Channel Instability and Sediment Contamination Risk to Lower Big River Mussel Beds

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ABSTRACT

Missouri State University will refine previous measurements on Big River to determine whether the few remaining mussel beds on the Big River containing federally endangered pink mucket (Lampsilis abrupta) and federally endangered scaleshell (Leptodea leptodon) are under immediate risk from contamination or are stable over a longer term. The study will evaluate the lowermost reach of the river and evaluate the stability of upstream sediment deposits, banks, dams, and channels, and evaluate sediment geotechnical properties. This more intensive evaluation of the lower reach of the stream will be integrated into a larger stream-wide sediment transport and load analysis.

INTRODUCTION

The Big River drains the majority of the mining areas in the Old Lead Belt in St. Francois County in southeastern Missouri. Past and ongoing releases of chat and fine tailings to the river have resulted in the large-scale contamination of channel sediment and floodplain deposits with toxic levels of lead (Pb) along more than 170 km of the Big River from Leadwood to its confluence with the Meramec River (MDNR, 2008; Roberts et al., 2009; Pavlowsky et al., 2010) (http://www.fws.gov/midwest/semonrda/). A Total Maximum Daily Load has been approved for Pb, Zn, and fine sediment for 149 km of the Big River, 8 km of Flat River Creek, and 3 km of Shaw Creek (MDNR, 2008). Ecological consequences of mining contamination have been documented in the Big River. Reduced freshwater mussel density and diversity have been reported in stream reaches below tailings input points (Buchanon et al., 1979; Schmitt et al., 1987; Roberts and Bruenderman, 2000). A 2008 survey of mussel populations and sediment metal concentrations in the Big River demonstrated that mussels are less abundant and less diverse in sampling locations below mining impacts where sediment concentrations exceed either the Pb or Zn Probable Effects Concentration (PEC) (Roberts et al., 2009). Moreover, elevated levels of metals have been found in aquatic plants and animals in contaminated segments of the Big River (Schmitt and Finger, 1982; Gale et al., 2002).

In St. Francois County, tailings inputs were the primary source of contamination to the Big River and sediment-associated Pb is the primary pollutant of concern. In response to this contamination, mussel populations have been negatively impacted in the upper and middle portions of the Big River near mining areas tailings sediment and Pb contamination. The long-term survival and population growth of these mussel beds is in question since contaminated sediment is still being actively transported and deposited on the river bed even though mining ceased in the 1970s. Recent investigations by U.S. Fish and Wildlife Service (USFWS) and Missouri State University (MSU) have shown that bed and bar sediments are contaminated with Pb from Leadwood in St. Francois County to nearly to the Meramec River (Roberts et al. 2009; Pavlowsky et al., 2010). Moreover, floodplain deposits are also heavily contaminated from Leadwood to the Meramec River confluence and represent both a present-day and long-term source of contamination to the Big River through remobilization of Pb via bank erosion and weathering (Pavlowsky et al., 2010). Mussel beds in the lower Big River, containing federally endangered mussel species, are threatened by these contaminated sediments due to both fine-grained sedimentation and geochemical toxicity.

The USFWS has analyzed historical data and identified a downstream-shifting trend of declining mussels in the lower Big River over the past 20 years (Roberts et al., 2009). Nevertheless, several relatively robust mussel beds have been located and inventoried in the Big River near the confluence of the Meramec River. Importantly, the endangered pink mucket and critically-endangered scaleshell mussel occur in the lower Big River segment below Rockford Beach Access. These beds may be threatened by several factors: (i) gradual downstream transport of contaminated channel sediment over periods of decades to centuries, that may have not yet fully reached the mussel bed; (ii) episodic release of contaminated sediment pulses or slugs due to flushing by large floods or other natural or anthropogenic events causing large-scale geochemical mobility; and (iii) release of metals and fine sediment to the channel by bank erosion along the lower segment of the Big River.

Previous water and sediment quality studies on the Big River have focused on the mining areas in St. Francois County with little effort on the lower segment. Recent studies by MSU (Pavlowsky et al., 2010 and other work in progress) indicate that the downstream extent of Pb-contaminated fine gravel and coarse sand in channel deposits has not yet reached the Jefferson County line. However, relatively high concentrations of Pb (>1,000 ppm) are found in floodplain deposits along the length of the Big River below Leadwood to the Meramec River. These findings underscore the need to specifically understand the sources of sediment and Pb to the lower Big River. In order to evaluate the long-term sediment and Pb risk to the mussel beds, more information is needed to describe the relative and absolute source rates of Pb released to the lower Big River from bank erosion, in-transit channel sediment, and upper watershed loadings.

PURPOSE AND OBJECTIVES

Good mussel habitat requires various sizes of sediment for both substrate and feeding purposes. In the Big River and other Ozark streams, pink mucket, scaleshell and many other mussels tend to occur in faster flowing channel areas such riffles, glides, and runs, where substrate contains a diversity of grain-size (cobble, gravel, sand, and minor silt) and the channel location is relatively stable through time. In order to determine the factors affecting number and diversity of mussels in Big River mussel beds, a better understanding of channel stability and fine-grained sediment transport, deposition, and contamination in the lower segments of the Big River is needed. In general, four sources of mining contaminated fine-grained sediment probably affect the lower Big River. First, contaminated sediment is released from upstream bank erosion and the breakdown of coarser chat particles deposited in the channel within St. Francois County where mining activities occurred. Second, bank erosion due to the mass-wasting and fluvial scour along channel bends releases contaminated sediment to the channel. It is known that >1,000 ppm Pb are found in floodplain deposits along the entire length of the Big River below Leadwood and that concentrations in floodplain soils along the lower segment are relatively high (Pavlowsky et al., 2010). A third source is also related to bank erosion, but is largely controlled by channel instability related to channel bar sedimentation. Migrating gravel bars in the lower segment can fill in or clog the channel and direct erosive flows toward contaminated bank deposits. Finally, it is probable that on-going weathering, dissolution, and biological processes cause the release of dissolved metals from mining contaminated sediment grains to the water column or saturated pore spaces. Typically, dissolved metals in the circum-neutral to alkaline waters of the Big River will rapidly bind to suspended sediments and finer bed particles in the channel.

Presently, the degree to which the lower Big River mussel beds are vulnerable to contaminated sediment is unknown. While the sources of contaminated sediment are generally understood as described above, the specific sediment transport and geochemical processes involved and the relative importance of each source in the contamination of mussel beds has not yet been determined. The purpose of this project is to evaluate the factors that may lead to contamination and reduced numbers and diversity of endangered mussels in the lower Big River. The objectives of the project are to assess the geomorphological and geochemical condition of the channel and banks, evaluate potential disturbance factors, and assess contamination risks to the lower Big River mussel beds. The results of this project will be based on: (i) existing data from previous reports (e.g. Smith and Schumacher, 1993; MDNR 2001, 2003; Roberts, et al., 2009; Pavlowsky et al., 2010), (ii) information from ongoing investigations by MSU (e.g. Pavlowsky et al., 2010), (iii) published water quality monitoring data from the Big and Meramec Rivers collected by the U.S. Geological Survey (USGS) and MDNR, (iv) historical aerial photography, and (v) new information derived from the Fiscal Year 2010-11 field work and laboratory analyses covered by this SOW.

Research Concept and Rationale

This assessment attempts to link the effects of mining sediment, channel flows, and physical disturbances to the mussel bed locations at three spatial scales: reach, segment, and watershed. In general, mussel beds can potentially be degraded from the influence of two disturbance regimes: short duration, highly contaminated inputs released from sources close to the habitat site and long duration, moderately contaminated sediments originating from watershed areas farther upstream. The three spatial units of disturbance assessment are described below for the lower Big River study area.

Local or reach-scale conditions include the characteristics of the channel and micro-habitats in the immediate vicinity of the mussel bed. Local examples are the texture and mobility of existing bed and bar substrate, degree and distribution of fine-grained sediment and associated Pb contamination, and condition and resistance of bank materials and riparian buffers. Local factors have the potential to affect the mussel bed through direct interaction and water/nutrient cycling. Further, measurements of bed and bank mobility are useful to evaluate the resistance of the mussel bed to physical disturbance and long-term sedimentation problems. In this study, reach-scale influence is generally limited to an area along the river that is about 10 channel widths upstream and downstream of the mussel bed, totaling about 1,000 m along the lower Big River.

Proximal or upstream segment sediment and contamination sources include the delivery of sediment and mining contaminants to the mussel beds released from systematic channel adjustments or large-scale disturbances along the river farther upstream. It is assumed that these contamination inputs could be released to the channel and transported to the mussel beds with the passage of several flood events. Proximal inputs include: (i) Pb stored in bed, bar, and floodplain deposits that may be potentially released to the river by bank erosion, weathering and leaching, and flood scour, (ii) degree of lateral channel migration and bank erosion occurring upstream as a source of fine-sediment, and (iii) location and mobility of sand and gravel sediment stored in the channel that could be flushed down over the mussel beds. These inputs may not seem important in a single reach, but the effects and mass of disturbance add up over a longer distance of source area to affect the target habitat. Segment monitoring would help to test for the presence of the leading edge of disturbances such as bed sediment waves, floodplain erosion zones, and geochemical inputs. Segment lengths typically range in length from 10 to 100 times the reach length depending on tributary location and geology. Given that the most upstream mussel bed is located below the Byrnes Mill Dam, the lower Big River segment evaluated in this study is about 23 km long extending from the Meramec River upstream to the Byrnesville Bridge at the site of USGS flow gage #07018500. The Byrnesville Dam is located just upstream of the bridge and Cedar Hill Access is located 5.8 km above the dam.

Distal or upper watershed inputs include the influence of longer-term land use disturbance and mass storage residence times on sediment and contaminant inputs to the lower Big River. Watershed input examples include evaluation of channel storage and mobility of mining sediment in the upper and middle portions of the Big River, relative importance of bed sediment delivery from different headwater locations in the watershed as well as from different sources (i.e. mining sediment versus accelerated upland gravel loads), and potential for long-term storage of contaminants in various valley segments. It is important to know if watershed inputs to the lower Big River have peaked and are now decreasing through time, or if they are expected to be maintained or even increase in the near future or long-term. The information provided by Pavlowsky et al. (2010), other reports produced by this project, and others will be used to evaluate watershed influence. Discharge and water quality data previously collected by the USGS at the Richwoods gage (#07018100) will be used to evaluate the water, sediment, and contaminant inputs from the upper watershed in relation to contributions generated from within the lower segment. The Richwoods gage is located about 64 km upstream of the Byrnesville gage (#07018500). The physical properties and geochemistry of sediment samples from major and secondary tributaries will be used to evaluate the additional contaminant loads, if any, from contributing drainage areas below the Richwoods gage.

Objectives

Building upon previous work by MSU, USFWS, and others, the purpose of this study is to assess the influence of hydrological, geomorphic, sediment, and contaminant disturbances on the lower Big River where endangered and threatened mussels occur. This segment is likely being affected by metal contaminants supplied from upstream sources in St. Francois County and locally from the erosion of contaminated floodplain deposits. The objectives are described below:

1) <u>Collaboration between MSU and USFWS.</u> With the help of USFWS, locate mussel beds and better understand mussel habitat conditions in the lower Big River (OEWRI will need one day with USFWS to become familiar with the specific attributes of the mussel bed and prime mussel habitat characteristics).

2) <u>Reach-scale characteristics and disturbance.</u> Data describing channel form, channel unit structure, and substrate will be collected and used to describe the physical status of three mussel beds located in the lower Big River. For each reach, the geomorphic and hydraulic conditions present will be quantified to describe flood influence, sediment inputs, and metal contamination in relation to mussel bed conditions.

3) <u>Segment-scale assessment and disturbance.</u> Determine the sources of geomorphic disturbance, sediment characteristics, and channel and bank stability in the Big River segment below Byrnesville Dam (R-km 24) to the confluence (R-km 0). Historical aerial photography will be used to determine temporal changes in bank erosion and gravel sedimentation. Field surveys will be used to determine channel morphology and sediment characteristics.

4) <u>Sediment budget assessment of mining sediment transport and storage.</u> Data from Phases I (FY 2008/09) and II (FY 2010) will be used to construct a sediment budget for the Big River that integrates

channel and floodplain storage, in-channel sediment transport, channel bank erosion, and suspended sediment/metal transport in the water column to evaluate sources of sediment and Pb contamination to the lower Big River segment.

5) Mussel bed risk assessment. Evaluate the hydrologic, geomorphic, and geochemical risks to the mussel bed over short- and long-term timescales. The results from objectives 2, 3, and 4 will be used to describe mussel bed conditions, threats, and management alternatives in the Big River.

METHODS

The methods used in this study will generally follow those used in Pavlowsky et al. (2010) (http://oewri.missouristate.edu/).

Sampling Design

The sampling sites for each objective are described below:

1) Mussel bed reaches- Three mussel beds previously studied by the USFWS will be evaluated for geomorphic stability and contaminated fine-sediment deposition. Mussel beds along the lower Big River were monitored by two previous studies by the Missouri Department of Conservation (Buchanon, 1979) and USFWS (Roberts et al., 2010). Reach lengths will vary from 500 to 1,000 m in length.

2) Study segment- Main stem of the Big River extending from just below Byrnesville Dam (R-km 24) to the confluence (R-km 0). This segment of the Lower Big River is known to contain endangered mussels and is threatened by contaminated fine-grain sediment.

3) Physical and geochemical properties of transported sediment- Downstream trends in sediment-metal association are needed to determine the source geochemistry of contaminated sediment in the lower segment and to evaluate the mobility and the factors that influence bioavailability of sediment Pb. Downstream sampling of channel unit sedimentology and geochemistry will occur at eight sites: (i) Highway 8-upstream control (R-km 181.2) ; (ii) Desloge (R-km 158.1); (iii) St. Francois State Park (R-km 140.8); (iv) Washington State Park (R-km 101.7); (v) Morse Mill (R-km 49.8); (vi) Lower segment-mussel bed below Rockford Beach Dam; (vii) Lower segment-mussel bed below Byrnes Mill Dam; and (vii) lower segment mussel bed near Hwy W.

4) Historical aerial photograph analysis of eroding channel segments- Presently, an ongoing investigation by MSU is describing the broad channel and bank erosion and deposition trends for the main stem of the Big River. This information will help to understand the long-term changes in contaminated sediment supply and transport in the river system. In the present work described by this SOW, a higher resolution temporal analysis of historical aerial photographs are used to track bar

and bank erosion/deposition trends in the lower Big River segment. Information on planform changes will be combined with topographic floodplain surveys to develop a sediment budget for the lower segment.

Procedures

1) Geomorphic assessment and channel unit mapping. Channel surveys using auto-level and GPS instrumentation will be used to map bed, bar, and bank topography and substrate conditions In general, reach assessments will involve similar methods as used in Pavlowsky et al. (2010) with additional physical habitat indicators as described in Fitzpatrick et al., (1998) and Panfil and Jacobson (2001).

2) Mussel bed sediment characterization and geochemical Assessment. Information on the present influence of fine-grained sediment disturbance and contamination in the reach is needed to develop a baseline understanding of the local sedimentation factors affecting the mussel bed. Fine-grained sediment deposition in presently stable and disturbed reaches can be used to predict the potential influence of excess loading and sedimentation in the future. Specific tasks to be completed are:

a. *Channel Unit Sediment Properties.* Characterize the texture and embeddedness of sediment deposits in individual channel units. Examples of channel units or microhabitats to be evaluated include: (i) Pools- upper pool/run, pool trough, glide; (ii) Riffles- riffle crest, mid-riffle, lower riffle/run, (iii) Side waters: back, head, tail; and (iv) Bars- bar head, mid-point, and tail. The substrate and channel unit map generated in #2 above will be used as a framework to subsample different channel unit types. The physical attributes (texture, density, OC/IC, lithology) of these deposits will be determined and compared statistically among the different unit sampled.

b. *Channel unit sediment geochemistry:* Chat-size and fine-grain sediment (sand, silt, clay, om) properties and contaminant geochemistry will also be sampled according to #2a above. Geochemical characteristics will be evaluated for three sizes of sediment: mud, sand, and chat gravel. These sizes potentially represent distinct sources of mining sediment in this river system. Metal concentrations in the sediment fractions will be determined using hot acid extraction and ICP-AES analysis.

3) Segment assessment of sediment sources and contamination. The river segment upstream of the mussel bed will be inventoried for bed and bank disturbances using rapid assessment procedures, GPS, and canoe access to evaluate local factors of disturbances. The segment may extend to 10+ km upstream of the mussel bed. Specific tasks to be completed are:

a. *Bank erosion source assessment*- Determine bank erosion history and prediction for the segment using historical aerial photograph analysis and rapid field surveys.

b. *Channel unit sediment geochemistry*- Evaluate characteristics of chat-sized and fine-grained sediments from relatively large deposits along the segment. Large accumulations of sediment today may become mobilized and affect the mussel bed in the future. Thus, knowledge of composition and contamination of these deposits is essential for understanding the fate of the mussel bed. If there are major differences in geochemistry between the mussel bed reach and the upstream segment, then this would suggest that there are local factors that are helping to flush contaminated sediment through the reach and thus reduce exposure to mussels. The same analytical methods used in #2a and 2b will be used for the segment sample analysis.

4) <u>Watershed input assessments.</u> Mining sediment inputs from St. Francois County may represent a long-term threat to the lower Big River. Information from recent studies in progress suggest that mining sediment “waves” composed of bed and bar forms are migrating down the Big River over decadal periods up in St. Francois County, but have not transported mining chat in measureable amounts to the lower segment. Specific tasks to be completed are:

a) *Historical bar form analysis*- Aerial photograph analysis will be used to monitor the location of bar forms over time and see if bar distribution is extending or shifting downstream over time. Bar forms at tributary confluences will be used as indictors of upland gravel sediment sources to the channel as distinct from the mining sediment inputs from St. Francois County. Past time series analyses for the Big River from Leadwood to the mouth were based on three photograph years: 1937, 1954, and 2007. In this SOW, additional photograph years will be added to the analysis. For the entire Big River study area below Leadwood, two more photograph years will be added: 1975 and 1992, to total five years. For the lower Big River segment below the Byrnesville dam, a total of six photograph years will be evaluated including 1937, 1954, 1968, 1979, 1992, and 2007.

b) *Channel unit sediment geochemistry*- As described above in Procedures 2 a and 2b, sediment geochemistry will be evaluated for specific sediment fractions to determine the mobility and fate of Pb and other metals throughout the river system to track source connections between mining areas in St. Francois County and the lower segment. The key questions to be addressed are whether contaminated particles are being transported all the way from the mining area to the mouth and, if so, what are the grain-size and geochemical characteristics of the contaminated sediments? Five sites planned for channel unit sampling of sediments will be located far upstream into St. Francois County as well as in Jefferson County. The characteristics of the upstream samples will be compared to the reach and segment samples collected to evaluate spatial trends in sediment geochemistry and contamination of specific grain size fractions.

c) *Tributary input assessment*- To evaluate the effect of tributary inputs on bed sediment geochemistry from different geologic units and land use types, bar and bank samples from major and secondary tributaries entering the Big River will be collected below the Richwoods gage to the mouth.

d) *Fluvial Pb loads*- Lead loadings to the lower segment of the Big River will be estimated for the lower Big River using water quality monitoring data previously collected by the USGS and MDNR. Water quality monitoring data is available for the Richwoods gage and other station along the Meramec River both upstream and downstream of the mouth of the Big River. Lead concentrations measured in tributary sediments (i.e., procedure 4c) will be used to check for contamination influence from barite and older Pb mine sites in Jefferson and Washington Counties.

5) <u>Sediment and Metal Budget.</u> The goal of the sediment-Pb budget will be to determine the primary source of fine-sediment, coarse sediment, and Pb to the mussel beds in the lower Big River. The construction of a sediment-metal budget requires data that describes the mass sources, transport rates, and sinks of fine-grained sediment and Pb for the for the lower Big River channel. Budgeting approaches are useful for quantifying sediment source contributions, residences times, channel-floodplain connections, and present-day/future transport trends. In this study, the sediment-Pb budget will be constructed as follows:

a) *Watershed inputs from upstream*- Suspended sediment and Pb loads to the lower Big River will be calculated from existing historical water quality data collected at USGS gaging stations in the Big and Meramec Rivers. Sediment samples collected from lower tributary streams will be used to make sure that Pb input rates are relatively low or below background in Jefferson County. Mill and Mineral Fork Creeks enter the Big River above the Richwoods water quality monitoring site so the influence of old Pb and Barite mine inputs on sediment and Pb transport will be accounted for in calculated river loads.

b) *Stored mass of sediment and Pb*- Storage amounts of sediment and Pb in the lower Big River have been calculated for channel and floodplain deposits by a previous study (Pavlowsky et al., 2010). Mass storage calculations will be further refined with additional channel and floodplain samples.

c) *Floodplain sources and sinks*- Historical aerial photograph analysis will be used to monitor and measure the mass of sediment and Pb released to the channel by floodplain bank erosion over the past 30 years. In addition, the amount of sediment moving into floodplain storage will also be quantified. In combination with measurement of planform areas from aerial photographs, multiple cross-sections collected along the lower Big River during this study will be used to determine the volume of sediment moving into and out of floodplain storage. Published soil survey maps will be used to map floodplain units along the lower Big River. Geochemical profiles measured in floodplain cores from different floodplain units will be used to combine Pb contamination and sediment volumes to calculate the remobilization rates of Pb mass associated with floodplain erosion.

d) *Sediment transport rates*- Fine-grained sediment transport rates will be determined from the analysis of suspended sediment and total Pb water quality data as described above. Coarse-grained channel sediment transport rates will be estimated by multiplying channel sediment areas derrirved from data in Pavlowsky et al., (2010) by downstream bed-wave migration rates determined using bar area derived from historical aerial photographs.

6) Logistics

a) *Fieldwork*- It is anticipated that 16 field days will be needed to complete the work above as follows: Reach mapping and channel unit sampling (5 days), segment rapid assessment and channel unit sampling (4 days), channel unit sampling in St. Francois and Jefferson Counties (5 days), and tributary sediment sampling (2 days).

b) *Sample processing*- For geochemical analysis, it is anticipated that this project will collect 24 samples from each of the seven channel unit sediment sampling reaches. A total of 170 bulk sediment samples will be collected and analyzed for dolomite chips in chat and XRF analysis of the 250 um to 2 mm fraction and the <250 um fractions. A selected subset of these samples will be subjected to ICP metal, combustion C, and heavy mineral analyses of multiple sediment size fractions.

c) *Aerial Photography.* The aerial photography required for the project is largely in hand and the analyses have begun for FY 2009 goals (a draft delivered to USFWS in June 2010). MSU will purchase additional aerial photographs for periods described above in procedure 4a.

Products

The study is planned to be 2 years in length beginning approximately December 1, 2010 and ending on November 30, 2012. The products and delivery dates to USFWS will be as follows:

1) Channel Stability, Bank Erosion, and Bar Mobility along the Lower Big River: Draft report on segment-scale disturbance factors including bank erosion, bar area changes, tributary inputs, and channel modifications in relation to mussel bed habitat (August 15, 2011);

2) Characteristics and Mobility of Contaminated Sediment in the Big River: Draft report on downstream variations in channel unit texture, mining sediment content, and geochemistry for the Big River and implications on downstream sediment dispersal and nature of contamination threat linking St. Francois County sediment contamination and transport to downstream mussel beds (December 15, 2011);

3) Sediment and Lead Budget for the Lower Big River: Draft report that describes the sediment and Pb budget for the lower Big River and implications on mussel habitat (April 15, 2012); and

4) Channel Instability and Sediment Contamination Risk to Lower Big River Mussel Beds: Draft report on the reach-scale evaluation of hydrologic, geomorphic, and geochemical threats to the three mussel beds in the lower Big River (August 15, 2012).

Proposed Budget

Salary	$18,700
Fringe	$5,984
Indirect	$6,595
Supplies/analyses	$4,000
Travel (lodging, meals, mileage)	$9,000
TOTAL	**$44,279**

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