiting grazing, scour, and shading due to deposition, rates of periphyton biomass accrual can approximate net primary production within the first one to two months of incubation. Three tiles from each array were collected at monthly intervals (9 tiles per stream per date) and returned to the lab on ice where they were frozen at -20°C until processing commenced. Tiles from each stream were composited by array for each collection, resulting in three replicate measurements of biomass per stream-date combination. Under subdued light, we scraped composited samples into periphyton slurry and then filtered the slurry onto pre-weighed glass-fiber filters. Filters were bisected, and we determined the amount of periphyton on one of the halves as AFDM. This measure indicates the total amount of biomass that has accrued on the tile, heterotrophic (microbial consumers) and autotrophic (microbial producers/algae) combined as well as any detrital material caught in the periphyton microbial complex that was not rinsed during sample processing. We placed the other half of each filter in a centrifuge tube, wrapped it in foil, and froze it at -20°C until extraction in 96% ethanol and subsequent spectrophotometric analysis of chlorophphyll-*a* (chl-*a*). In contrast to AFDM, chl-*a* measures represent only the amount of autotrophic (producers/algal) material in the periphyton complex. We are using both chl-*a* and AFDM areal concentrations, as well as the autotrophic index (chl-*a*/AFDM ratio), at each collection period to construct periphytic biomass time-series over the first (2010-2011) and second (2011-2012) year of study. Additionally, we are using a natural log growth model over time to determine periphyton biomass accrual rates (mg cm^{-2} d^{-1}) over standard incubation intervals of one to two months using both chl-*a* and AFDM data from both study years. For 2010-2011, only fall accrual rates will be calculated, whereas the remainder of samples will show a time series of algal standing crop. However, augmenting accrual rate sampling efforts by anchoring fresh strips of tiles to pavers during the second year allowed us to determine accrual rates for all four seasons while maintaining a similar sample schedule for periphyton standing crop.

Structural Measures. We deployed temperature data loggers (Onset Corp.; HOBO U-series) in the deepest pools of stream reaches in July 2010, which recorded stream temperature at half-hour intervals through September 2012. Dissolved oxygen (mg L^{-1}), temperature (°C), specific conductance (μS cm^{-1}), and pH were measured bi-weekly to monthly in a uniformly mixed portion of the water column using a water quality meter (Hydrolab Quanta, Hach Instruments, Loveland, CO), and grab samples were collected at identical intervals for chemical analysis. Samples were filtered on site (0.45 μm pore size), split by analytical procedure, transported to the lab on ice, and frozen (-20°C) until analysis. Samples for major cation analysis were preserved in 1+1 HNO_3 prior to transport. Chemical analyses to determine alkalinity, ammonium (NH_4^+-N), total oxidized nitrogen (NO_3^-N+ NO_2^-N), and soluble reactive phosphate (PO_4^{-3}-P), and major anions (SO_4^{2-} and Cl^-) have been completed.

We evaluated benthic macroinvertebrate community structure twice yearly from samples obtained via rapid bioassessment protocol (RBP) techniques (Barbour et al. 1999). Initial sampling occurred in fall 2010 and concluded in spring 2012. Specimens were preserved in 95% ethanol, subsampled to 200 organisms ± 10%, and identified to family-level. We calculated several family-level and functional feeding group (FFG) metrics using the Ecological Data Application System (EDAS; Tetra-tech, Inc.). Additionally, we used 100 iterations of a rarefaction process to randomly reduce our 200 count subsample to 100 and calculate the Virginia Stream Condition Index (VASCI) score (R-code; written by Tony Timpano).

In July 2010, we performed basic physical surveys of the channels at baseflow via methods outlined by Fritz et al. (2006). Measurements included slope, median bed particle size (D_{50}), and average wetted width measures. We estimated stream discharge (Marsh-McBirney Flo-mate) approximately monthly when stream depth was adequate. Using a spherical densiometer, we estimated canopy cover quarterly for the first year of study and monthly thereafter. We are converting current geospatial data (Virginia Base Mapping Program, Digital Terrain Models) to digital elevation models (DEMs), and determining each local catchment area from flow accumulation analysis. We are checking two land-use/land-cover (LULC) datasets against recent aerial photography to determine which most accurately reflects land-use in each local catchment. If these data accurately represent current catchment conditions, land-use types will be calculated as percent of total watershed area and tested as explanatory variables for our measures of stream function. In addition to basic LULC catchment-level variables, we are determining other parameters from a combination of aerial photos and a normalized difference vegetation index (e.g., distance of reach from toe of valley fill, presence of in-line ponds, age of stream restoration).

Statistical Analyses. We have assembled a set of continuous independent variables (Table 2), which may influence both OM function and biotic structure. Because measures of richness, density, evenness, and function are continuous dependent variables, regression coupled with multivariate techniques is well-suited to this study. In addition, streams are divided into two *a priori* classes (MINE and REF) for hypothesis testing. Correlations among continuous variables are being explored to determine relationships between explanatory (independent) and response (dependent) variables.

Table 2. Continuous independent and dependent variables to be used in regression and multivariate analysis, as well as *a priori* stream and catchment categories.

Independent Variables (x)	Dependent Variables (y)
Reach–Scale, Continuous	**Benthic Macroinvertebrate Structure**
Total alkalinity (mg L^{-1} as $CaCO_3$)	Taxa Evenness
SRP (mg PO_4-P L^{-1})	Total Taxa richness
Dissolved NH_4-N (mg L^{-1})	EPT Taxon richness
Dissolved NO_2+NO_3-N (mg L^{-1})	FFG metrics
Dissolved Mn (mg L^{-1})	Shredder richness
Dissolved Fe (mg L^{-1})	Diversity Index Scores
Dissolved Ca^{2+} (mg L^{-1})	
Dissolved Mg^{2+} (mg L^{-1})	**Riparian Inputs**
SO_4^{2-} (mg L^{-1})	Areal litterfall input (g AFDM m^{-2} y^{-1})
Cl^- (mg L^{-1})	Peak litterfall input rate (g AFDM m^{-2} y^{-1})
Specific Conductance (µS cm^{-1})	
Dissolved Oxygen (mg L^{-1})	**Leaf Litter Decomposition**
Temperature (°C)	$\lvert k \rvert$ (d^{-1} and degree-d^{-1})
pH	$k_{impacted} : k_{reference}$
Canopy cover (%)	$k_{coarse} : k_{fine}$
Sinuosity ratio	
Channel slope (%)	
D_{50} (mm)	**Biomass Accrual Rates**
	Periphytic accrual (mg AFDM cm^{-2} d^{-1} and degree-d^{-1})
Catchment–Scale, Continuous	Algal accrual (mg chl *a* cm^{-2} d^{-1} and degree-d^{-1})
Age since mined (yr)	Autotrophic index (mg AFDM cm^{-2} / mg chl *a* cm^{-2})
Age since restored (yr)	
Mining extent (% catchment mined)	
Forest extent (% forested)	
Reach- and Catchment-Scale, Categorical	
Un-mined Forest Reference (REF)	
Mined Receiving Reconstruction (MINE)	

Progress to Date

Results from a preliminary assessment in 2009 measuring ecosystem function (i.e., stream metabolism), conducted as a preliminary study prior to the Powell River Project research, were published in 2011 (Northington et al. 2011) following initial funding. During 2009-2010 we scouted over 100 prospective stream reconstructions for potential inclusion in the current study. Through this effort, we selected eight stream reconstructions in southwestern Virginia based on immediate mining influence (i.e., built using some mining overburden, and with influence from past or active mines in the immediate drainage area). Construction and deployment of litterfall traps, periphyton tile arrays, leaf litter decomposition bags, and temperature logger anchors were initiated in summer 2010, as were initial physical characterizations of stream sites. Sampling of stream chemistry and OM dynamics commenced in late summer and early fall 2010, respectively, and concluded in late September 2012. Laboratory processing concluded in mid-August 2013. Current activities are focused on data analysis and manuscript preparation.

Results to Date

Based on data from September 2010 through September 2012 several physicochemical differences within and among stream types were apparent (Table 3). Reconstructed streams selected for study exhibit a wide range of mean specific conductance values. The range of mean specific conductance values for REF streams, a range from 50 $\mu S\ cm^{-1}$ to 138 $\mu S\ cm^{-1}$ (Table 3) and is more densely clustered than that of MINE streams. Similarly, there is great variability with respect to benthic macroinvertebrate family-level metrics (Figure 1), which span the current biological impairment threshold (VASCI<60). We also see wide ranges of VSCI component metrics for the MINE streams (data not shown).

Table 3. Entire study period (Sept. 2010 - Sept. 2012) means for selected physical and chemical variables. Grand means with standard deviations are expressed below each stream group (MINE and REF).

Stream Name	Specific Conductance (µS cm^{-1})	pH	SO_4^{2-} (mg l^{-1})	Cl^- (mg l^{-1})	NO_2+NO_3-N (mg l^{-1})	NH4-N (mg l^{-1})	% Canopy Cover	D_{50} * (mm)
MINE								
Callahan Creek	714	8.29	87.5	4.61	1.21	0.007	21	32.0
Critical Fork	1413	8.06	283.2	2.58	4.16	0.014	9	22.6
Guest Mountain #3	634	7.97	99.5	1.30	0.42	0.013	21	128.0
Laurel Branch	666	7.73	84.1	4.31	1.26	0.007	19	16.0
Chaney Creek	431	7.60	61.0	1.93	0.38	0.008	58	16.0
Sewing Creek	1409	7.64	291.5	10.56	1.56	0.007	21	2.0
Shooting Range Creek	1789	8.05	354.7	3.75	6.46	0.004	19	32.0
Stonecoal Creek	176	7.39	18.3	1.30	0.74	0.010	8	5.6
Mean ± SD	904 ± 563	7.84 ± 0.299	160 ± 128	3.79 ± 3.03	2.02 ± 2.16	0.009 ± 0.004	22.0 ± 15.4	31.8 ± 40.4
REF								
Big Branch	84	7.39	8.6	8.10	0.57	0.004	77	16.0
Copperhead Branch	138	7.39	18.2	1.72	0.47	0.003	75	11.0
Crooked Branch	68	7.45	7.9	3.98	0.38	0.003	75	8.0
Middle Camp Branch	50	7.37	8.4	0.45	0.30	0.006	74	32.0
Mean ± SD	85 ± 38	7.40 ± 0.035	11 ± 5	3.56 ± 3.36	0.43 ± 0.12	0.004 ± 0.001	75.4 ± 1.4	16.8 ± 10.7

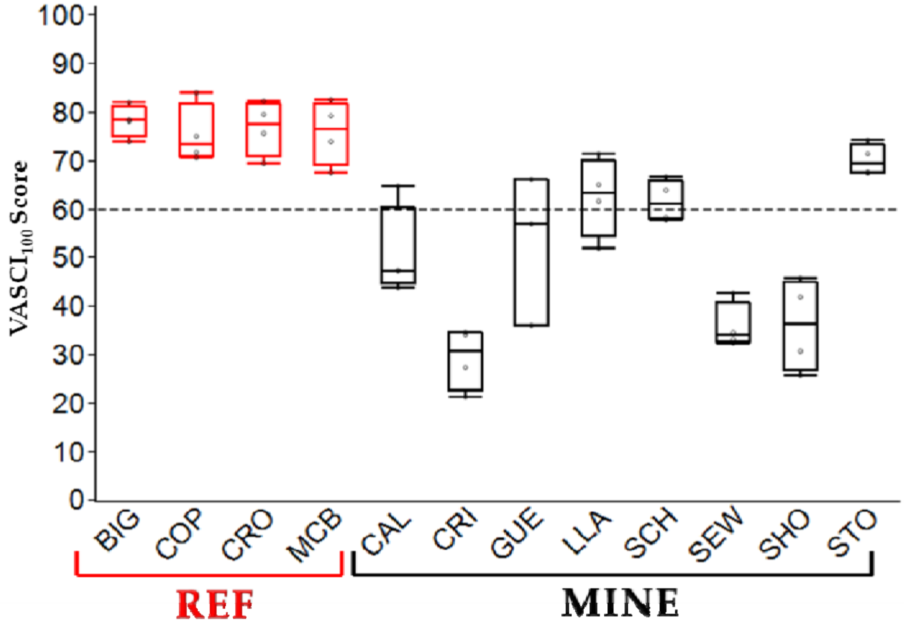

Figure 1. VASCI scores from macroinvertebrate sampling across four sampling seasons (fall 2010 – spring 2012) (REF = Reference; MINE = mining-impacted reconstructed streams).

Reference stream reaches received approximately 13 to 17.5 kg of OM inputs to 30 m of stream reach over the two year study period (Figure 2). In contrast, the reconstructed streams received OM inputs ranging between 1.5 and 9.5 kg over the same period (Figure 2). Additionally, all reference streams have leaf inputs alone greater than the total OM input to any single restoration. Wood and leaves comprised the majority of inputs to reference streams, with other OM fractions (i.e., herbaceous, reproductive parts, and unidentifiable detritus) contributing little to the overall load. In several of the reconstructed streams, the non-wood/non-leaf OM fractions contributed a disproportionate amount relative to total OM inputs, presumably due to lack of riparian overstory.

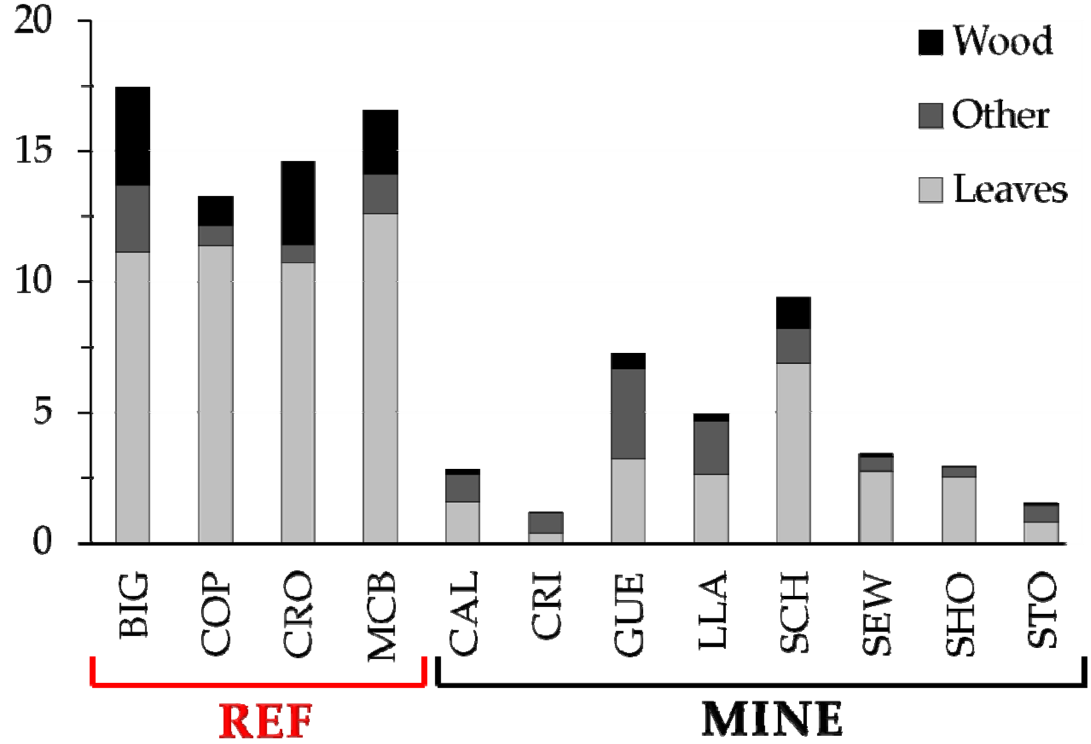

Figure 2. Estimated relative composition of total OM inputs to immediate riparian zone along 30 m stream reaches.

Mean breakdown of *Q. alba* leaves in coarse mesh over the two study years was nearly twice as rapid in forested reference streams than in reconstructed streams (Figure 3). Mean breakdown rates were always greater in reference streams than in reconstructed streams, regardless of mesh size or unit (day or degree-day) of measurement (Table 4; Table 5). Likewise, breakdown rates in reference streams were less variable than in reconstructed streams for both mesh sizes. For both stream types, mean leaf breakdown in coarse mesh was always greater than that observed in fine mesh bags (Table 4; Table 5). When measured on a per day basis, mean reference stream breakdown rates decreased between the first and second years for all mesh sizes; whereas for the reconstructed streams the coarse mesh mean breakdown rate was greater for the second year. However, when corrected for temperature by basing breakdown rates on degree-days rather than days, mean coarse mesh breakdown in reconstructed streams remained fairly constant between the first and second year of study (Table 4; Table 5). That is, most of the variability in coarse-mesh breakdown between years in the reconstructed streams was eliminated when temperature was taken into account. In contrast, the interannual variability in breakdown rates for reference streams is still apparent regardless of whether the measure is based on days or degree-days. This suggests that thermal regime is important to the litter breakdown process, and that breakdown in mined stream restorations was relatively more affected by temperature fluctuation than in reference streams where other factors contributed more to the variability in breakdown. Presumably this is due to a lack of thermal buffer provided by a developed riparian canopy, absent in many reconstructed streams, in addition to the relatively drier second year.

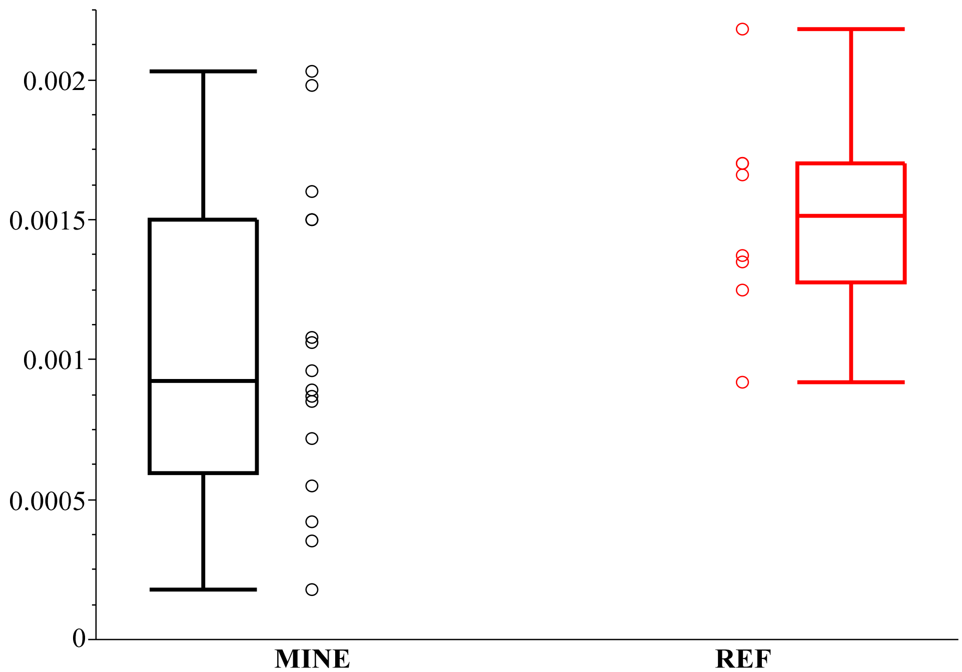

Figure 3. Leaf breakdown rates (per degree-day) in coarse mesh for both years.

Table 4. First year breakdown rates of Quercus alba in coarse and fine mesh bags per day and per degree day measured over ca. 10 months. Grand means with standard deviations are expressed below each stream group (MINE and REF).

Stream Name	**k coarse (day^{-1})**	**k fine (day^{-1})**	**k coarse ($deg.-day^{-1}$)**	**k fine ($deg.-day^{-1}$)**
MINE				
Callahan Creek	0.012	0.0063	0.0010	0.0005
Critical Fork	0.011	0.0065	0.0009	0.0005
Guest Mountain #3	0.009	0.0054	0.0007	0.0004
Laurel Branch	0.013	0.0106	0.0011	0.0009
Chaney Creek	0.012	0.0107	0.0009	0.0008
Sewing Creek	0.005	0.0043	0.0004	0.0003
Shooting Range Creek	0.017	0.0128	0.0020	0.0013
Stonecoal Creek	0.019	0.0053	0.0015	0.0004
Mean ± SD	0.0124 ± 0.0043	0.0077 ± 0.0032	0.0010 ± 0.0005	0.0006 ± 0.0004
REF				
Big Branch	0.020	0.0163	0.0017	0.0014
Copperhead Branch	0.023	0.0121	0.0022	0.0010
Crooked Branch	0.019	0.0121	0.0017	0.0010
Middle Camp Branch	0.018	0.0124	0.0014	0.0010
Mean ± SD	0.0201 ± 0.0023	0.0132 ± 0.0021	0.0017 ± 0.0003	0.0011 ± 0.0002

Table 5. Second year breakdown rates of Quercus alba in coarse and fine mesh bags per day and per degree day (^{o} C) measured over ca. 10 months. Grand means with standard deviations are expressed below each stream group (MINE and REF).

Stream Name	**k coarse (day^{-1})**	**k fine (day^{-1})**	**k coarse ($deg.\text{-}day^{-1}$)**	**k fine ($deg.\text{-}day^{-1}$)**
MINE				
Callahan Creek	0.021	0.0047	0.0016	0.0004
Critical Fork	0.008	0.0038	0.0005	0.0003
Guest Mountain #3	0.006	0.0033	0.0004	0.0002
Laurel Branch	0.025	0.0077	0.0020	0.0006
Chaney Creek	0.016	0.0067	0.0011	0.0004
Sewing Creek	0.003	0.0023	0.0002	0.0001
Shooting Range Creek	0.018	0.0055	0.0015	0.0005
Stonecoal Creek	0.013	0.0046	0.0009	0.0003
Mean ± SD	0.0137 ± 0.0076	0.0048 ± 0.0018	0.0010 ± 0.0006	0.0004 ± 0.0002
REF				
Big Branch	0.023	0.0099	0.0017	0.0008
Copperhead Branch	0.018	0.0077	0.0013	0.0006
Crooked Branch	0.012	0.0052	0.0009	0.0004
Middle Camp Branch	0.017	0.0132	0.0013	0.0010
Mean ± SD	0.0173 ± 0.0048	0.0090 ± 0.0034	0.0013 ± 0.0003	0.0007 ± 0.0003

Summary

We have presented data that describes selected functional and structural characteristics of reconstructed streams in the mining landscape of southwestern Virginia. Periphyton biomass accrual rate laboratory analyses were completed in mid-August and will serve as another characterization of OM functions in these streams. Currently, we are finishing local catchment characterization (e.g., watershed size, land-use) using current and past geospatial data. In addition, we are implementing a number of statistical techniques both to compare functional attributes of reconstructed to reference streams, and to determine structural factors within the reconstructed stream category that exert the most influence on these OM functions. By identifying reconstructed streams that are closest to reference with respect to structural and functional attributes, as well as factors that exert major influence on these attributes, we plan to inform science, industry, restoration professionals, and regulators regarding effective stream reconstruction methods and assessment of these restoration efforts.

Report of Activities

This ongoing research has been presented at two regional and three national conferences, as well as at local symposia. Additional dissemination of results through presentations and publications will continue upon completion of geospatial processing. Presentations and publications resulting from ongoing funding are listed below.

Presentations:

Krenz, R.J. 15 September, 2010. Use of selected carbon dynamics as functional indicators of reconstructed stream condition: a research approach. Powell River Project Symposium. Wise, VA.

Krenz, R.J. 30 March, 2011. Selected carbon dynamics as functional indicators of reconstructed stream condition: a research approach. Forest Resources and Environmental Conservation Graduate Research Symposium. Blacksburg, VA.

Krenz, R.J. 14 April, 2012. Leaf litter breakdown in reconstructed streams draining coal mines in Virginia's central Appalachians. Annual Conference of Mid-Atlantic Chapter Ecological Society of America. Blacksburg, VA.

Krenz, R.J. 21 May, 2012. Leaf litter breakdown in reconstructed Appalachian coal-mine streams. 60th Annual Meeting of the Society for Freshwater Science (formerly NABS). Louisville, KY.

Krenz, R.J. 12 June, 2012. Organic matter processing in reconstructed Appalachian coal-mine streams: relationships to environmental variables. 29th Annual Conference of the American Society of Mining and Reclamation. Tupelo, MS.

Krenz, R.J. 12 September, 2012. Organic matter dynamics in reconstructed Appalachian coal-mine streams. Annual Powell River Project Symposium. Wise, VA.

Krenz, R.J. 16 April, 2013. Functional assessment of coal-mine stream restorations using organic matter dynamics. Environmental Considerations in Energy Production Symposium: Appalachian Research Initiative for Environmental Science. Charleston, WV.

Krenz, R.J. 22 May, 2013. Riparian subsidies, leaf breakdown, and ecosystem structure in Virginia coal-mine stream restorations. 61st Annual Meeting of the Society for Freshwater Science (formerly NABS). Jacksonville, FL.

Publications:

Krenz, R.J., S.H. Schoenholtz, and C.E. Zipper. 2010. Select carbon dynamics as functional indicators of restoration success: a research approach. Powell River Project Research and Education Program Reports: pp.110-120.

Northington, R.M., E.F. Benfield, S.H. Schoenholtz, A.J. Timpano, J.R. Webster, and C.E. Zipper. 2011. An assessment of structural attributes and ecosystem function in restored Virginia coalfield streams. *Hydrobiologia* 671:51-63. DOI 10.1007/s10750-011-0703-7.

Krenz III, R.J, S.H. Schoenholtz, and C. Zipper. 2011. Select carbon dynamics as functional indicators of restoration success: progress from the first 2 years. Powell River Project Research and Education Program Reports: pp. 49-57.

Krenz III, R.J, and S.H. Schoenholtz. Organic matter dynamics as functional indicators of stream condition in constructed streams on Virginia coal mine sites. Powell River Project Research and Education Program Reports: pp. 87-100.

We anticipate this work will result in two to three peer-reviewed journal articles, as well as an extension publication to inform industry, consultants, and regulators.

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Literature Cited

Cummins, K. W. 1974. Structure and function of stream ecosystems. Bioscience **24**(11): 631-641.

Federal Register. April 10, 2008. Compensatory mitigation for losses of aquatic resources; final rule. **73**(70): 19594-19705.

Fritz K.M., B.R. Johnson, and D.M. Walters. 2006. Field operations manual for assessing the hydrologic permanence and ecological condition of headwater streams. EPA/600/R-06/126. USEPA, Washington, D.C.

Fisher, S. G. and G. E. Likens 1973. Energy Flow in Bear Brook, New Hampshire: An Integrative Approach to Stream Ecosystem Metabolism. Ecological Monographs **43**(4): 421-439.

Gessner, M. O., and E. Chauvet. 2002. A case for using litter breakdown to assess functional stream integrity. Ecological Applications **12**(2): 498-510.

Hall, R.O., J. B. Wallace, and S.L. Eggert. 2000. Organic matter flow in stream food webs with reduced detrital resource base. Ecology **81**(12): 3445-3463.

Harman, W., R. Starr, M. Carter, K. Tweedy, M. Clemmons, K. Suggs, C. Miller. 2012. A Function-Based Framework for Stream Assessment and Restoration Projects. US Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, DC EPA 843-K-12-006.

Northington, R.M., E.F. Benfield, S.H. Schoenholtz, A.J. Timpano, J.R. Webster, and C. Zipper. 2011. An assessment of structural attributes and ecosystem function in restored Virginia coalfield streams. Hydrobiologia: DOI 10.1007/s10750-011-0703-7.

USEPA and USACoE. July 30, 2010. Memorandum: Assessment of Stream Ecosystem Structure and Function under Clean Water Act Section 404 Associated with Review of Permits for Appalachian Surface Coal.

Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing 1980. The river continuum concept. Can. J. Fish. Aquat. Sci. **37**: 130-137.