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Changes In Fish Communties Throughout The Buck Creek Watershed In Relation To Land Use

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CHANGES IN FISH COMMUNTIES THROUGHOUT THE BUCK CREEK WATERSHED IN RELATION TO LAND USE

BY

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BY

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ABSTRACT

Physical alterations of terrestrial habitat surrounding aquatic systems lead to increases in runoff, sedimentation, and nutrient inputs. Tracking changes in fish communities can provide information regarding degradation of water quality and the biotic integrity of freshwater systems. Changes in fish communities, and specifically declines in Buck Darter (*Etheostoma nebra*) populations, have been observed throughout the Buck Creek watershed since the 1980's. Thus, goals of this project were to determine if shifts in fish community composition (eg., sensitive to less sensitive families, intolerant to tolerant species, and changes in feeding groups) and extirpation of the Buck Darter in 6 of 8 historically populated sub-watersheds are related to changes in land use/land cover (LULC) proportions from 1983, 2010, and 2020. LULC proportions were determined using GIS at a local and sub-watershed scale to discern (1) changes in fish communities relative to LULC between 1983 and 2012, (2) sub-watersheds for reintroduction of *E. nebra* based on historic LULC, and (3) streams in need of restoration relative to *E. nebra* conservation. A detrended correspondence analysis (DCA) was used to determine relationships between LULC and fish communities between years and spatial scales. A principal component analysis (PCA) of 1983 and 2020 LULC proportions was used to identify sub-watersheds for the reintroduction of *E. nebra* based on the least change from 1983 and stream buffers in need of restoration based on. Agriculture/pasture dominated LULC proportions in 1983, 2010, and 2020 at the watershed level. Intolerant fish species, invertivores, omnivores, herbivores and darter species distributions decreased in sub-watersheds dominated by agriculture/pasture LULC (>50%). Centrarchids occurred in sub-watersheds in 2012 where they were absent in 1983 and increased in abundance in streams that gained proportions of development. LULC proportions at the buffer level demonstrated riparian reforestation efforts occurring throughout the Buck Creek watershed from 1983-2010. With forest proportions higher in Crab Orchard Creek and Gilmore Creek in 2010, intolerant, invertivore, and darter species proportions still decreased. This suggests that changes in fish communities within the Buck Creek watershed are operating at the watershed scale. Results from a PCA demonstrated that Gilmore Creek and Crab Orchard Creek showed the least LULC change, and Brushy Creek remained associated with agriculture/pasture in 2020. With little change in LULC proportions observed between years, disturbance of the Buck Creek watershed occurred prior to 1983, with fish communities exhibiting a delayed response. Further reforestation of riparian buffers will reduce inputs of sediment and reduce inputs of organic and inorganic nutrients into tributaries of the Buck Creek watershed.

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Introduction

The southeastern United States has the richest fish diversity and highest number of endemic species in North America, north of Mexico (Burr & Mayden, 1992). Habitat degradation across landscapes both reduces and fragments ranges of already isolated species (Angermeier, 1995), and many are vulnerable to extirpation from localized watersheds (Burkhead et al., 1997). Declines in aquatic species have been frequently associated with physical habitat degradations in the form of impoundment, channelization, flow modifications, and sedimentation (Walsh et al., 1995). A global transition from undisturbed/pristine land cover to human-dominated land use, has impacted aquatic ecosystems and made the quantification of land type a valuable indicator of the health of an ecosystem (Meyer & Turner, 1994).

Land cover refers to land such as forests or open water that has not been altered by humans, whereas land use refers to land that has been altered for human benefit. Two predominant forms of land use that impact freshwater ecosystems include agriculture and urban land use. Agricultural land use is broadly defined as land primarily used to produce food and fiber (Anderson et al., 1976). Streams surrounded by highly agricultural landscapes tend to have poor habitat and water quality that is correlated with declines in habitat indices and bank stabilizations (Richards et al., 1996). Environmental impacts include increases in runoff of nonpoint source pollutants such as pesticides, organic, and inorganic fertilizers (Allan, 2004). Impacts from urbanization include increased amounts of runoff associated with urban pollutants, a decrease of riparian zones resulting in increased water temperatures, channelization, bank erosion, and sedimentation (Paul & Meyer, 2001). These localized aquatic ecosystems are integrated with surrounding terrestrial systems through runoff, sedimentation, and the transport of both biotic and chemical elements (Fisher, 1997).

Previous studies have investigated the impacts of nonpoint source pollution and land use alterations on aquatic communities in relation to stream bank and riparian buffer zones (Armour et al., 1991; Wohl & Carline, 1996). Riparian buffers are important to aquatic ecosystems in reducing inputs of urban and agricultural pollutants and trapping sediments (Argent & Carline, 2004), however, most effects of agricultural and urban land use occur at the watershed scale (Wang et al., 1997).

Globally, habitat alteration in the forms of agriculture and urbanization are main factors causing endangerment to imperiled species (Venter et al., 2006). Areas identified as prime fish breeding habitats have been found adjacent to agricultural fields where riparian zones have been developed or converted to cultivated crop fields (Steinman et al., 2003). Additionally, forms of anthropogenic fragmentation, including culverts and dams, further isolate endemic species by fragmenting habitat and preventing movement to higher quality breeding grounds (Roy et al., 2019).

Fish are useful for assessing the health of aquatic ecosystems because they are sensitive to anthropogenic effects (Gagen et al., 1993). They exhibit a variety of life history patterns and trophic levels (Argent & Carline, 2004) and occupy a variety of habitats (Aadland, 1983). Fish diversity, species richness, and biotic integrity in streams draining from highly developed watersheds (agricultural or urbanization) have been reported to be lower compared to streams in undeveloped or less developed watersheds (Limburg & Schmide, 1990). As stream habitat heterogeneity decreases from anthropogenic impacts, streams experience a shift in fish community structures (CITE). Common changes include the shift from intolerant to tolerant species and shifts in functional feeding groups based on the response of aquatic food webs (Klein, 1979). Disturbance in aquatic habitats results in a decline of intolerant species that require low temperatures and high levels of dissolved oxygen, to a higher abundance of tolerant species that are more opportunistic and can adapt to a variety of physicochemical alterations (Enkins, 2011). By documenting changes in fish communities over the years, information regarding water resource quality and the biotic integrity of freshwater systems can aid in making management decisions (Argent and Carline, 2004).

Notably, in 2018 approximately 33% of the 215 recognized darter species were included on the International Union for Conservation's (IUCN) Red List (IUCN, 2018). Declines in darter populations are attributed to industrial (Clay, 1975) and agricultural (Smith, 1986) pollution, siltation (Trautman, 1981), channelization, and the construction of impoundments (Smith, 1979). Previous studies have discovered potential associations between forest cover, instream physical characteristics, and physicochemical attributes of streams and the occurrence of darters and other endemic cold-water fishes (Leonard & Orth, 1986; Roth et al., 1996; Snyder et al., 2003; Scott, 2006; Roy et al., 2007; Gillette et al., 2012). Pugh et al. (2020) demonstrated that Kanawha darter (*Etheostoma kanawhae*) occupancy was associated with upstream forest cover, and negatively associated with the lack of upstream forest cover, NO_3^-, and fine sediments at the riparian and watershed scale in the Upper New River in North Carolina.

The Cumberland and Tennessee river basins are the richest ichthyofaunal regions on the continent (McAllister et al., 1986) The Kentucky portion of the upper Cumberland River drainage is characterized by streams with alternating riffles and pools, incised meanders, narrow floodplains, and rocky substrates (Burr & Warren, 1986). In Kentucky, the upper Cumberland River basin is composed of 58 fish species (Burr & Warren, 1986). The Buck Creek watershed is a major tributary of the Cumberland River (Thomas & Brandt, 2013; Harker et al., 1979; 1980) and historically had exceptionally good water quality (Thomas & Brandt, 2013; Harker et al., 1979; 1980) that supported a diverse assemblage of fishes (Cicerello & Butler, 1985).

The Buck Darter (*Etheostoma nebra*) is endemic to the Buck Creek system of Kentucky's Cumberland River Drainage (Near & Thomas, 2015). Cicerello and Butler (1985) found that *E. nebra* populations were historically located at 22 of 39 sites (56%) in the Buck Creek system, which flows through Lincoln, Pulaski, and Rockcastle counties of Kentucky. Streams with these sites included Gilmore Creek, Crab Orchard Creek, Brushy Creek, Flat Lick Creek, Clifty Creek, Bee Lick Creek, Caney Creek, and the mainstem of Buck Creek (Figure 1). Between 2010-2012, Thomas and Brandt (2013) observed *E. nebra* at only 2 of 47 sites (4%) in the Buck Creek system, including Big Spring Branch and Stewart Branch. Black (2018) found that *E. nebra* inhabited 9 of 12 reaches sampled along Big Spring Branch and Stewart Branch.

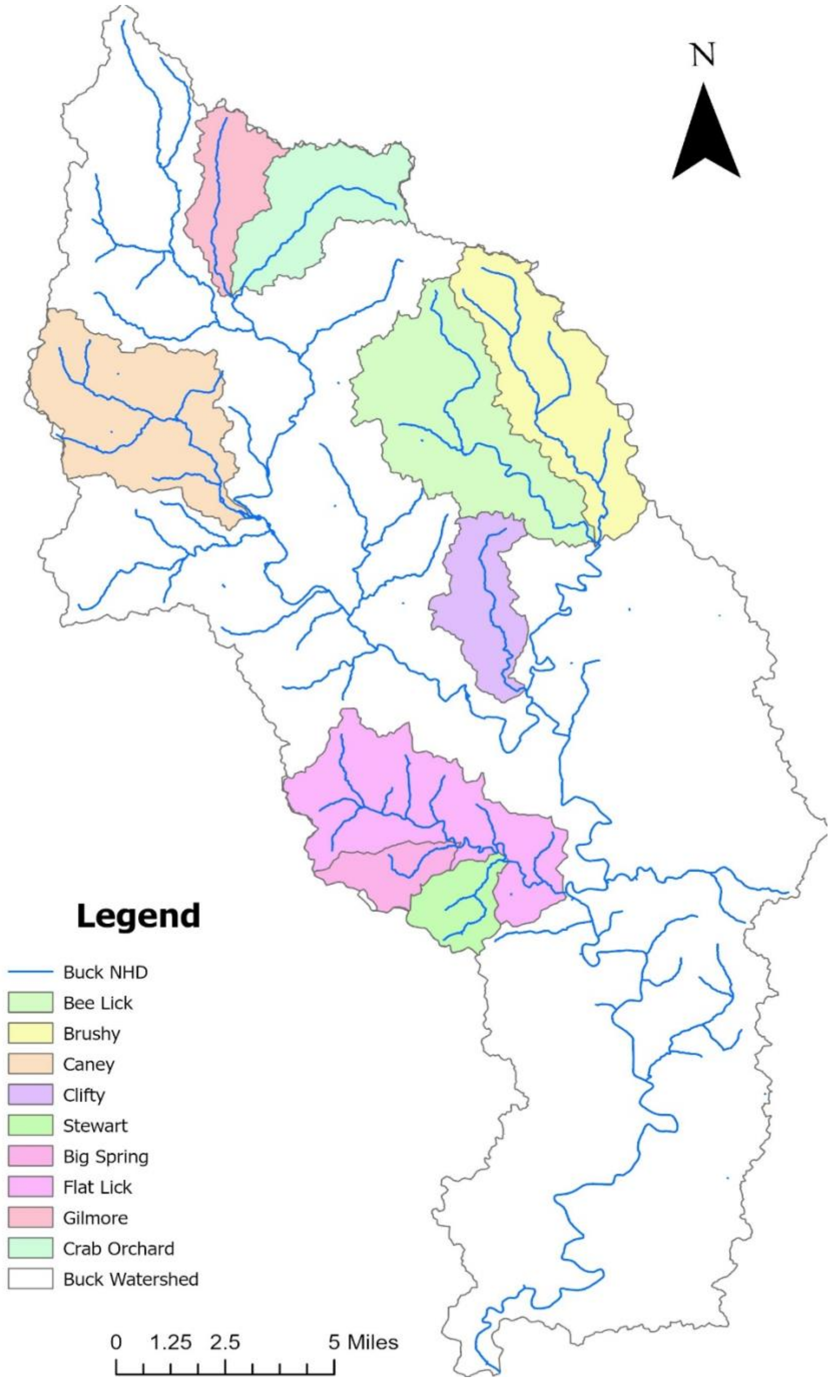

Figure 1. Sub-watersheds of the Buck Creek watershed, upper Cumberland River, Pulaski, Rockcastle, and Lincoln County, Kentucky, where the Buck Darter (*Etheostoma nebra*) occurred in 1983. Population also persisted in the mainstem of Buck Creek from the headwaters to the confluence of Flat Lick Creek. National Hydrology Dataset (NHD)

Many conservation efforts focus on a particular species or populations (Noss & Harris, 1986; Angermeier & Schlosser, 1995), leading to unrecognized declines in diversity, in-turn conservation of entire communities and ecosystems is often inadequate (Williams et al., 1985). Through modeling, it is possible to determine if hydrological alterations of surrounding land use/cover (LULC) at two spatial scales over time are related to fish community composition shifts in the Buck Creek watershed. Additionally, modeling can be used to prioritize areas of restoration based on current surrounding land use and produce habitat suitability models that identify areas with high proportions of habitat which are useful for conservation and reintroduction efforts (Johnston et al., 2013). Fish collections from 1983 and 2012 were used to assess community composition relative to LULC proportions. Changes in fish communities, and specifically declines in *E. nebra* populations, have been observed throughout the Buck Creek watershed since the 1980's (Thomas & Brandt, 2013). Thus, the goals of this project were to determine if shifts in fish community composition (e.g. sensitive to less sensitive families, intolerant to tolerant species, changes in feeding groups) and extirpation of the Buck Darter in 6 of 8 historically populated sub-watersheds of Buck Creek are related to changes in LULC proportions. The LULC proportions were determined at a local and sub-watershed scale from 1983 and 2010 to (1) discern changes in fish communities relative to LULC between historic 1983 and 2012 fish collections. (2) Use 1983 and 2020 LULC proportions to determine sub-watersheds for reintroduction of *E. nebra*. Finally, (3) identify streams in need of reforestation of riparian buffer zones to reduce negative impacts associated with agricultural and urban land use. Reforestation efforts may allow for the reintroduction of *E. nebra* in historic streams where they are currently extirpated.

Methods

Study Area

Buck Creek is a 5th order tributary, draining approximately 767 km^2 of Lincoln, Pulaski, and Rockcastle counties, eventually discharging into the Cumberland River (Cicerello & Butler, 1985). Buck Creek watershed lies predominantly in the Eastern Highland Rim Subsection of the Interior Low Plateaus Physiographic Province (Quarterman & Powell, 1978). Mississippian Age limestone composes the primary surface geology, with limited exposures of shale bedrock in the northeast region of the basin (Cicerello and Butler 1985). Sinking creeks are often associated with limestone deposits and are common in the southern regions of the basin, specifically a section of Flat Lick Creek. The southern portion of Buck Creek watershed lies within the western limits of the Cumberland Plateau Section of the Appalachian Plateaus Physiographic Province. This geographic area is overlaid with erosion resistant Pennsylvanian Age sandstone.

The study area consisted of LULC proportions associated with fish community data within Brushy Creek, Caney Creek, Crab Orchard Creek, Flat Lick Creek, Gilmore Creek, Indian Creek, Buckeye Branch, and Glade Fork Creek (Figure 2). LULC proportions were extracted from sub-watersheds where historic populations of *E. nebra* occurred, including Stewart Branch, Big Spring Branch, Clifty Creek, and Bee Lick Creek (Figure 2). LULC proportions were observed at two spatial scales, the sub-watershed scale, and the linear 100-meter buffer scale surrounding each selected stream within the Buck Creek watershed. Historic Buck Creek watershed fish community data were obtained from Cicerello and Butler (1985), where at each site, an effort was made to intensively sample all habitats via backpack shocking, seine nets, and ichthyocides. In 1983, there was no standardization of sampling procedures, such as reach length and sampling effort/time. The 2012 Buck Creek watershed fish community data was obtained from Thomas and Brandt (2013). Sampling was conducted at sites located in Brushy Creek, Caney Creek, Crab Orchard Creek, Flat Lick Creek, Gilmore Creek, Indian Creek, Buckeye Branch, and Glade Fork Creek following the wadeable stream sampling protocol that included backpack shocking 100 - 200 m reaches along with 10 - 20 seine hauls/sets to intensively sample all habitats at each site (Thomas & Brandt, 2013; KY Division of Water, 2002). If multiple sites were sampled within a sub-watershed, abundance from each site was added together to determine fish community compositions withing that sub-watershed.

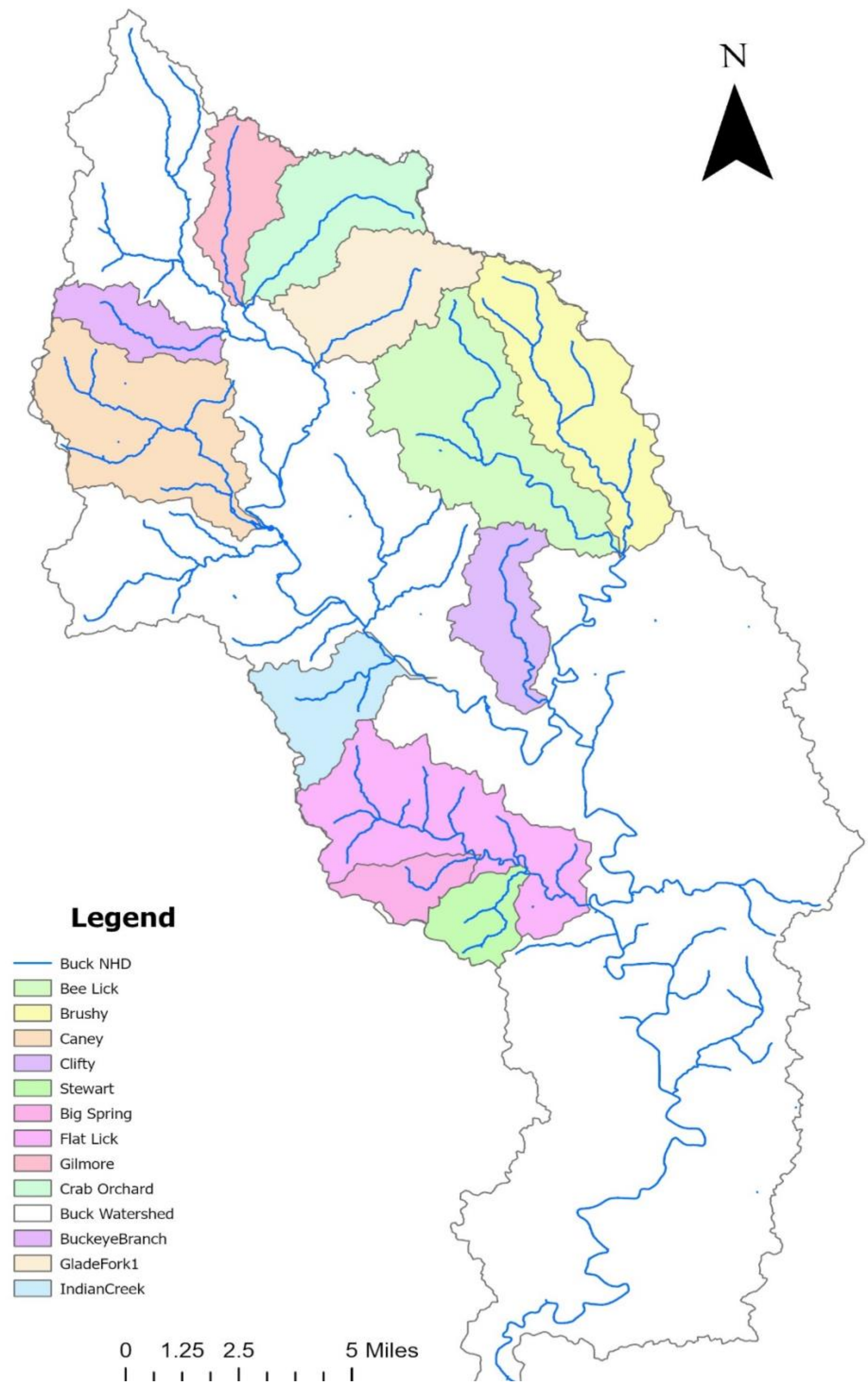

Figure 2. Sub-watersheds of the Buck Creek watershed, upper Cumberland River, Pulaski, Rockcastle, and Lincoln County, Kentucky, where LULC proportions were determined.

Land Use Land Cover

All mapping and spatial analysis utilized ESRI software ArcGIS Pro 2.9.0 (ESRI, 2021). To observe LULC change over time on a finer scale, aerial images with a 1-meter resolution were used. Aerial images from 1983, 2010, and 2020 were obtained from Earth Explorer, a data portal provided by the United States Geological Survey (Earth Explorer, 2000). Historic aerial images from 1983 were obtained from the National High-Altitude Photography (NHAP) dataset (Earth Explorer, 2000). Due to lack of images from 1983, the northwestern portion of the Buck Creek Watershed was extracted from 1975 images (Earth Explorer, 2000). Aerial images from 2010 and 2020 were obtained from the National Agricultural Imagery Program (NAIP) dataset (Earth Explorer, 2000). Historical images from 1983 were cropped and georeferenced because the spatial reference did not match with current base maps. The collection of mosaic images for each year was converted into a raster layer. For 2010 and 2020 images, band composition was altered from natural/composite to false inferred/CIR in order to identify LULC classes better.

Buck Creek watershed boundaries at the hydrologic unit code (HUC) level 8 were obtained from the National Hydrological Dataset (Geological Survey (U.S), 2004). Sub-watershed boundaries were created using Digital Elevation Models (DEM), flow accumulation, and flow direction rasters. Four LULC classes were determined: water, developed, forest, and agriculture/pasture. Water LULC consisted of visible reaches of streams, reservoirs, and farm ponds. Developed LULC consisted of roads, parking lots, residential and industrial infrastructure. Forest LULC consisted of fragmented and intact secondary forests. Finally, agriculture/pasture LULC consisted of cultivated crops, livestock grazing meadows, pastures, and residential lawns. For each year of imagery, 25 training samples were created for each LULC class. These training samples created a signature file that was implemented in a Maximum Likelihood classification algorithm, a supervised classification method, determining LULC proportions. Any incorrectly classified pixels were reclassified to correct the LULC class. An accuracy assessment was conducted using fifty random points per land use class (total N = 200 for each year of imagery) using original aerial imagery from the year being classified. The accuracy assessment determined users' accuracy, producers' accuracy, overall accuracy, and kappa values that indicate how well the classification compared to a random classification (Rwanga & Ndambuki, 2017). Users' accuracy measures errors of commission, which represents the likelihood of the classified pixel matching the land use type in the real world. Procedures' accuracy refers to how well the real-world land use types can be classified, or errors of omission. Finally, overall accuracy determined how well each pixel was classified versus the corresponding land use by adding the number of correctly classified pixels then dividing by the total number of accuracy assessment points (Rwanga & Ndambuki, 2017). The target overall accuracy for classifications was 85%, and no less than 70% for each land use class (Thomlinson et al., 1999).

Fish Community Analysis

R (R Core Team, 2021), version 4.1.0, was utilized for all statistical analyses. Proportions of tolerant fishes, intolerant fishes, functional feeding groups, and taxonomic families were determined by using raw count data from Cicerello and Butler (1985) (Appendix A) and Thomas and Brandt (2013) (Appendix B). Classifications of tolerant and intolerant fishes followed definitions by Compton et al. (2003) and fellow biologist opinions. Functional feeding groups and taxonomic family were determined following definition by Etnier and Starnes (1993). Various descriptors were utilized to indicate water quality and aquatic communities from fish community data (Table 1).

Table 1. Fish community descriptors selected to characterize community structure expressed as a proportion within each year. Descriptors were derived from Barbour et al. (1997).

Descriptors	Interpretation
Intolerant	Indicator of good water quality
Tolerant	Indicator of poor water quality
Omnivores	Indicator of physical and chemical degradation
Herbivores	Indicator of aquatic vegetation community
Insectivores	Indicator of diverse macroinvertebrate communities
Invertivores-piscivores	Indicator of high trophic level community stability

Relationships Between Fish Communities and LULC

Relationships between the Buck Creek sub-watershed fish communities (1983 and 2012) and environmental variables (LCLU classes) were explored using a detrended correspondence analysis (DCA), implemented using package “vegan” (Oksanen et al., 2022). Fish community count data from each year was calculated as percent relative abundance, then a percent maximum transformation was applied by dividing the percent relative abundance by the maximum of the species columns, ensuring that each species was provided equal weight throughout the ordination. A Pearson's product-moment correlation was then performed by measuring the strength of a linear association between the DCA axes and LULC classes (Humpherys et al., 2019). The resulting ordination was analyzed to determine relationships between fish communities in 1983 and 2012 and LULC percentages for sub-watershed and 100 m buffers.

A principal component analysis (PCA), package "vegan" (Oksanen et al., 2022), was used to evaluate streams for the possible reintroduction of *E. nebra* based off LULC, and streams with the greatest need of restoration for *E. nebra* conservation. LULC proportions from sub-watersheds and 100 m buffers where *E. nebra* was present in 1983 (Figure 1) were layered with LULC proportions from 2020 sub-watersheds and 100-meter buffers. To determine potential areas for the reintroduction of *E. nebra*, sites with similar LULC in 2020 to 1983 were identified using the results from the sub-watershed PCA. To determine streams for possible restoration, streams that shifted from predominantly forest in 1983 to developed or agriculture in 2020 were identified using the results from the 100-meter buffer PCA.

Results

LULC Accuracy Assessment

Overall accuracy for 1983 supervised classification was 85% (Table 2). Users' accuracy ranged from 82% to 86% and producers' accuracy ranged from 72% to 93%. Overall accuracy for 2010 supervised classifications was 92% (Table 3). Users' accuracy for each LULC class ranged from 86% to 100% and producers' accuracy for each LULC class ranged from 84%-100%. Overall accuracy for 2020 supervised classification was 90% (Table 4). Users' accuracy for each LULC class ranged from 74% to 100% and producers' accuracy ranged from 83% to 100%. Overall accuracy, producers' accuracy and users' accuracy for each year met the criteria for an accurate classification defined by Thomlinson et al. (1999).

Table 2. Confusion matrix for an accuracy assessment for 1983 image classifications.

LULC	Water	Developed	Forest	Ag/pasture	Total	Users Accuracy
Water	41	0	7	2	50	0.82
Developed	0	42	6	2	50	0.84
Forest	2	3	43	2	50	0.86
Ag/pasture	1	2	4	43	50	0.86
Total	44	47	60	49	200	
Producers Accuracy	0.93	0.84	0.72	0.87		
Kappa						0.84

Overall Accuracy= 85%

Table 3. Confusion matrix for an accuracy assessment for 2010 image classifications.

LULC	Water	Developed	Forest	Ag/pasture	Total	Users Accuracy
Water	50	0	0	0	50	1
Developed	0	43	3	4	50	0.86
Forest	0	2	45	3	50	0.9
Ag/pasture	0	0	3	47	50	0.94
Total	50	45	51	54	200	
Producers Accuracy	1	0.95	0.84	0.87		
Kappa						0.90

Overall accuracy= 92%

Table 4. Confusion matrix for an accuracy assessment for 2020 image classifications.

LUCL Class	Water	Developed	Forest	Ag/Pasture	Total	Users Accuracy
Water	37	1	4	8	50	0.74
Developed	0	44	5	1	50	0.88
Forest	0	0	49	1	50	0.98
Ag/pasture	0	0	0	50	50	1
Total	37	45	58	60	200	
Producers Accuracy	1	0.97	0.84	0.83		
Kappa						0.89

Overall accuracy= 90%

Watershed Scale LULC

LULC proportions were extracted from the sub-watersheds within the Buck Creek watershed present in 1983 (Table 5). At the watershed scale (Buck Creek watershed above KY 80) LULC proportions consisted of agriculture/pasture (59.5%), forest (38.3%), developed (1.6%) and water (0.5%). In 2010 LULC proportions consisted of agriculture/pasture (61.5%), forest (36.1%), developed (1.8%), and water (0.48%). In 2020 LULC proportions consisted of agriculture/pasture (59.7%), forest (37.5%), developed (2.1%), and water (0.8%).

In 1983, sub-watersheds with dominant forest LULC were Gilmore Creek and Stewart Branch (50.89% and 67.29% respectively; Table 7). Agriculture/pasture LULC dominated Bee Lick Creek, Brushy Creek, Buckeye Branch, Caney Creek, Clifty Creek, Flat Lick Creek, Glade Fork Creek, and Indian Creek (71.78%, 69.92%, 57.68%, 63.49%, 59.86%, 60.84%, and 67.29% respectively). Developed LULC proportions ranged from 1.1%- 1.9%, apart from Big Spring Branch (3.03%).

In 2010, forest dominated Stewart Branch (66.38%) and Big Spring Branch (49.78%; Table 5). All other sub-watersheds were dominated by agriculture/pasture LULC. Developed proportions varied from .08% to 2%, apart from Big Spring Branch (4.79%) and Flat Lick Creek (3.58%).

In 2020, forest dominated Big Spring Branch, Gilmore Creek, and Stewart Branch (53.19%, 50.04%, 71.16% respectively; Table 5). All other sub-watersheds were dominated by agriculture pasture LULC. Developed proportions comprised 0.98% to 2.5% of LULC proportions, apart from Big Spring Branch (4.93%).

Table 5. LULC proportions for sub-watersheds of the Buck Creek watershed from 1983, 2010, and 2020.

Year	Watershed	Water	Developed	Forest	Ag/pasture
1983	Bee Lick	0.467%	1.476%	26.275%	71.782%
1983	Big Spring	0.115%	3.032%	47.179%	49.674%
1983	Brushy	0.631%	1.686%	27.759%	69.924%
1983	Buck at Bridge	0.571%	1.606%	38.306%	59.516%
1983	Buckeye	0.061%	1.620%	40.631%	57.688%
1983	Caney	0.058%	1.863%	46.158%	51.921%
1983	Clifty	0.541%	1.453%	34.515%	63.491%
1983	Crab Orchard	0.741%	1.161%	49.225%	48.873%
1983	Flat Lick	0.260%	1.956%	37.924%	59.860%
1983	Gilmore	0.141%	1.138%	50.897%	47.824%
1983	Glade Fork Creek	0.448%	1.725%	36.983%	60.844%
1983	Indian	0.406%	1.466%	30.829%	67.298%
1983	Stewart	0.064%	1.104%	67.297%	31.535%
2010	Bee Lick	0.489%	1.846%	22.786%	74.879%
2010	Big Spring	0.074%	4.792%	49.798%	45.336%
2010	Brushy	0.422%	1.420%	29.576%	68.582%
2010	Buck at Bridge	0.485%	1.834%	36.166%	61.516%
2010	Buckeye	0.289%	1.182%	38.546%	59.983%
2010	Caney	0.306%	2.085%	39.708%	57.901%
2010	Clifty	0.649%	1.779%	29.034%	68.538%
2010	Crab Orchard	0.731%	0.898%	48.462%	49.909%
2010	Flat Lick	0.344%	3.582%	38.747%	57.327%
2010	Gilmore	0.198%	0.800%	48.411%	50.590%
2010	Glade Fork Creek	0.287%	1.286%	40.316%	58.110%
2010	Indian	0.390%	2.185%	30.777%	66.648%
2010	Stewart	0.310%	2.369%	66.383%	30.939%
2020	Bee Lick	0.778%	2.315%	22.989%	73.918%
2020	Big Spring	0.140%	4.936%	53.190%	41.734%
2020	Brushy	0.641%	2.117%	30.002%	67.240%
2020	Buck at Bridge	0.853%	2.174%	37.482%	59.492%
2020	Buckeye	0.558%	1.718%	37.947%	59.777%
2020	Caney	0.685%	2.534%	39.388%	57.393%
2020	Clifty	0.577%	1.728%	28.339%	69.357%
2020	Crab Orchard	0.852%	1.165%	48.776%	49.206%
2020	Flat Lick	0.389%	3.633%	41.003%	54.976%
2020	Gilmore	0.337%	0.989%	50.047%	48.627%
2020	Glade Fork Creek	0.470%	1.593%	41.004%	56.932%
2020	Indian Creek	0.710%	2.129%	29.219%	67.942%
2020	Stewart	0.160%	1.853%	71.161%	26.826%

Sub-watersheds with the greatest decrease in forest from 1983-2010 included Bee Lick Creek, Buckeye Branch, Caney Creek, Clifty Creek, and Gilmore Creek (-3.48%, -2.08%, -6.45%, -5.41%, -2.48% respectively; Table 6). Highest increases in agriculture/pasture included Bee Lick Creek, Buckeye Branch, Caney Creek, Clifty Creek, and Gilmore Creek (3.09%, 2.29%, 5.98%, 5.04%, 2.76% respectively). The highest increases in development occurred at Big Spring Branch (1.76%) and Flat Lick Creek (1.62%)

Sub-watersheds with the greatest decrease in forest from 1983-2020 were Bee Lick Creek, Buckeye Branch, Caney Creek, and Clifty Creek (-3.28%, -2.68%, -6.76%, and -6.17% respectively; Table 6). The greatest increase in agriculture/pasture occurred at Clifty Creek (5.86%) and Caney Creek (5.47%). Flat Lick Creek (1.67%) and Big Spring Branch (1.90%) showed the greatest increase in development.

Table 6. Changes in LULC proportions from sub-watersheds of the Buck Creek watershed from 1983-2010 and 1983-2020.

Years	Watershed	Water	Developed	Forest	Ag/Pasture
1983-2010	Bee Lick	0.022%	0.370%	-3.489%	3.097%
1983-2010	Big Springs	-0.041%	1.760%	2.619%	-4.338%
1983-2010	Brushy	-0.209%	-0.266%	1.817%	-1.342%
1983-2010	Buck	-0.087%	0.227%	-2.140%	1.999%
1983-2010	Buckeye	0.229%	-0.438%	-2.085%	2.295%
1983-2010	Caney	0.248%	0.222%	-6.450%	5.980%
1983-2010	Clifty	0.109%	0.326%	-5.481%	5.046%
1983-2010	Crab Orchard	-0.010%	-0.263%	-0.763%	1.036%
1983-2010	Flat Lick	0.083%	1.627%	0.823%	-2.533%
1983-2010	Gilmore	0.057%	-0.338%	-2.485%	2.766%
1983-2010	Glade Fork	-0.161%	-0.439%	3.333%	-2.733%
1983-2010	Indian	-0.016%	0.719%	-0.053%	-0.650%
1983-2020	Bee Lick	0.311%	0.839%	-3.286%	2.137%
1983-2020	Big Springs	0.025%	1.904%	6.011%	-7.940%
1983-2020	Brushy	0.011%	0.430%	2.243%	-2.684%
1983-2020	Buck	0.281%	0.567%	-0.824%	-0.024%
1983-2020	Buckeye	0.498%	0.098%	-2.684%	2.088%
1983-2020	Caney	0.627%	0.671%	-6.769%	5.472%
1983-2020	Clifty	0.036%	0.275%	-6.176%	5.865%
1983-2020	Crab Orchard	0.111%	0.004%	-0.449%	0.333%
1983-2020	Flat Lick	0.128%	1.677%	3.079%	-4.884%
1983-2020	Gilmore	0.196%	-0.149%	-0.850%	0.803%
1983-2020	Glade Fork	0.022%	-0.132%	4.021%	-3.911%
1983-2020	Indian	0.303%	0.664%	-1.611%	0.644%

Buffer Scale LULC

LULC cover proportions were extracted from 100 m buffers within sub-watersheds of the Buck Creek watershed (Table 7). In 1983, 100 m buffers around all blue line streams in the Buck Creek watershed indicated that forest dominated LULC (55.59%) followed by agriculture/pasture (40.77%), and development (1.01%). The highest forest proportions were found at Buckeye Branch, Caney Creek, and Gilmore Creek (73%, 76%, and 73%, respectively). Highest agriculture/pasture proportions occurred at Big Spring Branch, Brushy Creek, and Flat Lick Creek (61%, 63%, and 65%, respectively). Highest proportion of development occurred at Big Spring Branch (3.8%).

In 2010, buffers dominated by forest included Buckeye Branch, Caney Creek, Crab Orchard Creek, Gilmore Creek, Glade Fork Creek, and Indian Creek (67.24%, 70.59%, 64.13%, 78.40%, 65.74%, 66.13% respectively; Table 7). Dominant agriculture/pasture proportions occurred at Bee Lick Creek, Big Spring Branch, Brushy Creek, Flat Lick Creek, and Stewart Branch (55.73%, 50.83%, 62.11%, 58.63%, and 48.16% respectively). Developed proportions were highest at Big Spring Branch, Stewart Branch, and Flat Lick Creek (4.23%, 3.17%, and 3.47% respectively).

In 2020, forest proportions were dominant at Big Spring Branch, Buckeye Branch, Caney Creek, Clifty Creek, Crab Orchard Creek, Gilmore Creek, Indian Creek, and Stewart Branch (50.27%, 68.09%, 73.02%, 62.73%, 79.33%, 62.58%, 68.16%, and 56.13% respectively; Table 7). The highest proportions of agriculture/pasture occurred at Bee Lick Creek, Brushy Creek, and Flat Lick Creek (53.82%, 60.45%, and 55.8%

respectively). Big Spring Branch, Stewart Branch, and Flat Lick Creek had the highest proportions of development (4.65%, 3.61%, and 3.83% respectively).

Table 7. LULC proportions for 100-meter buffers surrounding each stream within the Buck Creek watershed from 1983, 2010, and 2020.

Year	Watershed	Water	Developed	Forest	Ag/pasture
1983	Bee Lick	1.294%	1.206%	45.450%	52.051%
1983	Big Spring	0.206%	3.833%	34.697%	61.264%
1983	Brushy	1.249%	1.116%	34.354%	63.281%
1983	Buck	2.622%	1.012%	55.595%	40.770%
1983	Buckeye	0.192%	0.731%	72.586%	26.492%
1983	Caney	0.104%	0.747%	76.299%	22.851%
1983	Clifty	1.981%	0.765%	46.134%	51.119%
1983	Crab Orchard	6.229%	0.764%	53.093%	39.914%
1983	Flat Lick	0.625%	2.692%	31.178%	65.505%
1983	Gilmore	0.004%	0.965%	72.667%	26.364%
1983	Glade Fork Creek	0.799%	2.777%	47.083%	49.340%
1983	Indian	1.297%	1.098%	61.190%	36.415%
1983	Stewart	0.273%	2.862%	39.924%	56.941%
2010	Bee Lick	0.381%	1.097%	42.779%	55.743%
2010	Big Spring	0.068%	4.231%	44.865%	50.837%
2010	Brushy	0.286%	0.943%	36.660%	62.111%
2010	Buck	1.145%	1.136%	57.312%	40.407%
2010	Buckeye	0.097%	0.581%	67.241%	32.082%
2010	Caney	0.259%	1.017%	70.597%	28.126%
2010	Clifty	1.104%	0.617%	49.172%	49.107%
2010	Crab Orchard	6.309%	0.345%	64.133%	29.213%
2010	Flat Lick	0.463%	3.178%	37.729%	58.630%
2010	Gilmore	0.067%	0.238%	78.408%	21.287%
2010	Glade Fork Creek	0.146%	1.918%	65.740%	32.195%
2010	Indian	0.598%	1.691%	66.136%	31.575%
2010	Stewart	0.844%	3.473%	47.522%	48.162%
2020	Bee Lick	1.357%	1.971%	42.846%	53.826%
2020	Big Spring	0.215%	4.648%	50.275%	44.862%
2020	Brushy	1.037%	1.884%	36.622%	60.457%
2020	Buck	2.256%	1.480%	58.802%	37.462%
2020	Buckeye	0.249%	0.617%	68.096%	31.039%
2020	Caney	0.957%	1.176%	73.026%	24.841%
2020	Clifty	0.823%	0.688%	50.871%	47.618%
2020	Crab Orchard	5.658%	0.486%	62.739%	31.117%
2020	Flat Lick	0.580%	3.611%	40.006%	55.803%
2020	Gilmore	0.118%	0.261%	79.338%	20.284%
2020	Glade Fork Creek	0.930%	0.895%	62.586%	35.588%
2020	Indian Creek	1.720%	1.179%	68.160%	28.941%
2020	Stewart	0.403%	3.833%	56.133%	39.631%

Observing LULC changes from 1983-2020, Big Spring Branch, Stewart Branch, and Glade Fork Creek had the highest increases in forest (16%, 16%, and 16% respectively; Table 8). The greatest change from forest to agriculture/pasture occurred at Buckeye branch, losing 4% forest.

Table 8. Change in LULC proportions for 100-meter buffers surrounding each stream within the Buck Creek watershed from 1983-2010 and 1983-2020.

Year	Watershed	Water	Developed	Forest	Ag/Hay
1983-2010	Bee Lick	-0.912%	-0.109%	-2.671%	3.692%
1983-2010	Big Springs	-0.138%	0.397%	10.167%	-10.427%
1983-2010	Brushy	-0.963%	-0.173%	2.306%	-1.169%
1983-2010	Buck	-1.477%	0.124%	1.717%	-0.363%
1983-2010	Buckeye	-0.095%	-0.150%	-5.345%	5.590%
1983-2010	Caney	0.156%	0.271%	-5.702%	5.276%
1983-2010	Clifty	-0.877%	-0.148%	3.038%	-2.012%
1983-2010	Crab Orchard	0.081%	-0.419%	11.040%	-10.701%
1983-2010	Flat Lick	-0.162%	0.486%	6.551%	-6.875%
1983-2010	Gilmore	0.063%	-0.728%	5.741%	-5.077%
1983-2010	Glade Fork	-0.653%	-0.859%	18.657%	-17.145%
1983-2010	Indian	-0.699%	0.592%	4.946%	-4.840%
1983-2010	Stewarts	0.571%	0.611%	7.598%	-8.780%
1983-2020	Bee Lick	0.064%	0.765%	-2.604%	1.775%
1983-2020	Big Springs	0.009%	0.815%	15.578%	-16.401%
1983-2020	Brushy	-0.211%	0.768%	2.267%	-2.824%
1983-2020	Buck	-0.366%	0.468%	3.207%	-3.308%
1983-2020	Buckeye	0.057%	-0.114%	-4.490%	4.547%
1983-2020	Caney	0.854%	0.429%	-3.273%	1.990%
1983-2020	Clifty	-1.158%	-0.077%	4.737%	-3.502%
1983-2020	Crab Orchard	-0.570%	-0.278%	9.646%	-8.797%
1983-2020	Flat Lick	-0.044%	0.919%	8.828%	-9.703%
1983-2020	Gilmore	0.113%	-0.705%	6.672%	-6.080%
1983-2020	Glade Fork	0.131%	-1.882%	15.503%	-13.752%
1983-2020	Indian	0.423%	0.081%	6.970%	-7.474%
1983-2020	Stewarts	0.130%	0.971%	16.209%	-17.310%

Family Classifications

In 1983, the highest sucker proportions occurred at Flat Lick Creek, Caney Creek, Crab Orchard Creek, and Gilmore Creek (10.87%, 12.12%, 21.59%, and 11.86% respectively; Figure 3). The highest minnow proportions occurred at Brushy Creek, Flat Lick Creek, Glade Fork Creek, and Buckeye Branch (72.26%, 78.26%, 83.93%, and 82.61% respectively). The highest darter proportions occurred at Brushy Creek, Caney Creek, Gilmore Creek, and Buckeye Branch (16.78%, 18.18%, 28.81%, and 18.67% respectively). Caney Creek (12.12%) and Crab Orchard Creek (13.64%) had the highest proportions of sunfish and basses.

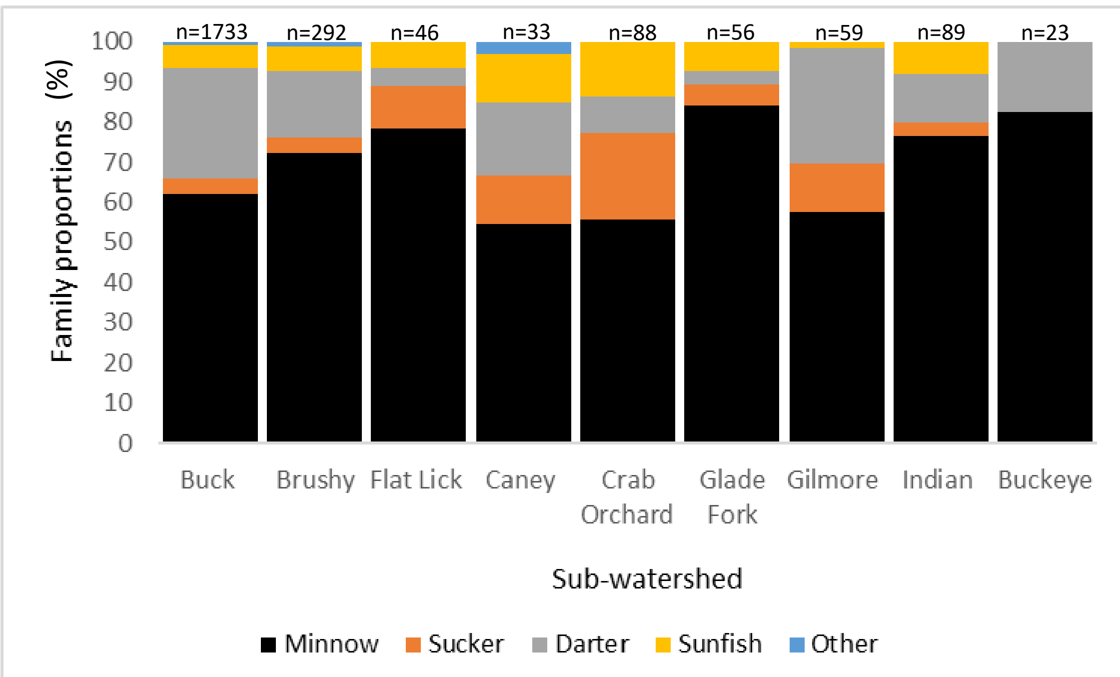

Figure 3. Fish family classifications of sub-watersheds within the Buck Creek watershed from 1983, obtained from Cicerello and Butler (1985).

In 2012, the highest sucker proportions occurred at Flat Lick Creek (22%) and Glade Fork Creek (18.75%) (Figure 4). Highest minnow proportions occurred at Glade Fork Creek, Indian Creek, and Buckeye Branch (50%, 50%, and 60% respectively). Darter proportions were highest at Brushy Creek, Crab Orchard Creek, Glade Fork Creek, and Gilmore Creek (18.67%, 19.35%, 18.75%, and 20.83% respectively). Sunfish and bass) proportions was highest at Flat Lick Creek, Caney Creek, and Crab Orchard Creek (36%, 33.33%, and 29.03% respectively).

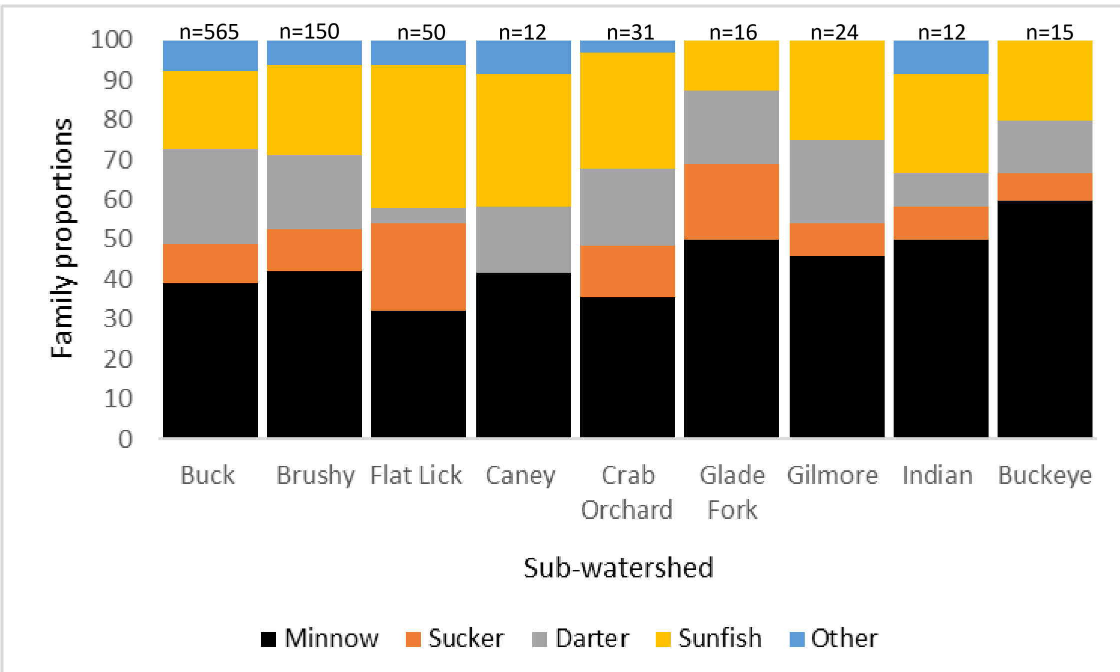

Figure 4. Fish family classifications of sub-watersheds within the Buck Creek watershed from 2012, obtained from Thomas and Brandt (2013).

From 1983-2012, Flat Lick Creek (+11%) and Glade Fork Creek (+13%) experienced an increase in sucker proportions (Table 9). All sub-watersheds experienced a decrease in minnow proportions with Flat Lick Creek, Glade Fork Creek, and Brushy Creek having the greatest decreases (-46%, -34%, and -28% respectively).

All sub-watersheds experienced an increase in sunfish and bass proportions, highest increases occurred at Flat Lick Creek, Caney Creek, Crab Orchard Creek, and Gilmore Creek (+29.48%, +21.21%, +15.39%, and +23.31% respectively). Darter proportions experienced the greatest decrease at Gilmore Creek, Indian Creek, and Buckeye Branch (-7.98%, -4%, and -4% respectively; Table 9).

Table 9. Change in family proportions from 1983-2012 in sub-watersheds of the Buck Creek watershed.

Watershed	Minnow	Sucker	Darter	Sunfish	Other
Buck	-22.8	5.92	-4.04	14.05	6.86
Brushy	-30.26	6.9	1.89	16.51	4.97
Flat Lick	-46.26	11.13	-0.35	29.48	6
Caney	-12.88	-12.12	-1.51	21.21	5.3
Crab Orchard	-20.2	-8.69	10.26	15.39	3.23
Glade Fork	-33.93	13.39	15.18	5.36	0
Gilmore	-11.8	-3.53	-7.98	23.31	0
Indian	-26.4	4.96	-4.03	17.13	8.33
Buckeye	-22.61	6.67	-4.06	20	0

Fish Feeding Classes

In 1983, feeding classes within the Buck Creek mainstem included invertivores (65.93%), omnivores (18.12%), herbivores (8.86%), invertivore/piscivores (IP;5.19%), and invertivores/piscivores/herbivores (IPH;0.17%) (Figure 5). All sub-watersheds were dominated by invertivores, apart from Buckeye Branch (17.39%). Highest proportions of invertivores occurred at Indian Creek, Brushy Creek, Gilmore Creek, and Glade Fork Creek (80.90%, 73.29%, 61.02%, and 76.79% respectively). The highest proportions of omnivores occurred at Caney Creek, Crab Orchard Creek, and Buckeye Branch (33.33%, 35.23%, and 30.43% respectively). The highest proportions of herbivores occurred at

Buckeye Branch, Flat Lick Creek, and Caney Creek (52.17%, 17.39%, and 12.12% respectively). Highest proportions of IP were found at Caney Creek (12.12%) and Crab Orchard Creek (13.64%). No IPH individuals were found at any sub-watersheds within the Buck Creek watershed.

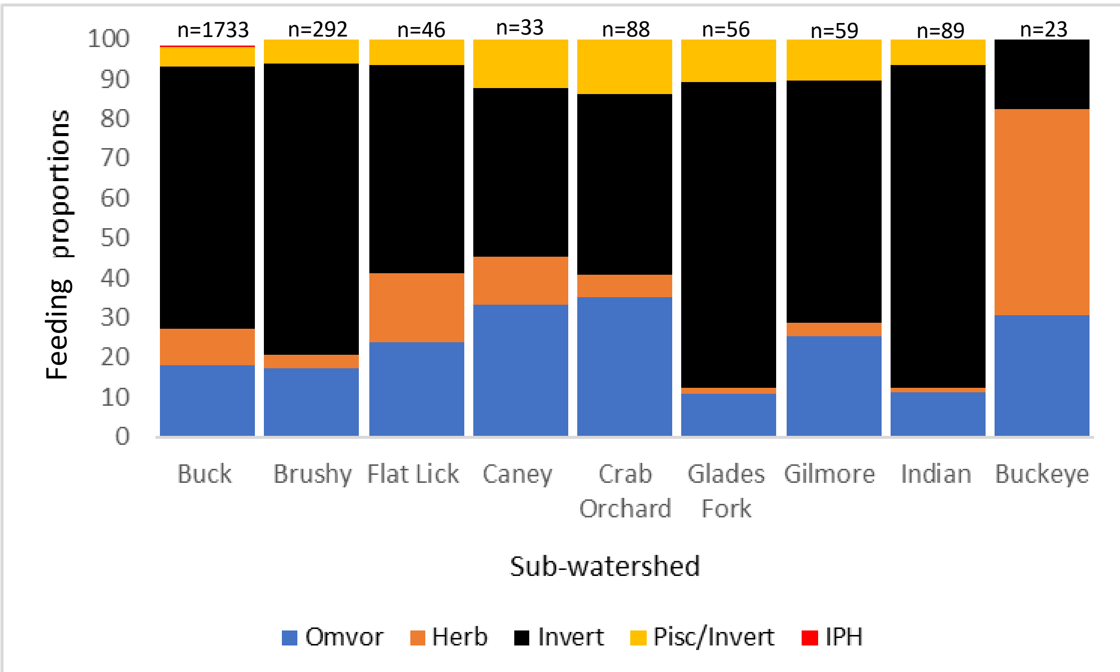

Figure 5. Fish feeding groups from sub-watersheds within the Buck Creek watershed from 1983, obtained from Cicerello and Butler (1985). Feeding classes are abbreviated as, omnvor= omnivore, herb= herbivore, invert= invertivore, pisc/invert=piscivore/invertivore, and IPH= invertivore/piscivore/herbivore.

In 2012, feeding group proportions in the Buck Creek mainstem included invertivores (59.29%), IP (18.76%), omnivores (17.17%), herbivores (3.89%) and IPH (0.88%; Figure 6). Highest proportions of invertivores occurred in Brushy Creek, Caney Creek, Glade Fork Creek, and Gilmore Creek (52%, 58.33%, 50%, and 50% respectively). Flat Lick Creek, Glade Fork Creek, Gilmore Creek, Indian Creek, and Buckeye Branch had the highest proportions of omnivores (20%, 25%, 20.83%, 25%, and 20%

respectively). Flat Lick Creek, Caney Creek, Gilmore Creek, and Indian Creek had the highest proportions of herbivores (8%, 8.33%, 8.33%, and 8.33% respectively). Highest proportions of IP occurred in Flat Lick Creek, Caney Creek, Crab Orchard Creek, Gilmore Creek, and Indian Creek (36%, 25%, 25.81%, 20.83%, and 25% respectively). Flat Lick Creek (6%) and Indian Creek (8.33%) had the highest proportions of IPH.

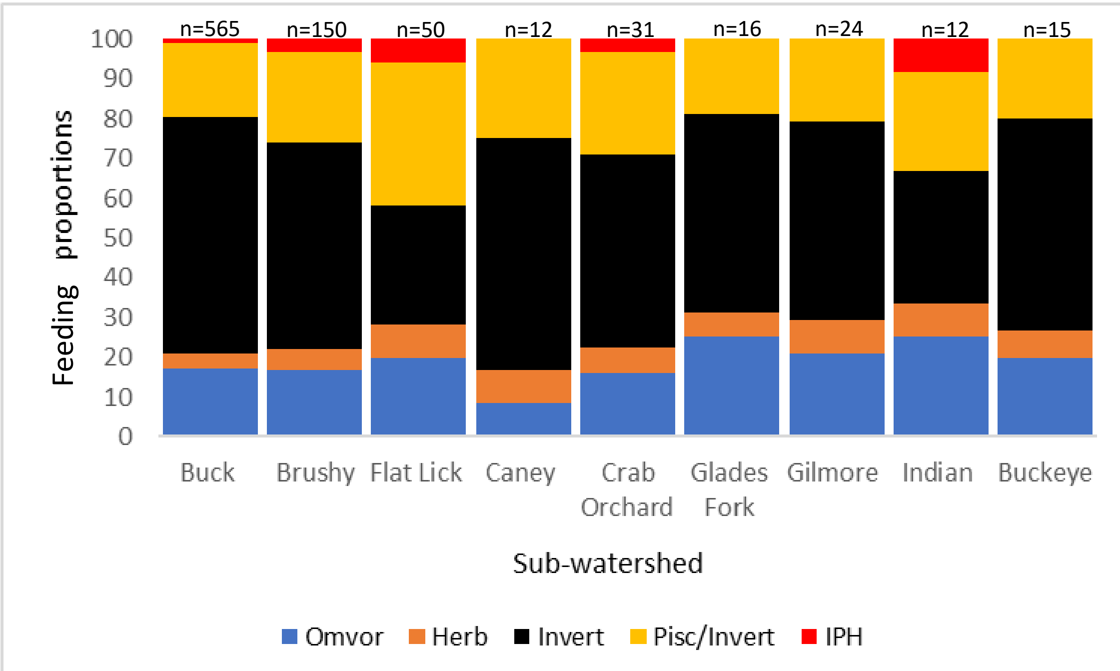

Figure 6. Fish feeding groups from sub-watersheds of the Buck Creek watershed from 2012, obtained from Thomas and Brandt (2013). Feeding classes are abbreviated as, omnvor= omnivore, herb= herbivore, invert= invertivore, pisc/invert=piscivore/invertivore, and IPH= invertivore/piscivore/herbivore.

Changes in fish feeding groups from 1983-2012 in sub-watersheds within the Buck Creek watershed indicate that all sub-watersheds apart from Caney Creek, Crab Orchard Creek, and Buckeye Branch experienced declines in invertivores (Table 10). Indian Creek, Brushy Creek, Flat Lick Creek, and Glade Fork Creek experienced the greatest losses of invertivore proportions (-47.57%, -21.29%, -22.17%, -26.79%). The greatest decreases in omnivores occurred at Crab Orchard Creek (-19.1%) and Caney Creek (-25%), and the greatest increase in omnivore proportions occurred at Glade Fork Creek (+14.29%) and Indian Creek (+13.76%). The greatest decrease in herbivore proportions occurred at Buckeye Branch (-45.5%) and the greatest increases in Indian Creek, Gilmore Creek, and Glade Fork Creek (+7.21%, +4.94%, and +4.46% respectively). All sub-watersheds increased in IP proportions with Flat Lick Creek, Indian Creek, and Brushy Creek gaining the highest proportions (+29.48%, +18.26%, and +16.51% respectively). Brushy Creek, Flat Lick Creek, Crab Orchard, and Indian Creek increased in IPH proportions (+3.33%, +6%, +3.23%, and +8.33% respectively).

Table 10. Changes in fish feeding groups from 1983-2012 from sub-watersheds of the Buck Creek watershed.

Watershed	Omvor	Herb	Invert	Pisc/Invert	IPH
Buck	-0.95	-4.97	-6.64	13.57	0.71
Brushy	-0.8	2.25	-21.29	16.51	3.33
Flat Lick	-3.91	-9.39	-22.17	29.48	6
Caney	-25	-3.79	15.91	12.88	0
Crab Orchard	-19.1	0.77	2.94	12.17	3.23
Glade Fork Creek	14.29	4.46	-26.79	8.04	0
Gilmore	-4.59	4.94	-11.02	10.66	0
Indian	13.76	7.21	-47.57	18.26	8.33
Buckeye	-10.43	-45.5	35.94	20	0

Tolerant and Intolerant Fishes

In 1983, Brushy Creek, Glade Fork Creek, Gilmore Creek, and Indian Creek had higher proportions of intolerant species (69.86%, 67.86%, 64.41%, and 73.03% respectively) (Figure 7). In 2012, only Crab Orchard Creek (32.26%) had a greater proportion of intolerant species (Figure 8). From 1983-2012, Brushy Creek, Glade Fork

Creek, Gilmore Creek, and Indian Creek experienced the greatest loss of intolerant species proportions (-23.55%, -17.86%, -22.74%, and -48.03% respectively).

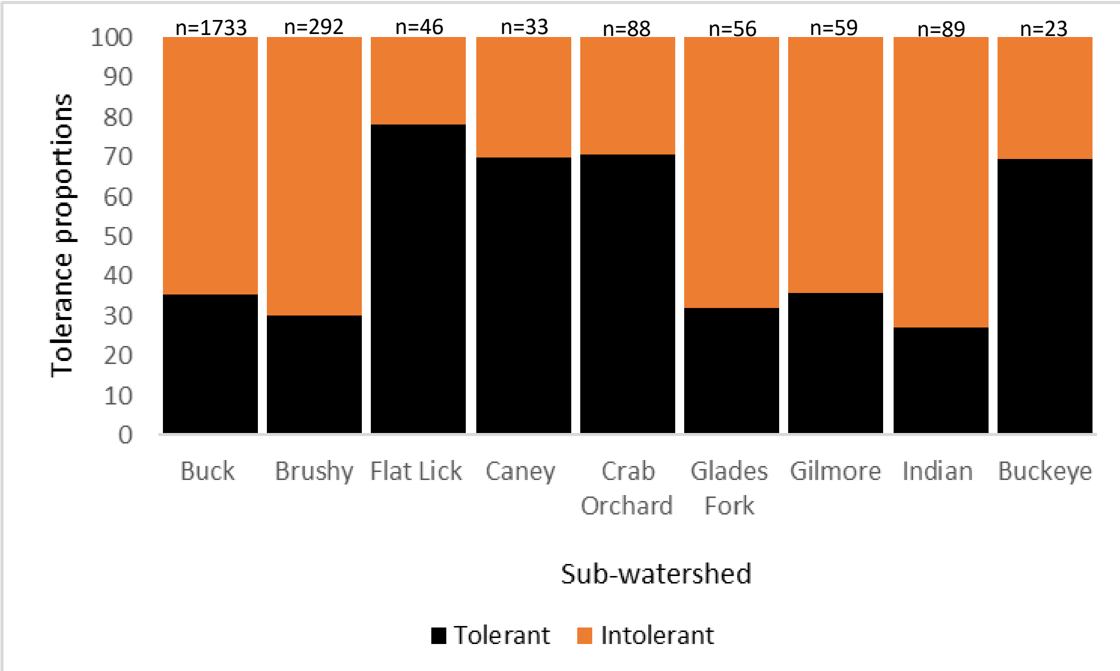

Figure 7. Tolerant and intolerant fish proportions from sub-watersheds within the Buck Creek watershed in 1983, obtained from Cicerello and Butler (1985).

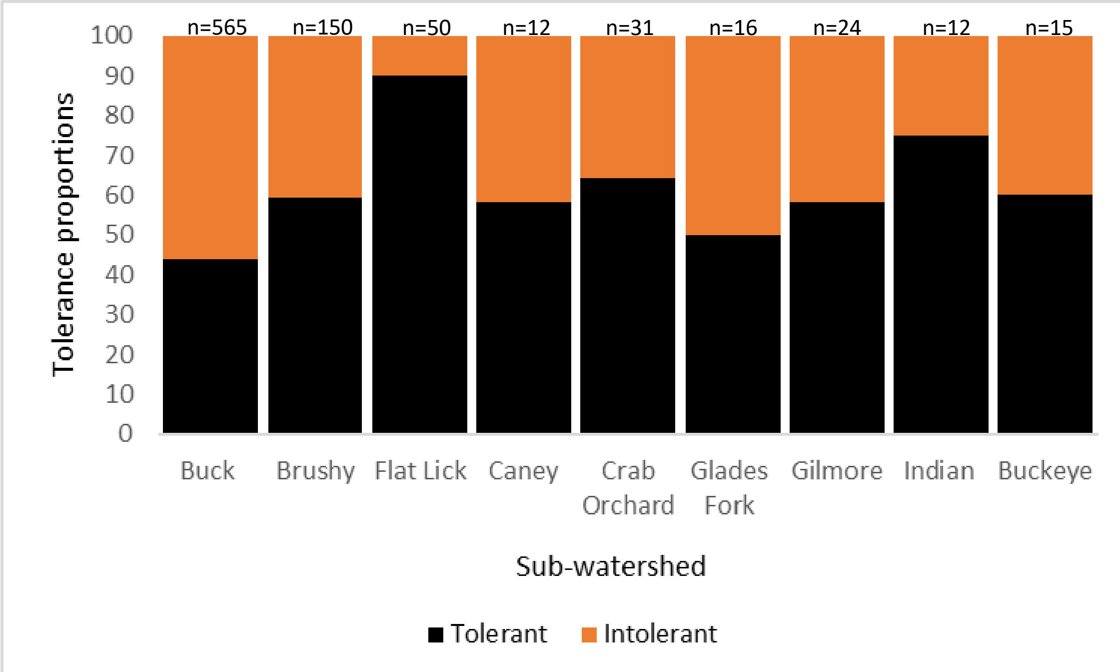

Figure 8. Tolerant and intolerant fish proportions from sub-watersheds within the Buck Creek watershed in 2012, obtained from Thomas and Brandt (2013).

Fish Communities and LULC

Results from the DCA for 1983 buffers indicated that forest had a strong negative correlation with DCA 1 (r^2= -0.999), while agriculture/pasture had a strong positive correlation with DCA 1 (r^2=-0.995)(Figure 9). Forest had a negative correlation with DCA 2 (r^2= -0.84) while agriculture/pasture and developed had positive correlations with DCA 2 (r^2= 0.83 , r^2= 0.88, respectively). The White Sucker (*C. commersonii*), Northern Hogsucker (*H. nigricans*), Western Blacknose Dace (*R. obtusus*), and Rock Bass (*A. rupestris*) were associated with streams influenced by agriculture/pasture LULC (Figure 9). Conversely, *Etheostoma caeruleum*, *Etheostoma flabellare*, and *Notropis telescopus* tended to be associated with streams influenced by forest. Fish associated with higher development included *Luxilus chrysocephalus* and *Semotilus atromaculatus*.

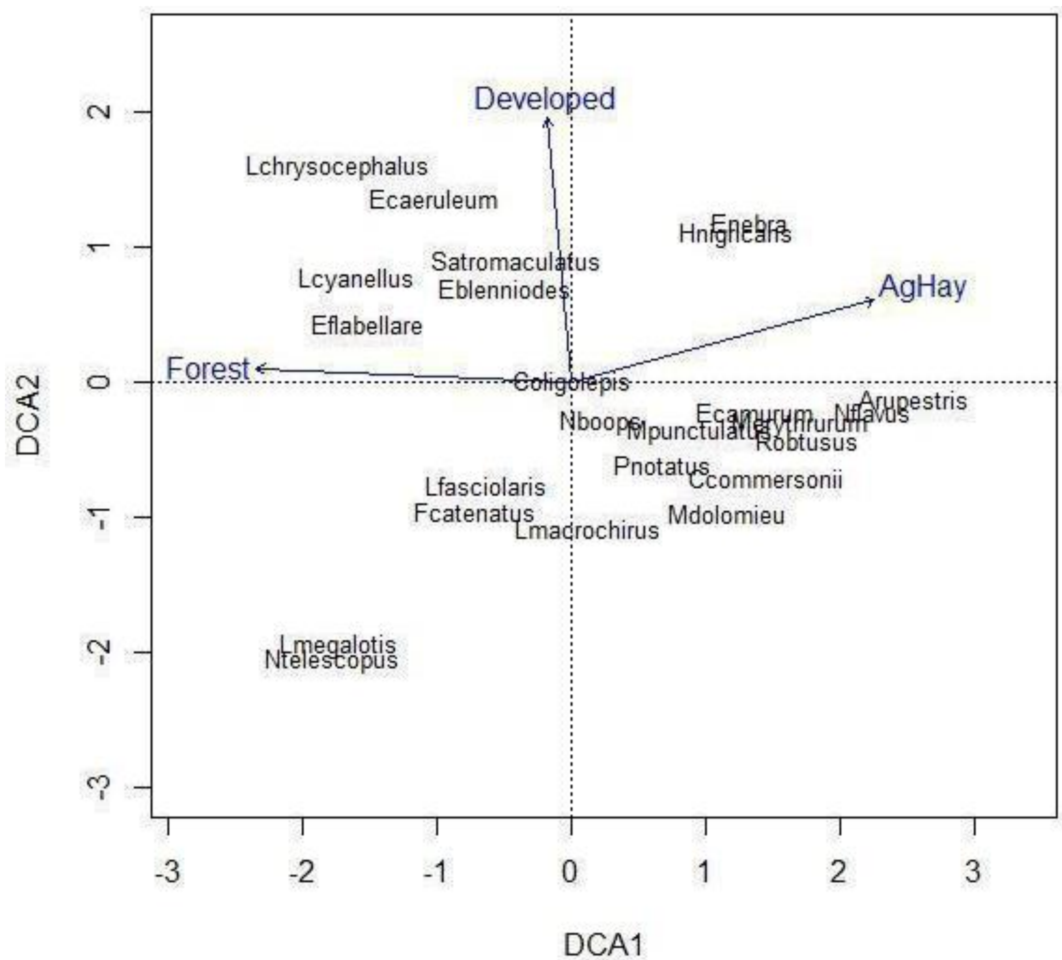

Figure 9. Ordinations from detrended correspondence analysis (DCA) of 1983 fish species, collected by Cicerello and Butler (1983), and LULC proportions from 100m buffer within each sub-watershed of the Buck Creek watershed in 1983. Names were abbreviated with the first letter of the genus, followed by the species name.

Results from the DCA for 2010 100 m buffers indicated that forest had a strong negative correlation with DCA1 (r^2= -0.98), while agriculture/pasture had a strong positive correlation with DCA 1 (r^2=0.99)(Figure 10). Trends displayed by the ordination plot suggest that *Moxostoma erythrurum, Notropis boops, Micropterus punctulatus, Micropterus salmoides*, and *Etheostoma flabellare* appeared to be associated with forest, while *Catostomus commersonii*, *Ambloplites rupestris, Hypentelium nigricans*, and *Micropterus dolomieu* appeared to be associated with development.

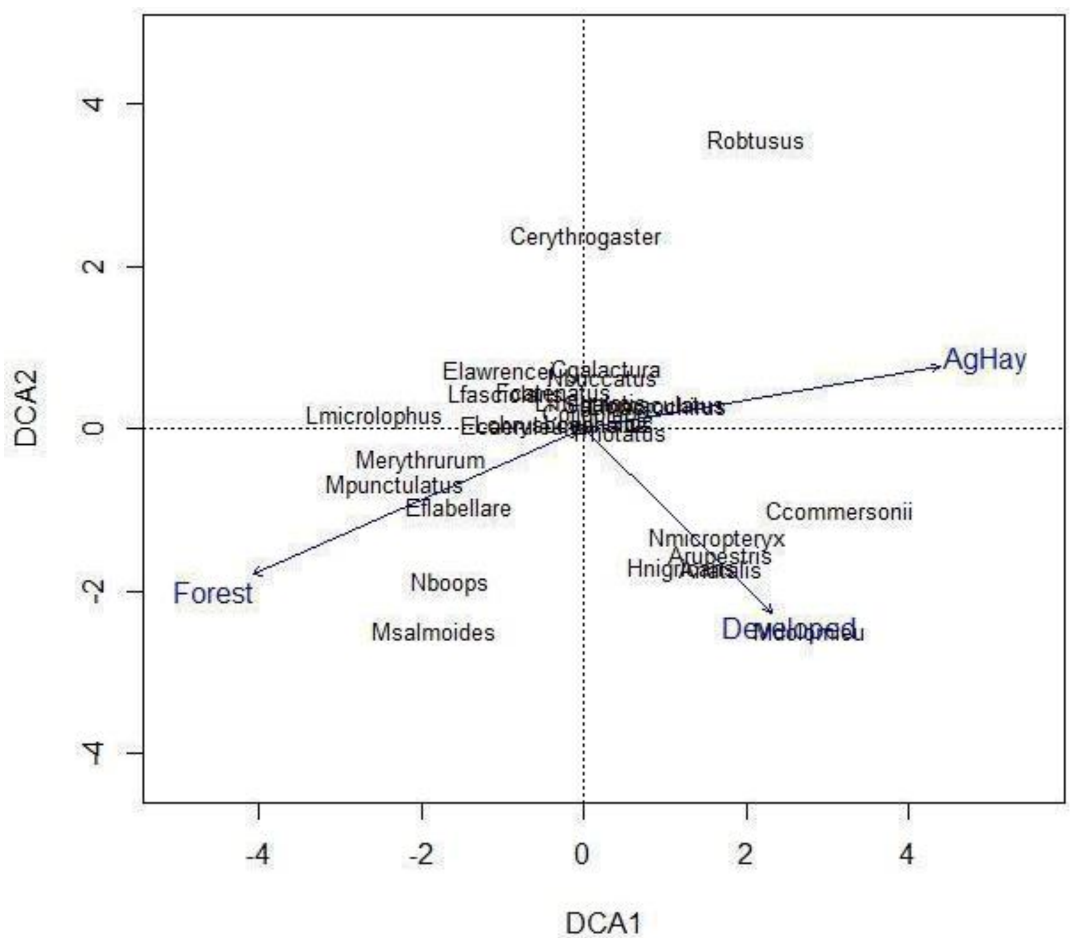

Figure 10. Ordinations from detrended correspondence analysis (DCA) of 2012 fish species, collected by Thomas and Brandt (2013), and LULC proportions from 100m buffer within each sub-watershed of the Buck Creek watershed in 2010. Names were abbreviated with the first letter of the genus, followed by the species name.

Results from the DCA for 1983 sub-watershed indicated that forest had a strong negative correlation with DCA1 (r^2= -0.99), while agricultural pasture had a strong positive correlation with DCA 2 (r^2=0.69) (Figure 11). Axis 1 explained 30.6% and axis 2 explained 12.6% of the proportions of variance explained by 1983 fish community data. Trends displayed by the ordination plot suggest that *L. chrysocephalus*, *E. caeruleum*, *S. atromaculatus*, *E. nebra*, and *H. nigricans* were associated with agriculture/pasture. *Lepomis cyanellus*, *E. flabellare*, Lepomis megalotis, and *N. telescopu*s were associated with forest. *M. dolomieu*, *C. commersonii*, *Pimephales notatus*, *A. rupestris*, and other tolerant species were associated with development.

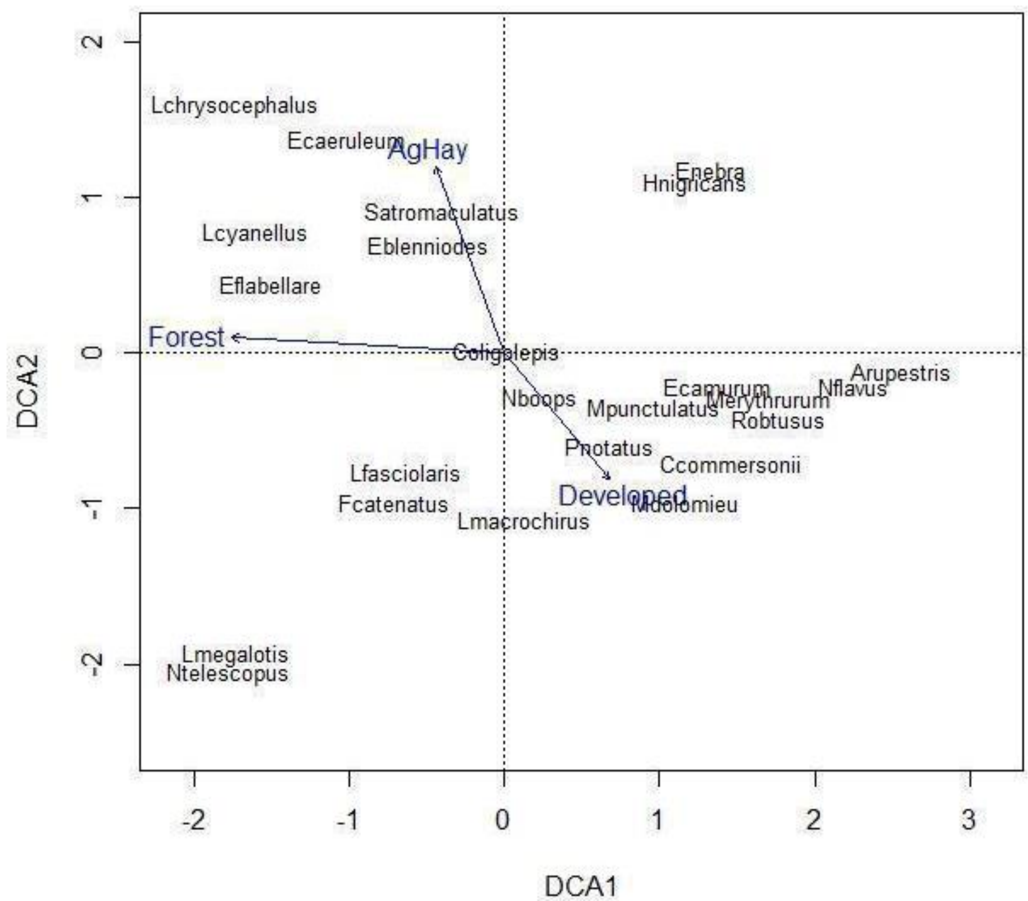

Figure 11. Ordinations from detrended correspondence analysis (DCA) of 1983 fish species, collected by Cicerello and Butler (1985), and LULC proportions from each sub-watershed of the Buck Creek watershed in 1983. Names were abbreviated with the first letter of the first letter of the genus, followed by the species name.

Results from the DCA for 2010 sub-watersheds indicated that forest had a strong negative correlation with DCA1 (r^2= -0.99), while agricultural/pasture had a strong positive correlation with DCA 1 (r^2=0.98) (Figure 12). Development had a positive correlation with DCA 2 (r^2=0.72). Axis 1 explained 32.1% and axis 2 explained 11.5% of the proportion of variance explained by the 2012 fish community data. Trends displayed by the ordination plot suggest that *Lepomis microlophus, Moxostoma* *erythrurum, M. punctulatus* were associated with forest, while *C. commersonii, Ameiurus natalis, A. rupestris, H. nigricans*, and *Micropterus dolomieu* were associated with agriculture/pasture.

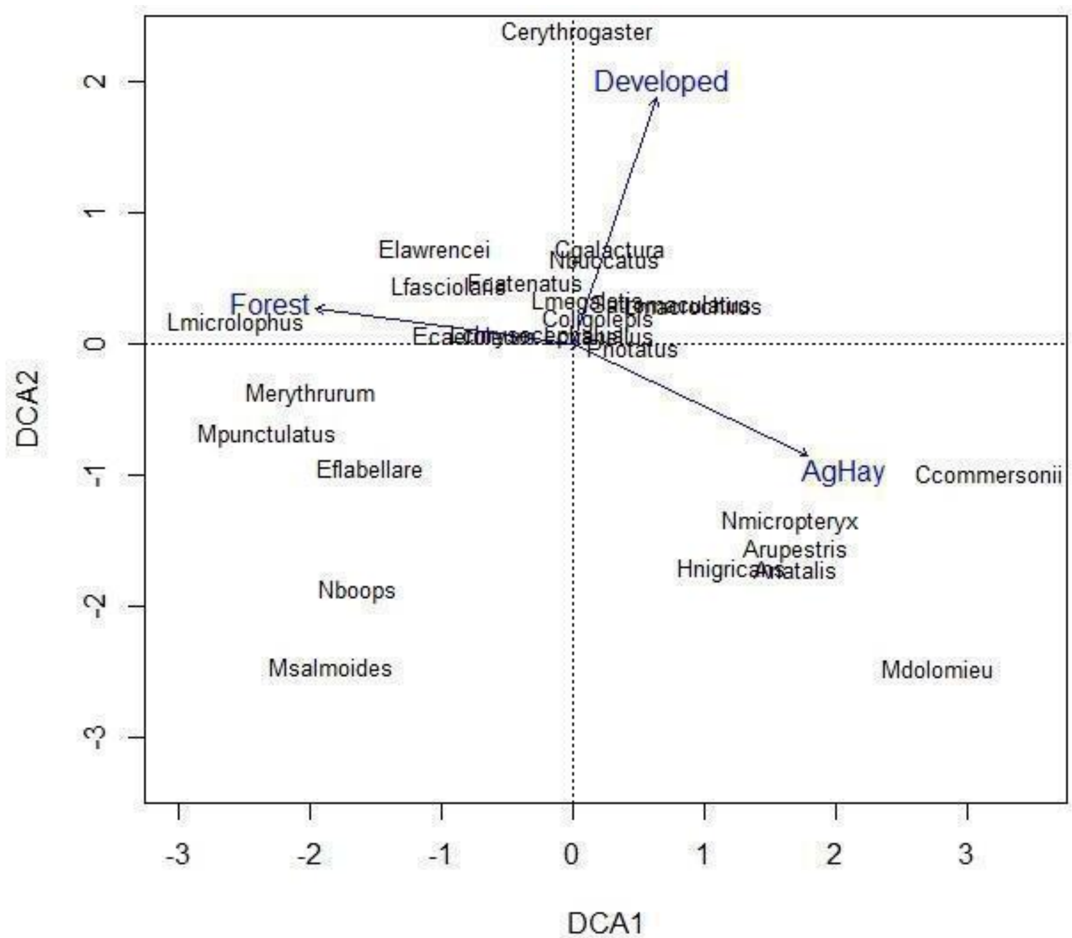

Figure 12. Ordinations from detrended correspondence analysis (DCA) of 2012 fish species, collected by Thomas and Brandt (2013), and LULC proportions from each sub-watershed of the Buck Creek watershed in 2010. Names were abbreviated with the first letter of the first letter of the genus, followed by the species name.

Management for the Buck Darter

Historically, the Buck Darter occurred in the Buck Creek mainstem, Brushy Creek, Gilmore Creek, Caney Creek, Crab Orchard Creek, Bee Lick Creek, Clifty Creek, and tributaries of Flat Lick Creek. Results from the PCA indicate that Crab Orchard Creek and Gilmore Creek showed the least amount of LULC change at the watershed level from 1983 to 2020 (Figure 13). At the 100 m buffer level, Brushy Creek and Bee Lick Creek remained associated with agriculture/pasture and exhibited the least change from agriculture/pasture to forest from 1983-2020 (Figure 14).

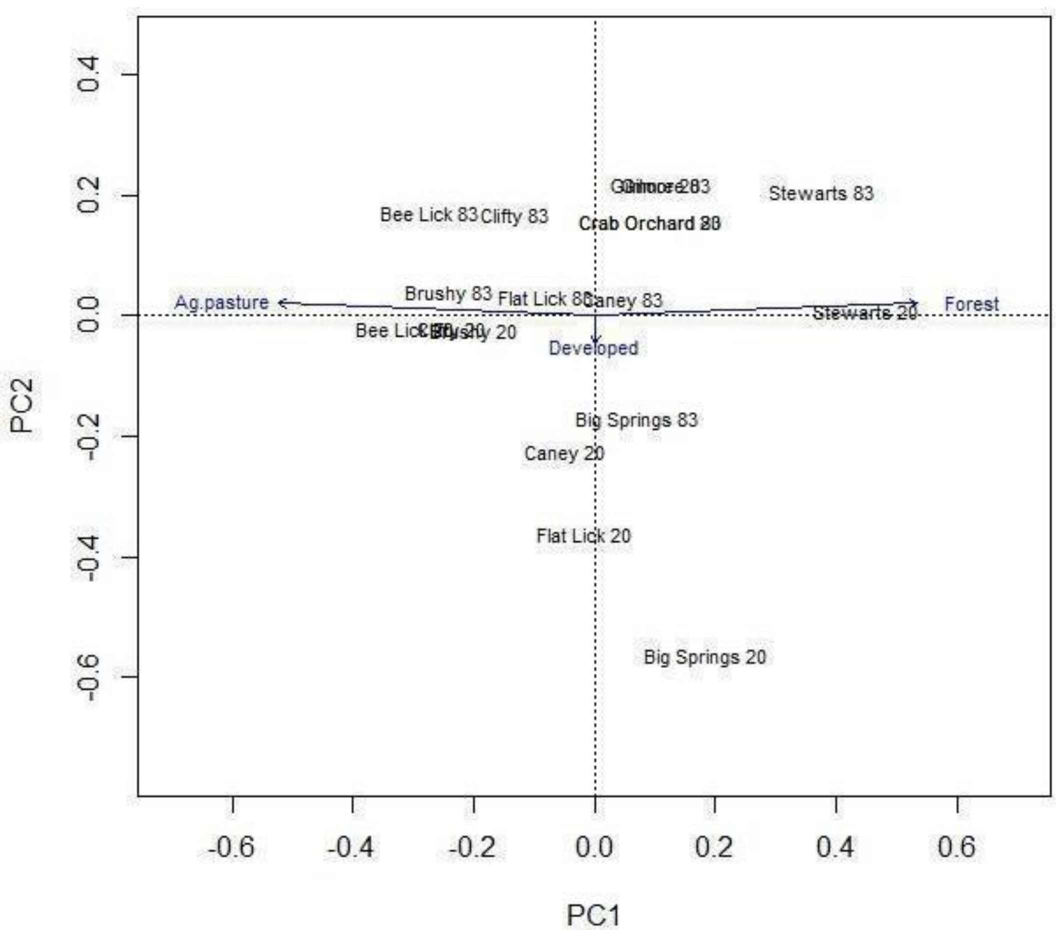

Figure 13. Principal component analysis (PCA) results of 1983 and 2020 sub-watershed LULC proportions from sub-watersheds with historic records of *E. nebra*.

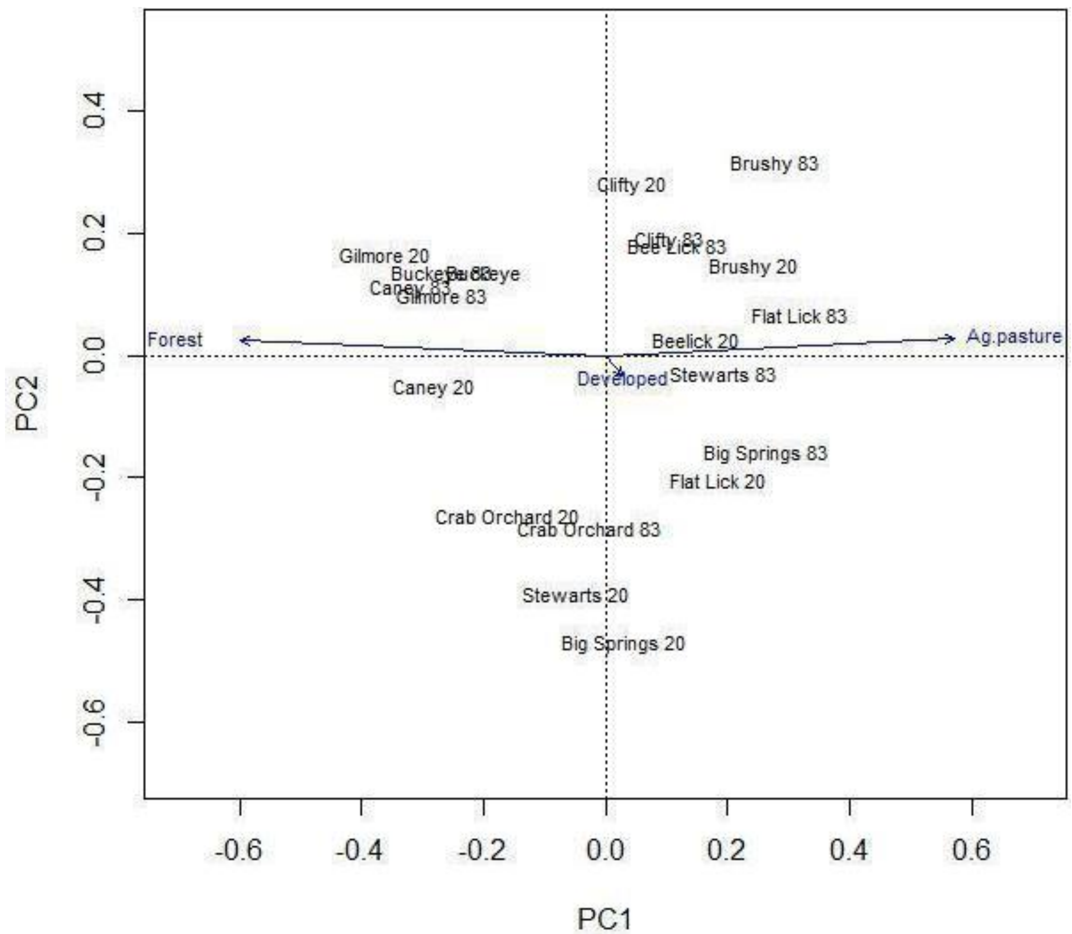

Figure 14. Principal component analysis (PCA) results of 1983 and 2020 100-meter LULC proportions from sub-watersheds with historic records of *E. nebra*.

Discussion

Relationship Between Fish Communities and LULC

Results illustrated relationships between the various fish community classifications and LULC classes present in 1983 and 2010. The physical effects of LULC changes on aquatic ecosystems have been well documented with advancements in spatial mapping since the 1990s (Argent & Carline, 2004). Forest dominated watersheds are critical to the biological integrity of aquatic systems due to the contribution of organic litter and woody debris, the reduction in stream bank erosion, and the reduction of sediment transport into aquatic systems (Karr & Schlosser, 1978; Stevens & Cummins, 1999). In 1983, Gilmore Creek had the highest proportion of forest, along with the greatest proportion of percid species (aside from Buck Creek mainstem) and 64% intolerant species. In 2012, there was a reduction of percid (-8%) and intolerant (-34%) species proportions, following a shift to agriculture/pasture being the dominant LULC class. Argent and Carline (2004) reported that within the Delaware, Susquehanna, and Ohio river basins, watersheds that contained greater than 90% forested land, headwater streams experienced few changes in fish communities from 1954 to 1995. We were unable to determine if heavily forested watersheds such as the ones examined in Argent and Carline (2004) caused little change in fish communities between years. In 1983, the sub-watershed with the highest forest proportion was Gilmore Creek with 50.8%, whereas in 2010, sub-watersheds with the highest proportion of forest were Crab Orchard Creek and Gilmore Creek, both with 48%.

Agricultural LULC is perhaps the most disruptive and detrimental to aquatic systems (Singh, 1992). Yearly applications of pesticides, tilling, fertilizing, and rotations of crops or grazing meadows leads to changes in infiltration, increased runoff, and the potential for contaminated runoff (Lenat, 1984; Singh, 1992). I found that the greatest losses in invertivores (-6.6% to -47.6%) occurred in Indian Creek, Brushy Creek, Flat Lick Creek, and Glade Fork Creek, with agriculture/pasture proportions greater than 57%. The greatest loss of intolerant species (-17.9% to -48%) occurred in Brushy Creek, Glade Fork Creek Creek, Gilmore Creek, and Indian Creek with agriculture/pasture proportions greater than 50%. These findings are similar to those of Wang et al. (1997) who demonstrated a negative relationship between the index of biotic integrity (IBI) and percent agriculture in 103 first-fifth order streams in Wisconsin, USA, showing that declines were greatest at sites where agriculture LULC exceeded 50%. Similar to Wang et al. (1997), Argent and Carline (2004) observed invertivore and intolerant species distributions decreasing as agricultural land proportions increased in various Pennsylvania watersheds. Barbour et al. (1997) suggest that high proportions of invertivores indicates a diverse community of benthic macroinvertebrates.

Flat Lick Creek (+1.63%) and Caney Creek (+0.22%) increased in developed LULC proportions, with centrarchid proportions increasing 29.5% and 21.1%, respectively. All sub-watersheds within the Buck Creek watershed had increases in centrarchid proportions, even in streams where they were absent in 1983. Our findings are similar to that of Onorato et al. (1998), who found that as urbanization of a watershed increased, cyprinid and percid distributions decreased, while centrarchids increased in distribution. Developed land, including impermeable surfaces such as roads, parking lots, and rooftops, increase runoff volumes to streams (Gustav et al., 1994) to levels nearly 16 times greater than would an undeveloped meadow the same size (Schueler, 1994). Additionally, urban development around streams can result in habitat alterations, nutrient overloading, and instream degradation of fish habitat (Scott et al., 1986).

The Division of Water collects water quality information that is integrated into the Water Quality Assessment Program for impaired streams in Kentucky, which is then submitted to Congress. In 1983, there were no reports of impaired streams within the Buck Creek watershed. Although, there was a reported fish kill in Big Spring branch, with approximately 100 fish harmed due to chloride inputs (Division of Water, 1990) and a fish kill in Sinking Creek, a sub-watershed located in the eastern portion of Pulaski County, resulting in approximately 400 fish dead due to organic enrichment from municipal waste (Division of Water, 1990). Integrated reports for 2010 indicated that Buck Creek, Bee Lick Creek, Gilmore Creek, and Indian Creek were listed as impaired (Division of Water, 2011). Sources of impairment for lower portions of Buck Creek included contamination of methylmercury (Division of Water, 2011). Sources of impairment for Bee Lick Creek included inputs of nitrate/nitrite and sedimentation because of agricultural/highway/road/bridge runoff, flow modifications, livestock grazing, and loss of riparian habitat (Division of Water, 2011). LULC proportions of Bee Lick Creek watershed indicated that agriculture/pasture comprised 75% of LULC and 100 m buffer proportions indicated 55.7% agriculture/pasture LULC. Due to channelization in Gilmore Creek and dredging/mining in Indian Creek sources of impairment included sedimentation and siltation (Division of Water, 2011). In 2020, Buck Creek, Bee Lick Creek, Big Spring Branch, Brushy Creek, Clifty Creek, Gilmore Creek, and Indian Creek remain listed on the 303 (d) list for impaired waters (Division of Water, 2021). Streams listed for the presence of E. coli which included Bee Lick Creek, Brushy Creek, and Clifty Creek are results of agriculture practices (Division of Water, 2020). All sub-watersheds impacted by E. coli had >67% agriculture/pasture LULC. Buck Creek remains listed for methylmercury (Division of Water, 2021). Gilmore and Indian Creek are both listed due to sedimentation and particle embeddedness because of channelization and dredging (Division of Water, 2021). Big Spring Branch is listed due to a decline in biota/habitat assessments due to habitat modification and inadequate instream habitat (Division of Water, 2021).

Spatial Scale

This investigation occurred at two spatial scales, the sub-watershed level and a 100 m buffer surrounding each stream within the sub-watersheds. This allowed for detection of large-scale changes in land use as well as for assessment of effects of stream buffer restoration efforts. Organizations including the Nature Conservancy, Kentucky Department of Fish and Wildlife Resources, Kentucky Transportation Cabinet, Natural Resources Conservation Service, Pulaski County, and United States Fish and Wildlife Service have all contributed to the conservation and restoration of riparian zones within the Buck Creek Watershed. The largest project was the restoration of the Pumphrey Tract. In 2005, 270 acres were partitioned and sold to local farmers in return for riparian zones. At the 100 m buffer scale, LULC proportions indicated that Big Spring Branch, Crab Orchard Creek, Glade Fork Creek, and Stewart Branch exhibited an increase in forest from 1983-2010, reflecting restoration of riparian buffers. Even though the 100 m buffer indicated that LULC of these sub-watersheds was predominantly forested in 2010, decreases in intolerant species, invertivores, cyprinids, and increases in centrarchids were observed. Many authors have observed LULC change at local scales (30m-100m buffers) but results rarely indicate correlations between LULC and fish community indices and become weak at local scales (Richards et al., 1996; Roth et al., 1996; Wang et al., 1997). My results concur with this assertion and suggest that LULC affecting resident fish communities in the Buck Creek watershed are most likely operating at a larger watershed scale.

Buck Darter Management

Our findings indicate that historic populations of *E. nebra* were located in streams that were predominantly agriculture/pasture LULC at the watershed level. In 2020, populations of *E. nebra* were restricted to Big Spring Branch and Stewart Branch. Both first order streams are predominantly forested, being well shaded and spring fed. Black (2018) found that stream temperature remained stable in Stewart Branch and Big Spring Branch. Both streams gradually increase in temperature throughout the spring (Black, 2018), possibly extending the spawning season. The sheer number of springs present on Big Spring Branch and Stewart Branch contributes to stable temperatures, but stream temperatures are also better regulated in forested watersheds than in open canopy watersheds (Gregory et al., 1991). Based on LULC proportions, I suggest that the reintroduction of *E. nebra* should occur at Gilmore Creek and Crab Orchard Creek due to high proportions of forest at the watershed and buffer level. Sponseller et al. (2001) found that stream temperature can experience large amounts of variability when stream side vegetation is removed in headwater watersheds. Observing interactions between LULC and fish communities was strongest at the watershed scale and conservation of natural ecosystems may require preservation of the entire watershed (Harding & Winterbourn, 1995). But this does not dismiss the importance of riparian restoration to pre-disturbance conditions. Richards et al. (1996) demonstrated that at local scales, riparian buffers were better predictors of sediment related habitat variables, including stream substrate characteristics and bank erosion, than at watershed scales. A restoration of riparian buffers in the Buck Creek watershed, specifically along Brushy Creek and Bee Lick Creek, would reduce transportation of sediment and pollutants (Aguiar et al., 2015). Restoration efforts would include fencing out cattle and allowing reforestation of native species within riparian zones. Riparian width should be considered when developing restoration/reforestation plans. Lin et al. (2011) recommends the ideal width of riparian buffers for trapping sediment alone is 4-8 meters, but a 15 m buffer is optimal for trapping soluble pollutants (Schmitt et al., 1999; Brumberg et al., 2021). Even after restoration/reforestation of riparian zones, it may take decades for aquatic fauna to return to pre-disturbance conditions (Harding & Winterbourn, 1995).

Problems

Changes in LULC class proportions between 1983 and 2010 were not as substantial as expected. There was little change between agriculture/pasture and forest LULC proportions from 1983 to 2010 at the watershed level. Much of the Buck Creek watershed LULC had been converted to agriculture/pasture prior to 1983. Market et al. (2003) reported that it may take years to decades to see changes in aquatic bioindicators due to issues in aquatic ecosystems. Fish communities may have demonstrated a delayed response to previous conversion from forest to agriculture/pasture that occurred prior to the 1950's. A limiting factor related to aerial images involves the time of year each image was taken. In 1983, images were taken in early March when flora had yet to develop leaves (leaf off imagery). In 2010 and 2020, images were taken during the late summer months when leaves were fully developed. This led to incorrectly classified agriculture/pasture pixels occurring in patches of forests. Although incorrectly classified pixels occurred in each year raster, accuracy assessments determined the raster to be sufficient for analysis. The lack of standardized sampling protocols in 1983 made analysis of fish community data difficult. There were 1733 fish collected in 1983, compared to 565 fish collected in 2012. This may be due to not establishing a standard reach length and sampling time/effort prior to sampling in 1983, whereas Thomas and Brandt (2013) followed the DOW wadeable stream protocols that define 100-200 meter reaches.

Future Work

There are no recent benthic macroinvertebrate assessments performed throughout the Buck Creek watershed. Aquatic insect communities are widely used in monitoring programs due to diverse life history, morphological features, behavioral adaptations, and the fact that benthic macroinvertebrates are directly affected by disturbances in relation to instream habitats (Plafkin et al., 1989; Buss et al., 2015; Resh & McElravy, 1993). Many of the sub-watersheds are surrounded by agriculture in the form of livestock and row crops. Sampling habitat characteristics, including channel substrate size and type, channel gradient, stream size and channel dimensions, complexity and cover, and structures of riparian zones can provide quantitative data that can be used to compare both fish and benthic macroinvertebrate communities to determine if significant relationships occur between LULC and aquatic communities.

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APPENDICES

Appendix A: Raw fish count data from sub-watersheds of the Buck Creek watershed in 1983, obtained from Cicerello and Butler (1983).

Appendix A: Raw fish count data from sub-watersheds of the Buck Creek watershed in 1983, obtained from Cicerello and Butler (1983).

Species	Buck	Brushy	Flat Lick	Caney	Crab Orchard	Glade Fork	Gilmore	Indian	Buckeye
C. oligolepis	199	9	8	4	5	1	2	1	12
P. erythrogaster	12	0	0	0	0	0	6	0	0
C. galactura	116	19	0	0	0	0	0	0	0
C. spiloptera	32	11	0	0	0	0	0	0	0
E. dissimilis	1	0	0	0	0	0	0	0	0
H. amblops	39	0	0	0	1	0	0	0	0
L. chrysocephalus	156	15	0	0	0	2	8	5	0
L. fasciolaris	387	81	8	2	8	21	15	18	0
N. boops	21	8	0	0	2	0	0	0	0
E. buccata	4	0	0	0	0	0	0	0	0
N. micropteryx	47	0	0	0	1	0	0	0	0
N. photogenis	1	0	0	0	0	0	0	0	0
N. telescopus	228	28	0	0	2	15	0	36	0
P. notatus	199	32	11	9	20	4	1	4	4
P. promelas	0	0	0	0	0	0	0	0	0
P. vigilax	3	0	0	0	0	0	0	0	3
R. obtusus	28	0	9	2	9	1	0	0	0
S. atromaculatus	33	4	2	0	5	3	5	2	0
C. commersonii	8	0	0	1	6	0	0	1	0
H. nigricans	46	3	3	2	4	0	2	0	0

M. duquesnei	2	0	0	0	0	0	0	0	0
M. erythrurum	29	4	0	1	4	0	0	0	0
A. natalis	3	0	0	0	0	0	0	0	0
N. flavus	7	3	0	1	0	0	0	0	0
L. sicculus	1	0	0	0	0	0	0	0	0
F. catenatus	81	7	0	1	1	3	2	4	0
G. affinis	0	0	0	0	0	0	0	0	0
C. carolinae	6	0	0	0	0	0	0	0	0
A. rupestris	21	3	1	2	0	0	0	0	0
L. cyanellus	9	3	0	0	0	1	1	0	0
L. macrochirus	43	4	2	0	5	1	0	3	0
L. megalotis	37	4	0	0	0	1	0	3	0
L. microlophus	0	0	0	0	0	0	0	0	0
M. dolomieu	19	1	0	2	3	1	0	1	0
M. punctulatus	20	3	0	0	4	0	0	0	0
M. salmoides	0	0	0	0	0	0	0	0	0
E. blenniodes	64	5	0	0	2	0	1	1	1
E. caeruleum	171	12	0	0	6	1	9	6	2
E. camurum	17	7	0	1	0	0	0	0	0
E. flabellare	100	9	0	0	0	1	3	4	1
E. gore	0	0	0	0	0	0	0	0	0
E. lawrencei	36	0	0	0	0	0	0	0	0
E. maydeni	2	0	0	0	0	0	0	0	0

E. nigrum	0	0	0	0	0	0	0	0	0
E. sanguifluum	36	0	0	0	0	0	0	0	0
E. nebra	74	11	2	5	1	0	3	0	0
E. zonale	12	0	0	0	0	0	0	0	0
P. caprodes	13	1	0	0	0	0	0	0	0
C. whipplei	1	1	0	0	0	0	0	0	0
E. stigmaeum	54	3	0	0	0	0	1	0	0
P. maculata	1	1	0	0	0	0	0	0	0

Appendix B: Raw fish count data from sub-watersheds of the Buck Creek watershed from 2012, obtained from Thomas and Brandt (2013).

Appendix B: Raw fish count data from sub-watersheds of the Buck Creek watershed from 2012, obtained from Thomas and Brandt (2013).

Species	Buck	Brushy	Flat Lick	Caney	Crab Orchard	Glade Fork	Gilmore	Indian	Buckeye
C. oligolepis	42	8	4	1	2	1	2	1	1
P. erythrogaster	7	0	2	0	0	1	1	0	1
C. galactura	29	7	0	1	0	0	0	0	1
C. spiloptera	20	0	0	0	0	0	0	0	0
E. dissimilis	10	0	0	0	0	0	0	0	0
H. amblops	13	0	0	0	0	0	0	0	0
L. chrysocephalus	41	9	2	1	2	1	2	1	1
L. fasciolaris	30	7	1	1	2	1	2	0	1
N. boops	19	5	0	0	1	1	1	0	0
E. buccata	16	6	0	0	1	1	0	1	1
N. micropteryx	19	2	0	0	0	0	0	1	0
N. photogenis	10	0	0	0	0	0	0	0	0
N. telescopus	18	3	0	0	0	0	0	0	0
P. notatus	37	9	3	0	2	1	1	1	1
P. promelas	1	0	0	0	0	0	0	0	0

P. vigilax	1	0	0	0	0	0	0	0	0
R. obtusus	4	0	3	0	0	0	0	0	1
S. atromaculatus	23	7	4	0	2	1	1	1	1
C. commersonii	6	1	3	0	0	0	0	0	0
H. nigricans	31	5	4	0	1	1	0	0	0
M. duquesnei	13	2	0	0	0	0	0	0	0
M. erythrurum	20	1	0	0	1	1	1	0	0
A. natalis	15	5	3	0	1	0	0	1	0
N. flavus	8	0	0	1	0	0	0	0	0
L. sicculus	18	3	0	0	0	0	0	0	0
F. catenatus	33	7	1	1	1	1	2	1	1
G. affinis	8	1	0	0	0	0	0	0	0
C. carolinae	9	0	0	0	0	0	0	0	0
A. rupestris	32	7	4	1	0	0	0	1	0
L. cyanellus	36	9	4	1	2	1	2	1	1
L. macrochirus	36	7	4	1	2	0	1	1	1
L. megalotis	36	7	4	1	2	1	1	0	1
L. microlophus	4	0	0	0	1	0	1	0	0

M. dolomieu	20	2	2	0	0	0	0	0	0
M. punctulatus	14	1	0	0	1	0	1	0	0
M. salmoides	13	1	0	0	1	0	0	0	0
E. blenniodes	25	5	0	0	0	0	0	0	0
E. caeruleum	38	9	0	0	2	1	2	1	1
E. camurum	18	1	0	0	0	0	0	0	0
E. flabellare	17	5	0	1	2	1	2	0	0
E. gore	19	0	0	0	0	0	0	0	0
E. lawrencei	14	5	0	1	2	1	1	0	1
E. maydeni	3	0	0	0	0	0	0	0	0
E. nigrum	1	0	0	0	0	0	0	0	0
E. sanguifluum	16	2	0	0	0	0	0	0	0
E. nebra	0	0	2	0	0	0	0	0	0
E. zonale	13	0	0	0	0	0	0	0	0
P. caprodes	17	1	0	0	0	0	0	0	0