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Effects of Changes in Land Use on Fish Assemblages in the French Broad River Basin, North Carolina

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Abstract

Human land use has been well documented as an influencing factor in riverine systems, impairing the chemical, hydrological and biotic properties of streams (Warren et al. 2000). This study quantified fish assemblages within 15 different tributaries of the upper French Broad River basin, previously sampled by the USGS in 1997. Fish assemblages were determined to be related to changing land use through a correlation analysis comparing changes in fish metrics since 1997 and land use change over a nine year period. Fish metrics were found to be most significantly affected by increasing high intensity development (>80% impervious surface), characterized by a significant positive correlation with the relative abundance in tolerant species and a negative significant correlation with that of intolerant species. Additionally, it was found that herbivorous species were positively correlated with an increase in grass/herbaceous land, likely stemming from the land's recent agricultural influences promoting algal growth and providing a food resource for populations of the basin's primary herbivore, *Campostoma anomalum*. The findings of this study provide an example of the importance of environmental indicators, such as fish metrics, for identifying effects of anthropogenic land disturbance. The identified relationships between these biological characteristics in streams and land use change can contribute to future land management's ability to mitigate the inevitable effects on streams, followed by biological alterations, in the face of increasing urbanization.

1. Introduction

Humans affect the quality and quantity of the earth's fresh water in various ways (Anderson et al. 2012). As the global human population grows rapidly, it also is becoming denser and by 2030, it is estimated that the global composition of people living in urban centers will rise by 10%, creating an increasing need to convert forests and wetlands into various types of development and agriculture (Paul and Meyer 2001). As a result, throughout the world intact freshwater ecosystems are becoming increasingly scarce (Abell et al. 2007). Streams and rivers are affected by human activities that threaten freshwater ecosystems and their natural hydrologic, chemical and biotic functioning (Paukert et al. 2011). In the United States, these threats, which become more severe as human development expands and concentrates (Clapcott et al. 2012), have led to a significant decline in freshwater species causing the imperilment, presumed imperilment, vulnerability or extinction of 68% of all mussel species, 46% of fresh water fish species, 51% of crayfish species, and 40% of salamander species (Masters et al. 1998 and Jelks et al 2008). Forty two percent of the country's wadeable streams are reported to be in poor condition, with 67% being "less than good" in terms of environmental health (Paulsen et al. 2008). Human's upstream land use has been well demonstrated as an influencing factor in riverine systems, contributing to the alteration and impairment of chemical, hydrological and biotic properties of streams (Warren et al. 2000). The US Environmental Protection Agency (EPA) states that the type of human land use within a watershed has significant effects on the structure and function of the aquatic community in stream ecosystems and without proper management, biotic assemblages within streams can experience a decrease in biological integrity due to human alteration of natural habitats (EPA 2005).

Land use, as defined by the EPA, "represents the economic and cultural activities that are practiced at a place, such as agricultural, residential, industrial, mining, and recreational uses". The EPA reports that agricultural land in the US has decreased by about 14 million acres from 1997 to 2002, while urbanization has increased by 48% from 1982 to 2002, with acres of forested lands remaining relatively constant (EPA 2005). As various anthropogenic processes affect freshwater ecosystems in numerous ways and across multiple spatial and temporal scales (Wang et al. 1998), urbanization has had well documented effects on physical, chemical, and biological properties of freshwater streams and rivers (Clapcott et al. 2012). This link between human development and freshwater habitat alteration and degradation is because streams and their biota are tightly connected to their catchment areas (Hynes 1995). A major characteristic of urbanization is the increase of impervious surface, which increases thermal pollution, nutrient enrichment and sedimentation in streams (Doyle et al. 2000), then affecting biotic communities within them (Paul and Meyer 2001).

Quantifying land cover, and using landscape metrics to describe the amount and the arrangement of human land use within a watershed, acts as a useful indicator for describing the status of the water chemistry, hydrologic properties, and the biotic integrity in freshwater streams and rivers (Gergel et al. 2002). And inversely, the study of biological indicators, such as fish communities, is useful in describing the integrity of entire watersheds, acting as early warning signals of environmental degradation (Karr 1981). In fish assemblages, the Index of Biotic Integrity (IBI), first developed for streams in the mid-western United States, uses fish assemblages to describe environmental conditions. Metrics are used in IBI for grouping fishes useful as particular indicators. These groupings represent different attributes of fish assemblages that are classified into categories of richness and composition, abundance, trophic composition, and health or condition. Each metrics type characterizes a particular influence of human impacts on aspects of the fish assemblage (Raburu et al. 2011). Therefore, because of this inevitable link between a particular catchment area's land use type and the chemical and hydrologic properties of an aquatic environment, which in turn affect the biotic communities, land use can describe fish assemblages and, in turn, fish assemblages can indicate the severity of environmental degradation from human land use (Hynes 1995).

On a smaller scale, a recent article by Kirk (2009), reported that a decline of forested land by 5% and agricultural land by 12% by 2030 is forecast for western North Carolina (WNC) due to urban development. Western North Carolina lies within the southern Appalachian Mountains, a region that hosts the greatest biodiversity in the southeast region of the United States, where fishes alone represent 345 of the region's species (Sutherland et al. 2002). However, fish species of this region are becoming increasingly threatened as jeopardized fish species in the southeastern US have increased by 120% in the past 20 years (Warren et al. 2000).

A previous study concerning land use within WNC by Rashleigh (2004) assessed how fish assemblage differences among sites within the French Broad River's upper tributaries were related to environmental characteristics in 1997. Rashleigh's study also quantified the change in metrics of the fish populations due to known environmental gradients, including land use type. The study found that land use within a watershed, whether agriculture, urban, or forested, had an influence on the characteristics of fish assemblages. Additionally, urban land use resulted in an increase in particular native and non-native species and an overall decline in piscivorous fishes, while land use in the form of agriculture caused a shift in trophic guilds, from specialized insectivores to generalist insectivores and herbivores.

This study 's objective is to quantify the change in land use in the French Broad watershed since Rashleigh's (2004) study to determine whether a shift in land use practices from 1997-2006 has had an effect on the fish assemblage metrics. In the presence of developing and changing landscapes within the United States (EPA 2005), our study allows the comparison of a quantifiable environmental characteristic (land use type) and fish assemblage metrics to determine whether a shift in terrestrial habitat has had an effect on the present day fish communities within the upper French Broad's tributaries.

2. Materials and Methods

2.1 Description of Study Area

The French Broad River (FBR) basin comprises nearly 3,000 square miles of western North Carolina. This region, which composes about 11% of the entire state, is home to over 4,000 miles of streams (NCSU WQP 2006). The FBR originates near the North Carolina-South Carolina state line. It then flows north, crossing the Appalachian divide and eventually becoming the largest tributary of the Tennessee River (Omernick 1987). As of 1997, within the basin there was 70% forested land, 21% agricultural land, and urban land use comprised roughly 9%, being mostly concentrated around the city of Asheville (Rashleigh 2004).

Currently, water quality in most of the French Broad River basin is good. However, as of 1998 11% was in poor condition due to agriculture runoff, urban runoff, and construction, as well as fecal coliform bacteria and toxic substances (NCSU WQP 2006). Historically the water quality in the region has varied greatly. The Tennessee Valley Authority (TVA) reported in the 1940s that the textile and the tannery industry within the region had led to severe impairment of the basin's water quality. Also at the time**,** the TVA reported that bacterial contamination was a significant problem due to the municipal systems discharging raw sewage into streams without treatment (TVA 1945). But throughout the 1950s and 60s industry's technological advancements in pollution control and newly developed water treatment systems allowed the French Broad River basin's water quality to improve dramatically despite population growth (North Carolina Department of Environment and Natural Resources, 1998).

This study was conducted between May and July, 2012, at 15 sites (Table 1) within the upper French Broad River basin previously sampled by the National Water Quality Assessment (NAWQA) Program in 1997.

Table 1. fifteen study sites within the upper French Broad River basin

Big Laurel Creek near Stackhouse, NC	Little River near Little River, NC
Cane Creek at US 25 at Fletcher, NC	Mills River at Mills River, NC
Davidson River at Brevard, NC	Mud Creek at Naples, NC
Flat Creek near Weaverville, NC	Newfound Creek near Alexander, NC
French Broad River at Rosman, NC	Reems Creek near Weaverville, NC
Hominy Creek near W. Asheville, NC	Sandymush Creek near Volga, NC
Ivy River at Marshall, NC	Spring Creek near Hot Springs Spring, NC
	Swannanoa River near Biltmore Village, NC

2.3 Fish Community Sampling

All samples were collected using a single pass backpack electrofisher technique, while using a seine for deep pools or areas of difficult access, in accordance with the NAWQA Program protocol for backpack electrofishing and seining (Meador et al., 1993). Sample area at each site was determined by measuring stream width. The length of the stream sampled was determined by multiplying the stream's width by 20. Each site included at least two riffles and two pools. The electrofisher sampled from downstream to upstream, zig-zagging as to include all microhabitats within the sampling area. All fish collected in processes of sampling were contained in a bucket until the end of the single pass. All fish were then identified in the field.

2.4 Analysis

After being identified to species and grouped by family, all fish data of the present study were arranged into nine established fish assemblage metrics in a Microsoft Excel spreadsheet. Metrics chosen were herbivores, omnivores, insectivores, specialized insectivores, piscivores, suckers, and darters. These metrics were quantified by establishing feeding guild and known sucker and darters and using the abundance of each of these to represent a particular metric. Tolerant species and intolerant species metrics were established by determining their relative abundance per sample and calculating their percent composure for each study site. The darter species metric was determined by the darter diversity per site, with the total species metrics representing the species diversity from each of the 15 samples; Once grouped, the nine metrics of the 1997 sampling could be compared to the 2012 sampling.

The National Land Cover Data Base and Geographic Information Systems (GIS) software were used to quantify land use composition from 1997 and 2006 for each watershed. There were 15 land use types, including: open water, open space development, low-intensity development, mid-intensity development, high-intensity development, barren land, deciduous forests, evergreen forests, mixed trees, shrub/scrub, grassland and herbaceous, pasture and hay, cultivation, woody wetlands, and herbaceous wetlands. For each of the watersheds, the percent cover of each land use type was determined for the two time periods.

Table 2. land cover and fish metrics variables removed due to colineaity

Variable Removed	**Positive Correlates**	**Negative Correlates**
Omnivores	Total Species	
Sucker Species	Total Species	Tolerant Species
Barren Land	Grassland & Herbaceous, Herbaceous Wetland, Low, Mid, and High-Intensity Development	Cultivation
Shrub/Scrub	Open space Development, Deciduous Forests, Grassland & Herbaceous	Pasture & Hay, Cultivation
Mixed Trees	Cultivation, Evergreen Forest	Low, Mid and High-Intensity Development
Pasture & hay	Evergreen Forest	Open Space Development, Deciduous Forest
Evergreen Forest		Low-Intensity Development
Herbaceous Wetland	Low, Mid, High- Intensity Development, Barren Land	

The land use types and the fish assemblage metrics were then compared to the 1997 data. By subtracting the 1997 data from 2012's for both land use types and metrics for each watershed, the values for the differences in land use composure and fish metrics between both time periods could be obtained. Positive values represented a decrease in the particular variable from 1997 -2006, while negative value represented an increase. These values were entered into a new Microsoft Excel spreadsheet and the transferred into SAS (Statistical Analysis System) to test for colinearity between the different metrics variables and between the different land use types. All collinear variables (Table 2) were eliminated from the correlation analysis. When two variables were found to be collinear, the one most relevant to the study was chosen for analysis (e.g. sucker species and total species were collinear, total species was kept for analysis because the variable was more relevant to the study). With all nonlinear variables, a Pearson's coefficient was used to test for significant correlations between changes in both land use and fish metric variables, and any tests with a p-value less than 0.05 were considered to indicate significant correlation.

3. Results

In the 2012 study there were 1,770 fish collected, for a total of 38 species (Table 3) representing eight families. Of the 38, 5 species were introduced: fatlips minnow, redbreast sunfish, brown trout, rainbow trout, and the flat bullhead. *Cyprinidae* (minnows) represented the majority of the fish collected at 960 individuals and15 out of the total 38 species. This was similar to the USGS collection where *Cyprinidae* represented 18 out of the 38 total species. Our study found *Percidae* (perches) as the second most diverse family having 8 species, followed by *Centrarchidae* (sunfish) which had 7. Number of species collected in 2012 varied from 8 species at Reems Creek near Weaverville, NC to 22 at the FBR at Rosman, NC.

Table 3. fish data grouped by family with feeding guild and tolerance for known tolerant or intolerant species

Family	Common Name (* Introduced Species)	Feeding Guild	Tolerance
Petromyzontidae	Mountain Brook Lamprey	Herbivore	
Cyprinidae	Central Stoneroller	Herbivore	
	Warpaint Shiner	Specialized Insectivore	
	Whitetail Shiner	Insectivore	
	River Chub	Omnivore	
	Bigeye Chub	Specialized Insectivore	
	Tennessee Shiner	Specialized Insectivore	
	Silver Shiner	Specialized Insectivore	
	Saffron Shiner	Specialized Insectivore	
	Mirror Shiner	Specialized Insectivore	
	Telescope Shiner	Specialized Insectivore	Intolerant
	Fatlips Minnow*	Specialized Insectivore	
	Creek Chub	Insectivore	Tolerant
	Blacknose Dace	Insectivore	
	Longnose Dace	Specialized Insectivore	
Catosomidae	White Sucker	Omnivore	Tolerant
	Northern Hog Sucker	Insectivore	
	Redhorse	Insectivore	Intolerant
Ictaluridae	Flat Bullhead*	Insectivore	
Salmonidae	Brown Trout	Insectivore	
	Rainbow Trout*	Insectivore	
	Brook Trout	Insectivore	
Cotidae	Mottles Sculpin	Insectivore	
Centrarchidae	Redbreast Sunfish *	Insectivore	
	Green Sunfish	Insectivore	Tolerant
	Bluegill	Insectivore	
	Rock Bass	Piscivore	Intolerant
	Smallmouth Bass	Piscivore	
	Spotted Bass	Piscivore	
	Largemouth Bass	Piscivore	
Percidae	Gilt Darter	Specialized Insectivore	Intolerant
	Greenside Darter	Specialized Insectivore	
	Greenfin Darter	Specialized Insectivore	
	Fantail Darter	Specialized Insectivore	Intolerant
	Redline Darter	Specialized Insectivore	
	Swannanoa Darter	Specialized Insectivore	
	Banded Darter	Specialized Insectivore	
	Log Perch	Specialized Insectivore	

The land use data showed that deciduous forests witnessed the greatest mean change from 1997-2006 in the 15 watersheds. An average loss in deciduous forests by 10.9 % was found, with no watersheds having an increase in deciduous forests; the highest was in the Big Laurel watershed with a 21% decrease. Other notable mean changes for all watersheds included mixed trees having an average increase of 6.5 % cover, shrubs/scrub land witnessed an increase of 2.9 %, and evergreens an average increase of 2.4 %. Agricultural land showed an overall decline. Mills River and Little River were the only two site that showed an increase in pasture and hay or cultivation land use, while all other sites showed a decrease in both. Most significant agricultural land loss was the Newfound Creek watershed, with a decrease of nearly 10% of its pasture and hay land in the nine year period. All watersheds in the study had an increase in high-intensity development (>80% impervious surface), mid-intensity development (50-79% impervious surface), low-intensity development (20-49% impervious surface), or open space development. However, all but high-intensity development were not used in the analysis due to collinearity.

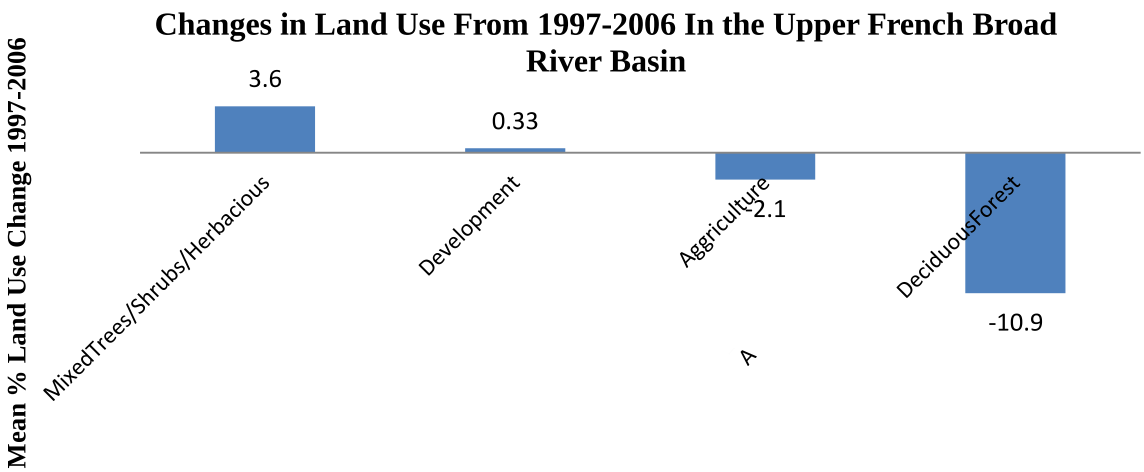

Figure 1. mean change in land use calculated by subtracting 1997 from 2006 % land cover: average of all development types, pasture and cultivation combine to represent agriculture, deciduous forests, and mixed trees, shrubland, and grassland/herbaceous combine representing the early successional states

There were also surprising differences between the 1997 and 2012 data in average fish sample sizes. Our study, which used the same electrofisher protocol and sampled the same sites, collected less than one-fourth as many individuals over the course of sampling the 15 streams, with 1997 collecting over 8,100 individuals and our study just 1,770. Most notably, on average the 2012 study collected 234 fewer individual specialized insectivores at each site. Also, the 2012 study on average collected 60 fewer individual darters per site. However, the average numbers of darter species as well as the total number of species encountered in 1997 and 2012 was relatively close, with total diversity at 46 and 38, respectively.

Table 4. significant correlations, whether negative or positive, between changes in stream quality metrics and changes in land use variables

Metrics Changes	High-Intensity Development Change	Deciduous Forest Change	Grass & Herbaceous Land Change
Herbivore			+
Piscivore		+	
Tolerant	+		
Intolerant	-		

As shown in table 4, the results of the correlation analysis found 7 significant correlations between the changes in land use and the changes in fish metrics. Most notably, there were significant correlations between tolerant and intolerant species and high-intensity development. The tolerant species metric was positively correlated (P-value of

.0091) with increased high-intensity development, while intolerant species was negatively correlated (P-value .0047) with increasing high-intensity development. The change in the herbivore metric showed a positive correlation with the change in grass/herbaceous land (P-value .0449). Also, changes in the piscivorous species metric were positively correlated with the 10.9% decline in deciduous forest, generating a P-value of .0004.

4. Discussion

This study allowed for us to examine and quantify the effects of the upper French Broad River Basin's changing landscape on fish assemblages within 15 streams previously sampled in 1997. Our study's major findings identified significant relationships existing between high-intensity development (>80% impervious surface) and tolerant and intolerant species, herbivores and grassland, and deciduous forests and piscivore species. Due to the changes in land use from 1997-2006 in WNC, with increasing development and decreasing deciduous forests and agricultural lands, this study predicts that fish assemblages will continue to shift in the coming decades due to significant geomorphologic alterations from increasing development (Doyle et al. 2000). As found by Walters et al. (2003), this shift from tolerant specialists to intolerant generalists will promote a decrease in biological integrity in WNC streams, allowing more cosmopolitan taxa- those that are generalists, tolerant and widespread- to better compete against the less tolerant endemic species.

In comparison to the USGS's 1997 fish data, a noticeable difference existed in the sample sizes from each site. Although sampling the same area, at the same time of year, with the generally the same flow conditions and with the same sample methods as our study, the USGS collections included many more individuals, their total individuals from all 15 sites was approximately four times the number that we collected. The vast fewer fish found in our study is likely due to the prevailing trend of freshwater fish abundance decline that has been occurring in the United States since the early 17th century, as European settlers increased in numbers (Vickers 2004). Frontiersmen and Explorers in the early stages of colonization in North America spoke super abundances of fishes in the rivers and streams they encountered (Finney 1984). However, as more lands were colonized requiring fish harvesting for food, devastating stocks of the most economically valuable species, and mill and weir construction that impaired the migratory patterns of fishes in those streams, these super abundances were increasingly reduced (Walter and Merrits 2008). Today, other sources of human activities, such as land use, are contributing to the still declining abundances we see in freshwater streams today (Humphries and Kirk 2009).

As shown in Table 3, there existed a significant negative correlation between increasing high-intensity development land use and intolerant species, while tolerant species showed a positive correlation in the presence of such development. It has been found in previous studies (Harding et al. 1998; Scott and Helfman 2001; Walters et al. 2003) that forested watersheds that undergo little development can generally support higher diversity, as the tolerant species are able to adequately compete with the less tolerant taxa of the fish assemblage. On the other hand, more intensive development, causing an increase in impervious surfaces from high intensity development will result in an alteration in the stream geomorphology (Doyle et al. 2000), that, in turn, effects fish assemblages (Paul and Meyer 2001). These types of disturbances greatly increase thermal pollution, nutrient enrichment and sedimentation in streams, allowing warm water trophic generalists, such as native and non-native sunfish and minnow species, to efficiently invade and outcompete intolerant cool water trophic specialists (Rashleigh 2004). Therefore, it is justifiable that we found a significant positive correlation between increasing high intensity land use and tolerant species, while intolerant species showed a negative correlation to that particular land use change.

Our study found that piscivorous fish were positively correlated with the mean decline in deciduous forests. However, little literature existed on the relationship between piscivorous fishes and deciduous forests.

Herbivores were found to be positively correlated with the mean increase of 1.5% in grass and herbaceous land, generating a P-value of .0449. Agriculture has negative effects on fresh water streams by introducing a non-point source of pollution that increases inputs of sediment, nutrients, and pesticides into streams (Gardiner et al. 2009). However, these effects contribute to algal growth and, therefore, the relative number of herbivores can increase (Matthews et al., 1987). As agriculture in the watershed is decreasing, it is likely that this grass and herbaceous land type has recently been agricultural land and is now in the first stages of succession. This type of land use, then, has past agricultural influences on the stream, such as nutrient loading. These excess nutrients promote excessive algal growth and increase the food available for the Central Stone Roller, which represented 92% of all herbivore individuals collected.

This study allowed for a basin wide examination of the effects of land use change on fish assemblages over nearly a decade, providing insight to the effects of human induced land disturbance, such as high-intensity development, on different fish metrics. Ecologists have pointed to the need for more studies aimed at identifying the effects of urbanization growth in primarily forested watersheds, or those between 6- 12%, to increase our understanding of the initial characteristics of environmental degradation in streams (Wang et al. 2003). As land use has changed in the studied portions of the French Broad River basin from 1997-2006, and fish assemblages within them also changed in response to land use composition, this study provides a useful insight to the effects of this urbanization within a primarily forested river basins that will likely, in coming years, pass the 10% impervious surface threshold for stream impairment caused by human development.

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