EVALUATING BIOLOGICAL EFFECTS OF DAM REMOVALS IN PENNSYLVANIA

FINAL REPORT
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INTRODUCTION

The dramatic effects of dams on riverine ecosystems and their biota have been well documented (Ward and Stanford 1983; Dynesius and Nilsson 1994; Ligon et al. 1995; Rosenberg et al. 2000). Although dams have provided many benefits for society, many are now physically deteriorating or no longer serve the purpose for which they were constructed (Stanley and Doyle 2003). The aging of these dams, coupled with an increasing awareness of the negative impacts of dams on lotic systems, has raised dam removal as a viable management option (Born et al. 1998, Stanley and Doyle 2003). Few studies have quantified the effects of dam removals on biological communities (Stanley et al. 2002; Doyle et al. 2005; Thomson et al. 2005), resulting in a significant gap in our ability to predict how a stream and its biota will respond to the removal of any particular dam. Pennsylvania provides a unique opportunity to evaluate the effects of dam removal on both fish and benthic macroinvertebrate assemblages because the Pennsylvania Fish and Boat Commission (PFBC) has been actively engaged in dam removal as part of their efforts to restore stream habitat. As of June 2009, the PFBC had removed 115 dams and had a list of 103 on-going projects (S. Carney, PFBC, personal communication).

Objectives

The goal of this study was to develop a database to facilitate state-wide analysis of the effects of dam removals on aquatic biota in Pennsylvania and provide a basis for recommendations for future monitoring efforts. Specific objectives included:

1. Conduct a comprehensive literature review of the effects of dam removals on stream ecosystems and their biota (with an emphasis on studies completed in Pennsylvania and the Northeast);
2. Identify and inventory data (including georeferencing data) currently available in Pennsylvania regarding effects of dam removals on stream geomorphology, physical habitat, and aquatic biota;
3. In partnership with cooperators identified in objectives 1 and 2, create a database of available information regarding dam removals in Pennsylvania with an emphasis on biological monitoring;
4. Synthesize, to the extent possible, the current information to evaluate the effects of dam removals on aquatic biota on a state-wide basis;
5. Based on the data analysis and synthesis, provide recommendations for future monitoring of dam removal projects.

RESULTS & DISCUSSION

OBJECTIVE 1: Literature Review

A review of peer-reviewed literature related to dam removal was completed for the project progress report in September 2008 (Appendix 1). The number of peer-reviewed publications increased substantially over the last several years as many monitoring studies were finally reported. Ms. Brianna Hutchison (MS Graduate Research Assistant) compiled a summary of the literature related to effects of dam removals on fish and benthic macroinvertebrate assemblages as part of the introduction to her final MS thesis completed in December 2008 (Appendix 2).

OBJECTIVE 2: Identify and Inventory Available Data for Pennsylvania Dam Removals

To facilitated discussion about potential sources of data for dam removals in Pennsylvania, we held a workshop on May 8, 2008 at the School of Forest Resources, Penn State University. The goals of the workshop were to: 1) share information about dam removal projects in Pennsylvania; 2) explore opportunities to collaborate with existing data to develop a state-wide assessment of the impacts of dam removal; and 3) provide recommendations for focusing future research and monitoring efforts. The agenda (Appendix 3) for the workshop was split between individual presentations that were meant to provide background information on different projects for everyone and small breakout groups that focused on identifying information currently available and provide guidance for future monitoring efforts. Twenty-five people attended the workshop representing academia, federal and state agencies, and non-profit organizations (Appendix 4).

From this workshop, it became clear that the Pennsylvania Fish and Boat Commission has the most information on fish community responses to dam removals. However, when we delved into their files, we found information about fish populations at only five projects (in addition to the five that we were involved in at PSU). The most intensive monitoring of a dam removal project in Pennsylvania was conducted by the Academy of Natural Sciences on Manatawny Creek which is now available in several publications. Few other projects monitored biological assemblages in Pennsylvania. At PSU, we have data on fish and benthic macroinvertebrates on two removal projects on the Conestoga River, one removal project in Middle Creek, one removal project in Conodoguinet Creek, and one removal project in Spring Creek.

OBJECTIVE 3: Create a Database of Existing Information on PA Dam Removals

After participating in the dam removal workshop, searching the PFBC database, and working on the literature review, we have identified the primary sources of information on biological effects of dam removals (described above). The data available on the impacts of dam removal on biological assemblages are limited. We began to work with Sara Deuling (American Rivers) to develop a database on PA dam removals. Unfortunately, Ms. Deuling left for another position, and I am unaware of the status of this effort. Ms. Deuling's goal was to eventually interface the Pennsylvania information with the Dam Removal Clearinghouse (http://wrca.library.ucr.edu/CDRI/); however, to date only six projects are currently listed in the clearinghouse.

OBJECTIVE 4: Synthesize Available Information for PA

As stated above, data for the response of fish and macroinvertebrate assemblages to dam removals in Pennsylvania were very limited. As a result, a synthesis of information was not possible.

In addition, through our studies at Penn State, we found that each dam removal can be somewhat unique due a number of different confounding factors including the size of the dam, the amount of sediment trapped by the dam, and the land use in the watershed above the dam. As a result, it is difficult to generalize impacts of dam removal based on the few cases where data are available. In the case of our studies, our results were confounded by differences in sampling gear and methodology used to sample the impoundments versus the free-flowing reaches, so direct comparisons between the samples collected in the impoundment and those collected from free-flowing reaches were not possible. Differences in sampling gear and methodology resulted from the fact that the impoundments behind the dams were sampled using boat electrofishing because they were deep and long, while samples in the free-flowing sections were collected by wading and using a towboat electrofishing unit. Because the gears have different selectivities, direct comparisons are not possible. However, results from our studies contribute to the growing body of dam removal research by demonstrating that fish and macroinvertebrate assemblages in formerly impounded stream reaches become nearly indistinguishable from those in permanently free-flowing reaches following dam removal (Hutchison 2008, Appendix 2).

OBJECTIVE 5: Make Recommendations for Future Dam Removal Monitoring in PA

Unfortunately, analysis of a larger set of dam removals in PA was not possible due to lack of available data on biological assemblages. Our results were confounded by differences in sampling gears used in the impoundments and the free-flowing reaches, making direct comparisons between the impoundments and upstream, formerly impounded, and downstream free-flowing reaches difficult. Future dam removal studies should develop sampling methodology that allows for direct comparison between the very different types of habitat found in small dam impoundments versus free-flowing reaches. In addition, our sampling occurred annually, which may not be frequent enough to detect changes in the biological assemblages in these rivers. Our studies were further hampered by the fact that we did not have habitat or water quality information to support our findings related to biological communities. Expanding monitoring efforts to include quarterly or at least biannual collections, as well as habitat and water quality monitoring, will greatly enhance understanding of the ways in which small dams and their removal affect stream ecosystems.

CONCLUSIONS

Unfortunately, there was not enough information about the response of biological communities to dam removals in Pennsylvania to meet the objectives of this study. Our studies show that dams and their associated removals can be somewhat unique; however, in our study sites, fish and benthic macroinvertebrate assemblages in the area that was formerly impounded become nearly indistinguishable from those in free-flowing sections of the river after the dam is removed (Hutchison 2008).

LITERATURE CITED

Born, S.M., K.D. Genskow, T.L. Filbert, N. Hernandez-Mora, M.L. Keefer, and K.A. White. 1998. Socioeconomic and institutional dimensions of dam removals: the Wisconsin experience. Environmental Management 22:359-370.

Doyle, M. W., E. H. Stanley, C. H. Orr, A. R. Selle, S. A. Sethi, and J. M. Harbor. 2005. Stream ecosystem response to small dam removal: Lessons from the Heartland. Geomorphology 71:227-244.

Dynesius, M., and C. Nilsson. 1994. Fragmentation and flow regulation of rivers systems in the northern third of the world. Science 266:753-762.

Hutchison, B. 2008. Fish and macroinvertebrates assemblages following the removal of low-head dams in two Pennsylvania streams. M.S. Thesis. The Pennsylvania State University, University Park, PA.

Ligon, F.K., W.E. Dietrich, and W.J. Thrush. 1995. Downstream ecological effects of dams. BioScience 45:183-192.

Rosenberg, D. M., P. McCully, and C. M. Pringle. 2000. Global-scale environmental effects of hydrological alterations: introduction. BioScience 50:746-752.

Stanley, E.H., M.A. Luebke, M.W. Doyle, and D.W. Marshall. 2002. Short-term changes in channel form and macroinvertebrate communities following low-head dam removal. Journal of the North American Benthological Society 21:172-187.

Stanley, E.H., and M.W. Doyle. 2003. Trading off: the ecological effects of dam removal. Front Ecol Environ 1(1):15-22.

Thomson, J. R., D. D. Hart, D. F. Charles, T. L, Nightengale, and D. M. Winter. 2005. Effects of removal of a small dam on downstream macroinvertebrate and algal assemblages in a Pennsylvania stream. Journal of the North American Benthological Society 24(1):192-207.

Ward, J.V., and J.A. Stanford. 1983. The serial discontinuity concept of lotic ecosystems. Pages 29-42 *in* T.D. Fontaine and S.M. Bartell (eds). Dynamics of lotic ecosystems. Ann Arbor Science, Ann Arbor, MI.

APPENDIX 1

DAM REMOVAL EFFECTS ON FISH AND BENTHIC MACROINVERTEBRATE ASSEMBLAGES: A REVIEW OF THE LITERATURE

BY: BRIANNA HUTCHISON

Of particular interest to the public and natural resource management agencies are the effects of dams and dam removal on aquatic organisms, namely fish and benthic macroinvertebrates. Not only are these organisms highly visible and relatively easy to study and document, they are also the focal point for recreational activities associated with the stream, river, or former impoundment. Studies have shown that biotic assemblages in the impoundments created by low-head dams may be significantly different from those found in lotic stream reaches not influenced by dams. Dams interrupt the natural connectivity of lotic systems by severing the flow of water, sediment, nutrients, energy, and biota between the upstream and downstream segments of streams and rivers (Ligon et al. 1995). Directly upstream of the dam, water depth and temperature increase, terrestrial riparian habitat is flooded, and water velocity decreases, resulting in the creation of lake-like lentic habitat in what would otherwise be a free-flowing stream. Sediment that would normally remain in the water column and flow downstream becomes trapped within the impoundment, resulting in uniform, fine substrates that lack the structure necessary to support the survival and reproduction of lotic fish and macroinvertebrates (Power et al. 1988). These changes in habitat are often accompanied by the proliferation of species adapted to life in still waters, including undesirable and nuisance species such as common carp *Cyprinus carpio* (Winston et al. 1991). Fortunately, studies investigating the response of fishes and benthic macroinvertebrates to dam removal give favorable indications that restoration or enhancement of native species may be possible.

The Mid-West: Wisconsin, Illinois, and Michigan

The Mid-Western states have consistently been leaders in terms of small dam removal research, with the majority of published studies originating from this part of the country. Wisconsin leads the United States in terms of the overall number of dams removed, and there have been scientific investigations associated with many of these projects covering removal effects on both abiotic and biotic components of stream ecosystems. Approximately 100 dams have been removed across the state since 1967 with the majority of removals taking place within the past 15 years (WDNR 2003). In addition to the Wisconsin experience, dam removal studies focusing on fish and benthic macroinvertebrates have also been conducted in Illinois and Michigan.

Wisconsin

Kanehl et al. (1997) studied the fish community at four stations, each approximately 1,000 m in length, along the Milwaukee River in Wisconsin before and after the removal of the Woolen Mills Dam in 1988. One of these stations was located upstream and beyond the influence of the Woolen Mills Dam, two were located within the impoundment itself, and the fourth station was located 1,300 m below the dam site. Additionally, the authors surveyed fish at a “reference” station in the North Branch Milwaukee River, a tributary stream that enters the mainstem Milwaukee River 28 km downstream of the Woolen Mills Dam site. They sampled the mainstem stations once per year in mid-summer, beginning a few months prior to the removal of the dam in 1988 and ending in 1993, while the North Branch station was sampled in 1987 and in 1989-1993. Tow-barge electrofishing for smallmouth bass, the primary game species in the Milwaukee River, was completed in a zigzag pattern along the entire length of each station. The authors also conducted additional electrofishing passes along 280-480 m segments in the center of each station, targeting all species for assessment of the fish assemblages. Because common carp were so abundant in the Woolen Mills Dam impoundment, all carp were weighed in aggregate for comparison between smallmouth bass and common carp biomass.

Kanehl et al. (1997) compared the abundance and biomass of the smallmouth bass and common carp populations, and calculated Index of Biotic Integrity (IBI) scores for the entire fish assemblage using an IBI developed for use in Wisconsin wadeable warmwater streams/rivers. This IBI consisted of 12 metrics, including: # native species, # native darters, # native catostomids, # native centrarchids, # intolerant species, % tolerant individuals, % omnivores, % insectivores, % top carnivores, % simple lithophils, combined catch per unit effort (CPUE) of all individuals except tolerant species, and the % diseased or deformed individuals. The scores for the IBI range from 0 to 100, with higher scores being indicative of better biotic integrity, and differences between scores for two sites that are greater than 25 points are considered biologically significant.

Prior to dam removal, abundance and biomass of smallmouth bass was low at the impoundment and upstream stations compared to similar rivers throughout Wisconsin. Kanehl et al. (1997) found that smallmouth bass abundance and biomass increased dramatically at the mainstem Milwaukee River stations located upstream of Woolen Mills Dam following dam removal. The authors suggest that this increase can be primary accounted for by successful reproduction and recruitment rather than smallmouth bass permanently moving into formerly impounded areas due to the increased CPUE for larger length classes that was observed near the end of the study. Common carp abundance and biomass decreased drastically following removal at the two stations located within the area of the former impoundment, with an overall decrease in abundance of 94% and an 88% decline in biomass between 1988 and 1993. Similar dramatic decreases in common carp abundance and biomass were not observed at the upstream, downstream, or North Branch stations following removal of Woolen Mills Dam, although these statistics did exhibit a downward trend between 1988 and 1993. IBI scores at the two impoundment stations increased from 30 (fair) in 1988 to 52 (good) in 1993 at the station closest to the dam site, and from 24 (poor) to 55 (good) in 1993. The metrics primarily contributing to these improved IBI scores included % tolerant species and % omnivores, which decreased following dam removal, and % top carnivores, which increased. The shifts in these metrics were attributed to declines in common carp and increases in smallmouth bass populations in post-removal years. The IBI scores at the upstream, downstream, and reference stations remained relatively high over the course of the study.

Kanehl et al. (1997) concluded that dam removal improved smallmouth bass recruitment, and subsequently abundance and biomass, above the Woolen Mills Dam site due jointly to elimination of a barrier to movement and creation of improved habitat in the former impoundment, part of which was enhanced with habitat structures. Common carp abundance and biomass decreased upstream of the impoundment as the lentic habitat preferred by this species was replaced by lotic conditions. In addition to the improved IBI scores caused by changes in the smallmouth bass and common carp populations, an increase in the number of native darter and catostomid species at the upstream stations also contributed to the higher IBI scores calculated for these sites in post-removal years. The authors again cited removal of a barrier to fish movement and enhanced habitat quality as reasons for the higher upstream IBI scores following dam removal. This study provided some of the first evidence that dam removal can result in beneficial changes to the fisheries and biotic integrity of Midwestern warmwater rivers.

Catalano et al. (2007) studied the effects of dam removal on fish assemblage structure and spatial distributions in another warmwater Wisconsin stream, the Baraboo River in the south-central part of the state. Four low-head dams, ranging from 1.5-2.4 m in height, were constructed on the river in the late 1800s, three of which were located in a fast-flowing, higher gradient, riffle-dominated section known as the Baraboo Rapids. All four dams were removed between 1997 and 2001, and instream habitat enhancement structures were added to areas immediately upstream of the former dam sites following removal. Catalano et al. (2007) evaluated the effects of dam removal on fish assemblage structure at dam sites by sampling the four impoundments, three tailwater sites, and three reference sites unimpacted by the dams in 1997 and 1999-2003. Sampling was done once annually between late May and early October, with a tow-barge electofisher at wadeable sites and a boat electrofisher at non-wadeable sites. To evaluate changes in the fish assemblages, the authors calculated IBI scores using a collection of metrics developed for Wisconsin wadeable warmwater streams. Values for the IBI range from 0 (poor) to 100 (excellent), with differences between scores from two sites of 25 points or greater considered biologically significant. They also looked at four individuals metrics (species richness, % tolerant species, # intolerant species, and % riverine species) that were components of the IBI separately to indicate how different parts of the fish assemblage responded to dam removal. In addition to evaluating changes in fish assemblage structure following dam removal, Catalano et al. (2007) also examined changes in basinwide fish distributions by sampling 35 sites between 2000 and 2003, 10 of which were located at dam sites and 25 of which were located throughout the Baraboo River basin. These sites were sampled using either backpack or tow-barge electrofishing, during summer months. An additional spring sampling period was added in the area of the farthest downstream dam to detect potential spawning movements of species that might have gone undetected in summer samples. Spring samples were collected from areas directly upstream and downstream of the dam, and from upstream and downstream reaches beyond the dam's area of influence.

Catalano et al. (2007) found that IBI scores increased at impoundment sites in the Baraboo Rapids by 35-50 points following dam removal, while the fourth impoundment site upstream of the Baraboo Rapids remained relatively stable over the course of the study. Changes in IBI scores and individual metrics at the tailwater and reference sites were transient and not biologically meaningful. The improved IBI scores observed at the Baraboo Rapids impoundment sites were attributed to decreases in % tolerant species, and increases in # intolerant species and, to a lesser extent, species richness. Although habitat characteristics were not measured as part of this study, the authors cited changes in physical habitat as reasons for the observed shifts in the IBI metrics, referring to a study by Stanley et al. (2003) documenting changes in substrate composition following removal of the Baraboo Rapids dams. The percentage of riverine species in the impoundment fish assemblages varied over the course of the study by Catalano et al. (2007), and although this metric did not change following dam removal, they did observe a shift in species composition of the riverine guild. Trends in IBI scores and individual metrics at the fourth impoundment, which was not part of the Baraboo Rapids, differed from what was observed at the other three dams. The authors attribute these discrepancies to differences in geomorphology at the reach scale. The Baraboo Rapids reach was characterized by steep gradient, high water velocity, and coarse substrates, while the fourth impoundment was located in a low-gradient area with slower velocities and silty substrates. Regardless of the origin of these differences in fish assemblage recovery patterns, these results do suggest that assemblage response to dam removal may differ among sites located within a single river system.

The pre-removal fish distribution samples indentified nine species with truncated distribution patterns in the Baraboo River relative to the farthest downstream dam. Five species were collected below, but not above, this dam prior to removal, while the other four were found in large numbers downstream and very small numbers (i.e., one or two individuals) upstream. Two additional species not found in the annual summer samples were found in the samples collected in the vicinity of the farthest downstream dam during the spring. Ten of the 11 species colonized reaches upstream of this dam following removal of all four barriers. Truncated fish distributions could contribute to lower species richness, and therefore IBI scores, in impoundments and areas upstream of dams, although the method of extirpation could not be identified within the scope of this study. However, Catalano et al. (2007) suggested that the rapid upstream colonization by species with truncated distributions provided evidence that the dam was preventing fish movements from source populations into upstream reaches. The results of this study corroborate those of Kanehl et al. (1997), with similar patterns in post-removal increases in IBI score also observed by Catalano et al. (2007).

Although the effects of removing low-head dams from warmwater rivers in Wisconsin have primarily been deemed beneficial, the situation is somewhat different in coldwater, low-order, headwater streams dominated by native salmonids. It has been suggested that removal of existing dams located in headwater systems would lead to invasion by introduced species and subsequent extirpation of natives, and construction of additional barriers has also been suggested as a means of keeping exotics out of headwater streams (Novinger and Rahel 2003). Stanley et al. (2007) conducted a study in Boulder Creek, a second-order tributary of the Baraboo River in south-central Wisconsin, to determine the effects of removing two low-head dams on the stream's native brook trout population and to explore the possibility of colonization by brown trout. The smaller upstream dam, a structure approximately 1 m high, had no conspicuous effects on channel morphology as it lacked a distinct impoundment pool, channel widening, or difference in substrate composition. The downstream dam, which stood about 2.5 m high, had an associated pond that was 38 m long and almost completely filled with sediment with the exception of a deep pool near the downstream end of the impoundment. Both dams were removed in July 2003, and the channel in the area of the downstream impoundment was transformed to a narrow, shallow riffle. Stanley et al. (2007) surveyed fish populations in three reaches of Boulder Creek in July 2001 and September 2005 using an electrofishing backpack. The sampling reaches included an area immediately downstream of the lower dam, a dam-affected area upstream of the lower dam, and a reference reach upstream of both dams. The sampling reaches were primarily associated only with the lower dam because this was the structure deemed to have the greater effect on the stream and its inhabitants.

Both the pre- and post-removal collections were dominated by brook trout at all three sites, with all fish collected being brook trout in 2005, and only four individuals of other species collected in 2001 (one central mudminnow, two brook sticklebacks, and one green sunfish). No brown trout were collected during either time period. The greatest changes in the Boulder Creek brook trout population were observed in the reaches nearest to the dam, indicating that the dam and its removal had an effect on brook trout. CPUE for young-of-year (YOY) brook trout was greater in all reaches in 2005, with the greatest increase occurring in the reach directly upstream of the dam site. CPUE for adults was lower in 2005 than in 2001, a decline that was most apparent at the site immediately downstream of the dam, which was filled in by mobilized sediments from the impoundment following dam removal. Whether the decline in adult brook trout was a result of increased mortality or dispersal could not be determined. Stanley et al. (2007) state that whatever changes occurred as a result of dam removal made the area surrounding the impoundment more suitable for YOY brook trout and less suitable for adults, indicating that different life stages are affected by dam removal in different ways. Most importantly, the brook trout population of Boulder Creek remained abundant and was not supplanted by brown trout within two years of removal, indicating that invasion by non-native species following barrier removal is not necessarily inevitable.

Although the effects of dams and dam removals on fish are often a major focus of researchers, a few studies conducted in Wisconsin have also focused on benthic macroinvertebrates. Stanley et al. (2002) examined the effects of the removal of two of the three Baraboo Rapids dams on benthic macroinvertebrates in the Baraboo River, Wisconsin. The middle dam was removed in December 1997, while the farthest upstream dam was removed in January 2000. The farthest downstream dam remained intact over the course of this study. The authors collected macroinvertebrates from five reaches using a D-frame kick net or core sampler (used in waters too deep for wading) annually or biannually from 1996-2000. The Baraboo Rapids study area was divided into six reaches based upon impoundment history and proximity to a dam and included reaches that were permanently free-flowing and impounded over the course of the study. The authors evaluated spatial and temporal differences in macroinvertebrate assemblages using the Hilsenhoff Biotic Index (HBI) and nonparametric multivariate statistical techniques of classification and ordination.

Stanley et al. (2002) found that the number of taxa occurring in Baraboo Rapids lotic sites was nearly double that of impounded sites, and that no overlap among the 10 most abundant taxa from each habitat type existed. The impoundments were dominated by lentic taxa, particularly tubificid worms and two chironomid genera (*Chironomus* and *Polypedilum*) known to prefer lentic habitats. The most abundant taxa in the lotic reaches were hydropsychid caddisflies and heptageniid mayflies, both of which generally require habitats typified by swift currents. The HBI scores associated with the impoundments generally indicated poor to fair water quality, while the lotic reaches fell within the limits for fair to good water quality, although differences in HBI between the two types of habitats were not dramatically different. Unlike the HBI scores, multivariate analyses showed strong divergence in composition between assemblages found in impoundments and lotic reaches. Within one year of dam removal, the macroinvertebrate community in the former impoundment became indistinguishable from the communities in the unimpounded and reference reaches. Stanley et al. (2002) concluded that lack of suitable habitat in the former impoundment limited use by lotic taxa and that removal of the dam and subsequent return to lotic conditions allowed these organisms to colonize the area, thus homogenizing the macroinvertebrate assemblages in lotic and impounded reaches. Additionally, the extent to which the assemblages differed between the two habitat types indicates that even relatively small dams can case profound changes in macroinvertebrate community composition directly upstream.

Pollard and Reed (2004) demonstrated that low-head dams can also affect benthic macroinvertebrate assemblages in stream reaches directly downstream. These authors studied changes in macroinvertebrate assemblages in Turtle Creek, a fourth-order stream located in southeastern Wisconsin, following removal of Shopiere Dam. Shopiere Dam, which stood 4 m high, was removed in two stages beginning in December 1999 when it was breached and much of the physical structure was deconstructed. The removal process was completed in the fall of 2000. Pre-removal sampling took place in September 1999 at a "reference" site located 1.8 km upstream and at two "impact" sites, one located 50 m below the dam and the second 4.9 km downstream of the dam. All sites were considered lotic in nature; samples were not collected from the impoundment created by Shopiere Dam. Pollard and Reed collected three macroinvertebrate samples from cobble substrates only at each site using a Surber sampler. They focused solely on cobble substrates in the hopes of minimizing variation in community composition related to substrate preference of individual taxa. Post-removal sampling occurred in September 2000 after Shopiere Dam was completely removed. Estimates of abundance, richness, and evenness (using Hurlbert's probability of an interspecific encounter, which is the probability that two randomly selected individuals from the same sample represent different genera) were calculated from these data. Principle components analysis (PCA) was also performed on the assemblage data to elucidate changes in community composition following dam removal.

Prior to the removal of Shopiere Dam, this site had the most diverse composition of functional feeding groups (60% gatherers, 23% filterers, and 13% scrapers) and had the highest evenness among the three study sites. In contrast, the macroinvertebrate assemblages at the upstream site and the site 4.8 km downstream were dominated by predators (84 and 90% of relative abundance, respectively) and had low evenness. The dam site also had high occurrence of lentic taxa (e.g., the pyralid moth *Acentria*, shore flies of genus *Cirrula*, and the gray drake mayfly *Siphlonurus*) prior to removal, whereas the upstream and downstream sites were dominated by lotic-depositional taxa (e.g., the dance fly *Clinocera*, and stoneflies of the genera *Haploperla*, and *Neoperla*). These differences were reflected in the PCA output where the dam site was separated from the pre-removal upstream and downstream sites.

Following dam removal, the upstream and dam sites exhibited distinct changes in macroinvertebrate assemblage. Functional feeding composition became more diverse at the upstream site following dam removal, while taxonomic composition at the dam site following removal shifted from lentic to lotic taxa. Overall, the upstream and dam sites became more similar to one another, with similarly high evenness and diverse functional feeding groups. The downstream site remained relatively unchanged between pre- and post-removal time periods. Although PCA analysis still separated the dam site from the upstream and downstream sites following removal, this separation reflected a dominance of lotic-erosional rather than lentic taxa at the dam site, whereas the upstream and downstream sites were still dominated by lotic-depositional taxa.

Pollard and Reed (2004) stated that it is unclear whether or not the removal of the dam and its associated impoundment resulted in the differences they observed in the pre- and post-removal macroinvertebrate assemblages at the upstream and dam sites. They postulated that stream flow and sedimentation rates (independent of dam removal), both of which changed over the course of their study, may have contributed to the differences in functional feeding group composition and evenness they observed at the upstream sites. However, Pollard and Reed (2004) determined that dam removal was likely to have affected taxonomic composition at the dam site. The lentic habitat found in Shopiere Dam impoundment was probably dominated by macroinvertebrate taxa preferring lake or pond conditions, and the lentic taxa observed at the dam site prior to removal could have drifted into the area from the impoundment upstream. Once the dam was removed and the area of the impoundment returned to a free-flowing state, habitat was no longer suitable for these lentic organisms and they either died or were transported downstream. Thus, these organisms were not detected at the dam site following removal.

Illinois

Two studies investigating the impact of dams and dam removal on fish and benthic macroinvertebrates in the Fox River in northern Illinois were published in recent years. Santucci et al. (2005) studied the effect of multiple low-head dams on fish and macroinvertebrates by sampling these organisms at 40 stations on the Fox River between July and September 2000. Their study area included 15 run-of-river dams on the mainstem Fox River ranging in size from 0.8 to 9.0 m high. Fifteen stations were located within dam impoundments (although safety precautions prevented sampling within 100 m of dams), 15 were located downstream of dams in free-flowing reaches, and the remaining 10 stations were located in the middle of between-dam reaches and were classified as either free-flowing or impounded.

Santucci et al. (2005) collected fish at each of the 40 stations using boat and backpack electrofishing, as well as a bag seine. All three fish sampling gears were utilized at each station. The authors characterized the fish assemblages at each station based upon a 12-metric Index of Biotic Integrity developed for use in Illinois warmwater streams and the abundance of harvestable-size sport fishes. IBI component metrics included: species richness, # suckers, # sunfish, # darters, # intolerant species, % green sunfish, % omnivores, % insectivorous minnows, % top carnivores, % hybrids, % diseased or deformed individuals, and relative abundance of all species. Possible values for the IBI range from 12 to 60 and scores represent aquatic resources classified into the following categories: unique (IBI score = 51-60), highly valued (41-50), moderate (31-40), limited (21-30), and restricted (12-20). Santucci et al. (2005) examined data from 14 fish community surveys conducted between 1980 and 1999 in addition to their own data to determine if the Fox River dams limited species distributions in the river. Macroinvertebrates were collected from the substrate, surface, and water column in wadeable areas at each station using kick nets. Randomly selected rocks and woody debris were removed from the water and hand-picked with forceps. Where substrate type was suitable (i.e., free of large cobbles), the authors sampled deeper offshore habitats for macroinvertebrates using a petite ponar dredge. Because the state of Illinois had not yet developed a standardized community index for benthic macroinvertebrates, Santucci et al. (2005) developed a multimetric macroinvertebrate community index (MCI) for the Fox River based upon the U. S. Environmental Protection Agency's rapid bioassessment protocols. Their MCI included the following metrics: taxa richness, # of Ephemeropter-Plecoptera-Trichoptera (EPT) taxa, % EPT, % Chironomidae, # intolerant taxa, Illinois macroinvertebrate biotic index (a version of the HBI specific to Illinois), and % clinger organisms. The range of possible values for the MCI was 0-700, with higher scores being indicative of higher quality (i.e., more sensitive) macroinvertebrate communities.

Santucci et al. (2005) found that low-head dams were having a negative effect on the biotic integrity of the Fox River not only on a local scale (e.g., within impoundments), but also on a landscape scale through fragmentation of habitat and restricted movements of fish. IBI scores were higher at free-flowing stations than in the impoundments, with free-flowing reaches averaging an IBI score of 46.1 (highly valued resource) and impoundments averaging 30.2 (limited resource). Fish assemblages at free-flowing stations had higher species richness, more sucker species, more intolerant species, and higher percentages of insectivorous minnows than those at impoundments. The impoundments were dominated by tolerant and omnivorous species. The abundance of harvestable sport fishes was also higher in free-flowing reaches (80.2 fish/ha) than in impoundments (36.1 fish/ha). Data collected by Santucci et al. (2005) combined with the data from previous fish surveys revealed that the Fox River dams altered the distributions of more than one-third of the species found in the river by preventing upstream movements. Fifteen species were found only at stations downstream of the South Batavia Dam, which is the sixth dam upstream of the Fox River's confluence with the Illinois River. Ten of these 15 species were found only below Dayton Dam, the lowermost dam on the Fox River. Fifteen additional species had discontinuous distributions, meaning they were found at both upstream and downstream stations but were absent at one or more stations in between.

Macroinvertebrate assemblages in the Fox River were also adversely affected by the presence of dams. MCI scores at free-flowing stations were more than twice as high as those calculated for impounded stations, at 445.5 and 204.4, respectively. Free-flowing macroinvertebrate assemblages had greater EPT taxa richness, higher percentages of EPT individuals, and higher percentages of clingers than impoundment assemblages. MBI scores were highest in the impoundments, indicating tolerant, poor quality macroinvertebrate communities at these stations.

Santucci et al. (2005) attributed the differences in fish and macroinvertebrate assemblages at free-flowing and impounded stations to degraded habitat and poor summer water quality in the impoundments. Habitat and water quality were also monitored at 11 impounded and 11 free-flowing reaches downstream of dams as part of their study. Impounded stations were classified as having poor quality habitat based on qualitative habitat evaluation index (QHEI) criteria, primarily due to the absence of riffle/run sequences in these areas. Statistical analysis revealed that a strong positive relationship existed between QHEI and IBI and QHEI and MCI scores (Pearson's product-moment correlation: $r = 0.89$, $P = 0.001$ and $r = 0.84$, $P = 0.001$, respectively). Total phosphorous, total nitrogen, dissolved oxygen, and pH in impoundments frequently failed to meet Illinois state water quality standards over the course of the study. Degraded habitat and water quality conditions were ubiquitous in the impoundments, as were poor quality fish and macroinvertebrate assemblages, and were not limited to areas directly above the dams. In contrast, habitat, water quality, and biotic assemblages were consistently of good quality throughout the river at free-flowing stations.

Although Santucci et al. (2005) clearly demonstrate that individual dams negatively affected fish and macroinvertebrates in the impoundments, based on their data it appeared that the effects of the dams were not cumulative in a downstream direction. Based on their data, dams affected habitat, water quality, fish, and macroinvertebrates in similar ways throughout the Fox River. Santucci et al. (2005) suggest that multiple low-head dams across a single river may have greater local influence rather than acting as cumulative disruptors of the downstream transport process. However, the truncated and discontinuous distribution patterns of more than one-third of the Fox River fish species suggests that low-head dams do have a cumulative upstream effect on highly motile organisms.

The work of Santucci et al. (2005) in the Fox River was followed with a study by Maloney et al. (2008) describing changes in macroinvertebrate and fish assemblages in the vicinity of the South Batavia dam following the breaching of this structure. The South Batavia Dam, located 88.4 km upstream of the Fox River's confluence with the Illinois River, naturally breached in winter 2002, initially creating a 2-3 m opening that widened to 10 m by summer 2003. Maloney et al. (2008) sampled reaches above and below three unbreached dams (North Batavia, Geneva, and North Aurora) on the Fox River for use as "references", and at the South Batavia dam during the months of June or July from 2002 to 2005. Two of their reference dams were located upstream of the South Batavia dam and the third was located downstream in an attempt to account for longitudinal variation.

Maloney et al. (2008) collected fish using boat and backpack electrofishing. The authors calculated values for a region-specific IBI consisting of ten metrics: # native species, # sucker species, # centrarchids species, # minnow, # intolerant species, # benthic invertivore species, % benthic invertivores, % omnivores, % sensitive lithophilic spawers, and % tolerant species. Additional individual metrics calculated included total biomass, CPUE, species richness, diversity (Shannon *H*), and % common carp. Macroinvertebrates were collected from wadeable areas at using a Hess sampler and kick nets. In deeper waters at the impoundments, a petite ponar dredge was used to collect macroinvertebrate samples. Insect taxa were identified to family or genus, while non-insects were identified only to class or order. The macroinvertebrate assemblages were characterized using the following metrics: taxa richness, # EPT taxa, % EPT, and % Ostracoda. The latter is not a metric typically used in studies of biotic integrity, but it was included by the authors because preliminary analysis indicated that these taxa differed between impounded and free-flowing sites.

An additional two years of fish data from the study by Santucci et al. (2005) were added for a total of three years each of pre-breach and post-breach data. This enabled Maloney et al. (2008) to test for differences in fish metrics across treatment levels using a “replicated” before-after-control-impact (BACI) analysis. Because the macroinvertebrate data set consisted of only one year of pre-breach data, a similar BACI analysis was not possible. Instead, the authors calculated and plotted 95% confidence limits (CLs) for each macroinvertebrate metric for the reference impoundments and free-flowing reaches and superimposed the values from the South Batavia impoundment and free-flowing reach onto these plots. This was also done with the fish metric data. To assess changes in fish and macroinvertebrate assemblages following the dam breach, Maloney et al. (2008) performed NMDS ordinations on the abundance data after removing rare taxa (e.g., taxa occurring in <10% of samples).

Fish assemblages in the impounded and free-flowing reference reaches differed in terms of both the IBI and individual metrics. Free-flowing reaches had higher IBI scores, biomass, CPUE, species richness, and diversity than the impoundments. The impoundments had a higher % common carp than the free-flowing reaches. These generalizations include the pre-breach South Batavia impoundment and free-flowing site. BACI analyses strongly suggested ($P < 0.05$) that the breach affected fish biomass, species richness, diversity, and IBI scores because these metrics differed more post-breach than pre-breach between the reference impoundments and the South Batavia impoundment. BACI analysis also indicated that breach affected the % common carp, which differed more post-breach than pre-breach between the reference impoundments and the South Batavia impoundment ($P < 0.10$). Finally, the difference between the South Batavia impoundment and free-flowing reach was reduced after the breach for total taxa and the IBI ($P < 0.05$), as well as for % common carp ($P < 0.10$).

The results of the macroinvertebrate analyses were highly variable. Maloney et al. (2008) found that taxa richness and # EPT taxa had overlapping and variable confidence limits for both the reference impoundments and free-flowing reaches. Taxa richness declined in the South Batavia impoundment following the breach, but fell within the confidence limits for the reference free-flowing reaches from 2003-2005. The South Batavia impoundment % Ostracoda fell outside the confidence limits for free-flowing reaches from 2002-2004, but moved within these limits in 2005. The % EPT at the South Batavia impoundment fell within the confidence limits for free-flowing reference reaches in 2003 and 2004, but increased beyond these limits in 2005.

The reference impoundments and free-flowing reaches formed separate clusters on the NMDS ordination plots created using either fish or macroinvertebrate data, indicating a dissimilarity between the assemblages found within these habitats. Prior to the breach and one year post breach, the South Batavia impoundment fell within the cluster created by the impoundments for plots made using each data set. In 2004 and 2005, the South Batavia impoundment appeared closer to but not within the cluster created by the free-flowing sites when fish data were used to create the NMDS plot. When macroinvertebrate data were used, the South Batavia impoundment appeared within the cluster of free-flowing reaches in 2004 and 2005. In the case of both fish and benthic macroinvertebrates, more lotic taxa were collected in the South Batavia impoundment section following breaching of the dam, whereas pre-breach assemblages were dominated by lentic taxa. Maloney et al. (2008) attributed the NMDS results to this shift towards more lotic assemblages.

By the conclusion of this study in 2005, three years after the breach of South Batavia dam, the fish assemblage in the South Batavia impoundment still had not become indistinguishable from the assemblages found within free-flowing reaches. However, the macroinvertebrate assemblage at the South Batavia impoundment exhibited a shift towards an assemblage more characteristic of free-flowing reaches within two years of the breach. Maloney et al. (2008) suggest that this difference in recovery time may be attributed to the high turnover rates and rapid recolonization ability of benthic macroinvertebrates, traits that are not mirrored by most fish species.

Michigan

Burroughs (2007) studied the effects of the removal of Stronach Dam on the fish community of the Pine River in the northwestern lower peninsula of Michigan. Stronach Dam was a 5.49 m high earthen and concrete dam built constructed in 1912 and decommissioned in 1953. This dam created a 26.7 ha impoundment that impacted habitat for 3.89 km upstream. Habitat in this impoundment was uniform in depth, with a wide channel, slow-flowing waters, and sandy substrates. Stronach Dam was removed in stages beginning in spring 1997 in order to allow for gradual adjustment of the river channel and to reduce environmental impacts. Fish passage upstream past the dam was restricted until 2002, and removal was completed in December 2003.

Using boat electrofishing, Burroughs (2007) sampled fish from three reaches along the Pine River from 1997 to 2006, including the 3.89 km impoundment, a 3.70 km upstream "reference" reach, and a 0.63 km downstream reach. Fish were sampled at four sites within the upstream reach, four sites in the impoundment, and two sites in the downstream reach. All species were collected for analysis of changes in the fish community over the course of the dam removal, and five species (e.g., brown trout, rainbow trout, brook trout, white sucker, and shorthead redhorse sucker) were targeted for multiple pass removal sampling in order to estimate population densities. Fish community data were analyzed for similarity between study reaches using Morista's similarity index and the diversity of the fish communities in the different reaches was assessed using the Shannon-Weaver diversity index (H').

Burroughs (2007) observed that the fish communities in the upstream, impoundment, and reference reaches became more similar to one another following removal of Stronach Dam. Prior to dam removal, the fish communities in these three study reaches were distinctly different. The upstream reference reach supported a coldwater fish community dominated by slimy sculpin, brown trout, rainbow trout, and white sucker, whereas the fish community of the downstream reach consisted of primarily coolwater species, such as shorthead redhorse, northern pike, and smallmouth bass. Three species were collected only upstream of the dam, 18 were found only downstream, and 14 were present in both upstream and downstream reaches. The species compositions of the upstream and downstream reaches were highly dissimilar to one another, while the fish community of the impoundment was intermediate between the two. Burroughs (2007) attributed the differences in the fish communities among the three study reaches to both differences in habitat and the effects of the dam on connectivity between reaches.

Before the removal of Stronach Dam, the upstream reach was characterized by narrow channel widths, coarse substrates, and a variety of velocity-depth regimes, including abundant riffles. The downstream reach and the impoundment were similar in terms of habitat, with wide channel widths, sandy substrates, and slow-moving, deep water throughout. Despite the differences in habitat between the upstream reach and the impoundment, these two study zones were connected while the downstream reach was effectively isolated due to the presence of the dam. Following dam removal, habitat changed in both the impoundment and the downstream reach, and connectivity between all three reaches was restored. Quality and availability of lotic habitat improved in the impoundment following dam removal, but habitat was somewhat degraded downstream due to increased sedimentation from mobilized impoundment substrates that persisted over the course of the study. Seventeen of the 18 species found only downstream of the dam before it was removed migrated into upstream reaches following removal, and one species observed only upstream prior to the removal of Stronach Dam was collected downstream in post-removal surveys. However, most of these species remained in low abundance in newly colonized areas. Burroughs (2007) postulated that this difference in abundance may have been due to the habitat preferences of these species and the availability of such habitats in the upstream versus downstream reaches. After Stronach Dam was removed, the fish communities in the upstream, impoundment, and downstream reaches became more similar to one another and species diversity increased across all three zones. Burroughs (2007) points out that these changes do not necessarily add up to "restoration" of the fish community; rather, diversity in each reach improved while homogeneity of the fish community throughout the portion of the Pine River studied increased.

Burroughs (2007) also monitored changes in population densities of brown trout, rainbow trout, brook trout, white sucker, and shorthead redhorse sucker in the upstream, impoundment, and downstream reaches over the course of dam removal. Brown trout densities were low in all three reaches from 1997-1999, but began to increase in 2000, a trend that continued through the end of the study in 2006 when population density was 450% higher in the impoundment than in had been in 1997. Although brown trout density increased in all three reaches over the course of the study, statistical analysis showed that a significant year effect existed only for the impoundment (one-way ANOVA; $F = 4.00$, $p = 0.002$, $df = 39$) and downstream reaches ($F = 3.70$, $p = 0.027$, $df = 19$). Burroughs (2007) reported that length-frequency distributions showed a significant increase in recruitment beginning in 2000, and by 2006 all size classes were more abundant, although the shape of the length-frequency distribution was still the same was it had been in 1997. The author attributes the increased recruitment and population density of brown trout in the impoundment primarily to changes in habitat favorable to spawning that occurred as a result of dam removal, particularly the increase in water velocity, substrate size, and frequency of riffles. Burroughs (2007) did state that the abundance of brown trout generally increased throughout Michigan and that trout harvest regulations were changed on the Pine River over the course of the study period, both of which may have affected the densities observed in the Stronach Dam removal study. However, the population growth rate observed at the former impoundment was substantially greater than what was observed elsewhere. In addition, although the new harvest regulations may have increased survival of larger brown trout, no significant shift in the length-frequency distribution towards larger size classes was observed. This suggests that the increases in brown trout density observed in the former impoundment were due to positive changes in habitat following dam removal.

The rainbow trout population followed a similar pattern to brown trout in terms of population density. Rainbow trout density increased in the impoundment and upstream reach between 2003 and 2006. By 2006, the rainbow trout density was 300% greater than what was observed prior to dam removal in 1997. A statistically significant increase was detected only for the impoundment ($F = 5.32$, $p = 0.0002$, $df = 39$). Similar to the brown trout population, rainbow trout recruitment increased in the impoundment following the removal of Stronach Dam. Length-frequency distributions for this species showed a large increase in frequency of juveniles and a slight increase in frequency of larger individuals. Burroughs (2007) again attributed the increase in recruitment and density to improved spawning habitat in the impoundment, particularly the addition of larger gravel substrates, following dam removal.

Brook trout populations in the upstream reach and the impoundment exhibited a different pattern over the course of the study. Brook trout density in these reaches declined between 1997 and 2006, but Burroughs (2007) did not attribute this response directly to habitat changes due to the removal of Stronach Dam. Instead, he suggests that the increases in density of brown and rainbow trout, species which frequently outcompete brook trout in interspecific interactions, led to the decrease in brook trout.

White suckers were found at relatively low and stable densities in the upstream reach and the impoundment from 1997-2002. White sucker density was higher and more variable in the downstream reach due to the influx of spawning adults migrating upstream from the Tippy Dam reservoir. After passage past Stronach Dam became possible, spawning adult white suckers were observed at much higher densities in the impoundment and upstream reach, and in 2006 white sucker density was 550% greater than in 1997. Although the abundance of juvenile white suckers in the upstream reach and the impoundment had increased substantially by 2006, adult abundances in these areas remained low, suggesting that adult habitat availability was low in these areas. Burroughs (2007) stated that the dam removal was beneficial to white suckers both through the removal of a barrier to adult spawning migrations and also by opening up previously inaccessible upstream areas with habitat suitable for juveniles.

Finally, the shorthead redhorse population demonstrated a different response to dam removal than either the salmonids or the white sucker. When Stronach Dam was intact, adult shorthead redhorses (< 300 mm total length) were collected only in the downstream reach at variable densities, again due to spawning migrations. After dam removal was completed in 2003, adult shorthead redhorses became widely distributed throughout all three study zones, albeit in low densities. No juveniles were collected in any of the reaches, but this was likely due to the fact that the shorthead redhorse generally moves into tributary streams to spawn; therefore, habitat in the Pine River was not suitable for this life stage.

Burroughs (2007) concluded that removal of Stronach Dam benefitted the fish community of the Pine River through improvement of the lotic habitat in the area of the former impoundment and through the removal of a barrier to fish migrations and other movements. However, habitat in the downstream reach was negatively impacted by the dam removal in terms of sediment deposition and an increase in fine substrates, an effect which was still being felt three years following removal. Burroughs (2007) did report that no new net erosion occurred in the former impoundment in 2006, so it is possible that the negative effects of dam removal on the downstream reach will be ameliorated in the future. As is often the case, it remains to be seen how much time is needed for the full potential benefits of dam removal to be realized in the Pine River.

The Northeast: Pennsylvania

The Commonwealth of Pennsylvania is second only to Wisconsin in terms of the number of dams removed over the past several decades. Very few of these dam removals were accompanied by scientific studies, especially investigations into dam removal effects on fish and benthic macroinvertebrates. The Academy of Natural Sciences' Patrick Center for Environmental Research completed a study to evaluate the pattern and rate of ecological recovery following removal of the Manatawny Creek dam in Pottstown, PA in 2000 (ANS 2006). Dam removal appeared to have short-term negative impacts on downstream algal biomass and diatom species richness. Prior to removal, downstream sites had higher biomass and species richness than upstream sites. Within the first year after removal, biomass and species richness decreased significantly in downstream sites (Thomson et al. 2005), but these trends were reversed in 2004, four years after dam removal. The authors attribute these changes to changing habitat within the former impoundment, especially changes in substrate composition (from sandy to rocky substrates), channel morphology, and current velocity. The macroinvertebrate community located directly downstream of the Manatawny Creek Dam was still being negatively affected by removal four years later (ANS 2006). Overall macroinvertebrate abundance and density decreased downstream of the dam immediately following complete removal and remained low until 2005 when these characteristics returned to pre-removal levels. Thomson et al. (2005) found decreased downstream macroinvertebrate abundance and density were correlated with the increase in fine sediments. Taxa richness, number of EPT taxa, and Hilsenhoff Biotic Index scores were not affected by dam removal. Fish assemblages in the former Manatawny Creek impoundment exhibited the shift from lentic to lotic species commonly reported in other studies. The authors reported the shift to lotic fish species was not discernible until one year after dam removal. In addition to the changes in fish assemblage observed in the area of the impoundment, the assemblage directly downstream was also affected by dam removal. Density decreased immediately following removal, a decline that the authors related to the mobilization of fine sediments that also negatively affected algal and macroinvertebrate assemblages.

The Special Case of Anadromous Fishes: Examples from the Southeast

Restoration or enhancement of anadromous fish populations has been one of the most common arguments made in favor of dam removal (Doyle et al. 2005). It has long been suggested that dams negatively affect the distribution and reproductive cycle of migratory fish species by creating barriers to upstream spawning habitats (Poff et al. 1997; Kinsolving and Bain 1993; Petts 1980). However, these assumptions have primarily been based on information gathered from studies investigating the effects of hydroelectric dams on salmon migrations in the large rivers of the Western United States. Few studies documenting the effects of low-head dams and their removal on non-salmonid anadromous fishes in the Eastern United States have been published.

The North Carolina Cooperative Fish and Wildlife Research Unit monitored the movements of migratory fishes in the Neuse River, North Carolina before and after the removal of the Quaker Neck Dam (Beasley and Hightower 2000; Burdick and Hightower 2006). Historically, striped bass and American shad migrated to the farthest upstream reaches of the Neuse River to spawn. Following the construction of the Quaker Neck Dam in 1952, a structure rising only about 1 m above the water's surface during average flows, the numbers of striped bass and American shad returning to the headwaters of the river decreased substantially in the 1960s and 1970s. To determine the fraction of fish migrating upstream of the Quaker Neck Dam, Beasley and Hightower (2000) tagged 25 striped bass and 25 American shad in the lower reaches of the Neuse River with sonic transmitters prior to upstream migration in 1995-1997. Over the course of their study, only three tagged striped bass made it past the dam, and these fish were observed to circumvent the structure during a period of high river flow when the dam was completely submerged. No American shad made it past the Quaker Neck Dam during the two years of the study. Beasley and Hightower (2000) indicated that migrations of both striped bass and American shad were impeded by the presence of the Quaker Neck Dam and that these species would benefit from its removal, which did occur in 1998, one year after the completion of their study. Unpublished data collected by Bowman and Hightower as a post-removal follow-up to Beasley and Hightower's (2000) study indicate that 12 of 22 American shad and 15 of 23 striped bass tagged with transmitters migrated upstream of the former dam site following removal (Burdick and Hightower 2006). Although these results are promising, the focus on only two species and small numbers of tagged individuals limit the conclusions that can be drawn from the Neuse River anadromous telemetry studies.

In addition to the telemetry studies, Burdick and Hightower (2006) completed a study investigating the distribution of spawning activity by anadromous fishes in the Neuse River in 2003 and 2004, including sites upstream of the former location of the Quaker Neck Dam. These authors conducted plankton sampling at nine Neuse River mainstem and five tributary sites to detect presence of anadromous fish eggs and larvae, particularly American shad, hickory shad, and striped. They compared these data to historical spawning distribution data collected in the 1970s when the Quaker Neck Dam was still in place. American shad spawning distribution was substantially expanded following removal of the Quaker Neck Dam, with 91.8% of eggs and 89.1% of larvae found upstream of the former dam site in 2003, and 65% of eggs and 20% of larvae found upstream in 2004. Hickory shad also showed significant upstream expansion in 2003-2004 compared to their 1970s spawning distribution, although this species primarily utilized the tributaries rather than the mainstem Neuse River where the majority of American shad spawning activity occurred. Striped bass expanded their spawning range 120 km upstream of the farthest upstream location where spawning was documented for this species in the 1970s. In 2003, 76.8% of striped bass eggs and 77.8% of larvae were collected upstream of the former Quaker Neck Dam site. As was the case for American shad, occurrence of striped bass eggs and larvae was significantly reduced in 2004. Burdick and Hightower (2006) cite low flows in 2004 as the reason for the decline in spawning activity upstream of the former dam site. This study demonstrates that removal of low-head dams can benefit anadromous species through upstream expansion of spawning ranges.

More research into the effects of small dams and their removal on anadromous fishes is clearly needed. Although the efforts of the North Caroline Cooperative Fish and Wildlife Research Unit in the Neuse River have provided some enlightenment regarding these seldom-researched topics, more information is needed before a true understanding is accomplished. Future research should focus on smaller-scale habitat factors contributing to anadromous fish spawning site selection and success. Finally, the Neuse River studies were conducted over short periods of time and represent only a snapshot of conditions. Long-term studies investigating the effects of small dams and their removal on anadromous fish species are needed to determine enduring trends.

LITERATURE CITED

Academy of Natural Sciences (ANS). 2006. Evaluating the pattern and rate of ecological recovery from the Manatawny Creek dam removal. Report # 06-05. Patrick Center for Environmental Research, Philadelphia, PA.

Beasley, C. A. and J. E. Hightower. 2000. Effects of a low-head dam on the distribution and characteristics of spawning habitat used by striped bass and American shad. Transactions of the American Fisheries Society 129:1316-1330.

Burdick, S. M. and J. E. Hightower. 2006. Distribution of spawning activity by anadromous fishes in an Atlantic slope drainage after removal of a low-head dam. Transactions of the American Fisheries Society 135:1290-1300.

Burroughs, B. A. 2007. The effects of the Stronach Dam removal on fish in the Pine River, Manistee County, Michigan. Chapter 2 of "The effects of dam removal on fluvial geomorphology and fish," a dissertation of the Department of Fisheries & Wildlife, Michigan State University.

Catalano, M. J., M. A. Bozek, and T. D. Pellett. 2007. Effects of dam removal on fish assemblage structure and spatial distributions in the Baraboo River, Wisconsin. North American Journal of Fisheries Management 27:519-530.

Doyle, M. W., E. H. Stanley, C. H. Orr, A. R. Selle, S. A. Sethi, and J. M. Harbor. 2005. Stream ecosystem response to small dam removal: Lessons from the Heartland. Geomorphology 71:227-244.

Kanehl, P. D., J. Lyons, and J. E. Nelson. 1997. Changes in the habitat and fish community of the Milwaukee River, Wisconsin, following the removal of the Woolen Mills Dam. North American Journal of Fisheries Management 17:387-400.

Kinsolving, A. D. and M. B. Bain. 1993. Fish assemblage recovery along a riverine disturbance gradient. Ecological Applications 3(3):531-544.

Ligon, F. K., W. E. Dietrich, and W. J. Trush. 1995. Downstream ecological effects of dams. BioScience 45(3):183-192.

Maloney, K. O., H. R. Dodd, S. E. Butler, and D. H. Wahl. 2008. Changes in macroinvertebrate and fish assemblages in a medium-sized river following breach of a low-head dam. Freshwater Biology 53:1055-1068.

Novinger, D. C. and F. J. Rahel. 2003. Isolation management with artificial barriers as a conservation strategy for cutthroat trout in headwater streams. Conservation Biology 17:772-781.

Petts, G. E. 1980. Long-term consequences of upstream impoundment. Environmental Conservation 7(4):325-332.

Poff N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The natural flow regime. Bioscience 47(11):769-784.

Pollard, A. I. and T. Reed. 2004. Benthic invertebrate assemblage change following dam removal in a Wisconsin stream. Hydrobiologia 513:51-58.

Power, M. E., R. J. Stout, C. E. Cushing, P. P. Harper, F. R. Hauer, W. J. Matthews, P. B. Moyle, B. Statzner, and I. R. W. DeBadgen. 1988. Biotic and abiotic controls in river and stream communities. Journal of the North American Benthological Society 7:456-479.

Santucci, V. J., S. R. Gephard, and S. M. Pescitelli. 2005. Effects of multiple low-head dams on fish, macroinvertebrates, habitat, and water quality in the Fox River, Illinois. North American Journal of Fisheries Management 25:975-992.

Stanley, E. H., M. J. Catalano, N. Mercado-Silva, and C. H. Orr. 2007. Effects of dam removal on brook trout in a Wisconsin stream. River Research and Applications 23:792-798.

Stanley, E. H., M. A. Luebke, M. W. Doyle, and D. W. Marshall. 2002. Short-term changes in channel form and macroinvertebrate communities following low-head dam removal. Journal of the North American Benthological Society 21:172-187.

Thomson, J. R., D. D. Hart, D. F. Charles, T. L, Nightengale, and D. M. Winter. 2005. Effects of removal of a small dam on downstream macroinvertebrate and algal assemblages in a Pennsylvania stream. Journal of the North American Benthological Society 24(1):192- 207.

Winston, M. R., C. M. Taylor, and J. Pigg. 1991. Upstream extirpation of four minnow species due to damming of a prairie stream. Transactions of the American Fisheries Society 120:98-105.

APPENDIX 2

FISH AND MACROINVERTEBRATE ASSEMBLAGES FOLLOWING THE REMOVAL OF LOW-HEAD DAMS IN TWO PENNSYLVANIA STREAMS

BRIANNA HUTCHISON

M.S THESIS

DECEMBER 2008

APPENDIX 3

DAM REMOVAL WORKSHOP AGENDA

Dam Removals in Pennsylvania
Workshop Agenda

School of Forest Resources & Department of Landscape Architecture
104 Forest Resources Building, Penn State University, May 8, 2008

Workshop Goals:
1. Share information about dam removal projects in Pennsylvania
2. Explore opportunities to collaborate with existing data to develop a state-wide assessment of the impacts of dam removal
3. Provide recommendations for focusing future research and monitoring efforts

Agenda:

9:00 Welcome & Introductions

9:15 McCoy Dam Removal Project – Katie Ombalski, ClearWater Conservancy

9:30 PA Fish & Boat Commission's Dam Removal efforts – Dave Kristine, PFBC

9:45 American Rivers Dam Removal Projects – Sara Deuling, American Rivers

10:00 Visualization of Dam Removal Projects – Craig Harvey, PSU

10:15 Regulations & Dam Removals – Tom Pluto, Army Corps of Engineers

10:30 Break

10:45 Dam Safety Perspectives– Vince Humenay, DEP Dam Safety

11:15 Legacy Sediments -- Jeffrey Hartranft, DEP Dam Safety

11:45 Lunch

12:30 McCoy dam video

12:45 Sprogels Run dam removal – David Williams, Delaware Riverkeeper Network

1:00 Manatawny Creek – Rich Horwitz, Patrick Center

1:15 Good Hope Dam Removal – Jeff Chaplin, USGS

1:30 Conestoga River & Middle Creek – Brianna Hutchison, PSU

1:45 Cuddebackville Dam Removal – Rich Horwitz, Patrick Center

2:00 Break

2:15 Breakout Groups

3:00 Reporting Back & Large Group Discussion (Facilitator: Brian Orland)

4:30 Concluding remarks

APPENDIX 4

DAM REMOVAL WORKSHOP LIST OF PARTICIPANTS

Preliminary List of Workshop Participants

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