PROJECT SUMMARY
Of State Wildlife Grant

PROJECT NUMBER: T-66-R-1

PROJECT TITLE: Demonstrating the benefits of Stream Restoration to Aquatic Communities in the Cache River Basin

LEGAL NAM E OF ENTITY: Southern Illinois University Carbondale

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PROJECT GOALS:

The project had three main objectives as follow:

1- Validate hydrologic models that predict the stream response (mean cross-sectional velocity) to the addition of water (increased flow) to the lower Cache River
2- Quantify oxygen dynamics in the lower Cache River before and after the addition of water.
3- Determine how increasing flow in the lower Cache channel will affect the production, abundance, and diversity of macroinvertebrate communities

INTRODUCTION AND NEED:

The Cache River watershed, located in the Cache River Conservation Opportunity Area, has been the site of numerous restoration efforts focused on reversing habitat loss and degraded water quality associated with human alterations of the watershed. Returning the stream hydrology to a more natural state by reconnecting the upper Cache River to the lower Cache River has been proposed, with the goal of benefiting in-stream communities. However, this is a controversial topic, as there are concerns about how re-connection will affect flooding and questions regarding the degree of biological benefits that will actually be realized (e.g., cost/benefit issues). In response to this, we performed an experimental manipulation that allowed us to assess and demonstrate the effects of increasing stream flow on oxygen dynamics and macroinvertebrate communities in the lower Cache River. We did so by pumping water into the lower Cache River to simulate reconnection. Documenting in-stream responses like these will allow for informed decision making regarding costs and benefits of future restoration efforts.

Stream restoration projects have increased ten-fold since 1990, with nearly 10 billion dollars spent in the US to date (Bernhardt et al. 2005). Unfortunately, designs of many restoration projects often do not take into consideration basic ecological concepts (Palmer 2009). Others, although designed more prudently, have not been monitored for "ecological success" (Bernhardt et al. 2005, Palmer and Bernhardt 2006). Given the increasing demand for restoration projects, and the need for quantitative measures of their effects on communities and ecosystem functioning, studies of restoration projects are critical for justifying and guiding future efforts.

The Cache River watershed lies at the confluence of four major physiographic provinces and harbors high aquatic species diversity (McNab and Avers 1994). The Cache watershed is also recognized as one of the few regions in the US containing wetlands of international significance, which include critical breeding and overwintering grounds for migratory birds. The Cache supports 44% of the native fish species and 60% of native mussels species in Illinois, as well as 34 crustacean and >340 macroinvertebrate species (IDNR 1997). However, the Cache has experienced impaired water quality that threatens this biodiversity, and much of this is related to human modifications to the landscape and channel (IEPA 2008).

Several restoration projects have been carried out in the Cache River basin. These include construction of weirs to stabilize the channel. These weirs also act as "hotspots" of aquatic insect production (Walther and Whiles 2008), and potentially provide important food and habitat for fish. Reconnecting the upper and lower Cache River channels, which were separated to facilitate logging and drainage of agricultural lands, has been proposed as a restoration project to address water quality issues and ecological integrity in the lower Cache. Reconnection would increase flow in the Lower Cache River and influence oxygen dynamics (e.g., Garvey et al. 2007), presumably resulting in positive responses by aquatic communities, but the pros and cons of reconnection are difficult to assess without quantitative information on potential ecological responses.

METHODS:

To assess and demonstrate potential benefits of increasing flow to water quality and stream communities in the lower Cache, we simulated reconnection to the upper Cache by pumping water into the lower Cache from the adjacent Buttonland Swamp. We focused on responses of dissolved oxygen (increasing oxygen levels with increased flow; Garvey et al. 2007) but also predicted that macroinvertebrate community structure will change, with increases in diversity, abundance, biomass, and production of important groups such as filter-feeding caddisflies, which represent major food sources for many stream fishes. This study is novel, as simulation of stream reconnection has not been attempted, and it will provide quantitative information on the ecological effects of reconnection prior to the implementation of a restoration project. Thus, the products of this effort will allow for informed decision-making regarding the potential reconnection of the Cache River.

We sampled monthly for 3 years before pumping and 1 summer (2013) during the flow addition to allow us to accurately assess oxygen dynamics and calculate annual production of macroinvertebrates, while accounting for seasonal and annual variability. In addition, we sampled both the upper and lower Cache River weekly during the water addition demonstration. Estimating secondary production, although time-intensive, will allow for an accurate, quantitative measure of potential changes in food availability to higher trophic levels such as fishes.

Stream Oxygen Dynamics. Datalogging dissolved oxygen meters were placed at sites in the upper (reference reach) and lower Cache to measure dissolved oxygen and temperature every 10 minutes for at least 24 continuous hours once a month. Dataloggers were mounted to a fence post within a meter of the bottom of the stream. Primary production was also assessed, using benthic and sestonic chlorophyll-*a* concentrations as proxies, at 8 stream reaches before and after pumping by scraping attached algae from snag habitat, filtering through a glass-fiber filter and extracting in 90% acetone. The concentrations of chlorophyll-*a* were measured using fluorometry (Arar and Collins 1997). Turbidity and duckweed cover, both which limit light penetration in the water column, was assessed monthly at 4 stream reaches in each the upper and lower Cache River (n=8 stream reaches total).

Macroinvertebrate community structure and function. The effects of increased flows on stream communities was assessed by monthly sampling of macroinvertebrates associated with snag habitats (submerged wood) and drifting in the channel. Three snags were sampled at each of 4 stream reaches in the lower and upper (reference) Cache by placing a 250 μm mesh bag over a piece of submerged wood and removing it with a saw. Surface area of each snag sample were determined by measuring length and circumference. Macroinvertebrates were identified to the lowest feasible taxonomic level (usually genus), measured, and biomass was calculated using length-mass relationships (Benke et al. 1999). Snag surface area was used to normalize biomass data to mg/m^2 and secondary production was estimated using the size-frequency method (Benke and Huryn 2006). Stream reaches were surveyed once to determine total amount of wood in the stream, which was used to estimate a habitat-weighted estimate of secondary production (Wallace and Benke 1984).

Invertebrate biomass in drift was measured by placing three drift nets (250 μm mesh) in the stream for 15 minutes at the four study sites in each reach (upper and lower) and samples were processed as described above. Mean velocity during sampling was determined for each drift net to normalize biomass of invertebrates per liter of water.

MAJOR FINDINGS:

Predictive model. Using the data we collected from both the upper and lower Cache River, we were able to use Bayesian statistical techniques to model the effects of water addition to the lower Cache River. The model used the current scenario, to predict the probability histogram of daily minimum dissolved oxygen (DO) in the lower Cache during low flow periods if reconnection is not perused (Figure 1). We also used data collected from the upper Cache (the free-flowing section of the river) to model the effects of reconnection of the upper and lower Cache on DO (Figure 2). This model predicts that delivery of small amounts of water from the upper to lower Cache (mean=0.4 cms in the model) would decrease the likelihood of hypoxic conditions in the lower Cache River.

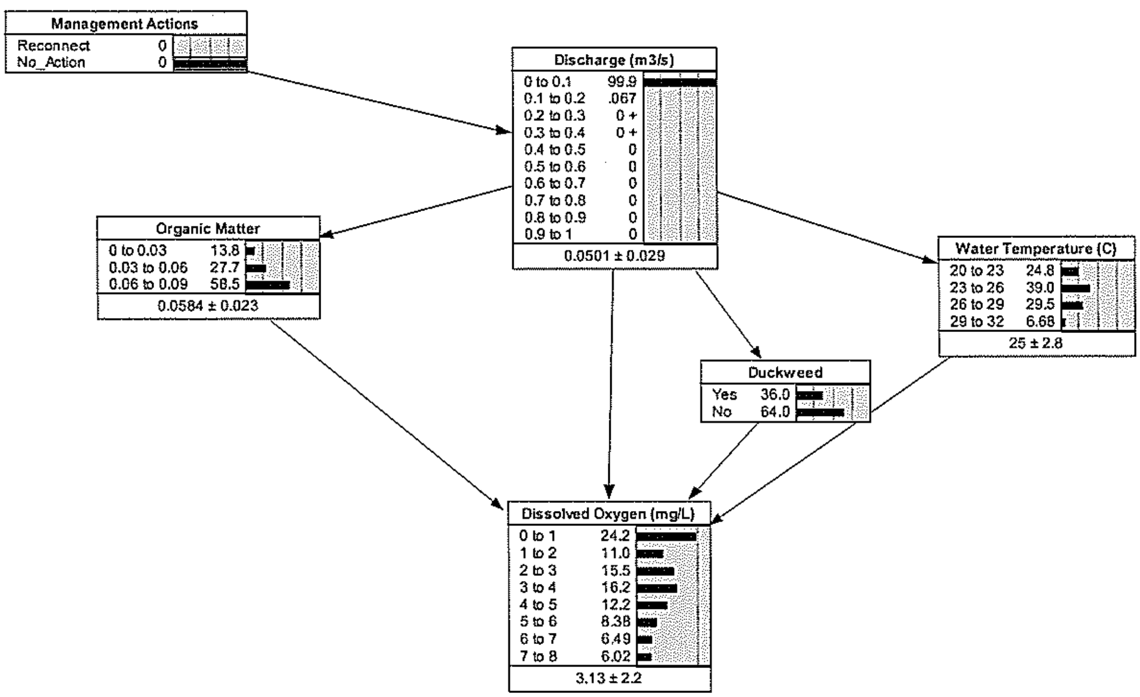

Figure 1. A Bayesian belief network used to predict the likely concentration of minimum dissolved oxygen (mg/L) during summer baseflow in the lower Cache River if the upper and lower Cache River are not reconnected (from Rantala et al., *in review*).

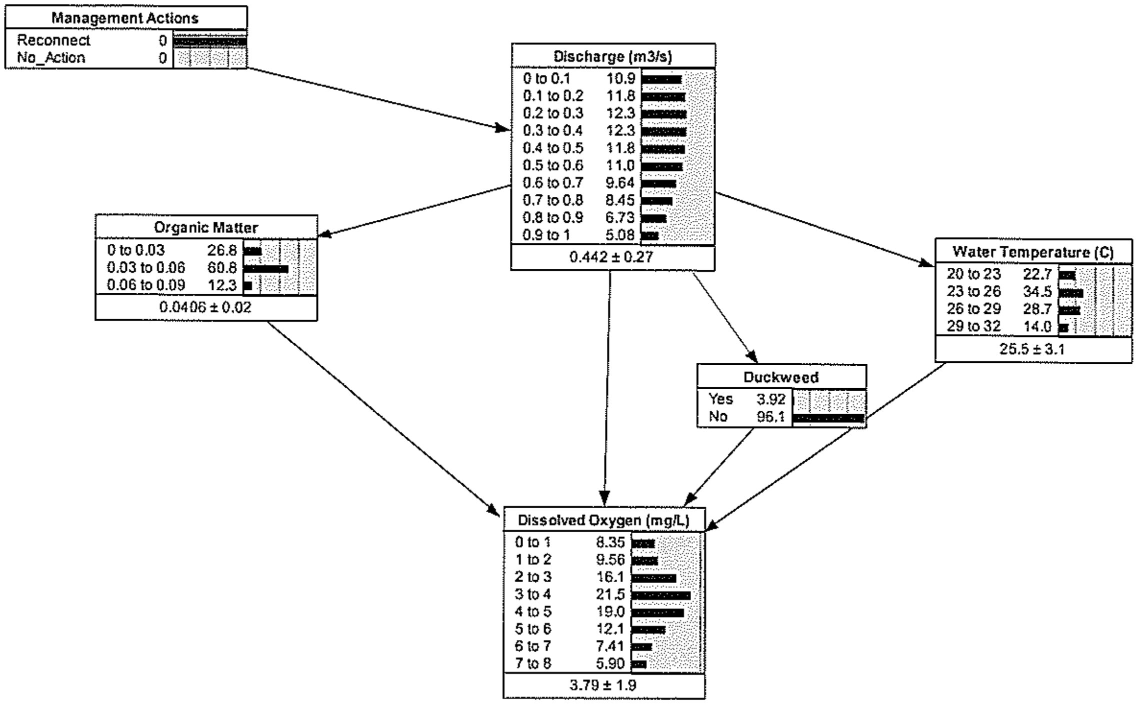

Figure 2. A Bayesian belief network used to predict the likely concentration of minimum dissolved oxygen (mg/L) during summer baseflow in the lower Cache River if the upper and lower Cache River are reconnected (from Rantala et al., *in review*).

Oxygen dynamics. During the period of sampling, we documented several periods of hypoxia and anoxia in the lower Cache River (Figure 3). Hypoxic conditions are due to a combination of high oxygen demand in the system and little reaeration from the atmosphere. We found that oxygen demand in the sediments from the lower Cache River had a higher sediment oxygen demand than those from the upper Cache River (Figure 4).

The lack of oxygen in the system creates a positive feedback loop, increasing oxygen demand, as organic matter that settles in the stream bottom decomposes slowly under low oxygen conditions, enhancing the accumulation of organic matter over time. We found that breakdown rates of leaf litter in the lower Cache River were significantly lower than breakdown rates in the upper Cache River (Figure 5), concurrent with laboratory studies showing that even slight decreases in dissolved oxygen decrease the rate of leaf litter breakdown and that differences in breakdown rates may be due to the lack of aerobic microbes, especially aquatic hyphomycetes, in the lower Cache (Mederios et al. 2009).

Low oxygen conditions are exacerbated by duckweed and ice cover. Flow in the LCR has been drastically reduced because of disconnection of the headwaters allowing a thick layer of duckweed to form across many reaches of this section of the river during low flow periods, reducing both dissolved O_2 and light penetration (Figure 7). Decreased light penetration further reduces oxygen levels by inhibiting photosynthesis of submerged vegetation, and duckweed does not contribute O_2 to the water column.

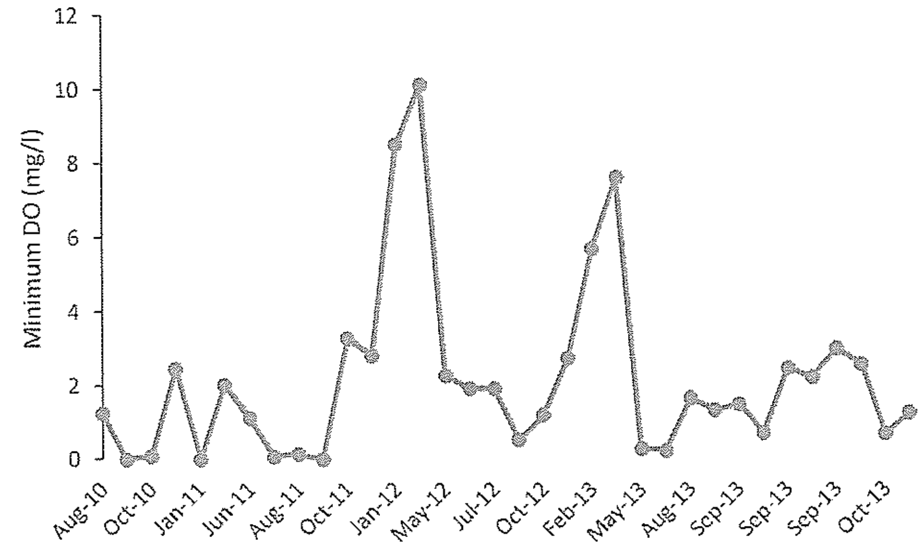

Figure 3. Minimum daily dissolved oxygen in the lower Cache River, as measured from our 24-hour measurements collected monthly.

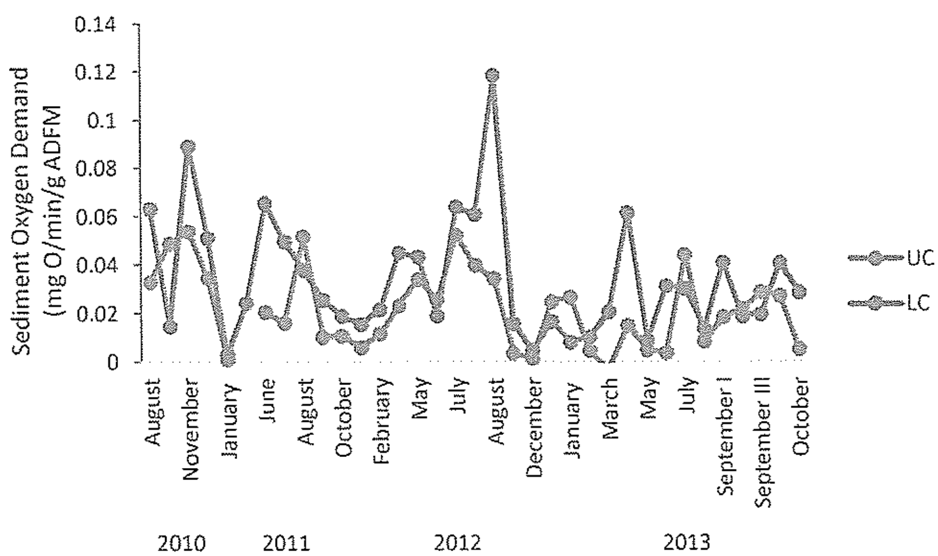

Figure 4. Sediment oxygen demand (SOD) from benthic sediments in both the upper (blue line) and lower (red line) Cache River. Mean SOD is higher in the lower Cache River than the upper Cache River (P<0.01, paired t-test, df=33)

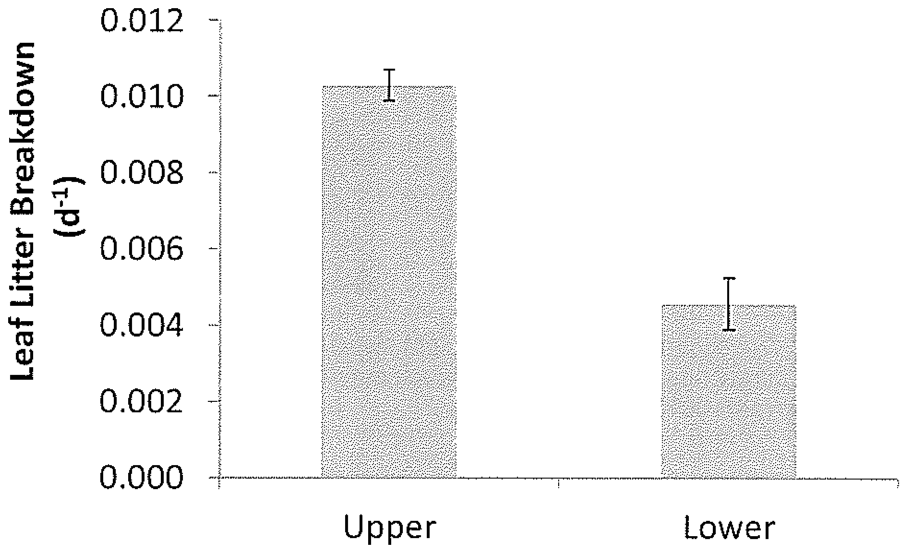

Figure 5. Leaf litter breakdown rates from a litterbag experiment in the fall of 2010 in the upper and lower (red line) Cache River. Breakdown rates were higher in the upper Cache River than the lower Cache River (P<0.001)

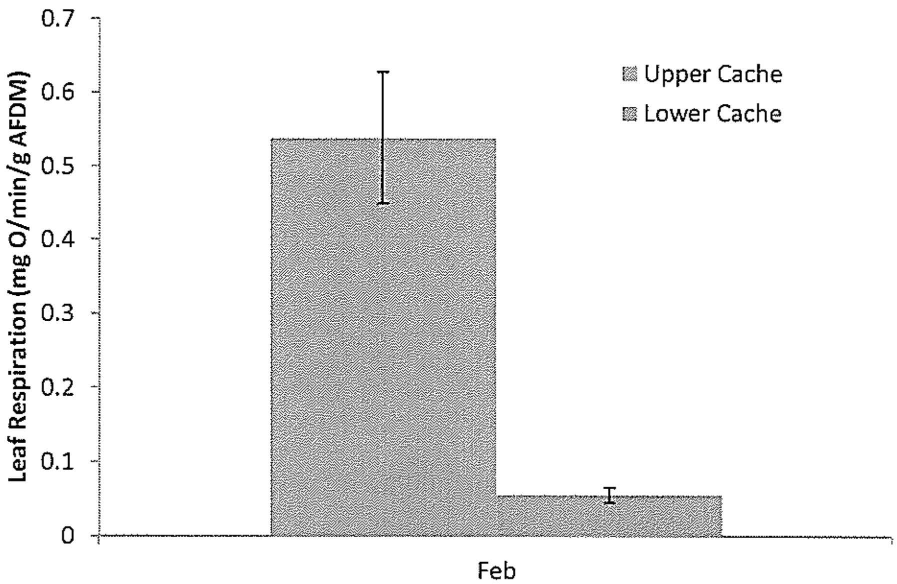

Figure 6. Leaf litter respiration rates (mg O/min/g AFDM) from a litterbags collected in February 2011, 89 days after they were first placed in in the upper (blue bar) and lower (red bar) Cache River. Oxygen consumption rates were higher for leaves incubated in the upper Cache River than the lower Cache River (P=0.05), suggesting that leaves from the lower Cache River had fewer aerobic microbes associated with them.

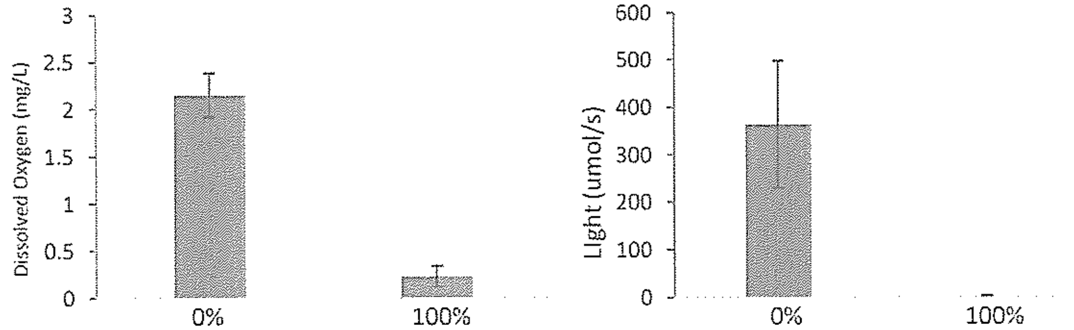

Figure 7. Dissolved O_2 concentrations (left) and light levels (right) in the water column were lower in reaches with 100% duckweed cover than in reaches with 0% duckweed cover ($p<0.001$).

Macroinvertebrate communities. We found that macroinvertebrate communities varied significantly between the upper and lower reaches of the Cache River, and the lower Cache River had more variability in macroinvertebrate production than the upper Cache (Figure 8). This variability was driven by the presence of larval non-Tanypodinae chironomids in the lower Cache (Figure 8).

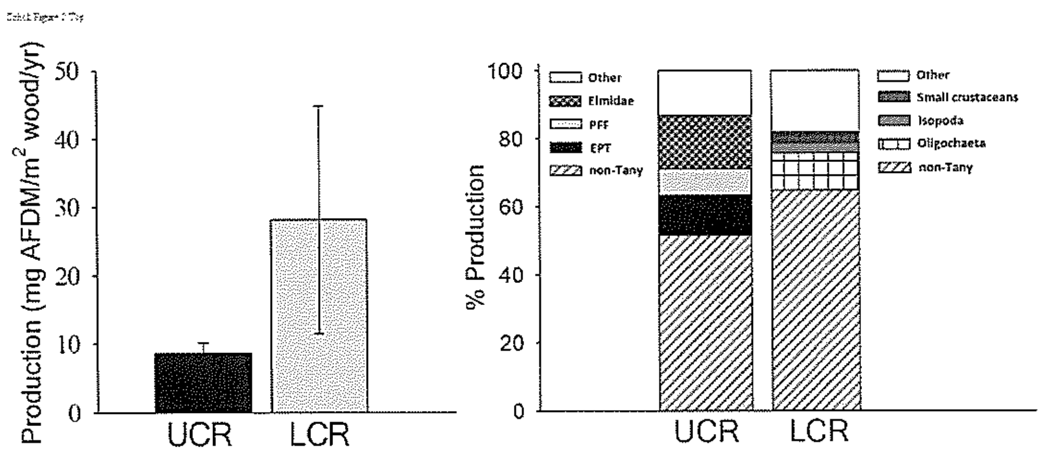

Figure 8. (left) Mean community production (g AFDM m^{-2} wood $year^{-1}$) in the upper Cache River (UCR) and lower Cache River (LCR). Error bars are 95% confidence intervals. (right) Percent contributions to total macroinvertebrate production in the upper Cache River (UCR) and lower Cache River (LCR). non-Tany represents Chironomidae excluding the subfamily Tanypodinae. EPT includes members of the orders Ephemeroptera Plecoptera Trichoptera; small crustaceans includes Cladocera Copepoda Ostracoda; PFF are passive filter-feeders. From Scholl et al., *in Press.*

The upper Cache River had higher biomass of macroinvertebrate taxa that are associated with higher quality (e.g., less sedimentation, less organic pollution, and higher dissolved oxygen) streams (Figure 9). Specifically, those taxa are

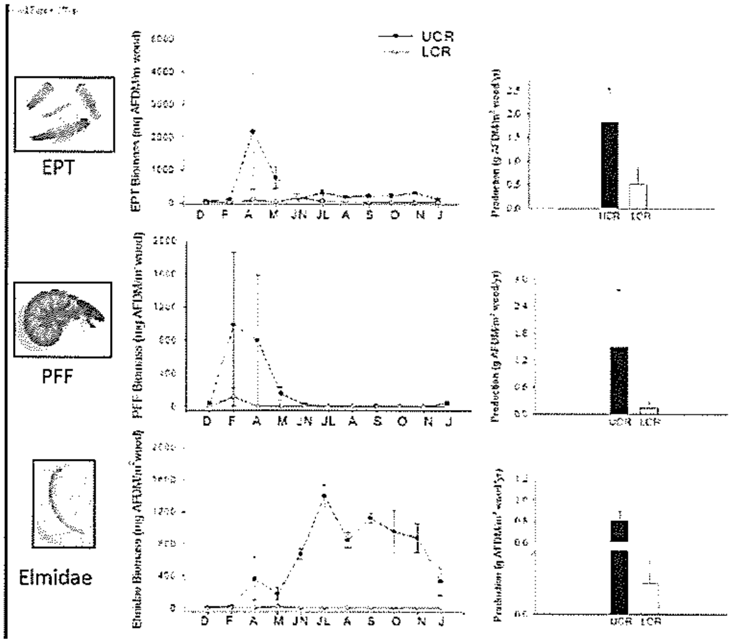

Figure 9. (left panel) Photos of representative Ephemeroptera, Plecoptera, Trichoptera (EPT) taxa, passive filter feeders (PFF), and Elmidae. (Middle panel) Trends in EPT, PFF, and Elmidae (larvae and adults) biomass (mg AFDM m^{-2} wood) over the sampling period. The black symbols represent estimates from the upper Cache River (UCR) and the white symbols represent estimates from the lower Cache River (LCR). Error bars are standard error. (right panel) Mean annual production estimates (g AFDM m^{-2} wood $year^{-1}$) for EPT, passive filter feeders, and Elmidae (larvae only) between the UCR and LCR. Error bars are 95% confidence intervals. From Scholl et al., *in review*.

Ephemeroptera, Plecoptera, and Trichoptera (EPT). There were also higher biomass values for passive filter-feeders, which rely on water movement for food delivery, and Elmidae, which are sensitive to low oxygen conditions (Figure 9).

Non-metric multidimensional scaling analyses indicated significant differences ($p<0.001$, ANOSIM) between the macroinvertebrate communities of the upper and lower Cache River. When physical and basal resource (chlorophyll concentrations and the amount of organic matter in the benthos) were plotted on the ordination using their correlation to the individual sites in the stream, we saw that velocity was highly correlated with the community structures in the upper Cache River sites, while the amount of basal resources was highly correlated with the communities in the lower Cache River (Figure 10).

Climate variability. During the study, two years were classified as drought (moderate drought in 2010, exceptional drought in 2012) and 2011 had a flood in late May. Climate variability is expected to increase was climate change progresses, with the frequency of extreme event increasing (IPCC 2014). The snag-dwelling macroinvertebrate dataset we collected provided an opportunity to investigate the effects of variability in water flow on the communities in both the free-flowing (upper) and water-starved (lower) reaches of the Cache River.

Again, communities from the upper and lower Cache River were significantly different (p<0.001). There were significant differences in each reach among years (p<0.001, Figure 11).

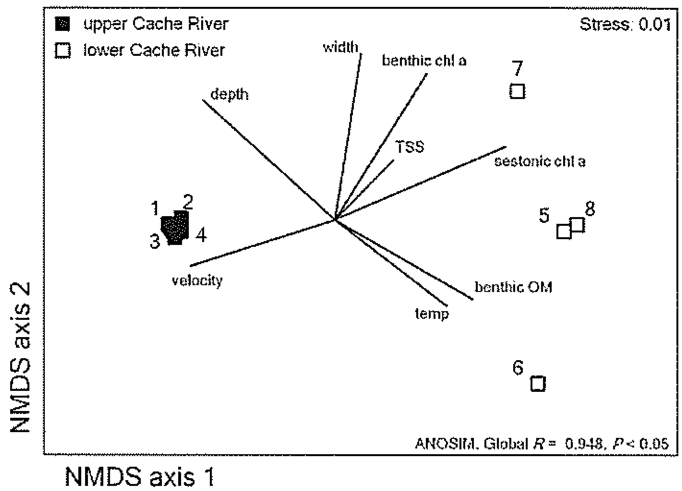

Figure 10. Non metric multidimensional scaling (NMDS) ordination of macroinvertebrate community production and abiotic variables. There was significant relationship between PC1, which loaded positively for velocity and negatively for sestonic chlorophyll a, and benthic organic matter, and NMDS axis 1 (p = 0.001 overall r^2=0.87). There was a significant relationship between PC2, which loaded positively for mean channel width, mean channel depth, and negatively for mean annual temperature, and NMDS axis 2 (p = 0.01 overall r^2=0.69). The overlain vectors were based on Pearson correlations of the mean values of the environmental variables at each stream reach and MDS axes 1 and 2. These vectors are overlain for visualization and do not represent the PC variables. From Scholl et al., *in Press.*

Effects of water addition to the lower Cache River. We added water to the lower Cache River, east of State Hwy 37 for ~5 weeks in the summer of 2013. The pump was run continuously from 30Aug13-6Sep13 at ~850,000 l/day and run intermittently from 9Sep13-5Oct13 at ~130,000 l/day. After 6 Sep13, we were forced to reduce the amount of water we pumped to stay within the bounds of our permits.

Mean and max DO increased at a site 1200 m downstream of the pump during pumping (Figure 13), while there was no change in minimum daily DO. Interestingly, there was no change in the DO at a site 800 m downstream of the pump, indicating that other processes (besides water flow) is driving DO dynamics.

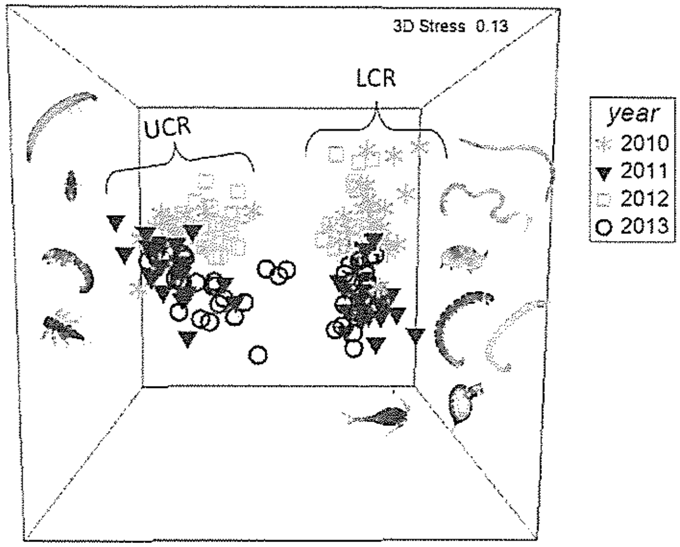

Figure 11. Ordination from non-metric multidimensional scaling analysis of samples of the macroinvertebrate community from snag habitats from June of 2010-2013. Individual symbols represent samples, LCR=lower Cache River, UCR=upper Cache River. Community structure was significantly different among years and between UCR and LCR (p=0.001 for both). Differences in the UCR communities among years were driven by Elmidae, Polycentropodidae, and *Stenacron* (Heptageniidae). Differences in the LCR communities among years were driven by Chironomidae, Ceratopogonidae, Oligochaeta, Ostracoda, and zooplankton. Baumann, unpublished.

The macroinvertebrate drift community varied among pre-pumping, pumping, and post-pumping time periods at sites 800 m, 1200m, and 3000 m downstream of the pump location (Figure 14, p=0.001, 0.026, 0.004, respectively). In all three sites, the community shifted from having zooplankton (ie., cyclopoids and/or daphiinds) driving similarity among samples prior to pumping, zooplankton decreasing in importance in community structure during pumping, and then zooplankton again driving similarity among samples post-pumping. These results suggest that the addition of small volumes of water can have profound effects on shaping stream communities in short time periods.

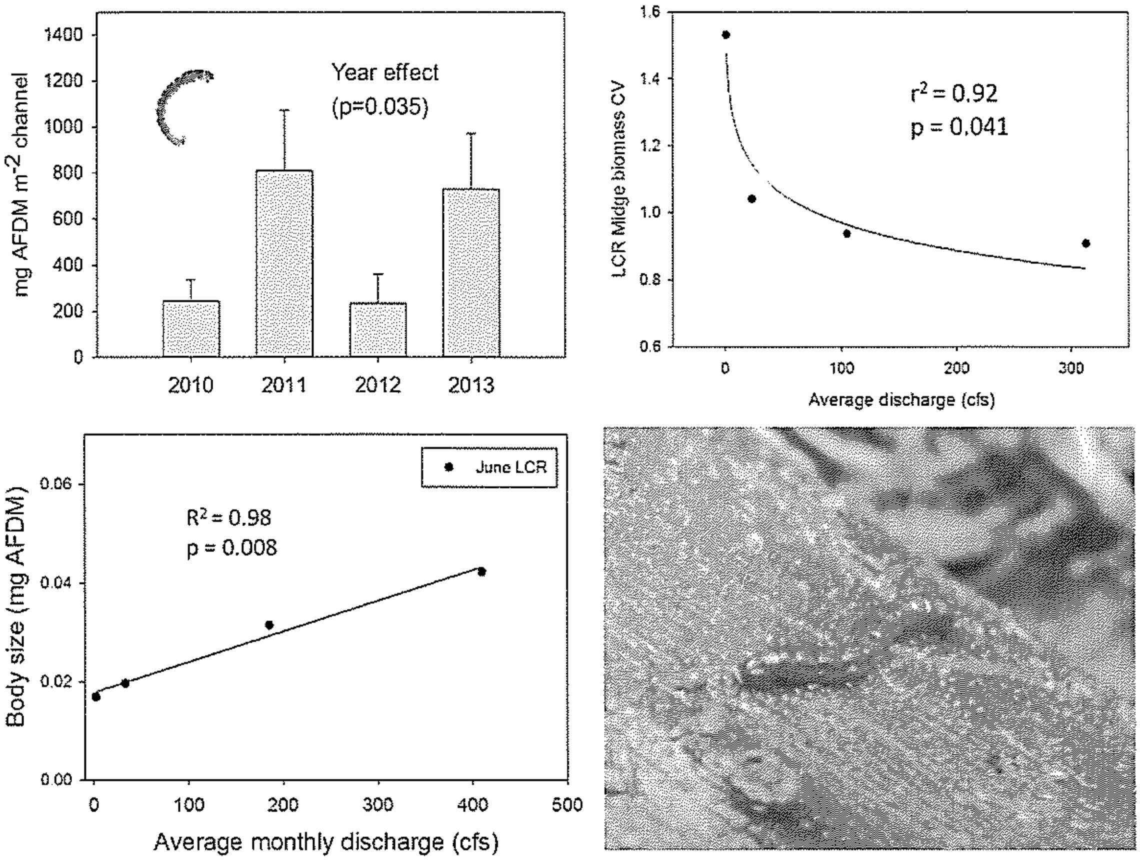

Figure 12. We found large variability in the mean June biomass Chironomidae on snag habitats in the lower Cache River among years (upper left). In dry years (2010 and 2012), mean weights of individuals were lower (lower left) and the variability in the biomasses among sites (n=4 sites sampled each June, n=4 years) was higher (upper right). The larval midge (lower right) is typical of specimens collected in the watershed. Large, red-bodied (due to the presence of hemoglobin) individuals such as this are often found in eutrophic systems and are adapted to low oxygen conditions. Baumann, unpublished.

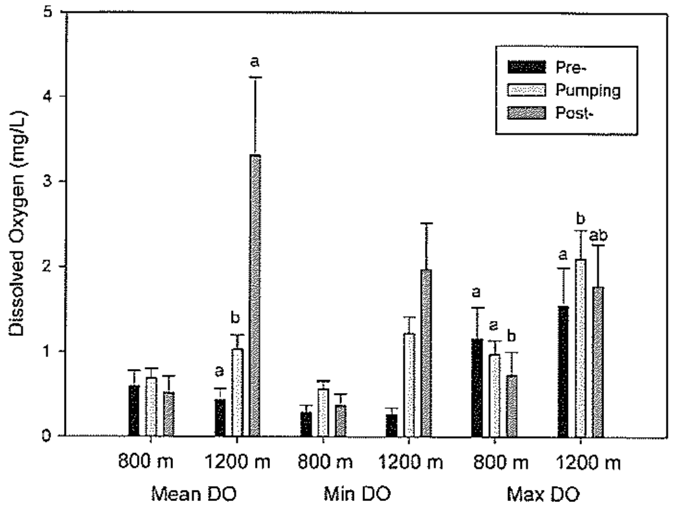

Figure 13. Data from the demonstration in summer 2013 where water was added to the lower Cache River from Buttonland Swamp. While minimum DO did not change during the demonstration, the maximum DO increased at a station 1200 m downstream of the pump. When the pump was turned off, Max DO decreased at a station 800 m downstream of the pump.

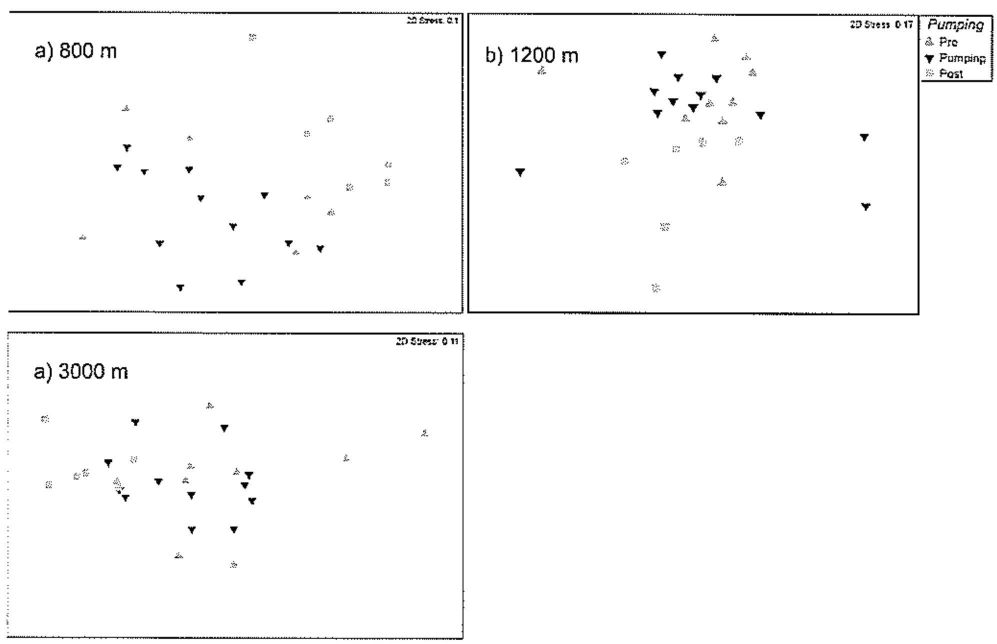

Figure 14. The macroinvertebrate drift community varied among pre-pumping (green triangles) , pumping (blue triangles), and post-pumping (blue squares) time periods at sites (a) 800 m, (b) 1200m, and (c) 3000 m downstream of the pump location (Figure 9, p=0.001, 0.026, 0.004).

PRODUCTS OF GRANT:

Publications

Scholl, E. A., H. M. Rantala, M. R. Whiles, and G. V. Wilkerson. *In Press.* A quantitative framework for predicting biological responses to a proposed river restoration. *River Research and Applications.*

Rantala, H. M., E. A., Scholl, B. Trushel, and M. R. Whiles. *In review.* Modeling ecological responses to a proposed stream restoration: relationships between flow and dissolved oxygen in a low gradient Midwestern river. *Environmental Management.*

Theses

Scholl, E.A. 2012. The influence of water velocity on macroinvertebrate functional structure and production in the Cache River in southern Illinois. MS Thesis, Department of Zoology, Southern Illinois University, Carbondale, IL.

Baumann, K. A. *In progress.* Macroinvertebrate community responses to hydrologic extremes in the upper and lower segments of the Cache River, IL and implications for restoration efforts. MS Thesis, Department of Zoology, Southern Illinois University, Carbondale, IL.

Degrees

Baumann, K. A. *Expected graduation August 2015.* Matt R. Whiles, advisor. M.S., Department of Zoology, Southern Illinois University, Carbondale, IL.

Scholl, E.A. *December 2012.* Matt R. Whiles, advisor. M.S., Department of Zoology, Southern Illinois University, Carbondale, IL.

Presentations

Baumann, K.A., E. A. Scholl, H. M. Rantala, and M. R. Whiles. 2014. Macroinvertebrate community responses to natural hydrologic disturbances: implications for predictive models in the Cache River. Illinois Water Conference, Champaign, IL, 14-15 October 2014.

Bonjour, S. M., H. M. Rantala, M. G. Bennett, and M. R. Whiles. 2014. Influence of a common stream restoration practice on fish community structure and diets. Illinois Water Conference, Champaign, IL, 14-15 October 2014.

Rantala, H. M., S. M. Bonjour, and M. R. Whiles. 2014. Biotic and abiotic responses to flow addition in a water-starved stream in southern Illinois. Illinois Water Conference, Champaign, IL, 14-15 October 2014.

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Scholl, E. A., Rantala, H. M., Whiles, M. R., Wilkerson, G. V. 2012. Predicting macroinvertebrate responses to a hydrologic restoration in a southern Illinois river. Annual meeting of the Society of Freshwater Science, Louisville, Kentucky, 20-24 May 2012.

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Kennington, A. K., Scholl, E. A., Garcia, G., Rantala, H. M., Wilkerson, G. V., and Whiles, M. R. 2012. Predicting ecological responses to a proposed river restoration: influence of enhanced flow on duckweed, light penetration, and oxygen in an Illinois river. Annual meeting of the Society for Freshwater Science, Louisville, Kentucky, 20-24 May 2012.

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Rantala, H. M., E. A. Scholl, T. Egdorf, A. K. Kennington, M. R. Whiles, and G. Wilkerson. 2012. Effects of hydrologic fragmentation on stream ecosystem structure and function, Cache River, IL. American Fisheries Society, North Central Division, Rivers and Streams Technical Committee Meeting, Milan, Illinois, 26 March 2012.

Rantala, H. M., E. Scholl, M. R. Whiles, and G. V. Wilkerson, 2011. Effects of hydrologic alteration on macroinvertebrate community structure and ecosystem metabolism in a southern Illinois river. Midwest Fish and Wildlife Conference, Des Moines, Iowa, 4-7 December 2011.

Scholl, E. A., Rantala, H. M., Whiles, M. R., and Wilkerson, G. V. 2011. Influence of water velocity on snag-dwelling macroinvertebrates in a southern Illinois river. Annual meeting of the North American Benthological Society, Providence, Rhode Island, May 22-26, 2011.

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