THE EFFECTS OF LOW-HEAD DAMS AND LAND USE CHANGE ON NORTH CAROLINA ATLANTIC SLOPE FISH COMMUNITY STRUCTURE

A Thesis
by
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Abstract

Effects of Low-Head Dams on North Carolina Atlantic Slope Fish Community Structure

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Dams impound streams, alter sediment regimes and other physicochemical characteristics, and fragment populations. Low-head dams (<15m height) are ubiquitous in eastern North America and impact communities across broad geographic scales. We sampled fish at 25 dams (9 breached, 7 relict, 9 intact) in the Tar, Neuse and Roanoke basins including reaches upstream, immediately downstream (mill reach) of and >500m downstream from each dam (*n*=75 reaches). Analyses revealed fish CPUE, taxa richness, percent intolerant taxa, individual intolerant taxa and eel abundance were significantly higher in intact dam mill reaches and upstream of breached dams compared to other reaches. Relict dams had no between reach differences. Nonmetric Multi-Dimensional Scaling and Indicator Species Analysis revealed streams in the Tar and Roanoke with intact dams and all relict dams supported fish species and communities indicative of natural communities, whereas Neuse streams with intact dams and all streams with breached dams contained disturbed habitats and communities. These data suggest breached dams warrant higher removal priorities than intact dams and intact dams should be entirely removed on a case by case basis.

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Foreword

Chapters 1 and 2 will be submitted for publication and are formatted according rto specific journal formats: Canadian Journal for Fisheries and Aquatic Ecology (Chapter 1), Landscape Ecology (Chapter 2).

CHAPTER 1

Effects of Low-Head Dams on North Carolina Atlantic Slope Fish Community Structure

INTRODUCTION

Dams are one of the most widespread human impacts to streams and affect over 1 million kilometers of river in the U.S. alone (Poff et al. 1997). Low-head dams, typically < 15 m in height and impound short reaches of streams, are epilimnetic or spillway release meaning only impoundment surface waters are passed to downstream reaches (Poff and Hart 2002). These structures are ubiquitous in small to medium order streams across the southeastern US. By 1840, >65,000 mill dams existed on streams in the eastern US (Walter and Merrits 2008). Larger dams are less common may impound many kilometers of streams and rivers. Many large dams are hypo-limnetic release structures and release cold, oxygen depleted water to downstream reaches.

It is well-established that large dams have strong negative impacts on freshwater fish communities. Large dams are barriers to fish migrations because they offer no or very limited fish passage (Baxter 1977, Zhong and Power 1996, Fukushima et al. 2007, Reid et al. 2008, Lucas et al. 2009). Cold, oxygen depleted waters and hydro-peaking flows from hypolimnetic release structures cause shifts in fish community assemblages and promote existence of non-native species in downstream reaches (Kinsolving and Bain 1993, Quinn and Kwak 2003).

Impoundments created by low-head and larger dams may also reduce fish community diversity. Impoundments may create habitat favoring invasive species and habitat generalists, and facilitate their colonization of adjacent stream reaches (Ruhr 1957, Tiemann et al. 2004, Falke and Gido 2006, Taylor et al. 2008, Han et al. 2008, Kanno and Vokoun 2010). Increased sediment retention in impoundments and reaches some distance downstream due to reduced high flow events may eliminate sediment-intolerant taxa (Osmundson et al. 2002).

In contrast, evidence suggests low-head dams do not significantly fragment riverine fish populations (Chick et al. 2006). Recent studies also suggest some low-head structures may provide some ecological benefit to other freshwater biota. Freshwater mussel assemblages are more abundant and diverse, and exhibit increased growth and juvenile survivorship immediately downstream of intact low-head dams (Singer and Gangloff 2011, Gangloff et al. 2011, Hoch 2012, McCormick 2012). Helms et al. (2011) found higher fish assemblage diversity immediately downstream of breached low-head dams than at upstream sites, and a study in North Carolina documented increased abundances of invasive sunfishes in streams with breached dams (Thoni et al. in review). Although dams serve as barriers to migratory fish, they may also prevent range expansion of invasive species. Flathead catfish, *Pylodictus olivaris*, are introduced in Atlantic Slope drainages and may detrimentally impact native fisheries (Thomas 1995). Small dams may limit flathead catfish range expansion to upstream reaches (Brown et al. 2005, Walker et al. in review), thus protecting native fish species.

The negative effects of large dams have prompted managers in many states to begin extensive removals of more prevalent low-head dams. However, recent studies documenting potentially beneficial impacts to stream biota by low-head dams suggest more quantitative research is needed. This is especially true in North Carolina with an estimated 3382 dams, 1796 of which are <7 m in height (USACE National Inventory of Dams). The objective of our study was to measure the effect of low-head dams on Atlantic slope fish assemblages in eastern North Carolina and provide quantitative criteria for stream restoration projects.

MATERIALS AND METHODS

Study Area

Our study sites were located primarily in the upper coastal plain along the fall-line and throughout the piedmont of eastern North Carolina in the Tar, Neuse, and Roanoke basins (Fig. 1). Streams in these basins harbor diverse faunal assemblages including approximately 122 fish species including 12 species *(Roanoke logperch, Percina rex; Carolina madtom, Noturus furiosus; Roanoke bass, Ambloplites cavifrons; Rustysided sucker, Thoburnia hamiltoni; Orangefin madtom, Noturus gilberti; Bigeye jumpock, Moxostoma arriomus; Carolina darter, Etheostoma collis; Blue Ridge sculpin, Cottus caeruleomentum; Riverweed Darter, Etheostoma podestemone; Cutlips minnow, Exoglossum maxillingua; Roanoke hogsucker, Hypentelium roanokense; Least brook lamprey, Lampetra aepyptera;) with listings of state or federal concern* (NC Natural Heritage Program 2012, NC Division of Water Quality 2013).

Study Design

Dams were categorized as either relict, breached, or intact. Relict dams have been removed and there is only minor evidence (e.g., dam footers or foundations along the channel margin) of the former dam’s presence. Breached dams are partially intact and obstruct 25-75% of the stream channel. Breached dams impound little to no water and are not barriers to fish passage. Intact dams form upstream impoundments and obstruct fish passage under most flow conditions. Fish and habitat were sampled at 9 intact, 9 breached, and 7 relict dams.

At each dam, three 150-m study reaches were established 1) immediately downstream, 2) farther downstream, and 3) upstream of the dam site. The mill reach extended from the dam (or former dam site in the case of relict dams) to ~150 m downstream. The downstream reach, was located 500-1000 m downstream of the dam site and the upstream reach was located 500+ m upstream of the existing or former impoundment.

Fish Sampling

We sampled fish between June and September under summer base-flow conditions. Our sampling protocol was modified from Helms et al. (2011). Electro-fishing was conducted using a Smith-Root LB-12 backpack electro-shocker. Within each reach, we collected 3 replicate samples in each of 4 meso-habitats (e.g., run, riffle, pool, and bank; n = 12 replicate samples per reach). Each meso-habitat replicate was sampled for 100 seconds (300 seconds total per meso-habitat). All fish were anesthetized (MS-222), identified to species, and released after sampling was completed. Fish not readily identifiable in the field were preserved in 10% formalin and returned to the laboratory for identification. All vouchers were deposited in the North Carolina Museum of Natural Sciences.

Habitat Sampling

Physical habitat parameters were measured with five evenly-spaced 0.25 m2 quadrats along 15 cross channel transects (10 m apart) within each 150-m reach. At each quadrat we measured depth and mid-channel current velocity (Marsh-McBirney Flo-Mate, model 2000, Loveland CO). Additionally, we took 12 random substrate measurements (measureable lithic particles, clay, silt, sand, organic, bedrock, mudstone, or wood) within each quadrat.

Statistical Analyses

We evaluated habitat parameters at each reach with MANOVA to test interactions between drainage, dam status, and reach and comparison-wise error rates. We used ANOVA to further evaluate habitat parameters with significant treatment effects. Habitat parameters included were mean depth, mean current velocity, stream width, mean measured particle size, median measured particle size, % sand, % wood, % bedrock, % organic, % silt, % clay, % mudstone, % Justicia americana, % fines (sand, silt, clay), percent gravel-cobble (measureable particles).

Fish species richness and catch per unit effort (CPUE) were calculated for each meso-habitat and analyzed using a mixed general linear model with dam status and reach as fixed factors, and a nested term with each dam within drainage as random factors. Shannon's diversity index (H'), the percentage of tolerant and intolerant taxa and abundance, abundance of widespread intolerant taxa (*Lythrurus matutinus, Percina nevisense, Percina roanoka*), and abundance of *Anguilla rostrata* were calculated for each reach and analyzed using two-way ANOVA with dam status and reach as fixed factors. We obtained fish tolerance data from the North Carolina Index of Biotic Integrity for Stream Fishes (NC Division of Water Quality 2006).

Fish communities were classified into ordinal axes (components) using nonmetric multi-dimensional scaling (NMS). NMS has been shown to be effective at assessing trends in community data and can handle data sets with zeroes, categorical data (i.e. species), and unequal sample sizes better than other ordinations (McCune and Grace 2002). Community metrics included spawning guilds of all taxa which were primarily obtained from FishTraits Database and supplemented with other literature (Johnston and Paige 1992, Jenkins and Burkhead 1993, Frimpong and Angermeier 2011, Table 1). We omitted spawning guilds representing less than 5 individuals from NMS (McCune and Grace 2002). NMS was also performed on the abundance of all taxa present at study reaches. NMS axis scores were evaluated with MANOVA to further test for effects of and interactions with drainage, dam status, and reach. NMS axis scores were also correlated with habitat and respective community measures (spawning and feeding guilds and species abundance) using Spearman correlation to evaluate meaning of NMS axes. NMS was further complimented using blocked indicator species analysis (BISA) with dam status blocked by reach. Indicator species analysis (ISA) was then performed on reaches within each dam status. ISA is a useful tool for identifying species only occurring within (indicative of) of a treatment (McCune and Grace 2002).

NMS, BISA, and ISA were conducted in PC-ORD v. 6 (MJM Software, Glenden Beach, Oregon, U.S.A). Spearman correlations were performed in Sigmaplot v. 12 (Systat Inc.). All other analyses were performed using SPSS v. 20 (IBM).

Results

Basic Metrics

We sampled a total of 22,440 fish from 16 families representing 79 species. The most abundant fishes were minnows (Cyprinidae, 44%), darters (Percidae, 24%), and sunfishes (Centrarchidae, 18%). Mixed models revealed significantly increased species richness and CPUE at intact mill reach habitats when compared to up- and downstream reaches ($p < 0.004$ and $p < 0.001$, respectively). At breached dams, upstream reach habitats had higher CPUE than mill or downstream reaches ($p = 0.052$ and $p = 0.014$, respectively). There was no effect of status or reach on any fish metric at relict dams ($p > 0.131$). Two-way ANOVA revealed no effect of status or reach on Shannon's H' of fish assemblages ($p > 0.106$). There was no effect of status or reach on the percentage of tolerant fish taxa and abundance ($p > 0.146$), but streams with breached dams were comprised of significantly lower percentages of intolerant fish taxa and abundance when compared to streams with intact and relict dams ($p < 0.004$ and $p < 0.012$, respectively).

Examination of widespread intolerant fish taxa abundance found *L. matutinus* was significantly more abundant at intact mill reaches when compared to upstream sites ($p = 0.044$) and marginally more abundant than at downstream reaches ($p = 0.08$). *Percina roanoka* was significantly more abundant at intact mill reaches when compared to up- and downstream sites ($p < 0.001$). Though not statistically significant, *P. roanoka* was more abundant upstream of breached dams than at reaches downstream of the structure (p = 0.055). *Percina nevisense* was significantly more abundant in streams with relict dams when compared to streams with breached dams (p = 0.021). American eels were significantly more abundant at intact mill reaches when compared to up and downstream reaches ($p < 0.008$).

Habitat

We found no effect of reach, either alone or within dam status or drainage, on any habitat variable ($p > 0.201$), so we pooled reaches into larger "stream segments" around individual dams. Streams with breached dams were significantly shallower when compared to streams with intact dams (p = 0.024) and marginally shallower than streams with relict dams (p = 0.059). Streams with breached dams had significantly greater percentages of clay substrates when compared to streams with intact dams (p = 0.003) and marginally greater percentages of clay substrates than relict dams (p = 0.06). The fine substrates model was not statistically significant but perhaps ecologically meaningful (p = 0.067), and intact dams had marginally lower percentages of fine substrates than streams with relict dams (p = 0.095).

Current velocity, mean particle size, channel width, and percentage of bedrock showed significant drainage interactions ($p < 0.005$). MANOVA revealed ecologically important drainage-status interactions with percentage of wood substrates (p = 0.06). We subsequently split habitat data by drainage and analyzed for dam status effects using oneway ANOVA. Within the Neuse River basin, stream segments with breached dams had faster current velocities than segments with intact dams ($p = 0.027$). Within the Roanoke River basin, stream segments with breached dams had significantly slower current velocities than segments with relict ($p < 0.001$) and intact dams ($p = 0.004$). Similarly though not statistically different, in the Tar River basin, streams with breached dams also had slower current velocities than streams with intact dams ($p = 0.086$). Within the Roanoke River basin, stream segments with breached dams had significantly smaller mean measureable particle sizes than segments with intact dams ($p = 0.02$). Within the Tar River basin, stream segments with relict dams had significantly greater mean measureable particle sizes than segments with intact dams ($p = 0.014$) and breached dams ($p = 0.05$). Within the Roanoke River basin, stream segments with breached dams had significantly greater percentages of wood substrates than segments with relict and intact dams ($p = 0.012$ and 0.007, respectively).

Fish Communities

NMS axis scores for reproductive guilds and species analyzed using MANOVA revealed significant interactions between drainage and dam status ($p < 0.041$ and $p = 0.011$, respectively). We conducted NMS for each drainage independently and MANOVA was repeated on NMS axis scores. NMS identified 3 important axes within each river drainage for spawning guilds and species. There was no effect of reach, either alone or within dam status, on community structure of species or spawning guilds as revealed by MANOVA of NMS axis scores ($p > 0.254$ and $p > 0.285$, respectively).

Spawning Guilds

Within the Neuse River Basin NMS, axes 1, 2, and 3 explained 48.0, 22.6, and 20.8 percent of ordinal variation, respectively (91.4% total). MANOVA revealed significant effects of status only in NMS axis 1 scores, with relict dams having greater axis 1 scores than intact dams (*p* = 0.02, Fig. 2). Neuse NMS axis 1 scores were not significantly greater in streams with relict dams compared to streams with breached dams (*p* = 0.069, Fig. 2), but the observed differences may be ecologically important in light of reduced power. Axis 1 scores were not different in streams with breached and intact dams in the Neuse basin (*p* = 0.252 Fig. 2). There was no effect of dam type on Axis 2 or 3 scores in the Neuse basin; however there were visually discernible differences between breached and relict groupings associated with axis 3 (Figure 2). Axis 1 was predominately positively correlated with non-guarding spawning guilds preferring coarse substrates, axis 2 was significantly correlated with a number of guarding and non-guarding spawning guilds, and axis 3 was predominately correlated with guarding spawning guilds (Table 2). Axis 1 was correlated with velocity, axis 2 was positively associated with coarse substrate and negatively with fine substrates, and axis 3 was associated with woody substrates (Table 3).

Within the Roanoke River basin, NMS axes 1, 2, and 3 explained 45.4, 39.4, and 9.1 percent of ordinal variation respectively (93.9% total). MANOVA revealed significant effects of status only in axis 1 scores, with breached dams having significantly lower axis 1 scores than intact and relict dams (*p* = 0.004 and 0.017, respectively, Fig. 3). Axis 1 scores were not different between streams with relict and intact dams (*p* = 0.594, Fig. 3). Axis 1 predominately correlated positively with non-guarding spawning guilds preferring coarser substrates, axes 2 and 3 were significantly correlated with a number of non-guarding spawning guilds (Table 2). Axes 1 and 2 were positively associated with width, flow, and coarse substrates, and axis 3 was negatively correlated with flow and J. Americana (Table 3).

Within the Tar River basin, NMS axes 1, 2, and 3 explained 53.7, 20.9, and 13.2 percent of ordinal variation, respectively (87.8% total). MANOVA revealed significant effects of status only in axis 2 scores, with all dam types being significantly different from one another ($p < 0.031$, Fig. 4). Axis 1 was predominately positively correlated with non-guarding spawning guilds preferring coarse substrates, axis 2 was significantly correlated with non-guarding and guarding spawning guilds, and axis 3 was correlated with non-guarding, guarding, and live-bearing spawning guilds (Table 2). Axis 1 was negatively associated with depth and positively with width and % clay, axis 2 was negatively correlated with depth and coarse substrates and positively with clay substrate, and axis 3 was negatively correlated with clay substrates (Table 3).

Species

Species ordinations yielded similar results to ordinations with spawning guilds. Within the Neuse basin, NMS axes 1, 2, and 3 explained 43.6, 28.8, and 16.1 % of ordinal variation, respectively (88.4% total). MANOVA revealed significant treatment effects only in axis 1, with relict dams having statistically smaller axis 1 scores than breached and intact dams ($p = 0.037$ and $p < 0.001$, respectively, Figure 5). Streams with breached and intact dams did not differ significantly with respect to axis 1 ($p = 0.09$), but may be ecologically relevant. Lotic adapted taxa (e.g., Cyprinidae and Percidae) correlated negatively and lentic adapted taxa (e.g., Centrarchidae, Ictaluridae, and Esocidae) and flow velocity correlated positively with Axis 1 (Tables 4 & 5). Lotic taxa, width, and large substrate particles correlated positively and lentic taxa and fine substrates correlated negatively with Axis 2 (Tables 4 & 5). Axis 3 had fewer significant taxa relationships and was predominantly positively correlated with lentic taxa groups and percentage of silt and negatively correlated with percentage wood (Tables 4 & 5). BISA identified *Lepomis macrochirus* (*p* = 0.0018) as representative of intact dams. BISA indicated *L. gibbosus* (*p* = 0.0292) and *Noturus insignis* (*p* = 0.0152) as indicators of breached dams and *Cyprinella analostana* (*p* = 0.0004), *Etheostoma vitreum* (*p* = 0.0002), and *P. nevisense* (*p* = 0.0010) as indicators of relict dams. ISA ran on reaches within dams status revealed *Ameirus natalis* as a significant indicator of intact mill reaches (*p* = 0.04). ISA identified no other species as indicative of a reach, regardless of dam status.

Within the Roanoke River basin, NMS axes 1, 2, and 3 explained 48, 21.2, and 22.4 % of ordinal variation, respectively (91.6 % total). MANOVA revealed significant treatment effects only in axis 1, as streams with breached dams had significantly greater axis 1 scores than streams with relict and intact dams (*p* = 0.001 and 0.002, respectively, Fig. 6). Relict and intact dams were not significantly different with respect to Axis 1 scores (Fig. 6). Lotic taxa, flow velocity, substrate particle size, and width correlated negatively and lentic taxa and fine substrates correlated positively with Axis 1 (Tables 4 & 5). Axes 2 had similar but less intuitive relationships with axis 1 with taxa, in general lotic taxa correlated negatively and some lentic taxa were correlated positively (Table 4). Substrate particle size and percentage of *Justicia americana* correlated positively and percentage of clay substrate correlated negatively with Axis 2 (Table 4). Axis 3 had significant but not meaningful correlations with taxa groups encountered and depth and channel width were correlated positively (Tables 4 & 5). BISA identified *A. natalis* (*p* = 0.012), *E.* podestemone (*p* = 0.0002), *N. insignis* (*p* = 0.0288), *P. roanoka* (*p* = 0.0046), and *Scartomyzon ariommus* (*p* = 0.048) as indicator species at intact dams. BISA revealed *E. olmstedi* (*p* = 0.0012), *Fundulus rathbuni* (*p* = 0.0492), *Hybognathus regius* (*p* = 0.023), *L. cyanellus* (*p* = 0.0008), *L. gulosus* (*p* = 0.0314), *L. macrochirus* (*p* = 0.0092), *Micropterus salmoides* (*p* = 0.0188), and *Notropis procne* (*p* = 0.021) as indicator species at breached dams. BISA identified *Luxilus cerasinus* (*p* = 0.0228) and *Semotilus atromaculatus* (*p* = 0.0318) as an indicator species at relict dams. ISA ran on reaches within dam status revealed no species as indicators of a given reach (*p* > 0.1954).

Within the Tar River basin, NMS axes 1, 2, and 3 explained 45.8, 20.9, and 18.8 % of ordinal variation respectively (85.5% total). MANOVA revealed significant effects of treatment only in Axis 3, with breached dams having significantly lower axis 3 scores than relict and intact dams (*p* = 0.002 and 0.017, respectively, Fig. 7). Axes 1 and 2 relationships with taxa encountered were not intuitive, with positive correlations with both lotic and lentic species (Table 4). Channel width and percentage of clay correlated positively and depth and percentage of wood correlated negatively with Axis 1 (Table 5). Channel width and percent clay correlated positively and substrate particle size correlated negatively with Axis 2 (Table 5). Lotic taxa, depth, and flow velocity correlated positively and lentic taxa and percentage of clay substrate correlated negatively with Axis 3 (Tables 4 & 5). BISA revealed *A. rostrata* as an indicator species at intact dams (*p* = 0.022). Indicator species at relict dams include *Hypentelium nigricans* (*p* = 0.0052), *Luxilus albeolus* (*p* = 0.005), *P. nevisense* (*p* = 0.0216), and *Scartomyzon cervinus* (*p* = 0.0002). BISA showed *E. collis* (*p* = 0.035), *L. macrochirus* (*p* = 0.0028), and *Pylodictis. olivaris* (*p* = 0.0452) were indicators of breached dams. ISA of reaches within each dam status revealed no significant indicators of location around dams regardless of status in the Tar River basin.

Discussion

Analyses revealed numerous significant drainage-dam status interactions. Fish communities in the Tar and Roanoke basins seemed to have similar responses to various dam statuses. Fish communities at relict and intact dams in these basins were more indicative of lotic communities and habitat scores showed these sites have higher flow velocities, and coarser substrates compared to breached dams. Breached dams in these basins had communities indicative of disturbed habitats with lower flow velocities, increased of fine substrates, and more lentic adapted fishes (e.g., Centrarchidae, tolerant Cyprinidae, Catostomidae). Relict dams in the Neuse basin exhibited similar trends to Tar and Roanoke relict dams. There were no apparent differences between streams with intact and breached dams in terms of community and habitat composition as in the Tar and Roanoke basins. Streams with breached and intact dams in the Neuse Basin shared similar responses in fish community and habitat characteristics as streams with breached dams in the Tar and Roanoke basins.

Effect of Drainage

It is interesting that fish communities at Neuse Basin intact sites responded differently than Tar and Roanoke basin sites. Effects of drainage were not surprising because species composition in the Roanoke Basin is most dissimilar to the Tar and Neuse basins. The Roanoke basin harbors several endemic taxa, as well as a number of taxa not found in the Tar and Neuse drainages. The differences between drainages in response to dam status appear to be largely due to habitat shifts, which likely in-turn affect community structure. Although study sites in the Tar and Roanoke basins drain largely forested and low intensity agricultural watersheds, the Neuse basin as a whole suffers from urbanization (e.g., city of Raleigh) and intense agricultural land uses (Stow et al. 2001, Holcomb unpublished data). It is possible that increased pollutant and fertilizer laden runoff are accelerating nutrient loading within impoundments and overwhelming their pollutant filtering capacity (Fairchild and Valinsky 2006, Jackson and Pringle 2010). Sediment and pollutant laden runoff associated with urbanization and agriculture has been widely associated with declines in intolerant taxa and shifts in stream community assemblages (Walser and Bart 1999, Schoonover et al. 2006, Helms et al. 2009).

Effect of Dam Status on Stream Habitat

We found no effect of reach on habitat parameters. Previous studies have documented coarser substrates and deeper habitats associated with mill reach plunge pools (Helms et al. 2011). Failure to detect this trend is likely due to the relatively short extent and lack of bed scour of plunge pools at the dam sites surveyed in this study. Plunge pools rarely comprised >10 m of our 150 m study reaches and many stream habitats seemingly recovered within 40 m of intact dams. Interestingly, habitats in reaches around intact and relict dams were significantly different. The only overall difference was that intact dams have slightly lower percentages of fine substrates in the mill reach than relict dams. Relationships with dam status and habitat variables seem to suggest negative impacts of breached dams on in-stream habitat parameters. Reaches associated with breached dams were shallower, had slower current velocities, and had greater percentages of clay substrates when compared to stream reaches around relict and intact dams. This may be associated with the nozzle of breached dams, as the stream is forced to flow through a smaller area of the channel than normal. This may cause bank erosion and failure during high flow events and provide increased sediment subsidies from associated erosion and remnant impoundment sediments (Stanley et al. 2002, Doyle et al. 2003). Eroded sediments as well as sediments lingering in former impoundments may be accumulating in reaches downstream of breached dams, causing decreased stream depths. This is in stark contrast to relict and intact dams. Intact dams in this study have been in place > 50 years, with one dam being over 200 years old (land owner contact). As far as we can tell, most relict dams were removed more than 20 years ago. It is likely these sites have stabilized over time, possibly explaining why the majority of intact sites and all relict sites seem to have habitat and faunal communities indicative of natural systems. Precise dates of dam construction and time since breaching or removal were difficult to obtain, and may have helped explain disturbance regimes associated with breached dams. We assume the majority of breaches were catastrophic failures resulting from high flow events, with only 2 relict dams having been formally removed (Cherry Hospital and Lowell's Mill dams).

Effect on Communities

NMS revealed that streams with relict and intact dams were similar in species and spawning guild composition. Tar and Roanoke basin ordinations and BISA revealed positive associations with non-guarding spawning guilds preferring rock and gravel substrates as well as many lotic adapted taxa such as darters and minnows in streams with relict and intact dams. Habitats at these sites were more likely to have higher current velocities and coarser substrates, allowing taxa with specific, habitat-associated life history requirements greater spawning and feeding opportunities. As mentioned above, stream bed stabilization associated with duration since construction of intact dams and removal of relict dams may play a critical role in habitat suitability.

Simple fish metrics showed the greatest effects of reach at intact dams. Intact mill reaches had greater species richness, CPUE, percentages of intolerant taxa, and abundances of widespread intolerant taxa when compared to up and downstream sites. Increases in quantity and quality of basal food resources derived from impoundments may yield positive, bottom up effects throughout the food web (Singer and Gangloff 2011). Increased basal food resources may explain increased fish CPUE immediately downstream of intact dams, as basal trophic levels exhibit increased abundances at these structures (McCormick 2012, Gangloff et al. 2011). Increased habitat diversity immediately downstream of intact dams may also explain elevated fish species richness. For example, plunge pools and coarse mill reach habitats at intact dams likely contribute to increased taxa richness via increases in lentic adapted taxa. However, the quick transition from plunge pool to natural stream habitat also allows intolerant and lotic adapted taxa to exist in relatively high abundances within the same reach. This variation in community and habitat composition can be seen in the species and spawning guild NMS ordinations and correlation analyses, as fish communities in streams with intact dams show great variation along ordinal axes. Interestingly, there seems to be a switch in species-habitat relationships in the Neuse basin when compared to the Tar and Roanoke basins. Neuse sites were positively associated with sunfishes and generalist spawning guilds, and BISA revealed bluegill sunfish as an indicator species. This may be due in part to habitat degradation associated with the extensive agricultural land conversion discussed above. Further analysis of land cover in study watersheds is needed for confirmation.

There was no effect of reach in terms of basic fish metrics associated with relict dams. Despite similarities between relict and intact dam stream segments in species and spawning guild composition revealed by NMS axes, the lack of reach effects on species richness and CPUE is likely due to absence of increased impoundment derived basal food resources and heterogeneous habitats associated with intact mill reaches mentioned above.

NMS revealed positive associations between generalist spawners and tolerant taxa (e.g., Ictaluridae, catostomids, and centrarchids) in stream segments with breached dams. Sites upstream of breached dams consistently had elevated CPUE, species richness, percentage of intolerant taxa, and abundance of widespread intolerant taxa when compared to mill and downstream sites. This is most likely to due to continuous habitat disturbances associated with breached nozzles. Alteration of substrate regimes (i.e., changes from riffle-cobble to run-pool habitats) including elevated percent fine substrates is likely responsible for species and spawning guild assemblage shifts. These effects are similar to those documented by Thoni et al. (in review), however, directly contrast results found in Alabama streams (Helms et al. 2011).

Focal Taxa – American Eels and Intolerant Species

Intact low-head dams in this study are not complete barriers to American eel migrations. Eels were more abundant at intact mill reaches when compared to up- and downstream sites, but eels were still found upstream of all intact structures. Interestingly, we did not detect eels in the Roanoke Basin or sites on the main stem of the Tar River within the Tar basin. All sites in these regions were located upstream of large dams. The lower Roanoke River has 3 large, hypo-limnetic release structures (Roanoke Rapids, Gaston, and Kerr dams) in close proximity. Tar River Reservoir Dam is a large dam impounding >10 km of the lower Tar River and eels do not appear able of bypassing this structure.

Increases in basal resources (macroinverterbrates) and habitat heterogeneity in intact mill reaches likely resulted in *P. roanoka* and *L. matutinus* being more abundant at intact dam mill reaches than other sites. *Percina roanoka* was also more abundant upstream than at mill or downstream reaches of breached dams and *P. nevisense* was more abundant in relict than breached stream segments. This is most likely due to degraded, homogenized habitats associated with breached dams, as these species are riffle-dwellers.

Management Implications

These data suggest counter-intuitive effects of intact low-head dams on stream fish communities. Stream segments with intact dams harbor greater numbers of species and fish, intolerant taxa and intolerant fish, and do not appear to be full barriers to eel migrations. However, not all intact dams preserve or promote native fish diversity. Intact Neuse Basin sites and small dams in Alabama streams (Helms et al. 2011) seem to promote depauperate fish assemblages largely comprised of invasive species. These data suggest dam removal projects should be prescribed on a case by case basis, as dams promoting diverse, natural stream fish assemblages should be lower removal priorities than structures conducive to disturbed faunal communities and in-stream habitat. Because breached dams have largely negative effects on stream fishes, we suggest in some cases breached dams may warrant higher removal priorities than fully intact dams. Moreover, all intact dam removal projects should remove the entire dam, not simply breach it to restore fish passage. Finally, intact low-head dams upstream of large dams should not be high priorities for removal if migratory fish passage is an issue, as American eels were not found upstream of any large dam. Further study of the impacts of dams (particularly breached) on anadromous fish passage is needed as our study missed seasonal shad and herring runs.

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Tables and Figures

Tables

Table 1. Spawning guilds by code, guarding type, spawning mode, and habitat association.

Guarding Type	Code	Spawning Mode	Substrate Assoc.
Nonguarder	A13A	Open Substrate	Rock-Gravel
	A13B	Open Substrate	Sand-Gravel
	A13C	Open Substrate	Slit-Mud
	A14	Open Substrate	Phytolithophil
	A15	Open Substrate	Phytophil
	A23A	Brood Hider	Rock-Gravel
	A23B	Brood Hider	Sand-Gravel
	A24C	Brood Hider	Cavity Generalist
Guarder	B14	Substrate Chooser	Phytophil
	B22	Nester	Polyphil
	B23A	Nester	Rock-Gravel
	B23B	Nester	Sand-Gravel
	B25	Nester	Phytophil
	B27A	Nester	Rock Cavity
	B27B	Nester	Natural Holes
	B27C	Nester	Cavity Generalist
Live Bearer	C123	-	-

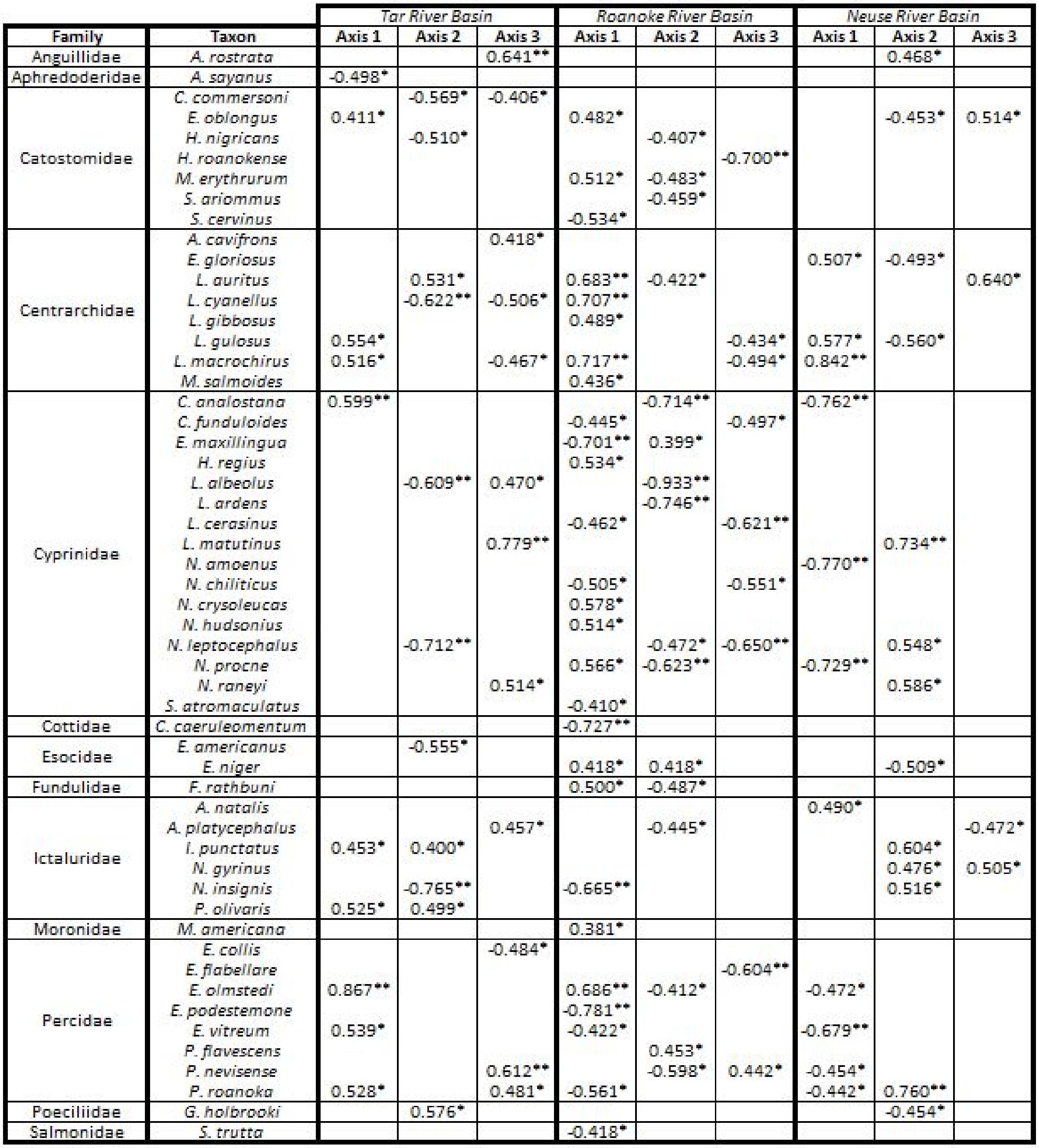
Table 2. Spearman correlations with NMS axis scores and spawning guilds in the Tar, Neuse, and Roanoke river basins. * denotes significance of p < 0.05; ** denotes significance of p < 0.001

		Tar River Basin			*Roanoke River Basin*			*Neuse River Basin*		
Guard Type	**Spawning Guild**	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 1**	**Axis 2**	**Axis 3**
Nonguarder	A13A	0.690**			0.668**			0.678**		
	A13B	0.559*				-0.807**		0.671**		
	A13C					-0.584*				
	A14			0.555*	-0.537*					
	A15				-0.445*		-0.408*		-0.597*	
	A23A		-0.794**		0.416*	-0.720**		0.681**	0.634*	
	A23B	0.554*	-0.604**		0.749**			0.652*	0.458*	
	A24C	0.593*				-0.513*	-0.453*	0.743**		
Guarder	B22	0.568*	0.585*		-0.703**	-0.496*		-0.798**		
	B23A		-0.494*	0.545*		-0.451*	0.549*		0.672**	
	B23B			-0.608**		-0.572*				0.682**
	B27A				0.752**		0.503*		0.514*	
	B27B	0.869**				-.0792**				
	B27C								0.563*	
Live Bearer	C123			-0.394*					-.0530*	

Table 3. Spearman correlations with spawning guild NMS axis scores and habitat parameters in the Tar, Neuse, and Roanoke river basins. * denotes significance of $p < 0.05$; ** denotes significance of $p < 0.001$

	Tar River Basin			*Roanoke River Basin*			*Neuse River Basin*		
Habitat	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 1**	**Axis 2**	**Axis 3**
Depth	-0.468*	-0.453*				-0.655**			
Width	0.418*			0.705**	0.415*			0.447*	
Velocity				0.721**	0.473*		0.658*		
Mean Substrate		-0.395*		0.520*	0.714**			0.583*	
Med. Substrate				0.415*	0.566*			0.685**	
% Sand								-0.525*	
% Silt				-0.422*				-0.644*	
% Clay	0.456*	0.447*	-0.390*	-0.436*	-0.631**			-0.543*	
% Wood				-0.589*					-0.511*
% *Justicia*						-0.434*			

Table 4. Spearman correlations with species NMS axis scores and species in the Tar, Neuse, and Roanoke river basins. * denotes significance of p < 0.05; ** denotes significance of p < 0.001



		Tar River Basin			*Roanoke River Basin*			*Neuse River Basin*		
Family	**Taxon**	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 1**	**Axis 2**	**Axis 3**
Anguillidae	*A. rostrata*			0.641**					0.468*	
Aphredoderidae	*A. sayanus*	-0.498*								
Catostomidae	*C. commersoni*		-0.569*	-0.406*						
	E. oblongus	0.411*			0.482*				-0.453*	0.514*
	H. nigricans		-0.510*			-0.407*				
	H. roanokense						-0.700**			
	M. erythrurum				0.512*	-0.483*				
	S. ariommus					-0.459*				
	S. cervinus				-0.534*					
Centrarchidae	*A. cavifrons*			0.418*						
	E. gloriosus							0.507*	-0.493*	
	L. auritus		0.531*		0.683**	-0.422*				0.640*
	L. cyanellus		-0.622**	-0.506*	0.707**					
	L. gibbosus				0.489*					
	L. gulosus	0.554*					-0.434*	0.577*	-0.560*	
	L. macrochirus	0.516*		-0.467*	0.717**		-0.494*	0.842**		
	M. salmoides				0.436*					
Cyprinidae	*C. analostana*	0.599**				-0.714**		-0.762**		
	C. funduloides				-0.445*		-0.497*			
	E. maxillingua				-0.701**	0.399*				
	H. regius				0.534*					
	L. albeolus		-0.609**	0.470*		-0.933**				
	L. ardens					-0.746**				
	L. cerasinus				-0.462*		-0.621**			
	L. matutinus			0.779**					0.734**	
	N. amoenus							-0.770**		
	N. chiliticus				-0.505*		-0.551*			
	N. crysoleucas				0.578*					
	N. hudsonius				0.514*					
	N. leptocephalus		-0.712**			-0.472*	-0.650**		0.548*	
	N. procne				0.566*	-0.623**		-0.729**		
	N. raneyi			0.514*					0.586*	
	S. atromaculatus				-0.410*					
Cottidae	*C. caeruleomentum*				-0.727**					
Esocidae	*E. americanus*		-0.555*							
	E. niger				0.418*	0.418*			-0.509*	
Fundulidae	*F. rathbuni*				0.500*	-0.487*				
Ictaluridae	*A. natalis*							0.490*		
	A. platycephalus			0.457*		-0.445*				-0.472*
	I. punctatus	0.453*	0.400*						0.604*	
	N. gyrinus								0.476*	0.505*
	N. insignis		-0.765**		-0.665**				0.516*	
	P. olivaris	0.525*	0.499*							
Moronidae	*M. americana*				0.381*					
Percidae	*E. collis*			-0.484*						
	E. flabellare						-0.604**			
	E. olmstedi	0.867**			0.686**	-0.412*		-0.472*		
	E. podestemone				-0.781**					
	E. vitreum	0.539*			-0.422*			-0.679**		
	P. flavescens					0.453*				
	P. nevisense			0.612**		-0.598*	0.442*	-0.454*		
	P. roanoka	0.528*		0.481*	-0.561*			-0.442*	0.760**	
Poeciliidae	*G. holbrooki*		0.576*						-0.454*	
Salmonidae	*S. trutta*				-0.418*					

Table 5. Spearman correlations with species NMS axis scores and habitat in the Tar, Neuse, and Roanoke river basins. * denotes significance of p < 0.05; ** denotes significance of p < 0.001

	Tar River Basin			*Roanoke River Basin*			*Neuse River Basin*		
Habitat	**Axis 1**	**Axis 2**	**Axis3**	**Axis 1**	**Axis 2**	**Axis3**	**Axis 1**	**Axis 2**	**Axis3**
Depth	-0.466*		0.555*			0.714**			
Width	0.501*	0.389*		-0.592*		0.637**		0.443*	
Velocity			0.454*	-0.897**			-0.655*		
Mean Substrate		-0.409*		-0.677**	0.483*			0.512*	
Med. Substrate				-0.509*	0.404*			0.622*	
% Sand								-0.537*	
% Silt				0.416*				-0.536*	0.465*
% Clay	0.532*	0.389*	-0.417*	0.545*	-0.459*			-0.475*	
% Organic								-0.517*	
% Wood	-0.428*			0.486*					-0.587*
% *Justicia*					0.478*				

Table 6. Fish species by family encountered during study.

Family	Scientific Name	Common Name	Family	Scientific Name	Common Name
Anguillidae	*Anguilla rostrata*	American Eel	Cyprinidae cont'd	*Notemigonus crysoleucas*	Golden Shiner
				Notropis altipinnis	Highfin Shiner
Aphredoderidae	*Aphredoderus sayanus*	Pirate Perch		*Notropis amoenus*	Comely Shiner
				Notropis chiliticus	Redlip Shiner
Catostomidae	*Catostomus commersoni*	White Sucker		*Notropis hudsonius*	Spottail Shiner
	Erimyzon oblongus	Creek Chubsucker		*Notropis procne*	Swallowtail Shiner
	Hypentelium nigricans	Northern Hogsucker		*Rhinicthys atratulus*	Blacknose Dace
	Hypentelium roanokense	Roanoke Hogsucker		*Semotilus atromaculatus*	Creek Chub
	Moxostoma collapsum	Notchlip Redhorse			
	Moxostoma erythrurum	Golden Redhorse	Cyprinodontidae	*Fundulus rathbuni*	Speckled Killifish
	Moxostoma pappillosum	V-lip Redhorse			
	Scartomyzon ariommus	Bigeye Jumprock	Esocidae	*Esox americanus*	Redfin Pickerel
	Scartomyzon cervinus	Black Jumprock		*Esox niger*	Chain Pickerel
Centrarchidae	*Ambloplites cavifrons*	Roanoke Bass	Ictaluridae	*Ameiurus natalis*	Yellow Bullhead
	Centrarchus macropterus	Flier		*Ameiurus nebulosus*	Brown Bullhead
	Enneacanthus gloriosus	Bluespotted Sunfish		*Ameiurus platycephalus*	Flat Bullhead
	Lepomis auritus	Redbreast Sunfish		*Ameiurus catus*	White Catfish
	Lepomis cyanellus	Green Sunfish		*Ictalurus punctatus*	Channel Catfish
	Lepomis gibbosus	Pumpkinseed		*Noturus furiosus*	Carolina Madtom
	Lepomis gulosus	Warmouth		*Noturus gyrinus*	Tadpole Madtom
	Lepomis macrochirus	Bluegill		*Noturus insignis*	Margined Madtom
	Lepomis microlophus	Redear Sunfish		*Pylodictis olivaris*	Flathead Catfish
	Micropterus dolomieu	Smallmouth Bass			
	Micopterus salmoides	Largemouth Bass	Lepisostidae	*Lepisosteus osseus*	Longnose Gar
	Pomoxis annularis	White Crappie			
	Pomoxis nigromaculatus	Black Crappie	Moronidae	*Moxostoma americana*	White Perch
Clupeidae	*Alosa aestivalis*	Blueback Herring	Percidae	*Etheostoma collis*	Carolina Darter
	Alosa sapidissima	American Shad		*Etheostoma flabellare*	Fantail Darter
	Dorosoma cepedianum	Gizzard Shad		*Etheostoma fusiforme*	Swamp Darter
				Etheostoma olmstedi	Tesselated Darter
Cottidae	*Cottus caeruleomentum*	Blue-Ridge Sculpin		*Etheostoma podestemone*	Riverweed Darter
				Etheostoma serrifer	Sawcheek Darter
Cyprinidae	*Cyprinella analostana*	Satinfin Shiner		*Etheostoma vitreum*	Glassy Darter
	Campostoma anomalum	Central Stoneroller		*Perca flavescens*	Yellow Perch
	Carassius auratus	Goldfish		*Percina nevisense*	Chainback Darter
	Chrosomus oreas	Mountain Redbelly Dace		*Percina rex*	Roanoke Logperch
	Clinostomus funduloides	Rosyside Dace		*Percina roanoka*	Roanoke Darter
	Exoglossum maxillingua	Cutlips Minnow			
	Hybognathus regius	Eastern Silvery Minnow	Poeciliidae	*Gambusia holbrooki*	Eastern Mosquitofish
	Luxilus albeolus	White Shiner			
	Luxilus cerasinus	Crescent Shiner	Salmonidae	*Oncorhynchus mykiss*	Rainbow Trout
	Lythrurus ardens	Rosefin Shiner		*Salvelinus fontinalis*	Brook Trout
	Lythrurus matutinus	Pinewood Shiner		*Salmo trutta*	Brown Trout
	Nocomis leptocephalus	Bluehead Chub			
	Nocomis raneyi	Bull Chub	Achiridae	*Trinectes maculatus*	Northern Hogchoker

Figures

Figure 1. Map of study locations in the Tar, Neuse, and Roanoke river basins, NC. Intact, breached and relict dams are represented as circles, triangles, and diamonds respectively.

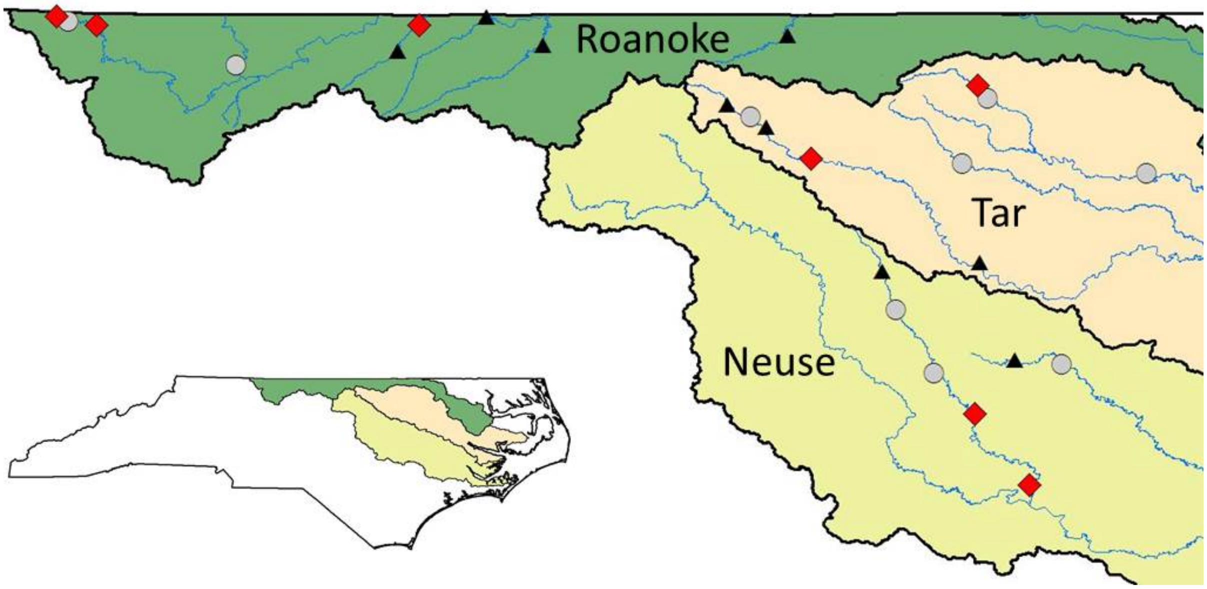


Figure 2. NMS ordination of spawning guilds in the Neuse River basin. Intact, breached and relict dams are represented as diamonds, triangles, and circles respectively. **+** represents centroids.

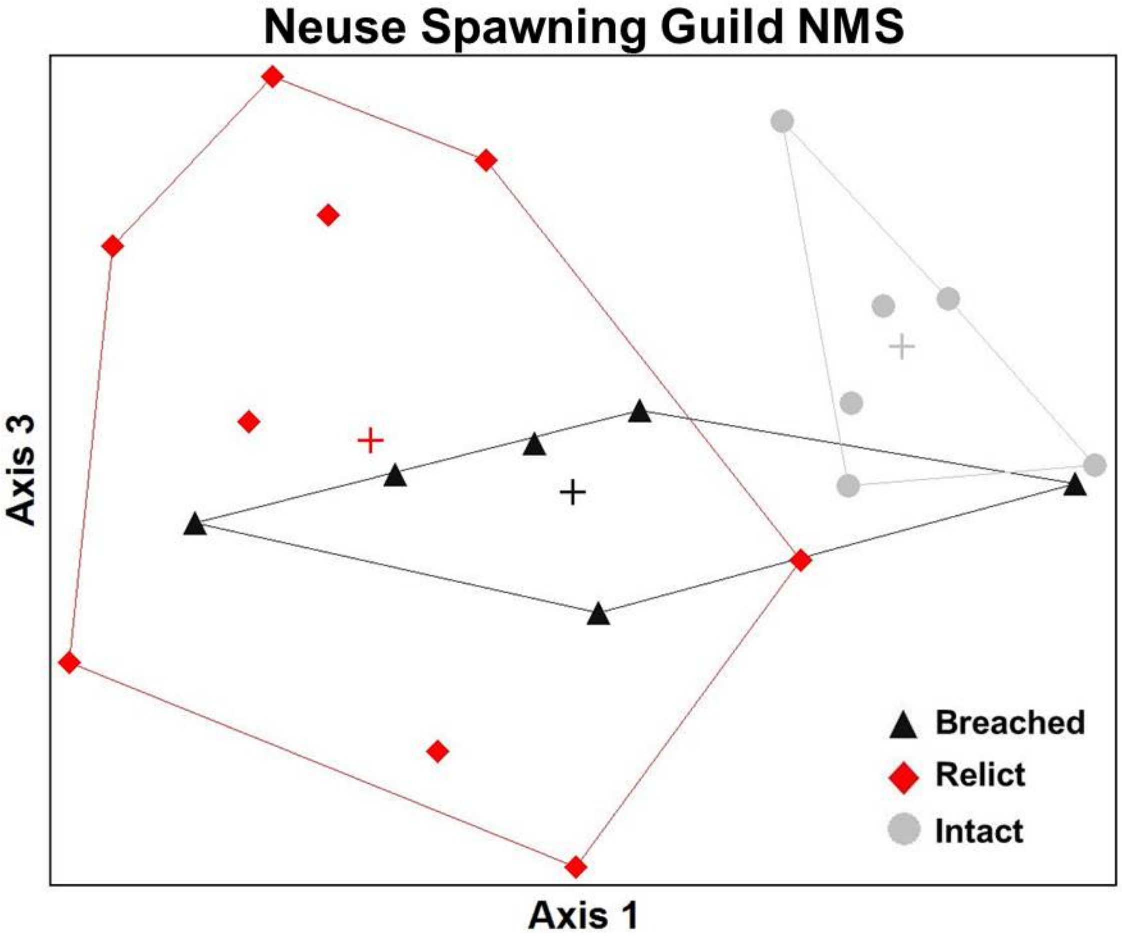


Figure 3. NMS ordination of spawning guilds in the Roanoke River basin. Intact, breached and relict dams are represented as diamonds, triangles, and circles respectively. **+** represents centroids.

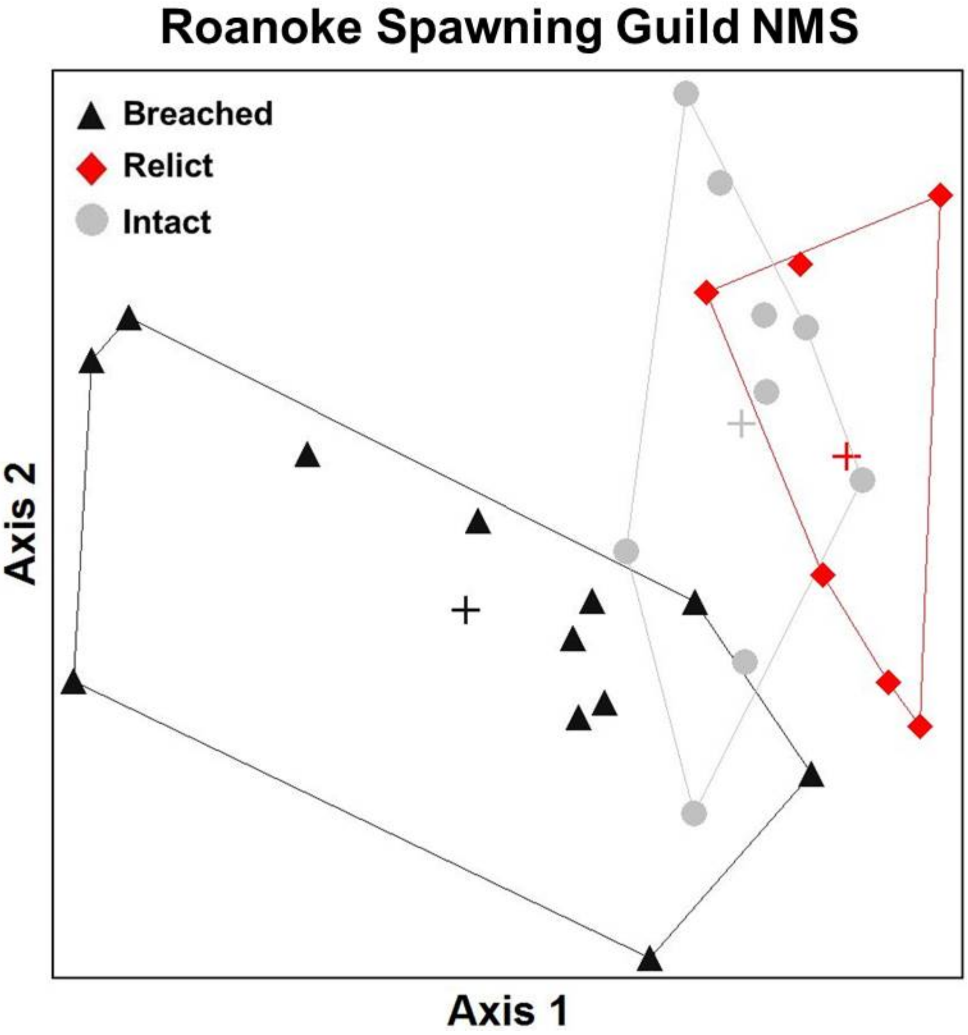


Figure 4. NMS ordination of spawning guilds in the Tar River basin. Intact, breached and relict dams are represented as diamonds, triangles, and circles respectively. **+** represents centroids.

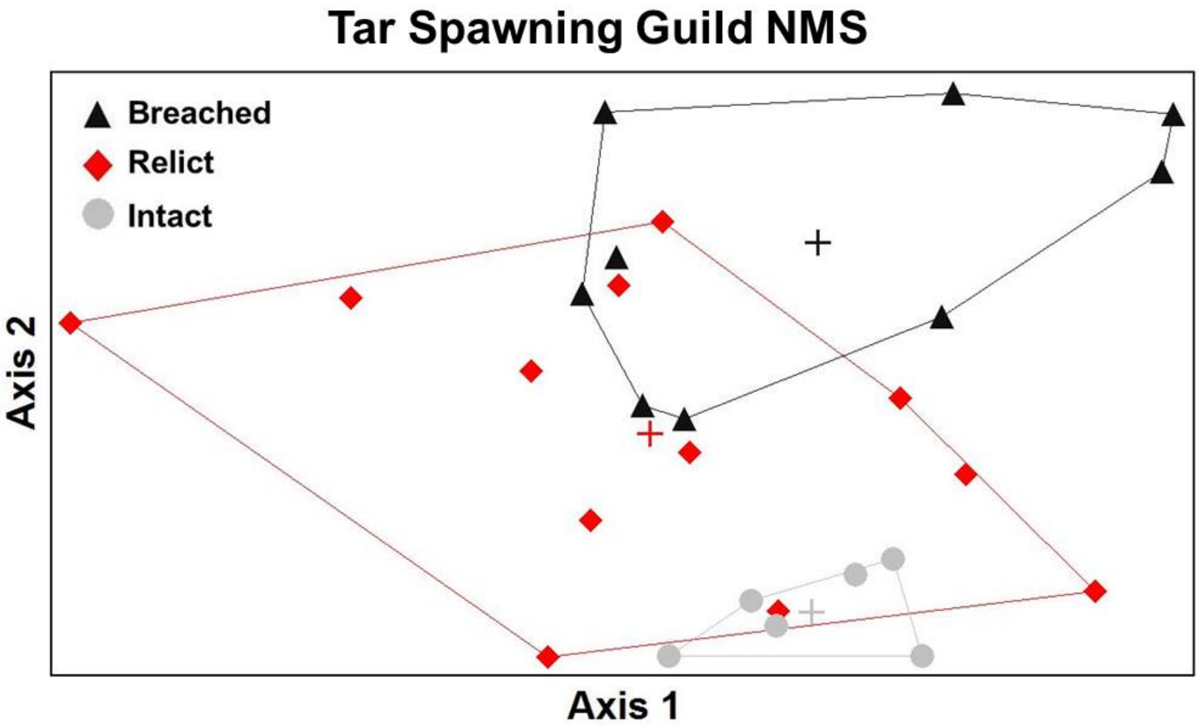


Figure 5. NMS ordination of species in the Neuse River basin. Intact, breached and relict dams are represented as diamonds, triangles, and circles respectively. **+** represents centroids.

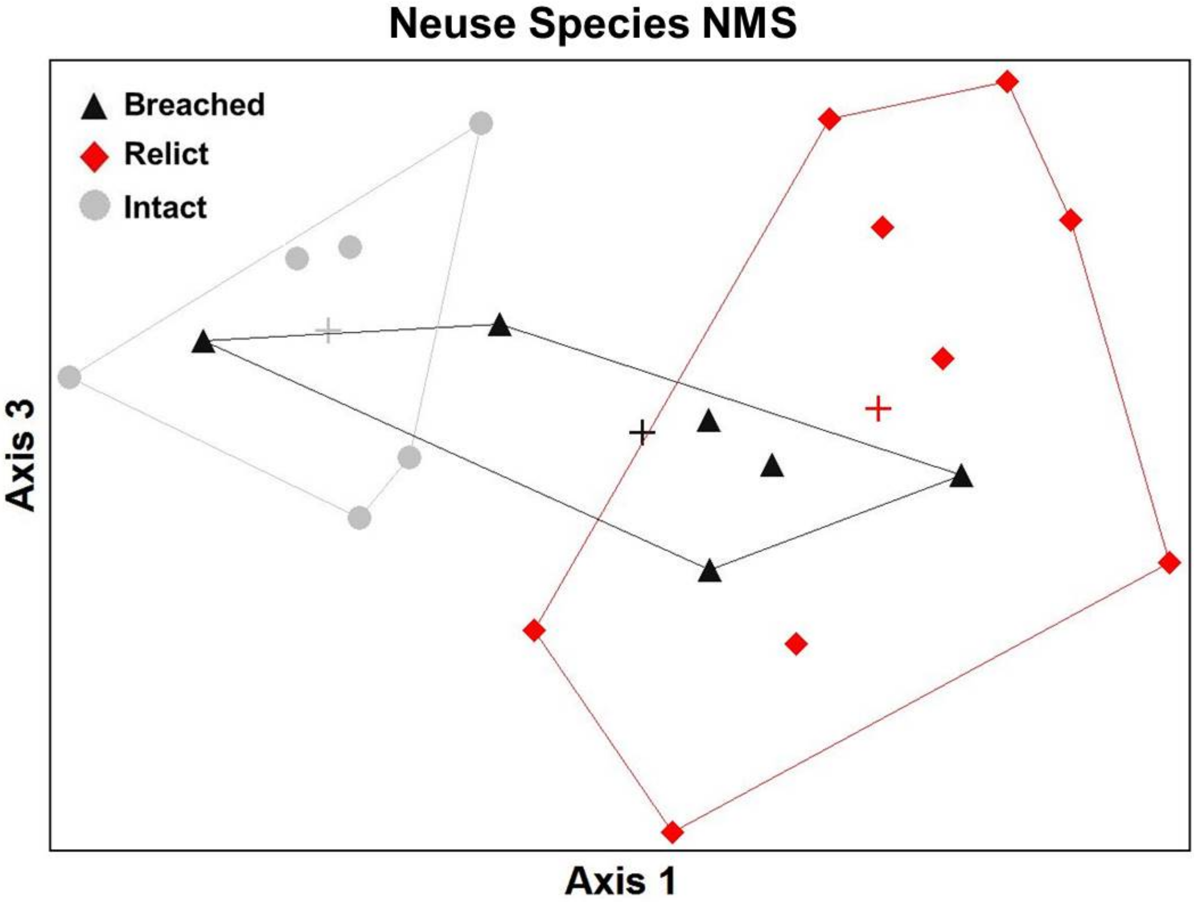


Figure 6. NMS ordination of species in the Roanoke River basin. Intact, breached and relict dams are represented as diamonds, triangles, and circles respectively. + represents centroids.

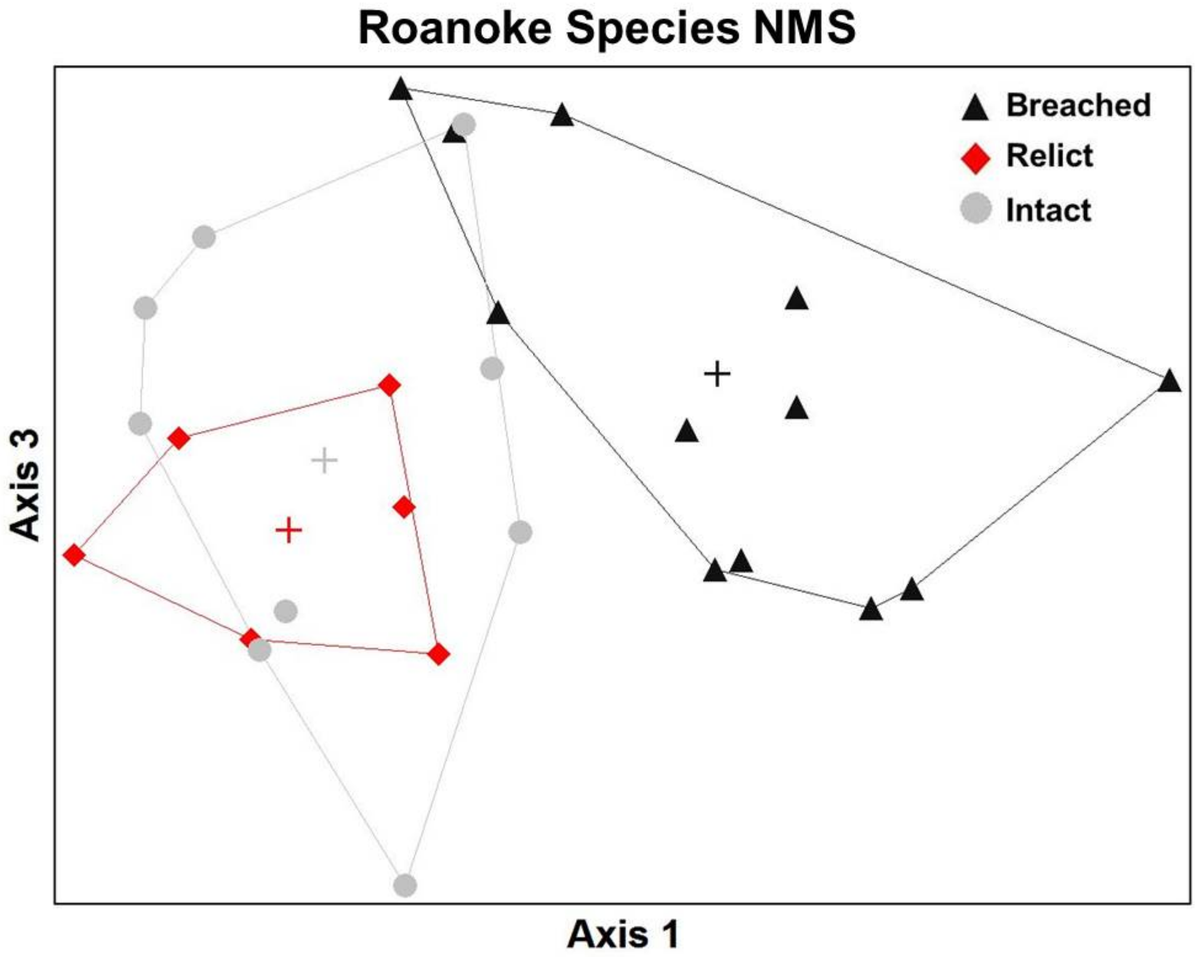
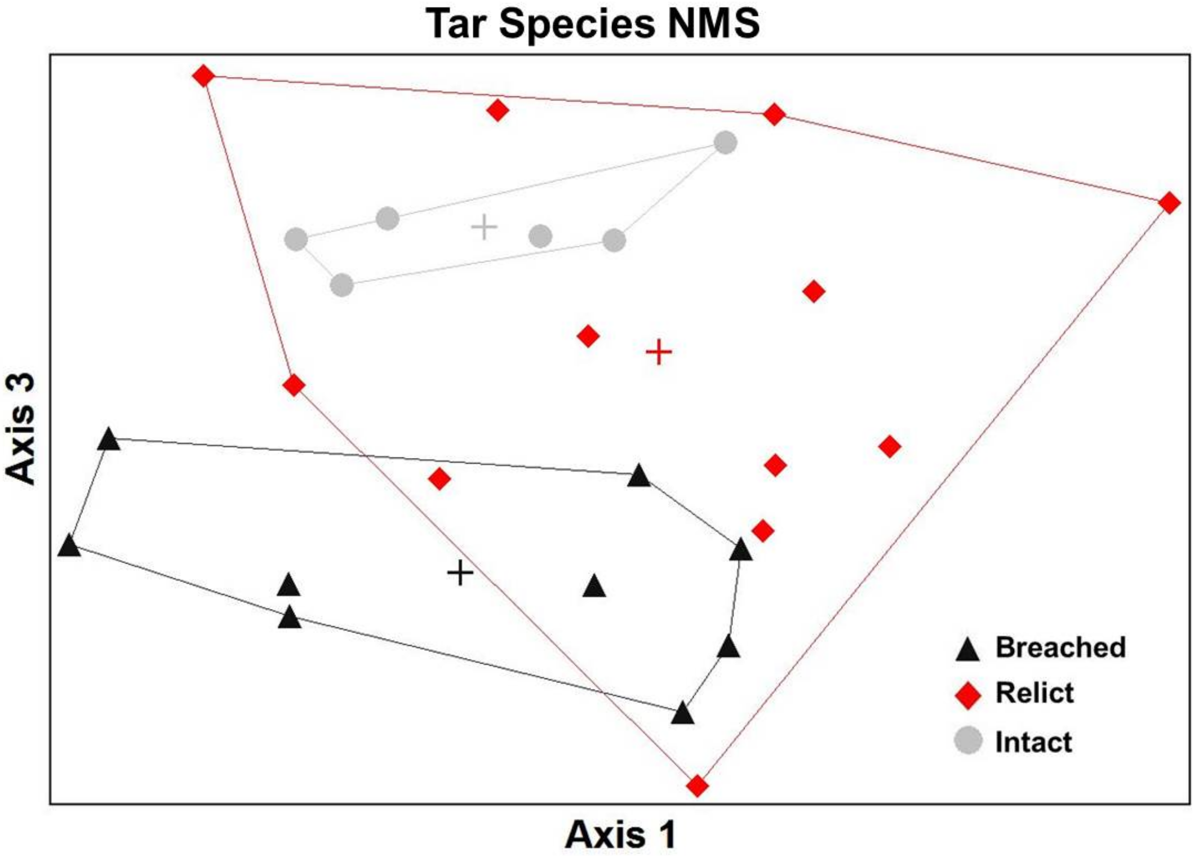


Figure 7. NMS ordination of species in the Tar River basin. Intact, breached and relict dams are represented as diamonds, triangles, and circles respectively. **+** represents centroids.



Chapter 2

Effects of Land Use and Dams on North Carolina Atlantic Slope Fish Communities

Abstract

Small dams are ubiquitous in streams across the southeastern US and fragment populations of aquatic organisms, alter flow regimes, in-stream habitat, and stream physicochemical properties. Recent research suggests some dams may promote fish species richness and enhance stream community composition of fish and benthic organisms. Although altered land use negatively impacts stream biota, the interactive effects of altered land use and dams on stream organisms are poorly studied. Our study was conducted in wadeable streams in the Tar, Neuse, and Roanoke river drainages in North Carolina. We assessed the effects of land use disturbance (total area of agriculture, urban, and cleared land covers) at riparian, reach catchment, and watershed scales in stream segments containing intact, breached and relict low-head dams on tolerant and intolerant fish and fish spawning guilds. Overall, land use at the watershed and reach catchment scales had the greatest effect on stream fish communities. Stream segments with intact dams had fewer fine substrates than stream segments with breached and relict dams in high disturbance watersheds. Generally, in low and intermediate disturbance watersheds and reach catchments, stream segments with breached dams contained lower percentages of intolerant fish and intolerant fish species, greater percentages of tolerant

fish, and fewer rock-gravel spawners than stream segments with relict and intact dams. Breached dams seem to exert strong, negative impacts on fish assemblages in lower disturbance landscapes. Breached dams may warrant higher removal priorities than intact dams. In high disturbance watersheds, intact dams may serve to benefit streams by trapping excess sediments in impounded reaches.

Introduction

North America's freshwaters include the most imperiled ecosystems in the world and North America has the greatest temperate freshwater biodiversity on earth (Jelks et al. 2008). Further, North American fishes have become increasingly imperiled in the last decade with > 700 species of freshwater and diadromous fish species considered at risk at state or federal levels (Jelks et al. 2008). The most likely causes of imperilment include overexploitation, invasive species and habitat degradation through dam construction and land cover conversion (Jelks et al. 2008).

Dams are one of the most widespread human impacts to streams and affect over 1 million km of riverine habitat in the U.S. alone (Poff et al. 1997). Low-head dams are typically < 15 m in height, impound short reaches of streams and are ubiquitous in small to medium order waterways across the eastern US (Poff and Hart 2002). For example, by 1840, >65,000 mill dams existed on streams in the eastern (Walter and Merrits 2008).

Dams are obvious barriers to fish migrations and impede migrations of anadromous (e.g., herring and shad (*Alosa spp.*), striped bass (*Morone saxatilis*), and sturgeon (*Acipenser spp.*) as well as catadromous species like American eels (*Anguilla rostrata*; Burdick and Hightower 2006, Carr and Whoriskey 2008). These structures also preclude range expansion of non-migratory stream fish (McLaughlin et al. 2006, Beneteau et al. 2009). Impoundments created by low-head and larger dams may reduce diversity of riverine species. Impoundments create habitat favoring invasive species and habitat generalists, and facilitate their colonization of adjacent stream reaches (Ruhr 1957, Tiemann et al. 2004, Falke and Gido 2006, Taylor et al. 2008, Han et al. 2008, Kanno and Vokoun 2010). Increased sediment retention in impoundments and reaches some distance downstream of the structure due to reduced high flow events may eliminate sediment-intolerant taxa (Osmundson et al. 2002).

However, recent studies also suggest some low-head structures may provide some ecological benefit to freshwater communities. Freshwater mussel assemblages are most abundant and diverse, and exhibit increased growth and juvenile survivorship immediately downstream of intact low-head dams compared to reaches upstream (Singer and Gangloff 2011, Gangloff et al. 2011, Hoch 2012, McCormick 2012). Helms et al. (2011) documented higher fish assemblage diversity immediately downstream of breached low-head dams than at upstream sites, and a study in North Carolina documented increased abundances of invasive sunfishes in streams with breached dams (Thoni et al. in press). Further, although dams serve as barriers to migratory fish, they may also prevent range expansion of invasive species. Flathead catfish, *Pylodictus olivaris*, have been introduced in Atlantic Slope drainages and these large, piscivorous fish may detrimentally impact native fisheries (Thomas 1995). Small dams may restrict flathead catfish range expansion to upstream reaches (Brown et al. 2005, Walker et al. in review), thereby protecting native fish species.

Land use and land cover (LULC) have dramatic and widespread effects on stream habitats and biota (Paul and Meyer 2001, Allan 2004, Helms et al. 2009). Urban areas are often characterized by a high degree of impervious surfaces, which increase stream flashiness and allows increased runoff containing pollutants to enter streams (Schoonover et al. 2006). Many intolerant species have narrow thresholds for coping with influxes of toxicants associated with urbanization. Helms et al. (2009) found a significant negative correlation between impervious surface cover and fish diversity (Shannon H'), species richness, and the percentage of fish that were characterized as benthic (i.e., rock-gravel) spawners. Agricultural land use may lead to elevated levels of fine sediments and other pollutants, decreased riparian canopy cover, and increased stream temperatures (Walser and Bart 1999, Paul and Meyer 2001, Allan 2004). Sedimentation reduced abundance of many pollution sensitive stream fishes as they require specific substrates for spawning. As a result, streams draining agricultural lands may have decreased fish diversity compared to forested reaches (Walser and Bart 1999).

Because watershed disturbance impacts to streams are cumulative, streams and stream organisms may be influenced by perturbations at multiple scales. While broader scale landscape disturbances certainly impact streams, other studies have documented more profound effects of land cover change at scales proximal to study reaches (Jones et al. 1999, Hopkins 2009, Hopkins and Burr 2009). The patch sizes of cleared land in riparian areas may reduce native fish taxa richness and increase prevalence of tolerant and invasive species (Jones et al. 1999). While overall watershed land use and geologic type exert influences, riparian and subcatcment scale land covers exerted the most influence on predicting presence or absence of threatened fish species in Kentucky (Hopkins and Burr 2009).

Interactions between dam status and LULC disturbance have been relatively understudied. Although Fairchild and Valinsky (2006) documented improved water quality downstream of impoundments in high disturbance systems fragmented by dams, no study to date has investigated interactions between landscape disturbance and dam status on stream fish assemblages.

Because dam removal is becoming an increasingly popular means of stream restoration, managers should consider recent research documenting potential net positive benefits of small dams on water quality and stream communities. Further, because landscape disturbance and dams are so prevalent, more quantitative research regarding the effects of interactions between disturbed landscapes and dam status on streams is needed for informed decision making. The objective of this study was to quantify effects on fish communities of LULC and dam status at three spatial scales in North Carolina Atlantic Slope streams and provide resource managers (e.g. USFWS, NCWRC) and regulatory agencies (e.g., USACOE, FERC) with prioritization criteria for more informed decision making.

Materials and Methods

Study Area

Our study sites were located primarily in the upper Atlantic Coastal Plain along the fall-line and throughout the Piedmont of eastern North Carolina in the Tar, Neuse, and Roanoke basins (Fig. 1). Streams in these basins harbor diverse faunal assemblages including approximately 122 fish species, including 12 species with listings of state or federal concern (NC Natural Heritage Program 2012, NC Division of Water Quality 2013).

Fish and Habitat Data

Detailed fish and habitat collection methods were obtained from Holcomb (2013). Fish and habitat were sampled at three 150 m study sites located upstream of the impoundment, immediately downstream, and >650 m downstream of 25 dams in varying states of functionality (9 intact, 9 breached, 7 relict, *n* = 75 reaches). Fish metrics included in analyses were : diversity (Shannon's H'), species richness, fish abundance, percentage of abundance and species richness of tolerant and intolerant fish, and percentages of fish that are rock-gravel benthic, sand-gravel benthic, mud-silt benthic, generalist benthic (polyphilic), crevice (all speleophilic), and vegetation (phytophilic) spawners. We obtained spawning guild data primarily from FishTraits Database (Frimpong and Angermeier 2009), but supplemented some problematic species with other literature (Johnston and Paige 1992, Jenkins and Burkhead 1993). Habitat metrics included percentage of fine and coarse substrates. Fine substrates included sand, silt, and clay, and coarse substrates included measureable lithic particles and bedrock.

GIS Analyses

All analyses were performed in ArcMap10 (ESRI 2011). One-third arcsecond (~10m) Digital Elevation Models (DEMs) covering all study watersheds were obtained from the National Elevation Dataset (USGS 2005) and mosaicked in ArcMap. We used ArcHydro tools and the AGREE method to delineate watersheds for the downstream most extent of each study site. We reconditioned DEM's with National Hydrography Dataset stream data (USGS 2007). To address LULC effects from multiple spatial scales, we also generated watersheds draining only into the 650 m reach (reach catchment) above sampling sites (Fig. 2). We chose 650 m because this was the average distance separating most study sites associated with respective dams and because of the cumulative nature of LULC effects on streams, we wanted catchment scale data unique to each site. Streams were clipped by the reach catchment watersheds and buffered by 100 m to obtain reach scale riparian data (Fig. 2). Entire study site watersheds, reach catchment watersheds, and riparian areas were then used to extract 2006 National Landcover Dataset data (Fry et al. 2011). Landscape composition metrics obtained from NLCD 2006 data included percentages of : open water; residential; low, medium, and high intensity urban; barren land; deciduous, mixed, and evergreen forest; shrub/scrublands; open land; pasture/hay and row-crop agriculture (combined into total agriculture); wetland areas. Percentages of all urban, residential, barren land, and total agriculture were combined to obtain total disturbed land area. For analyses, based on total LULC disturbance, we rated each scale (watershed, reach catchment, riparian) as high, intermediate, or low disturbance by identifying the 25 most, least, and intermediate disturbed study reaches, respectively. From this point on, we will refer to watershed, reach catchment, and riparian or local scale disturbance as WSD, RSD, and LSD, respectively.

Statistical Analyses

We performed all statistics in SPSS v.20 (IBM 2011). Differences in river basin total disturbed land, disturbance levels at each scale, and total disturbance between scales were assessed using multivariate General Linear Models (GLM). Additionally, we used discriminant function analysis (DFA) with a "one left out" cross validation approach on all %LULC metrics except for the composite total variables to classify high, intermediate and low disturbance levels at each scale. We used multivariate GLMs to identify effects and interactions of LULC disturbance level and dam status on fish and habitat metrics at each scale respectively. We further investigated significant interactions of dam status within disturbance level using univariate GLMs split by LULC disturbance level.

Results

DFA correctly classified 86.7% of LSD levels (X^2 = 7.98, *df* = 4, $p = 0.092$), 89.3% of RSD levels (X^2 = 11.52, *df* = 5, $p = 0.042$), and 92.0% of WSD levels (X^2 =50.99, *df* =6, $p < 0.001$). Overall, WSD and RSD level were not different ($p = 0.890$), but LSD zones had significantly lower percentages of disturbance than did RSD ($p < 0.001$) and WSD ($p < 0.001$) scales. All WSD, RSD, and LSD levels were significantly different from one another ($p \leq 0.001$). The primary disturbance at all scales was agricultural (pasture/hay and row-crop) and to a lesser extent urban land cover (Table 1). All drainages were significantly different in terms of land use disturbance ($p < 0.001$), but there was not a significant interaction between drainage and disturbance level at any scale. Interestingly, there was no effect of WSD level or interaction of dam status and disturbance level at any scale with basic fish metrics (diversity, fish abundance, species richness).

Watershed Scale Disturbance

Study sites with high WSD contained significantly smaller percentages of coarse substrates than reaches with low WSD ($p = 0.005$). Percentage of fine substrates were significantly lower in study reaches with low WSD when compared to intermediate ($p = 0.024$) and high ($p = 0.011$) disturbance watersheds.

The overall model identified marginally significant effects of WSD on percentages of tolerant ($p = 0.055$) and intolerant ($p = 0.057$) fishes. Further investigation revealed study sites in low WSD contained significantly smaller percentages of tolerant fishes than sites with high WSD (*p* = 0.018). Reaches with high WSD had marginally smaller percentages of intolerant fish than intermediate WSD (*p* = 0.055). Additionally, study sites with high WSD contained significantly smaller percentages of intolerant fish species than sites with low (*p* = 0.001) and intermediate (*p* = 0.013) WSD.

Sites with low WSD supported greater numbers of rock-gravel benthic spawners than sites with intermediate (*p* < 0.001) and high (*p* = 0.001) WSD. Reaches with high WSD contained significantly greater percentages of vegetation spawners than reaches with low (*p* = 0.029) and intermediate (*p* = 0.006) WSD. Reaches with intermediate WSD contained significantly fewer substrate generalist spawners than reaches with low (*p* = 0.002) and high (*p* = 0.003) WSD.

Watershed Disturbance and Dam Status Interactions

At high WSD, sites associated with intact dams had significantly smaller percentages of fine substrates than relict dams (Fig. 4). At low WSD, sites associated with relict dams contained significantly smaller percentages of tolerant species than breached (*p* = 0.001) and intact (*p* = 0.015) dams. Similarly, at intermediate WSD, sites associated with relict dams had significantly smaller percentages of tolerant fish than sites associated with breached (*p* = 0.011) and intact (*p* = 0.043) dams. At low WSD, sites associated with breached dams supported significantly lower percentages of intolerant species than sites associated with relict (*p* < 0.001) and intact (*p* < 0.001) dams. Similarly, at low WSD, sites associated with intact dams contained significantly greater percentages of intolerant fish than sites associated with relict (*p* = 0.016) and breached (*p* < 0.001) dams (Fig. 3). Sites associated with relict dams in low WSD levels supported greater percentages of intolerant fish than sites around breached dams (*p* = 0.006; Fig. 3).

At low and intermediate WSD, sites associated with relict dams supported significantly greater percentages of rock-gravel benthic spawners than sites around breached (low: *p* < 0.001; intermediate *p* = 0.005) and intact dams (low: *p* = 0.011; intermediate: *p* = 0.027; Fig. 3). Additionally, at low WSD, sites associated with intact dams had significantly greater percentages of rock-gravel benthic spawners than breached dams (*p* = 0.045; Fig. 3). A marginally significant interaction between dams status and WSD (*p* = 0.051) revealed that at low WSD, sites associated with breached dams had lower percentages of substrate generalist spawners than sites around intact (*p* = 0.003) and relict (*p* = 0.063) dams. A marginally significant effect of dam status on substrate generalist spawners at intermediate WSD (*p* = 0.052) revealed sites associated with relict dams have greater percentages of substrate generalist spawners than sites around breached dams (*p* = 0.016). At high WSD, sites associated with breached dams supported significantly greater percentages of crevice spawners than sites around relict (*p* = 0.002) and intact (*p* = 0.048) dams.

Reach Scale Disturbance

Study sites with high RSD contained significantly greater percentages of tolerant fishes than study reaches with low (*p* = 0.006) and marginally greater than sites in intermediate (*p* = 0.060) RSD levels. Study sites with high disturbance reach catchments supported significantly greater percentages of vegetation spawners than sites with low (*p* = 0.010) and intermediate (*p* = 0.016) RSD. Study sites with intermediate RSD contained significantly greater percentages of mud-silt benthic spawners than sites with high RSD (*p* = 0.024). Low RSD sites had significantly greater percentages of rock-gravel benthic spawners than sites with intermediate (*p* = 0.043) and high (*p* < 0.001) RSD, and sites with high RSD contained significantly fewer rock-gravel spawners than sites with intermediate RSD (*p* = 0.035). Sites with low RSD supported significantly fewer sand-gravel spawners than sites with intermediate (*p* = 0.049) and high (*p* = 0.005) RSD.

<u>Reach Scale Disturbance and Dam Status Interactions</u>

Analyses revealed several significant interactions between RSD and dam status. At low RSD, sites associated with relict dams have significantly lower percentages of tolerant fish species than sites around breached dams (*p* = 0.008) and marginally lower than sites associated with intact dams (*p* = 0.071). At low and intermediate RSD, sites associated with breached dams had significantly lower percentages of intolerant fish than sites associated with relict (low: *p* = 0.001; intermediate: *p* = 0.017) and intact (low: *p* = 0.001; intermediate: *p* < 0.001; Fig. 3) dams. Similarly, at low and intermediate RSD, sites associated with breached dams contained significantly lower percentages of intolerant fish species than sites associated with relict (low: *p* = 0.021; intermediate: *p* = 0.005) and intact (low: *p* = 0.002; intermediate: *p* = 0.001) dams.

At high RSD, sites associated with intact dams supported significantly greater percentages of vegetation spawners than sites around with breached dams (*p* = 0.016). At low RSD, sites associated with intact dams contained significantly lower percentages of crevice spawners than sites around breached (*p* = 0.037) and relict (*p* = 0.007) dams. In high RSD levels, sites associated with intact dams supported significantly larger percentages of vegetation spawners than sites associated with breached dams (*p* = 0.016) and greater percentages of mud-silt benthic spawners than sites associated with breached (*p* = 0.047) and relict (*p* = 0.017) dams. However, at low RSD, sites associated with relict dams had significantly greater percentages of mud-silt benthic spawners than sites associated with intact (*p* = 0.031) and breached (*p* = 0.028) dams. At intermediate RSD, sites associated with intact dams contained significantly greater percentages of sand-gravel benthic spawners than sites around breached dams (*p* = 0.006). At low RSD levels, a marginal interaction between dam status and RSD (*p* = 0.082) revealed sites associated with breached dams contained significantly lower percentages of rock-gravel benthic spawners than sites around relict (*p* = 0.005; Fig. 3) dams.

Local Scale Disturbance

Analyses revealed only that low LSD areas had significantly lower percentages of tolerant fish than high (*p* = 0.004) and intermediate (*p* = 0.009) LSD sites.

Local Scale Disturbance and Dam Status Interactions

A marginally significant interaction between low LSD and dam status (*p* = 0.054) revealed sites associated with breached dams contained significantly higher percentages of tolerant fish than relict dams (*p* = 0.020). At intermediate LSD, sites associated with relict dams supported significantly lower percentages of tolerant fish than sites around breached (*p* = 0.005) and intact (*p* = 0.032) dams.

Discussion

WSD and RSD level had the greatest impact on fish communities. At both spatial scales, low disturbance sites supported more diverse fish assemblages with greater numbers of intolerant fish and fish species as well as fewer tolerant fish and tolerant fish species. Additionally, highly disturbed reach catchments and watersheds had greater numbers of vegetation spawners. Surprisingly, riparian disturbance level had little impact on fish communities. In study sites with low LSD, however, there were fewer tolerant fish than in sites at intermediate or high LSD.

Breached dams had fewer intolerant fish, intolerant fish species, and polyphilic spawners than relict and intact dams; however, there were many significant interactions with LULC disturbance level and dam status. At low WSD and RSD levels, breached dams contained fewer intolerant fish and intolerant fish species. At high WSD, sites associated with intact dams supported greater numbers of vegetation spawners than breached or relict dams. At high RSD, sites associated with breached dams had greater percentages of crevice spawners than sites associated with intact or relict dams. At low and intermediate RSD, sites associated with breached dams contained fewer rock-gravel benthic spawners in than sites around intact and relict dams.

Effects of Disturbance Level and Spatial Scale

We observed a negative effect of high disturbance level across all spatial scales on habitat and fish community assemblages. At high WSD, study sites contained fewer coarse particles and higher percentages of fine substrates than sites at low or intermediate WSD. Substrate effects were not observed at the reach or riparian zone scales. At the watershed scale, the cumulative effects of urban and agricultural LULC may exert greater effects on habitat parameters than do more proximal LULC perturbations (Allan 2004); however, this localized habitat degradation can be seen in the fish community response, as study sites with low WSD contained fewer tolerant fish and more intolerant fish species than study sites in high disturbance watersheds. Habitat degradation associated with deforestation (e.g., increased sedimentation, temperature and nutrients) in high disturbance watersheds may explain reduced intolerant and elevated tolerant fish abundance (Walser and Bart 1999, Schoonover et al. 2006, Helms et al. 2009, Hopkins and Burr 2009). Similar trends were observed both at the reach and riparian scales, with low disturbance sites containing greater numbers of intolerant fish and species as well as fewer tolerant fish compared to intermediate and high disturbance levels. Further, effects of habitat disturbance can be seen across most spawning guilds as sites at high WSD and RSD contained smaller percentages of rock-gravel benthic spawners and increased vegetation spawners than did sites in low and intermediate WSD and RSD catchments. The increase in vegetation spawners may be due to increased nutrient loading associated with agricultural land conversion promoting increased growth of aquatic macrophytes.

Surprisingly, LSD had only minimal impact on fish communities. This may be due to the fact that the majority of study sites were selected because they had intact riparian zones. The overall mean percentage riparian disturbance was 18.4%, which was significantly lower than disturbance measured at watershed (41.7%) and reach (42.0%) scales. Previous studies have documented the importance of intact riparian zones to aquatic communities, but effects occurred when riparian areas were much more (i.e., >30%) disturbed (Jones et al. 1999, Poole and Downing 2004, Hopkins 2009, Hopkins and Burr 2009).

Disturbance Level and Dam Status

Significant interactions between dam status and disturbance level occurred only at low and intermediate disturbance levels. However, in high WSD, sites associated with intact dams had significantly reduced fine substrates compared to sites around relict dams. Impoundments created by dams have been shown to trap sediments, starving downstream reaches of sediment (Hauer et al. 1989). Because these structures are epilimnetic (i.e., surface release), the streambed immediately downstream of the structure may become scoured and sediment starved (Poff et al. 1997). In highly disturbed watersheds, small impoundments may trap excess sediments and nutrients associated with runoff from land cover disturbance (Fairchild and Valinsky 2006). Also at high WSD, sites associated with breached dams have greater abundances of crevice spawners than sites associated with relict and intact dams. Increased LULC disturbance in conjunction with disturbance from dam breaching may result in habitats more conducive to fishes that exploit crevices and bank cavities than species relegated to spawning on coarser lithic substrates.

At low and intermediate WSD and RSD, breached dams seem to exert the most negative influences on fish communities. In these streams, sites associated with breached dams had fewer intolerant fish, intolerant fish species, and more tolerant fish than sites around relict and intact dams. Effects on spawning guilds were more equivocal, as sites associated with breached dams in low RSD levels had lower percentages of substrate generalist spawners (e.g. Centrarchidae) than sites around relict or intact dams and at low RSD, sites around relict dams had greater percentages of mud-silt benthic spawners than sites associated with breached and intact dams. However, in low and intermediate RSD catchments, sites associated with breached dams had significantly lower percentages of rock-gravel benthic spawners than sites around relict and intact dams. The overall net negative effect of breached dams is likely due to degraded habitat associated with breaching and legacy effects of these structures. Breached dams have been shown to negatively impact stream communities (Gangloff et al. 2011, Thoni et al. in press, Holcomb in prep.). Contraction scour occurs when the stream is forced through the smaller breach or opening in the dam. This typically leads to excess bank erosion which may exacerbate sediment loading from the former impoundment (Stanley et al. 2002, Doyle et al. 2003). Increased sedimentation likely precludes intolerant fishes including rock-gravel benthic spawners from maintaining high abundances. The effects of breached dams were not observed in more disturbaned catchments because effects of sedimentation and water quality impairment resulting from highly agrarian or urbanized land use practices may overwhelm any habitat buffering abilities of breached dams.

Conclusions and Implications

In this study, WSD and RSD exerted the strongest effects on fish communities. Little effect of LSD was observed, most likely due to low LSD levels across sites. Because intact dams had a relatively minor impact on fish assemblages compared to breached dams, and because study sites had fewer fine substrates even in highly disturbed watersheds, it may be desirable to maintain, not remove small dams in highly degraded watersheds. Breached dams had a net negative impact on stream fish communities in low and intermediate disturbance watershed and reach catchments, and thus, may warrant higher removal priorities than intact dams in these instances. Because this and other studies have documented minimal to potential beneficial impacts of intact dams to stream communities (Fairchild and Valinsky 2006, Jackson and Pringle 2010, Hoch 2012, McCormick 2012, Holcomb in prep.), we urge managers tasked with prioritizing stream restoration projects to utilize a holistic approach on a case by case basis, considering potential benefits of retaining intact low-head dams, especially in highly degraded landscapes.

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Tables and Figures

Tables

Table 1. Means and standard deviations (SD) of agriculture, urban, and total disturbed LULC classes at WSD, RSD, and LSD scales for all sites (Overall), intact, relict, and breached dams.

	Overall		**Intact**		**Relict**		**Breached**	
LULC and Disturbance Level	Mean	SD	Mean	SD	Mean	SD	Mean	SD
WSD High % AG	42.55	4.95	42.26	4.24	44.78	3.51	40.78	6.78
WSD High % Urb	9.64	2.65	9.41	2.21	8.66	1.07	10.97	2.84
WSD High %Total Disturbed	53.84	3.08	53.30	2.79	55.06	2.91	53.48	3.74
WSD Low % Ag	23.23	2.58	22.01	3.61	24.07	1.69	24.04	0.56
WSD Low % Urb	4.60	1.07	4.75	0.53	4.56	0.11	4.47	1.75
WSD Low % Total Disturbed	29.78	2.53	28.97	3.33	29.58	1.51	30.81	1.82
WSD Intermed. %Ag	31.97	3.50	29.04	4.04	32.09	3.44	33.47	2.32
WSD Intermed. %Urb	7.01	2.50	7.26	2.99	8.66	1.31	5.67	2.27
WSD Intermed. %Total Disturbed	41.38	3.90	39.06	4.46	43.10	3.74	41.39	3.34
RSD High %Ag	48.58	10.69	49.89	11.18	44.82	9.68	49.15	11.30
RSD High %Urb	15.03	14.06	15.36	14.49	26.55	18.42	8.94	7.20
RSD High %Total Disturbed	65.80	11.28	67.91	13.29	72.50	10.97	60.33	6.82
RSD Low %Ag	12.38	7.31	13.21	7.58	11.22	7.65	12.53	7.48
RSD Low %Urb	4.83	5.68	3.62	4.32	7.67	8.29	3.30	2.24
RSD Low % Total Disturbed	19.97	8.12	20.81	8.86	21.39	7.84	17.16	7.83
RSD Intermed %Ag	29.78	6.90	27.81	8.02	31.64	7.28	29.68	6.07
RSD Intermed %Urb	8.03	5.57	7.33	7.92	8.56	4.93	8.09	4.62
RSD Intermed. %Total Disturbed	40.32	5.67	37.42	4.26	41.70	6.51	41.26	5.61
LSD High %Ag	27.49	10.75	24.55	7.03	23.78	5.12	33.30	14.77
LSD High %Urb	6.65	9.92	3.91	4.06	9.91	15.54	6.84	8.93
LSD High %Total Disturbed	36.57	10.70	31.75	6.28	34.17	10.75	43.27	11.66
LSD Low %Ag	1.11	2.18	1.26	2.82	0.51	1.25	0.94	2.17
LSD Low %Urb	1.36	2.01	1.22	2.45	1.17	1.90	1.50	1.96
LSD Low % Total Disturbed	3.33	2.46	3.66	2.81	3.40	1.89	2.98	2.63
LSD Intermed. %Ag	9.09	6.42	8.23	6.07	11.16	7.48	7.91	6.00
LSD Intermed. %Urb	3.44	4.12	3.66	4.72	2.60	4.40	4.13	2.82
LSD Intermed. %Total Disturbed	15.29	5.37	14.20	5.69	17.25	4.75	14.67	5.73

Figures

Figure 1. Map of study sites in the Tar, Roanoke, and Neuse river basins NC. Diamonds represent relict dams; triangles represent breached dams; triangles represent intact dams.

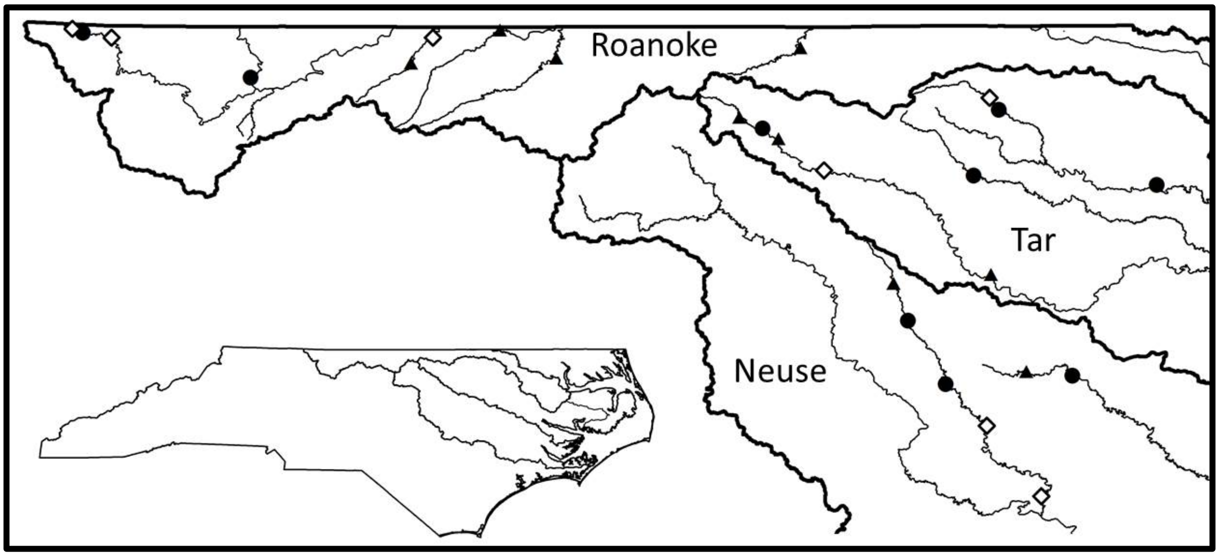


Fig. 2. Schematic of land use scales evaluated. Crosshatched area represents the watershed; gray area represents the reach catchment; open area represents the riparian zone.

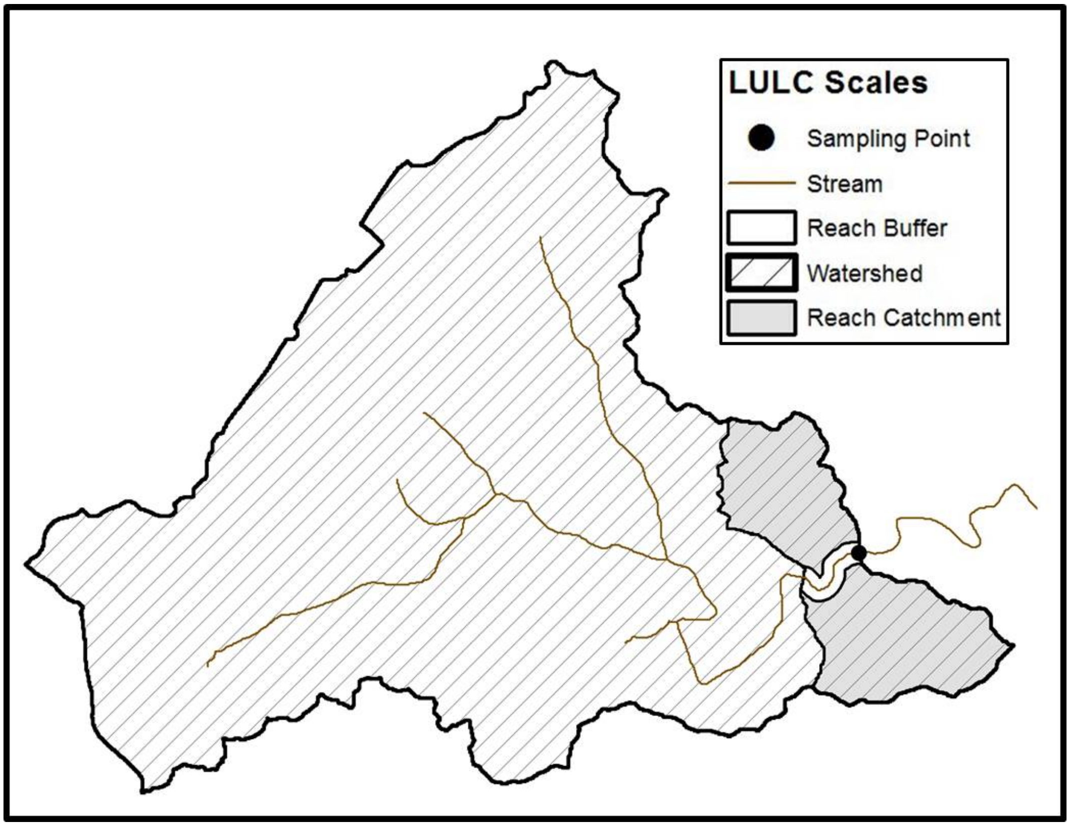


Figure 3. Bar graphs representing effects of LULC disturbance level at watershed, reach catchment, and riparian scales and dam status on the percentage of intolerant fish (panels A-C) and rock-gravel spawning fish (panels D-F). Error bars represent standard error; Letters denote significant differences (Tukey's LSD); NSD denotes no significant data.

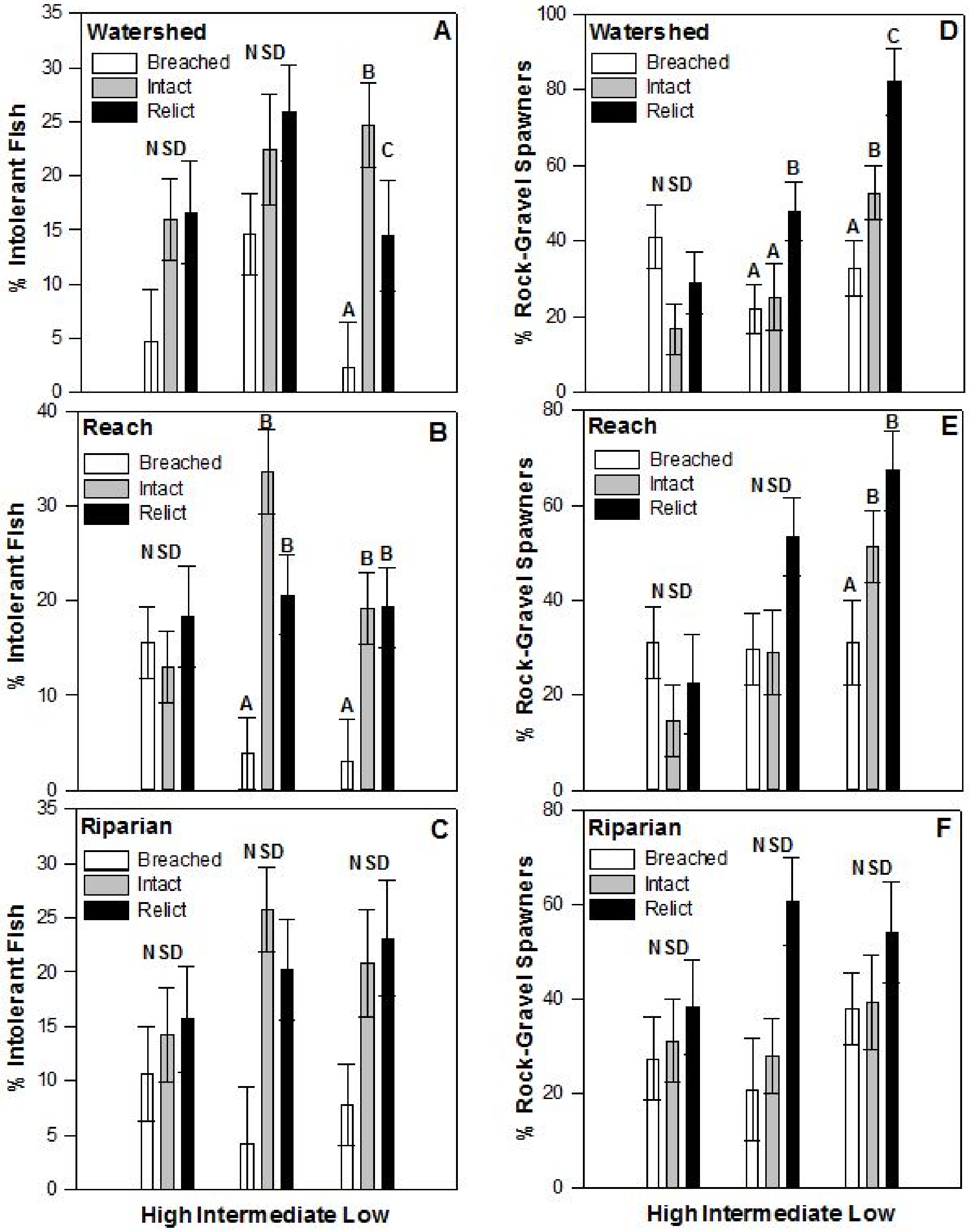
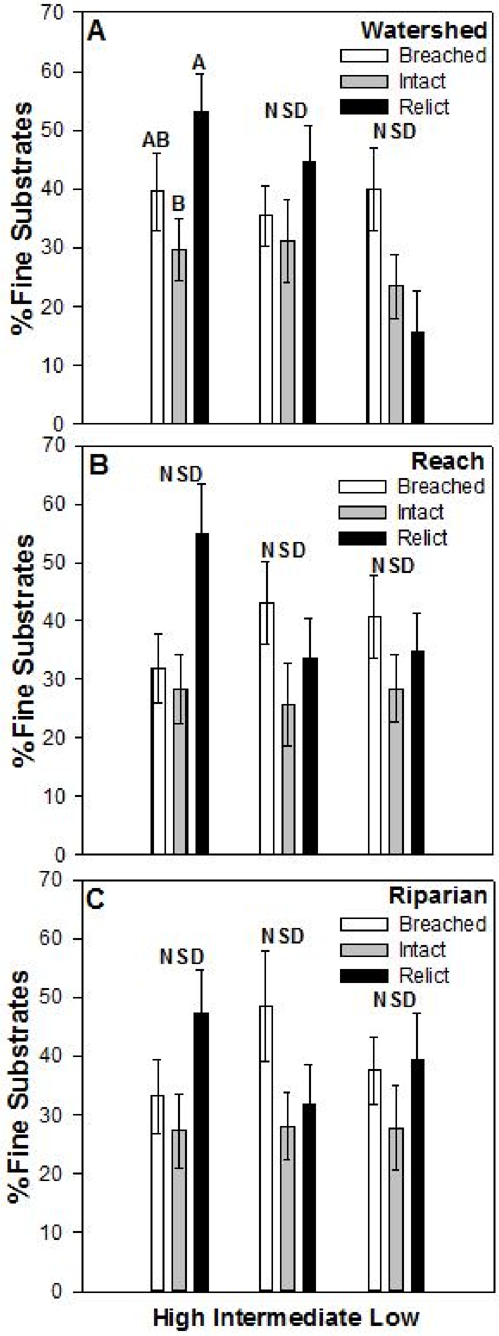


Figure 4. Bar graphs representing effects of LULC disturbance level at watershed, reach catchment, and riparian scales and dam status on the percentage of fine substrates. Bars represent standard error; letter denote significant differences (Tukey's LSD); NSD denotes no significant data.



Vita

Jordan Holcomb was born to Mark and Beth Holcomb 1988 in East Bend, NC. Jordan attended schools and grew up in East Bend, NC, graduating from Forbush High School in 2006. His passion for aquatic biology stemmed from many days spent fishing on the nearby Yadkin River. He graduated with a Bachelor's of Science degree in Environmental Biology at Appalachian State University in 2010 and started a master's program January of 2011 also at Appalachian State. The Master of Science degree was awarded in August 2013.