Organic Matter Dynamics as Functional Indicators of Stream Condition in Constructed Streams on Virginia Coal Mine Sites

R.J. Krenz and S.H. Schoenholtz

Department of Forest Resources and Environmental Conservation and Virginia Water Resources Research Center
Virginia Tech

Project Summary

The Clean Water Act [section 404; stream mitigation rule] mandates that operations permitted by the U.S. Army Corps of Engineers (COE) must mitigate streams impacted by valley fill and other mining activities (Register April 10, 2008). Agencies regulating coal mining operations are placing increased emphasis on functional measures for stream assessment. Guidance memoranda issued by the U.S. Environmental Protection Agency (EPA) and COE concerning mining permits state that the regulatory process should “ensure that compensatory mitigation adequately replaces lost stream functions” (2011) and that “permitting will not rely exclusively on an evaluation of structure in place of function” (2010). In this context, successful restoration of stream functions is of concern to industry, regulators, and restoration professionals. Additionally, in 2012 EPA released *A Function-Based Framework for Stream Assessments and Restoration Projects*, a document aimed at those implementing stream restorations and assessments, and clearly states that it would benefit “from review, comments, and example experiences and applications” (Harman et al. 2012). The research presented in this report is addressing needs of industry and regulators by directly measuring specific ecosystem functions in stream mitigation efforts on coal mine sites in southwestern Virginia, and can contribute as an example experience and application.

Organic matter (OM), primarily as leaf litter and detritus input, serves as habitat and an essential energy source for benthic macroinvertebrates within headwater and downstream 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 a crucial component to determine the overall functional condition of streams, and as an integral tool to meet the needs of industry and regulators to evaluate mitigation efforts through direct measurement of a crucial stream functions. To address these needs we are measuring litterfall input, leaf litter decomposition, and periphyton biomass accrual for reconstructions of eight low-order mining-impacted streams, and evaluating 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:

In addition to being an integral economic activity in central Appalachia, coal extraction is a large- scale disturbance known to affect aquatic ecosystems in the region. The Surface Mining Control and Reclamation Act (SMCRA) of 1977, the primary piece of legislation governing coal extraction and reclamation, 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 mining.

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. However, recent guidance from EPA 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; USEPA 2011).

Our ongoing 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, *viz.*, litterfall input, leaf litter decomposition, and periphyton biomass accrual. We chose to study OM processes because 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., mined reconstructions 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 stream reconstructions relative to forested reference streams.
2. Examine relationships between established assessments based on biotic structure and those based on selected OM dynamics.
3. Evaluate factors affecting selected OM dynamics in Central Appalachian coalfield stream reconstructions.
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. To meet the objectives above we will complete the second year of data collection in September 2012. Eight reconstructed and four reference streams in four counties (Wise, Dickenson, Russell, and Buchanan) in the Central Appalachian ecoregion (69; level III) of southwestern Virginia were selected in the first year (2010) of the organic matter study (Table 1). Streams selected are within the Appalachian Plateau and Ridge and Valley physiographic regions of Virginia. Sixty-meter stream reaches of contiguous channel morphology and riparian structure were delineated and subdivided into two reaches of 30 m for different components of the study. These reaches were subdivided into two major categories: un-mined forested riparian (UFR; reference), and mined receiving reconstruction (MRR; test). The MRR grouping is comprised of streams receiving a variety of treatments from channel construction alone to those receiving Natural Channel Design (NCD) efforts and riparian plantings.

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

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

[1] Two stream type categories have been identified, mined receiving reconstruction practices (MRR) and un-mined forested reference (UFR).

[2] Stream order was determined using 7.5' USGS quadrangles.

A majority of MRR streams initially visited were less than seven years-old, although a few older streams were available for study. Fortunately, stream <6 years-old that were selected are characterized by a wide variety of riparian canopies, including some that are well-developed due to the nature of the riparian plantings. The UFR streams drain relatively undisturbed forested areas featuring intact riparian forest canopies, and enable comparative analysis of OM dynamics in MRR streams and UFR streams.
Functional Measures. For the first year of data collection (2010-2011) leaf litter decomposition was evaluated by measuring mass loss from 6.5 g of dry *Quercus alba* (white oak) leaves through serial collection of samples during ~300 days. Leaves were collected from a single location, uniformly mixed, dried (65° C for 5 days), weighed and placed in mesh bags. Coarse mesh leaf bags were used to allow access by benthic macroinvertebrates, and fine mesh bags were used to give a measure of decomposition due to all other factors besides macroinvertebrates. In each stream, twenty-four bags of each type were deployed in early December 2010, secured in pool glides using paracord, and retrieved in triplicate monthly for three months, and bimonthly for the remainder of the deployment period. Leaf material was returned to the lab, rinsed of non-leaf material, dried at 65° C for five days, weighed, ground, sub-sampled, ignited at 550° C for 40 minutes, and weighed again to determine the percent OM. This figure was used to determine the percent OM remaining based on dry weight for each bag, which was subsequently averaged by collection date for each stream. The natural logarithm of mean percent OM remaining was plotted against days of in-stream incubation and the slope of the regression line was used as the leaf litter decomposition rate coefficient. Mean percent OM remaining was also plotted versus degree-days to determine a leaf litter decomposition rate coefficient corrected for temperature (these figures are not presented here). Procedures for the second year (2011-2012) of data were similar, except that the number of bags per stream was augmented to 30 to account for losses due to extreme flows, and deployment occurred in late November 2011.

During 2010-201,1 periphyton biomass accrual was measured by placing tile arrays consisting of 25 square unglazed, ceramic 5.08 cm tiles affixed to 30.5 cm X 30.5 cm concrete pavers using microbially inert aquarium silicon. Three arrays were placed in stream areas that were consistently inundated, but avoiding areas of extreme scour or deposition. Pavers elevate the tiles ~5 cm above sediment surface to limit grazing and scraping by benthic macroinvertebrates. By limiting the effects of grazing, scour, and shading (due to deposition) measurements 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 are frozen until processed. Tiles are being composited for each array-date combination, scraped to form a slurry of periphytic material, and filtered onto glass fiber filters. Pre-weighed filters are then bisected, and percent ash-free dry mass (AFDM) is determined after drying and igniting as described above for litter decomposition. This measure provides amount of biomass that has accrued on the tile, both heterotrophic (microbial consumers) and autotrophic (microbial producers/algae) combined. The other half of the filter is being analyzed for chl *a* to determine the amount of algal material per unit area, excluding material derived from heterotrophs. Algal biomass accrual rates (mg cm^{-2} d^{-1}) will be determined by applying a natural log growth model to chl *a* accumulations over a standard incubation interval of one to two months for both 2010 -2011 and 2011-2012. 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, accrual rate sampling efforts were augmented for the 2011-2012 period, and fresh strips of tiles were anchored to arrays during all four seasons for two-month periods to determine seasonal differences among accrual rates for study streams. Accrual rates (mg cm^{-2} d^{-1}) of entire periphyton assemblages will be defined by applying a similar model to AFDM. Additionally, the ratio of AFDM to chl *a* will be used to determine the autotrophic index (AI).

Litterfall inputs from the riparian zone of each stream are being determined using 10 direct-fall traps (five on each bank immediately next to the channel) spaced equidistant across a 30 m sub-reach downstream of leaf-litter decomposition bag deployment sites. Inputs from these traps are assumed to accurately represent inputs of leaf litter from the riparian assemblage where litter bags are deployed. Direct-fall traps were constructed using perforated 5-gallon buckets of known dimensions lined with aluminum mesh cones to provide for drainage. Traps were deployed in December 2010, and are being sampled approximately monthly through September 2012. OM inputs are being subdivided into five categories: wood, leaves/needles of woody taxa, reproductive parts of woody taxa (fruits, nuts, flowers), all herbaceous material, and unidentifiable detrital material. Similar to litter breakdown procedures, these fractions of litterfall input are being dried, weighed, ashed, and weighed again to determine yearly allochthonous inputs as well as peak litterfall input (usually autumn) for each stream.

Structural Measures. Temperature data loggers (Onset Corp.; HOBO U-series) were deployed in the deepest pools of stream reaches in July 2010 and are recording stream temperature at half-hour intervals through September 2012. Dissolved oxygen (mg L^{-1}), temperature (°C), specific conductance (µS cm^{-1}), and pH are being taken monthly in a uniformly mixed portion of the streamwater column immediately below the surface using a Hydrolab water quality meter (Hydrolab Quanta, Hach Instruments, Loveland, CO) at all sites. Additionally, monthly grab samples are being collected and filtered on site (0.45 µm pore size) for water chemistry determinations. Samples are split by analytical procedure, transported to the lab on ice, and frozen until analysis. Major cation samples are 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), major anions, and dissolved organic carbon are also underway.

Benthic macroinvertebrate community structure is being evaluated using seasonal (spring and fall) samples obtained via rapid bioassessment protocol (RBP) techniques (Barbour et al. 1999). Sampling for this phase began fall 2010 and concluded in spring 2012. Specimens are preserved in 95% ethanol and are currently being identified and enumerated to family-level. These data will be applied to the Virginia Stream Condition Index (VASCI) when completed. Additionally, taxa will be assigned to functional feeding groups using the keys of Merritt and Cummins (1996) and saved for genus/lowest practicable level identification if deemed necessary. Several assemblage structure statistics will be calculated, including: shredder density, benthic macroinvertebrate density, and Ephemeroptera-Plecoptera-Trichoptera (EPT) richness. Non-aquatic taxa and life stages will be eliminated from samples and will not be used in further analyses.

In July 2010, channel characteristics including slope, median bed particle size (D_{50}), and average wetted width were determined via methods outlined by Fritz et al. (2006). These procedures will be repeated in

September or October 2012. Sinuosity will be calculated as the quotient of thalweg distance (60 m) to valley distance determined by points taken at the end of each reach with a high accuracy GPS. Canopy cover is being determined using a spherical densitometer and stream discharge is estimated using a Marsh-McBirney velocity meter approximately monthly by methods outlined by Fritz et al. (2006).

Catchment level characterization will begin in September or October of 2012. The most current data from VA Department of Mines Minerals and Energy flyovers are available to us and will be utilized in conjunction with other available and appropriate geospatial data. The area of each catchment will be quantified from flow direction analysis of digital elevation models (DEM), ensuring that these models reflect post-mining contours. The most recent land-use/land-cover (LULC) data, and catchment-level variables will be quantified for each local catchment given that these data accurately reflect land-cover when checked against recent aerial photography. If these data accurately represent current site conditions, land-use types will be calculated as percent of total watershed area and tested as explanatory variables for our measures of stream function.

Statistical Analyses. We have assembled a potential 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 potentially supplemented with multivariate techniques is well-suited to this study. In addition, we will have categorical benthic macroinvertebrate taxonomic data and streams will be divided into a minimum of two *a priori* classes to facilitate hypothesis testing. Correlations among continuous variables will be 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[1]**
Total alkalinity (mg L^{-1} as $CaCO_3$)	Total density (#/g litter remaining)
SRP (mg PO_4-P L^{-1})	Total Taxon richness
DIN (mg L^{-1})	EPT taxon density (#/g litter remaining)
DOC (mg L^{-1})	EPT taxon richness
Dissolved NH_4-N (mg L^{-1})	Shredder density (#/g litter remaining)
Dissolved NO_2+NO_3-N (mg L^{-1})	Shredder richness
Dissolved Mn (mg L^{-1})	Diversity Index Scores
Dissolved Fe (mg L^{-1})	
Dissolved Ca^{2+} (mg L^{-1})	**Riparian Inputs***
Dissolved Mg^{2+} (mg L^{-1})	Annual litterfall input load (g AFDM m^{-2})
SO_4^{2-} (mg L^{-1})	Peak litterfall input rate (g AFDM m^{-2} y^{-1})
Br^- (mg L^{-1})	
Cl^- (mg L^{-1})	**Leaf Litter Decomposition[2]**
Specific Conductance (µS cm^{-1})	$\|k\|$ (d^{-1} and degree-d^{-1})
Dissolved Oxygen (mg L^{-1})	$k_i : k_r$
Temperature (°C)	$k_c : k_f$
pH	
Canopy cover	
Sinuosity (thalweg dist/channel dist)	**Biomass Accrual Rates**
Channel slope (%)	Periphytic accrual (mg AFDM cm^{-2} d^{-1} and degree-d^{-1})
D_{50} (mm)	Algal accrual (mg chl *a* cm^{-2} d^{-1} and degree-d^{-1})
	Autotrophic index (mg AFDM cm^{-2} / mg chl *a* cm^{-2})
Catchment–Scale, Continuous	
Age since mined (yr)	
Age since restored (yr)	
Mining extent (% catchment mined)	
Forest extent (% forested)	
Reach- and Catchment-Scale, Categorical	
Unmined Forest Reference (UFR)	
Mined Receiving Reconstruction (MRR)	
Restoration Type (e.g., Natural Channel Design Oth	

[1]Will also serve as explanatory variables when modeled vs. leaflitter decomposition and biomass accrual.
[2]Will be calculated for all sites, but will only apply Gessner and Chauvet (2002) index to those which are not UFR.

Results and Progress

Results from a preliminary assessment measuring ecosystem function (i.e., stream metabolism) were published in 2011 (Northington et al. 2011) following initial funding. During 2009-2010 we scouted over 100 prospective stream reconstructions to be included in the current OM study. Through this effort, eight stream reconstructions in southwestern Virginia were selected 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 OM dynamics and stream chemistry began in late summer – early fall 2010, and will continue through late September or early October 2012. Laboratory processing will continue through late fall – early winter of 2012, with subsequent data analysis.

Based on data from 2010-2011 several differences within and among stream types were apparent (Table 3). Reconstructed streams selected for study exhibit a wide range of mean specific conductance values (Table 3, Figure 1). Although the range of mean specific conductance values for reference streams is more densely clustered, a range from 49.8 $\mu S\ cm^{-1}$ to 134 $\mu S\ cm^{-1}$ (Table 3, Figure 1), these data lend themselves to regression analyses to determine the relationships between specific conductance and other structural and functional measures. Moreover, samples from these streams show a gradient of variation in other variables (e.g., SO_4^{2-}, percent canopy cover), which allow for analysis of factors that may influence litter decomposition, periphytic biomass accrual, and benthic macroinvertebrate community structure.

Table 3. Selected physicochemical and riparian variable means for mined streams receiving reconstruction practices (MRR) and un-mined forested reference streams (UFR).

Stream Name	Specific Conductance (µS cm^{-1})	Temperature (°C)	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)
MRR									
Callahan Creek	779	13.12	8.40	211.06	4.66	1.59	0.02	27	32.0
Critical Fork	1513	13.60	8.04	693.80	0.98	5.73	0.04	9	22.6
Guest Mountain #3	666	13.45	7.89	237.76	0.72	0.54	0.01	22	128.0
Laurel Branch	669	12.84	7.82	163.80	2.35	1.76	0.01	20	16.0
Chaney Creek	451	13.05	7.66	137.58	1.29	2.32	0.02	75	16.0
Sewing Creek	1386	14.03	7.81	691.70	25.82	3.75	0.02	25	2.0
Shooting Creek	1712	11.70	7.95	770.48	3.97	8.08	0.01	24	32.0
Stonecoal Creek	172	12.83	7.47	35.33	1.03	0.90	0.02	8	5.6
Mean + SE	918.4 ± 194.7	13.08 ± 0.2	7.88 ± 0.1	367.7 ± 5.1	5.1 ± 3.0	3.1 ± 0.9	0.02 ± 0.004	26.2 ± 7.4	31.8 ± 14.3
UFR									
Big Branch	80.3	12.00	7.45	12.18	5.36	0.55	0.02	86	16.0
Copperhead Branch	134	11.37	7.42	19.61	2.44	0.70	0.01	85	11.0
Crooked Branch	70.9	12.10	7.47	9.22	5.81	1.03	0.01	79	8.0
Middle Camp Branch	49.8	12.13	7.35	9.90	0.68	2.06	0.02	78	32.0
Mean ± SE	83.7 ± 17.9	11.90 ± 0.2	7.42 ± 0.03	12.7 ± 2.4	3.6 ± 1.2	1.1 ± 0.3	0.02 ± 0.002	82.0 ± 2.1	16.8 ± 5.3

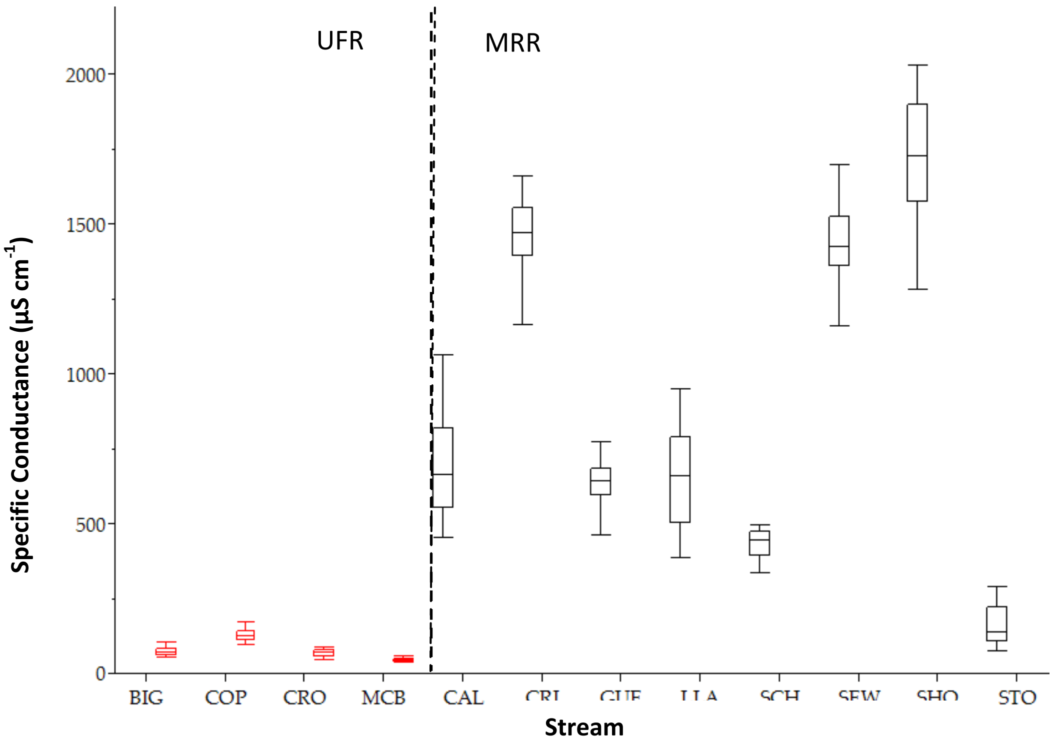

Figure 1. Mean specific conductance for UFR and MRR streams.

Mean decomposition of *Q. alba* leaves in forested reference streams was nearly twice as fast as that measured in mined streams for both coarse-mesh (Figure 2) and fine-mesh (Figure 2; Table 4). Likewise, means of several explanatory variables differed among stream type, and were notably variable within the MRR category (Table 3). With increasing consideration given to ionic strength of headwater streams in coal-mined landscapes, as well as the requirement for functional assessment of mitigation projects specific conductance as appears to be an important variable as we identify potential factors affecting function in these streams. Simple scatterplots show a negative linear relationship between coarse-mesh decomposition rates and specific conductance (Figure 3) when UFR and MRR streams are treated as a single population. However, relationships between litter decomposition and explanatory variables will be better served by more thorough multiple regression models given the variability in physicochemical properties among our study streams. Upon completion of field sampling and laboratory processing we will be analyzing a suite of stream-reach and catchment-level variables, which may exert control on our functional variables of interest (i.e., leaf litter decomposition and periphytic biomass accrual).

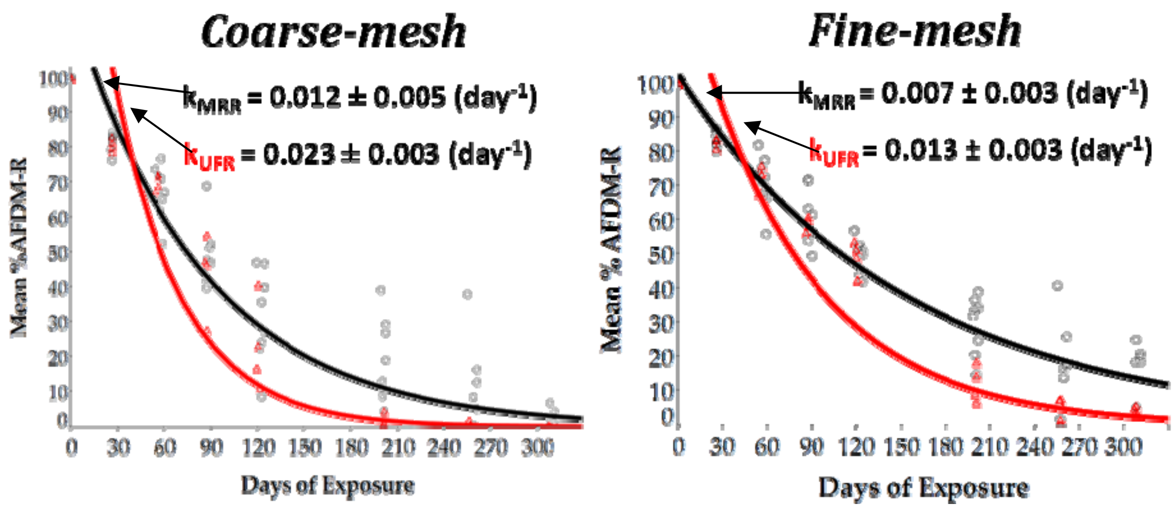

Figure 2. Mean percent ash-free dry mass remaining in coarse-mesh and fine-mesh bags versus days of exposure. Lines represent the mean exponential decay rate (k) for UFR and MRR stream categories

Table 4. Decomposition rates of *Quercus alba* leaves in coarse- and fine-mesh bags per day and per degree-day.

Stream Name	k coarse (day^{-1})	k fine(day^{-1})	k coarse (deg.-day^{-1})	k fine (deg.-day^{-1})
MRR				
Callahan Creek	0.010	0.0057	0.0009	0.0004
Critical Fork	0.012	0.0053	0.0009	0.0004
Guest Mountain #3	0.009	0.0050	0.0007	0.0004
Laurel Branch	0.010	0.0058	0.0009	0.0004
Chaney Creek	0.013	0.0087	0.0009	0.0006
Sewing Creek	0.004	0.0042	0.0002	0.0003
Shooting Range Creek	0.016	0.0144	0.0018	0.0015
Stonecoal Creek	0.019	0.0053	0.0015	0.0004
Mean ± SE	0.012 ± 0.0016	0.0068 ± 0.0012	0.00097 ± 0.0002	0.00055 ± 0.0001
UFR				
Big Branch	0.022	0.0131	0.0018	0.0011
Copperhead Branch	0.027	0.0168	0.0023	0.0014
Crooked Branch	0.023	0.0114	0.0019	0.0009
Middle Camp Branch	0.020	0.0107	0.0015	0.0008
Mean ± SE	0.023 ± 0.0015	0.0130 ± 0.0014	0.00187 ± 0.0002	0.00104 ± 0.0012

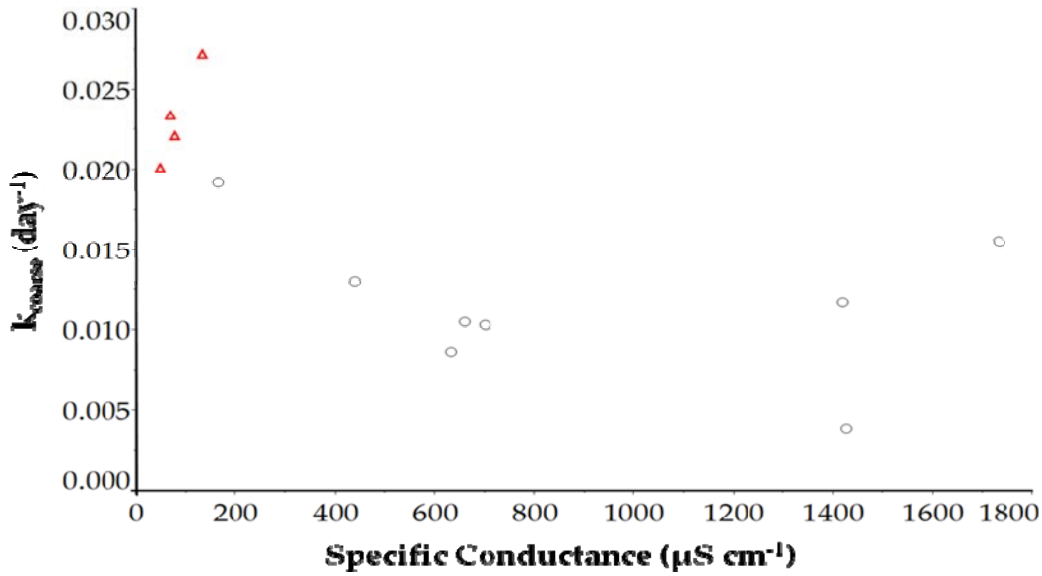

Figure 3. Scatterplot of coarse-mesh decomposition rates versus specific conductance treating UFR (triangle) and MRR (circle) streams as a single population.

Deliverables

This ongoing research has been presented at one regional and two national conferences, as well as at local symposia. Additional dissemination of results through presentations and publications will continue upon completion of laboratory 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. Annual 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.

Publications:

Krenz, R.J., S.H. Schoenholtz, and C.E. Zipper. 2010. Select carbon dynamics as functional indicators of restoration success: a research approach. *Proceedings of the Annual Powell River Project Symposium*: 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.* 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.

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. An abstract has been accepted for presentation at the ARIES Coal and Energy Symposium in April of 2013.

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