Geomorphic and Sedimentologic Analysis of Four Streams in Southeastern Alabama, Channel and Habitat Response to Changes in Land Use

by

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Abstract

Streams of the Southeastern US have varying degrees of degradation due to the long history of agricultural land use, reflected in incising and eroding banks with aggradation of fine grained legacy sediment. These effects of land use alteration result in a reduction in the physical and biological function of the stream, and thus inherently the biotic populations of the stream. Building upon biological and geomorphic data collected in 2011 we quantified sediment dynamics and channel and habitat response to changes in land use in four drainages in the Tallapoosa Basin, Alabama. Known land use alterations have occurred in these drainages since 2011 with deciduous forest conversion to conifer (silviculture operations) or to urban development.

The data shows the more urbanized drainages have the lowest fish diversity (Shannon *H'*) and richness, and since 2011 fish diversity and catch has decreased across all sites. Also, at all sites there has been a decline in macrobenthic diversity, and a change in feeding group distributions from collector/filterer to collector/gatherer. The crayfish populations have also declined since 2011. Furthermore, there was also marked differences in biotic populations across sites due to their land uses and drainage areas. The more urbanized drainage had the greatest suspended sediment concentration, but average suspended sediment concentration was less than 10 ppm for all sites. At all sites, the banks are composed of medium silt, and bank failure/slumping is evident in the urbanized drainages. From 2011 to 2016 there has been a

coarsening of bed substrate, with the exception of one site, and increase in exposure of bedrock. The width to depth ratio (WDR) and shear stress has increased at all but one site since 2011.

These results suggest that changes in land use, even on a short time scale of five years, has had marked effects on habitat quality and morphology of the channel reaches. Changes in bed substrate could be a result of increases in stream power, bank erosion appears to be the primary source of sediment delivery to the stream, and the increasing WDR is a symptom of channel widening due to bank stability. These data paired with the geomorphic and sedimentological characteristics of each site can inform restoration efforts and address the potential impacts of these alterations on local biotic populations if forest conversion continues in the Alabama Piedmont.

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My sincerest thanks to the faculty, staff, and fellow students at the Department of Geosciences for enriching and enhancing my experience at Auburn University, and for whom without I would not have graduated. I've had made lifelong friends during my time in Auburn and will cherish my time here. And lastly, I express the upmost gratitude to my family for their unending support throughout this experience.

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INTRODUCTION

Sediment, although a natural constituent of lotic systems, is the most common pollutant of rivers and streams in the United States (Macfall et al. 2014; Witmer et al 2009). Transportation and deposition of sediment in streams is natural, but land use modification (greater impervious surface, agriculture) within watersheds intensifies sediment flux and alters the morphology of a river (Pope and Odhiambo 2014; Hupp et al. 2013; Ricker et. al 2008). Morphological adjustments to land use alteration in a watershed are incised floodplains, and concave upward profiles of stream banks resulting in bank failure and reduced floodplain connectivity (Pope and Odhiambo 2014; Hupp et al. 2013; Gellis et. al 2009; Ricker et. al 2008). Urban and agricultural land use often limit floodplain and wetland effectiveness as sediment and nutrient sinks, causing enhanced erosion due to impervious surfaces and animal grazing respectively (Hupp et al. 2013; Ricker et al. 2008). The effect of land use alteration can be seen in watersheds in short-term time periods, as will be shown in my study.

The resulting siltation from land use disturbance also degrades aquatic habitats, where fish reproduction and photosynthesis of sub-aquatic vegetation is limited (Witmer et al. 2009; Allan et al. 2004). Understanding the relationship between the natural and anthropogenic induced physical processes is complex, but necessary to tease out how stream morphology and sediment load vary with respect to land use alteration and their inherent impacts on biological populations (Figure 1). This recently emerging field in fluvial studies is called biogeomorphology, which examines physical and biological processes that interact to produce equilibrated ecosystems (Osterkamp et al. 2012).

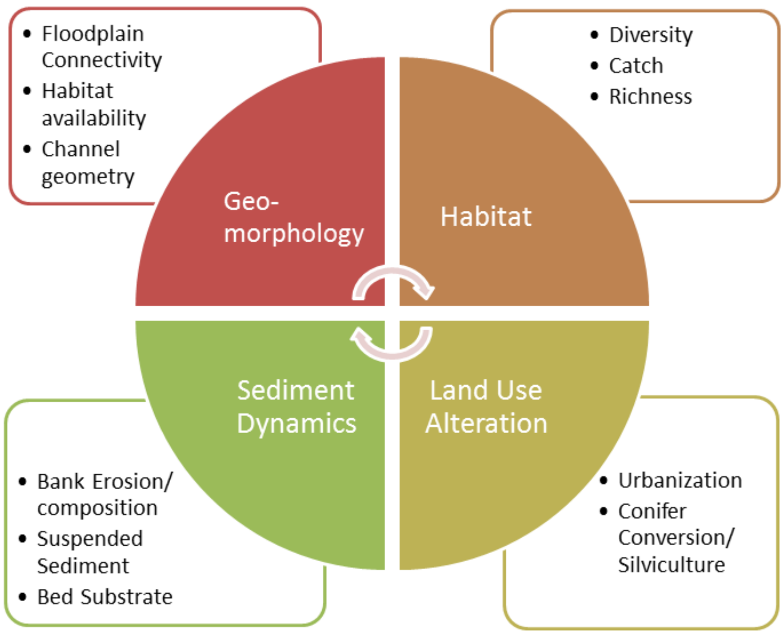


Figure 1: Model demonstrating the interplay of geomorphology, habitat, land use alteration, and sediment dynamics.

Landscape alteration can manifest in widening channels or incision, increased suspended sediment loads, and changes in bank/bed composition. The biotic populations inhabiting streams can reflect these landscape disturbances and changes in sediment dynamics, ultimately, providing insight into the health of a watershed (Simpson et al. 2014; Saalfield et al. 2012, Gangloff and Feminella 2007; Helms et al. 2005). Furthermore, fish populations have a longer residence time than benthic invertebrates and crayfish populations, and can reflect longer term changes of geomorphology and surrounding land use (Saalfied et al. 2012; Lammert and Allan, 1999). Stressed ecosystems typically contain a community dominated by smaller, rapidly reproducing, generalist species and lower diversity (Odum 1985; Rapport et al. 1985). Additionally, altered watersheds will experience a shift in benthic invertebrate assemblage mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Tricoptera) to more chironimid midges (Diptera) (Simpson et al. 2014). This study addresses short-term, watershed-scale land use alteration effects on four watersheds quantifying habitat/channel response coupled with unknown sedimentologic data.

Statement of Purpose

In Alabama recent biogeomorphic work has focused on Rosgen stream classification schemes and aquatic biota (Simpson et al. 2014; Helms et al. 2016), but in-depth sedimentologic characterization of streams has not been performed in the Alabama Piedmont. This research builds on previous work, integrating land use change analysis, biotic data, and geomorphologic field methods to examine morphologic and sediment controls (inherent vs. human induced) on habitats of varying quality. Using data collected by Helms et al. (2016), I compared changes in geomorphology and habitat from 2011 to 2016, characterized bank stability and erosion rates, and suspended sediment concentrations in four headwater streams within the Tallapoosa River Basin.

REGIONAL SETTING

The Tallapoosa River flows south-southwest from Paulding, Georgia in the Piedmont upland region joining the Coosa River in the East Gulf Coastal Plain of Alabama to form the Alabama River (Dennard et al. 2009; Griffith et al. 2001; Figure 2). The four focal Piedmont headwater streams in this study are Osborn Creek and Jones Creek in the Middle Tallapoosa and Clara Creek and Ropes Creek in the Lower Tallapoosa (Figure 2). Osborn and Jones Creek are in the Hillabee sub-basin and Clara and Ropes Creek are in the Saugahatchee sub-basin (Figure 2).

The major land cover types of the Tallapoosa River Basin are agriculture, residential development, and forested, but much of the forested areas is managed forestry operations. The most densely urbanized areas are Alexander City, Auburn/Opelika area, and Montgomery in order of increased development (Jin et al. 2013).The soils in the Middle and Lower Tallapoosa are in the Pacolet, Madison, and Cecil series, having a sandy loam/clay loam surface layer and deep red clay subsoil (Kara et al. 2014; Mitchell and Loerch 2008; GDNR: TRBMP 1998). Pacolet, Madison, and Cecil soils are well drained, with moderate permeability and runoff is moderate to rapid which may contribute largely to the sedimentation problem in the Lower Tallapoosa (Mitchell and Loerch 2008). These soils in the Piedmont of Alabama are derived primarily from granite, and mica schists enriched in quartz, feldspar, mica, and Mg-Fe silicates (Mitchell and Loerch 2008; GDNR: TRBMP 1998; Szabo et al. 1988). The soils in the Tallapoosa River Basin are a result of the Piedmont geology, shown in Figure 3, which primarily consists of extensively folded and faulted felsic igneous and high grade metamorphic rocks

Precambrian to Paleozoic in age (Szabo et al. 1988). Also the study area has extensive areas of highly permeable saprolite weathered from the Paleozoic schists and meta-igneous rocks (Poff et al. 2006). Saprolite, also called "rotten rock," is common in the Southern Piedmont because of the humid climate and has its own inherent effect on geomorphology/sedimentation (Poff et al. 2006; Daniels 1987). Saprolite is easily eroded, with a bulk density of 1.3-1.4 and moderate to low permeability, an example of where natural weathering patterns exacerbate erosional processes and sedimentation of watersheds in the Southern Piedmont (Daniels 1987).

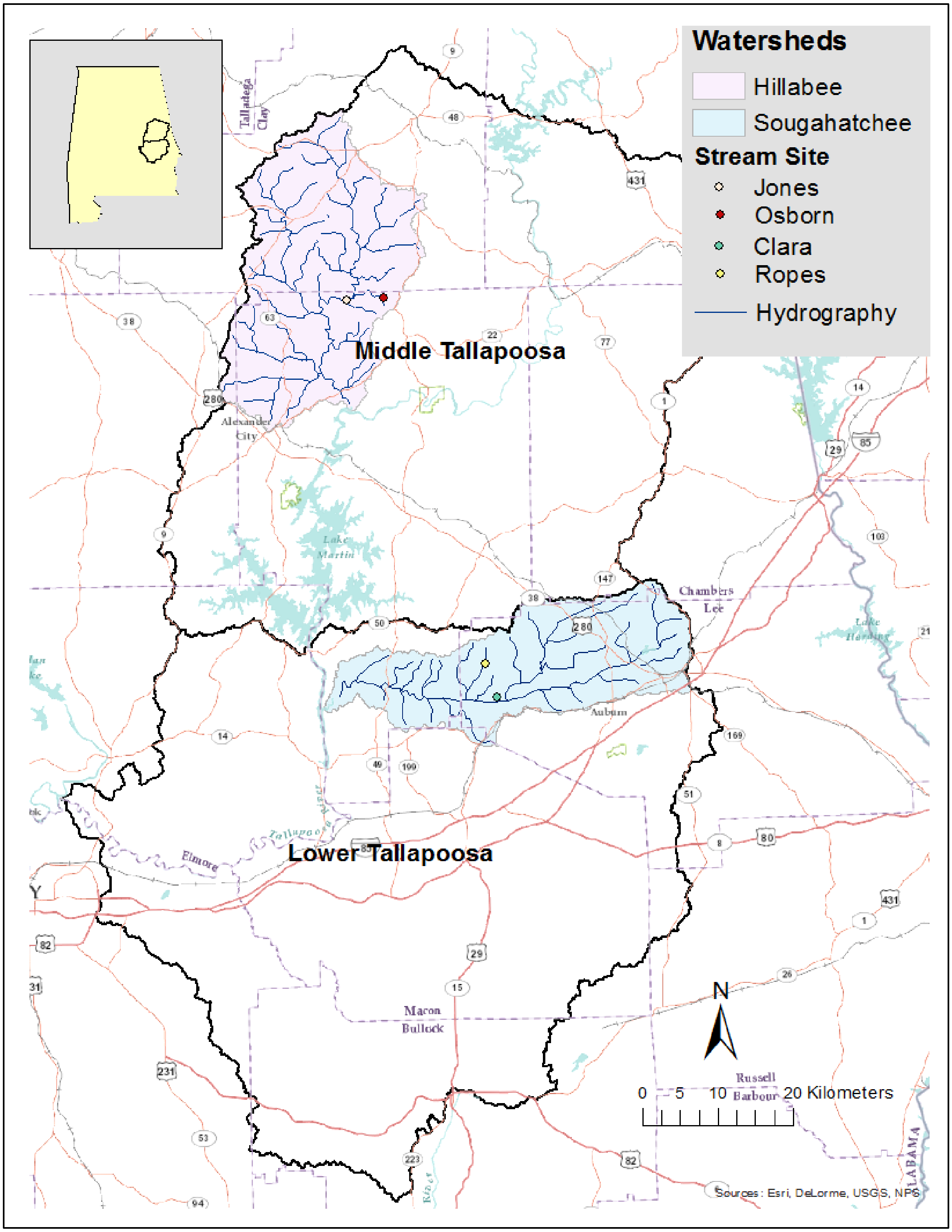


Figure 2: Reference map of the Hillabee and Saugahatchee Sub-basin within the Middle and Lower Tallapoosa Basin, respectively.

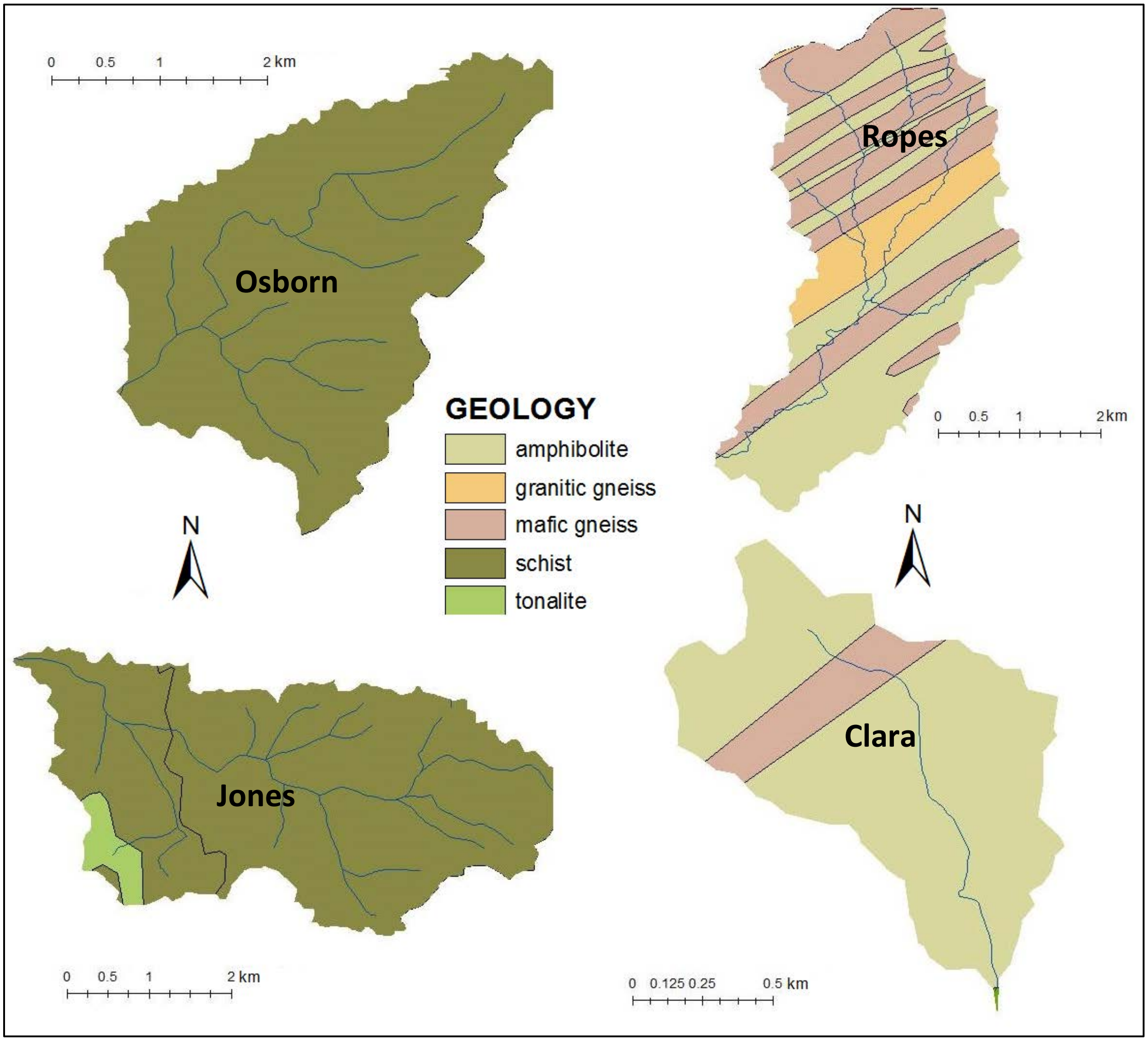


Figure 3: Geology of the four watersheds.

LITERATURE REVIEW

Several studies in Southeastern Alabama stream systems have mainly focused on aquatic biota, and their correlation to various metrics such as land use or stream dimensions (Simpson et al. 2014; Saalfield et al. 2012; Gangloff and Feminella 2007; Tabit and Johnson 2002), but in-depth sedimentologic characterization coupled with biota is still lacking. Hydrologic and channel response to urban land use has been well documented (Macfall et al. 2014; Poff et al. 2006; Walsh et al. 2005; Allan et. al 2004; Jones et al. 2000), however interdisciplinary approaches studying habitat and channel response of watersheds to forest conversion is deficient.

Geomorphology and land use research

The Haw River watershed has had a history of land clearing for agriculture, forest regrowth, and subsequent surburban developement similar to Piedmont streams of Alabama. Macfall et al. (2014) studied the Haw River in North Carolina and asessed the BEHI of several sites. Sites with low BEHI contained extensive vegetation (rooting) stabilizing banks, and low bank angles limiting erosion due to slope whereas sites with high BEHI scores were characterized by undercut trees and high bank angles (Macfall et al. 2014). The Haw River widened (bank retreat) 2.3 m over 6 years, which is common in disturbed streams, and as the river widened BEHI decreased (Macfall et al. 2014). The majority of the streams were characterized as having high BEHI (Macfall et al. 2014). These results are typical of the Piedmont region where erosion of legacy sedimentation, remnant of historical agricultural land use followed by urbanization causes incision (Macfall et al. 2014; Hupp et al. 2013). The land use history in the Haw is similar to that of the Tallapoosa, and similar channel response has been observed in this study.

Jones et al. (2000) studied stream channel response to roadway cuts in managed forestlands in Oregon. They found that during rainfall events landslides commonly occur on the downslope side of a road segment (Jones et al. 2000). Although the study area was mostly fir tree forest growth, road networks still had a substantial effect on the streams biologically and geomorphologically, which emphasizes the importance of factoring in land use when conducting sedimentologic studies of fluvial systems (Jones et al. 2000). Also Jones et al. (2000) found that peak flood discharges were much higher in roaded catchments, whether the flood peak magnitude increase was a result of forest clearing or roadways, the findings suggest land use change as a potential driver of ecological alteration on receiving streams, and that timber harvesting can affect stream morphology greatly. These findings suggest that at Osborn Creek and Jones Creek, currently owned by silviculture operations, have geomorphically changed due to forest harvesting.

Poff et al. (2006), divided the US into four regions: Southeast, Northwest, Southwest, and Central Region and analyzed the hydrologic variation in streams pre- and post-dam removal. Specifically they found that in agricultural watersheds flood peaks (“flashiness”) were intensified 8-33%, and in urban watersheds peaks intensified 22-84% (Poff et al. 2006). Such increases in flashiness can have severe implications for channel stability/morphology as the frequent rapid small flows cause bank instability, encourages bank retreat, and the resuspension of legacy sediments (Hupp et al. 2013; Poff et al. 2006).

Local ecological and land use research

Saalfield et al. (2012) studied fish assemblages in six streams in the Tallapoosa River and found that the contemporary land uses within the watershed had been negatively affecting fish assemblages. As expected in the forested stream areas, fish assemblages were diverse, but as the percent of agricultural land use increased, an integrative benthic index significantly ($p<0.05$) Furthermore, nutrient concentrations (total nitrogen, total phosphorous, total suspended solids) significantly increased as percent of agricultural land use increased (Saalfied et al. 2012). Commonly in agricultural areas nutrients such as N, C, and P adhere to soils and runoff into streams; evaluating suspended sediment concentrations within streams can be predictive of associated nutrient flux to receiving streams.

Similarly to Saalfied et al. (2012), Tabit and Johnson (2002) divided Buffalo Creek, a tributary of the Upper Tallapoosa Basin watershed into five regions based on geography, stream order, slope, and anthropogenic impact and compared fish assemblages across the regions (Tabit and Johnson 2002). The most impacted region which contained copper industrial waste and was channelized, had lower species diversity and evenness than the other regions (Tabit and Johnson 2002). These results mirror the findings of Saalified (2012) demonstrating that land use of a basin affects biological populations and can indicate degraded water quality.

Local geomorphology and ecologolical research

Previous studies involving geomorphology and aquatic populations in the Southeast have shown geomorphic and hydraulic factors influence fish and invertebrate richness and abundance (Simpson et al. 2014, Gangloff and Feminella 2007). Gangloff and Feminella (2007) in the Coosa River found that mussel populations were significantly linked to geomorphic dimensions. Simpson et al. (2014) used the Bank Erosion Hazard Index (BEHI), which estimates bank erosion based on measured physical characteristics, to predict fish, macroinvertebrate, and crayfish populations in Osborn Creek, a tributary of the Middle Tallapoosa sub-basin. There was an inverse relationship between macroinvertebrate richness and BEHI score (erosion potential) but no significant relationships between fish populations and BEHI, suggesting scale mismatches in biotic responses (Simpson et al. 2014). Overall, these studies suggests that biotic assemblages respond to changes in stream geomorphology and flow conditions, specifically high floodstage flow conditions. In my study, I analyzed short-term reach scale changes in geomorphology and biology, coupled with sedimentological characterization of the bed and bank to understand watershed response to decidious forest conversion to conifer or development.

STUDY SITES

The focus of this study is on headwater streams because although small, they comprise the majority of stream miles flowing in the United States and it has been well established that headwaters affect changes in channels downstream (Fritz et al. 2006; Poff et al. 2006; Kondolf et al. 2002). Furthermore, smaller streams are also more likely to reflect land use signatures, allowing for better interpretations on the geomorphic-sedimentologic-ecological interactions (Fritz et al. 2006; Poff et al. 2006; Kondolf et al. 2002). From the 21 sites studied by Helms et al. in 2011, I chose two headwater streams from the Hillabee sub-basin (Osborn and Jones Creek) and two headwater streams from the Saugahatchee sub-basin (Clara and Ropes Creek).

I chose these four sites because of their differences in land use cover spatially, ease of access, perennial nature, and varying drainage areas (Figure 4a. and 4b., Table 1). I wanted to examine geomorphic variation over temporal and spatial scales. All of the streams were classified as C or E using Rosgen's stream classification system (Brantley et al. 2013). C and E streams have moderate to high sinuosity, pool-riffle environments and are slightly entrenched (Rosgen 1994).

USGS Station ID	Sub-basin	Drainage Area (km²)	Site	Drainage Area (km²)
02415000	Saugahatchee	726	Clara	0.96
			Ropes	10.80
02418230	Hillabee	562	Osborn	8.06
			Jones	12.39

Table 1: Drainage area and USGS station ID of the two Sub-basins, and headwater streams' drainage areas.

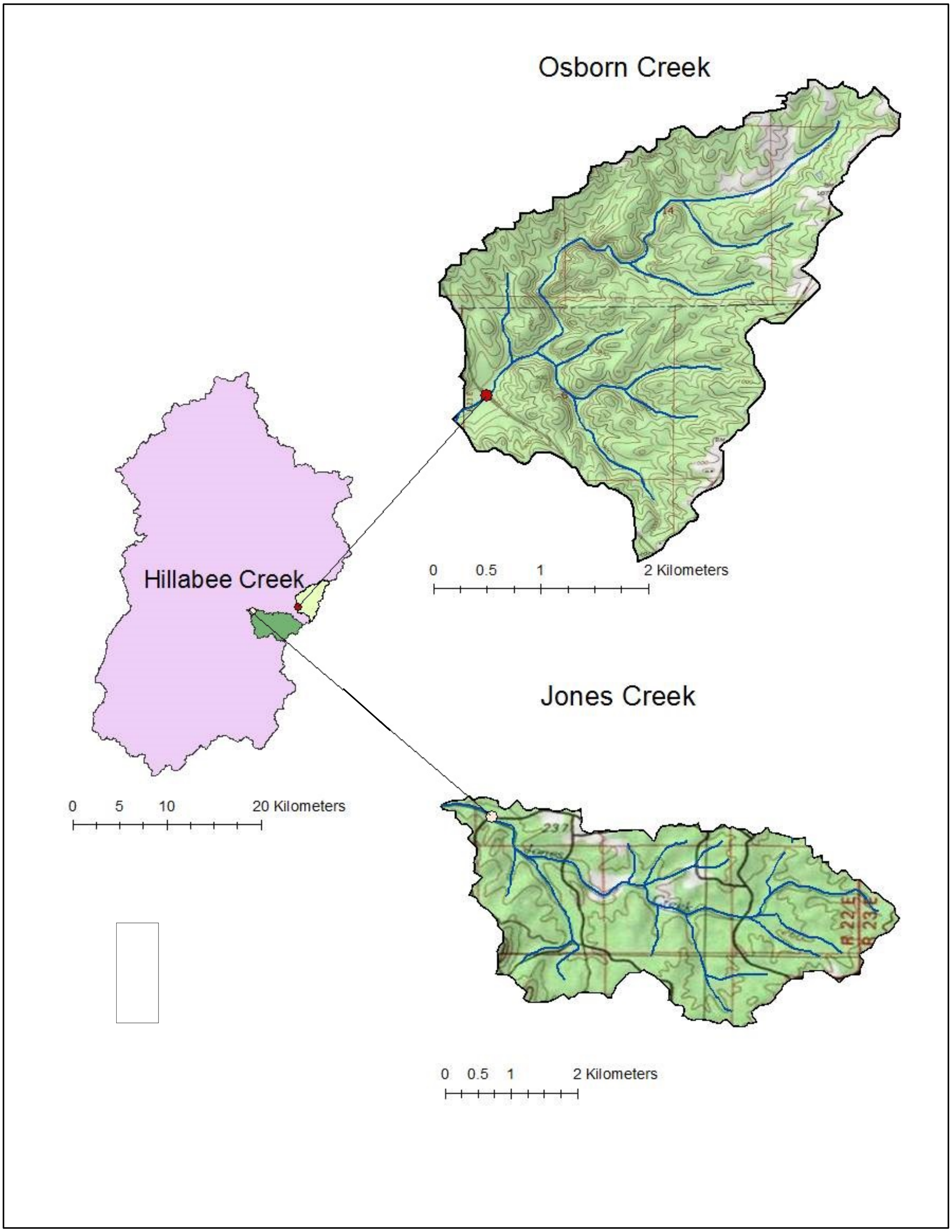


Figure 4a.: Reference map of Osborn and Jones Watersheds within the Hillabee Sub-basin.

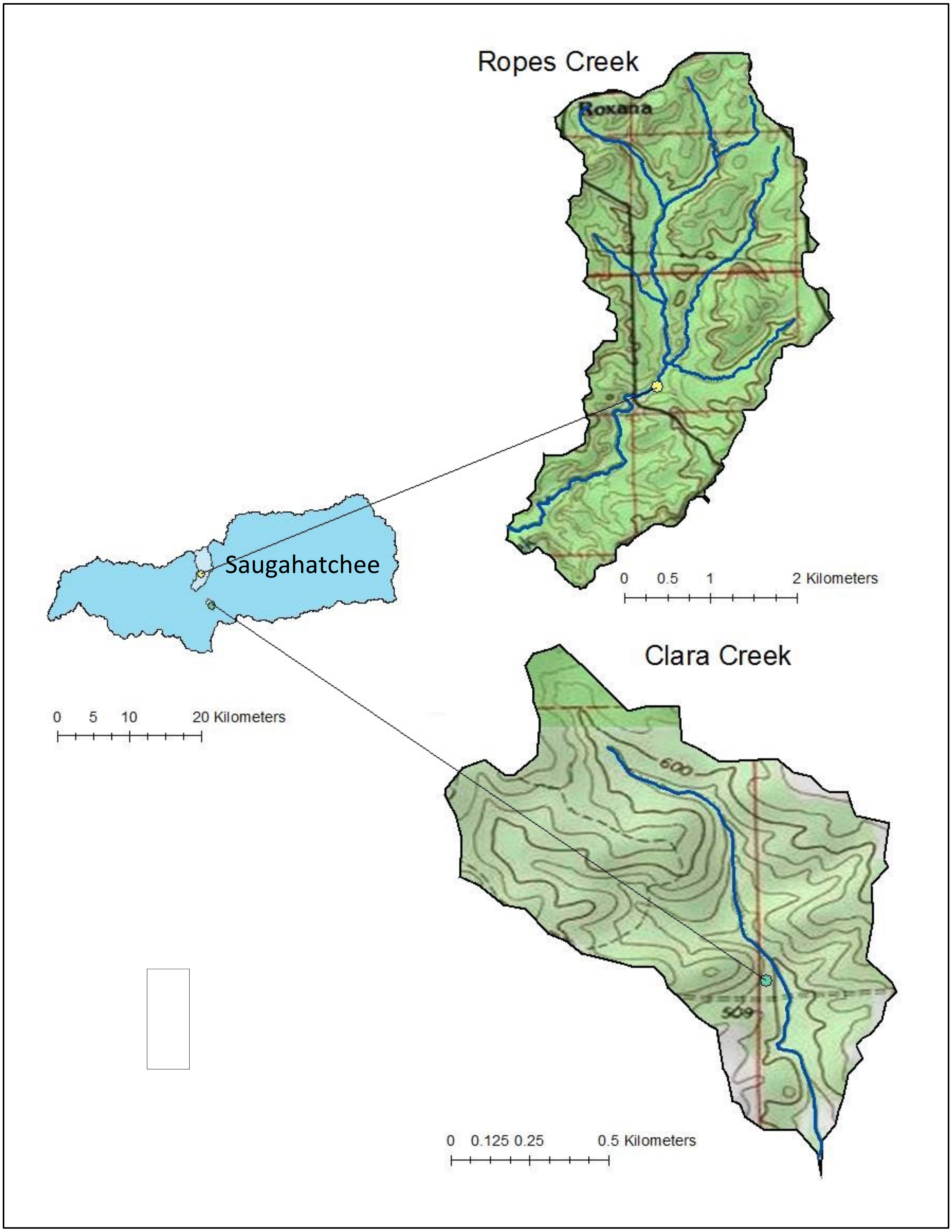


Figure 4b.: Reference map of Clara and Ropes Watersheds within the Saugahatchee Sub-basin.

OBJECTIVES

- Characterize longitudinal and cross-sectional dimensions of the four stream reaches
- Characterize bed and bank sediment composition
- Quantify bank erosion
- Assess/quantify biological metrics for fish, crayfish, and benthic invertebrate populations
- Quantify suspended sediment concentration for the 2016 Water Year
- Quantify land use alteration/change from 2011-2016
- Determine significant ($p<0.05$) relationships between these measured characteristics

METHODS

Geomorphic Assessment

Geomorphic surveys were conducted at each study site to determine cross section and longitudinal morphology of the study reaches using Trimble S6 5: Robotic Vision total station (Figures 5, 6, 7 and 8). Standard surveying techniques were used as described in Harrelson et al. (1994), and Kondolf and Piegay (2003). The reach-scale survey included elevation measurements at the thalweg, the water level on either side of the stream, and at bankfull height in long profile and at 2 cross-sections, where possible (Shepherd et al. 2010, Harrelson et al. 1994).

Pebble counts were conducted at the survey sites using the standard Wolman (1954) method. Pebble counts were performed along the longitudinal profiles and where the cross sections were surveyed (Shepherd et al. 2010, Harrelson et al. 1994). Using the Wentworth scale and adapted Wolman method (1954), described in Harrelson et al. (1994), the b-axis (medial axis) was measured with a ruler (Kondolf and Piegay 2003). Particles that were less than 2 mm were qualitatively measured by agitating the sediment between the thumb and forefinger, and estimated as very coarse-very fine sand or silt/clay (Shepherd et al. 2010).

Geomorphic survey data was input into Ohio's Department of Natural Resources STREAMS Module, an Excel-based software that calculates slope, bankfull dimensions, bank flow estimates, sinuosity, and sediment distribution (Mecklenburg and Ward 2004). These outputs were used to compare morphometrics and flow characteristics between study stream sites.

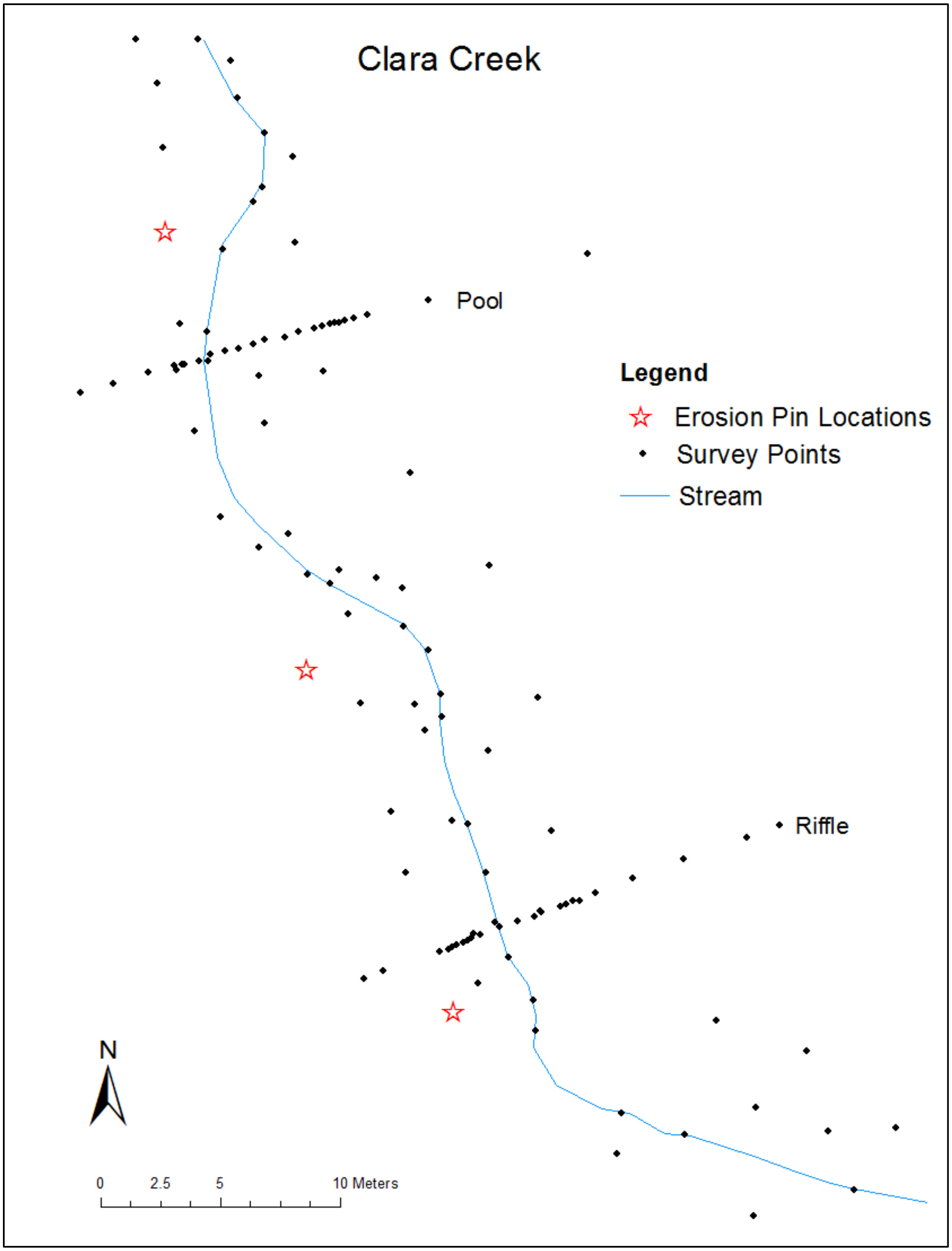


Figure 5: Longitudinal survey, cross section survey points and erosion pin locations of Clara Creek.

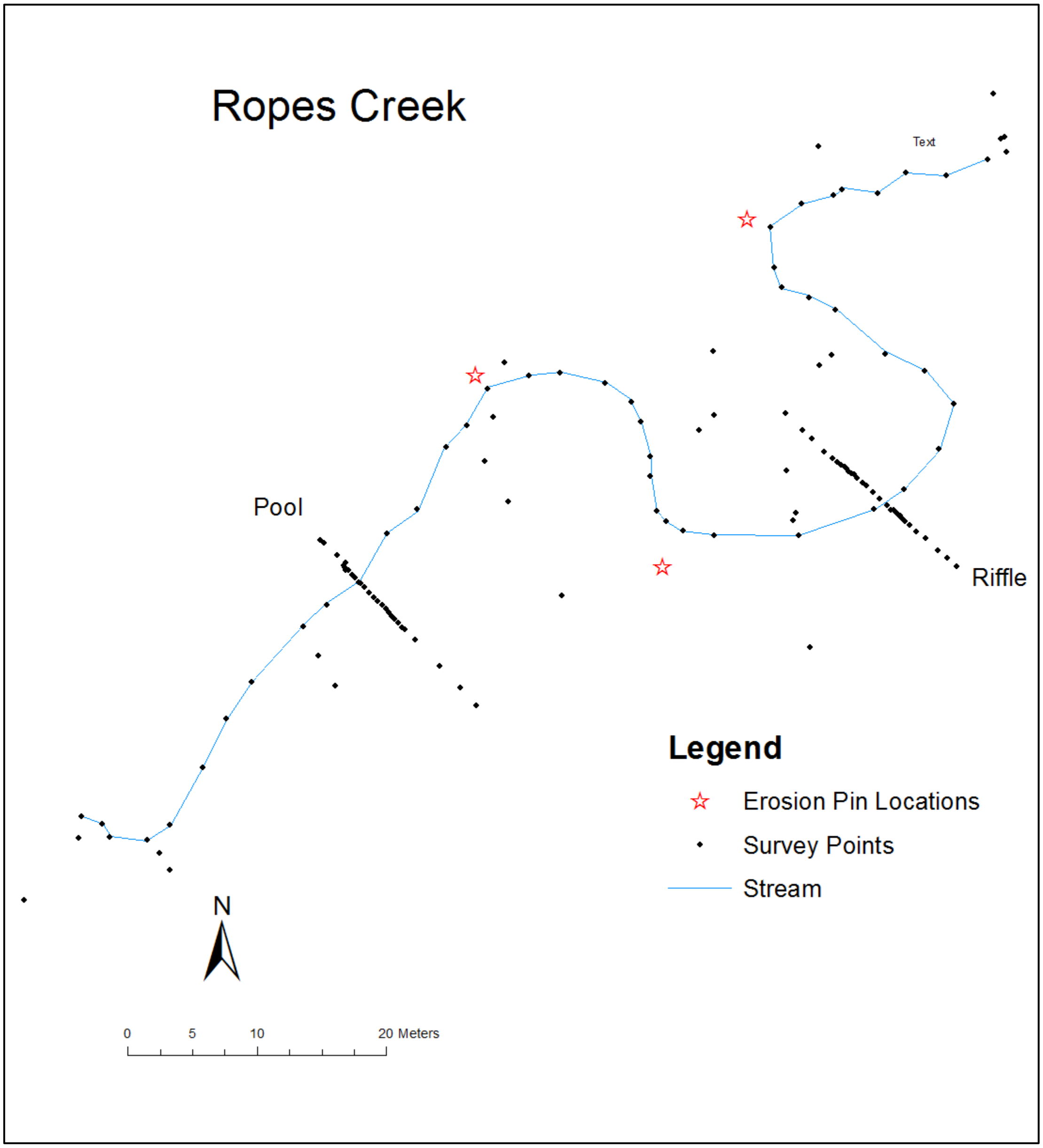


Figure 6: Longitudinal survey, cross section survey points and erosion pin locations of Ropes Creek.

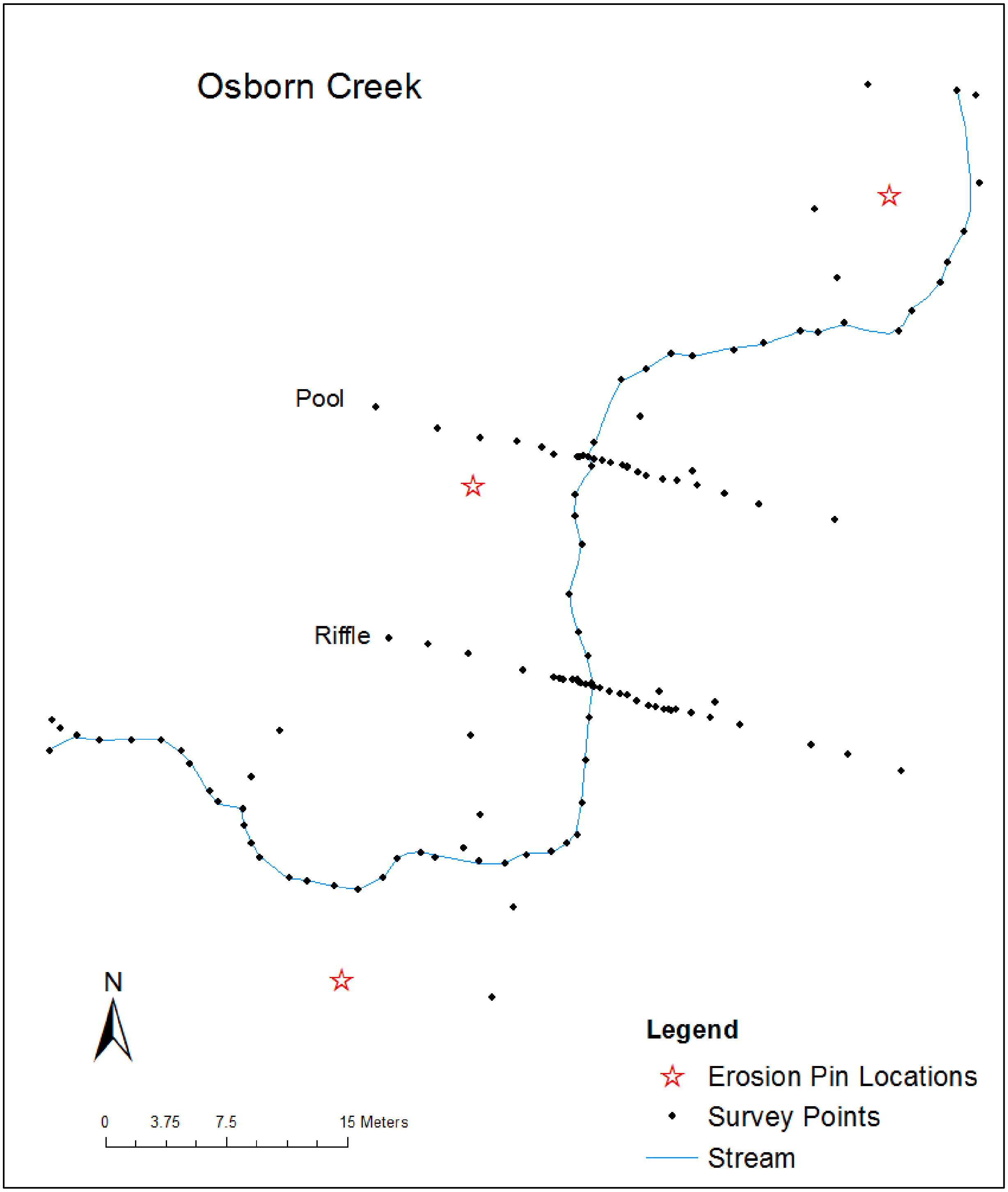


Figure 7: Longitudinal survey, cross section survey points and erosion pin locations of Osborn Creek.

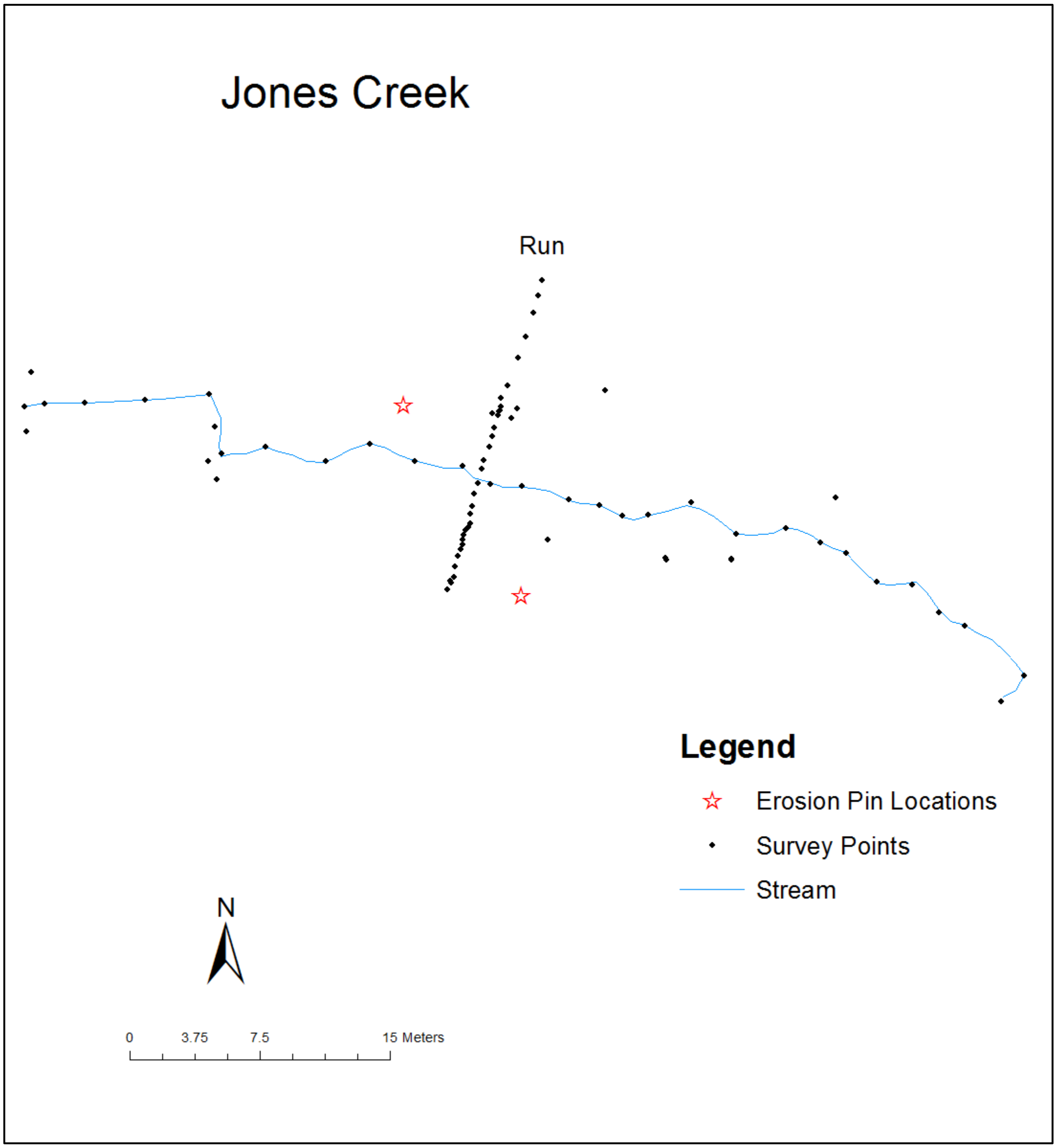


Figure 8: Longitudinal survey, cross section survey points and erosion pin locations of Jones Creek.

Bank Sampling

Stream bank analysis included estimates of bank erosion/bank loss as well as grain size characterization of the bank for inferences about erosional processes. Quantification of bank loss was attained through bank pin installation and monitoring as outlined in Ramirez et al. (2010) and Harrelson et al. (1994). Steel rebar bank pins were installed perpendicular to the stream bank wall, and measured throughout the water year (Ramirez et. al 2010; Harrelson et al. 1994). The pins were installed along varying heights along the bank dependent upon the site's bank wall height. Bank soil grab samples were collected when the surveys were performed, and adjacent to where erosion pins were installed to determine variations in grain size.

Water Sampling

Water grab samples were collected using an integrated depth approach (Edwards and Glysson 1999). Sampling was conducted proximally at the same thalweg location for each site throughout the sampling period. Water sampling was performed during normal flow throughout the water year (October 2015-September 2016).

Bioassesment

Biotic sampling methodologies were adopted from Helms et. al (2016) and Simpson et. al (2014). Aquatic biota were collected and their habitats characterized from the surveyed reaches at the four sites June of 2016. Fish and crayfish were collected with a Smith-Root LR24 backpack electroshocker unit with seine nets blocking upstream and downstream to limit fish/crayfish collected to the surveyed reach. The whole reach (150 m) was sampled for fish, with crayfish sampled for the first third (50 m) with a triple pass. Animals were collected from downstream to upstream with dip nets. The crayfish/fish were measured, identified to species, and assigned to their functional feeding and breeding guilds, and adapted from the FishTraits database (Frimpong and Angermeier 2010).

Benthic organisms were collected using a Surber sampler (0.09 m^2, 250 µm mesh) at three representative riffles within the study reach. At each riffle sampled, stream microhabitat was characterized by quantifying mean depth and velocity (Marsh-McBirney model 2000 flow meter). Upon collection, the samples were rinsed of excess sediment in a 500 µm mesh sieve, and put into 95% ethanol solution for transport to the lab. Under a dissecting scope, benthic organisms were sorted by family using a random grid sorting tray until >300 organisms were picked. After subsampling, the remaining sample was picked for larger organisms not represented in subsamples for 30 minutes. All macroinvertebrates were identified to genus except Chironomidae, which were identified to Tribe (Tanypodinae and Non-Tanypodinae), and subsequently assigned to functional feeding guilds (Helms et. al 2016; Merritt et al. 2008). The functional feeding guilds are defined as collector/gatherer which consumes fine particulate organic matter (FPOM) and bacteria and feeds by collecting surface deposits and burrowing into soft sediments, collector/filterers which feed on FPOM, bacteria, and periphyton in the water column (in suspension), shredder which feeds on coarse particulate organic matter (CPOM) such as leaves and woody debris, and scraper which feed on periphyton deposits on surfaces (Allan 2007). Diversity was calculated using Shannon's H' diversity, and richness was calculated based on number of different taxa (Helms et al. 2016)

Within each study reach 10 cross-sectional transects were established where depth, flow, and width were measured at five equidistant points along each transect. At each reach pH (Sharp pH52 meter, Milwaukee Instruments, Inc., Rocky Mount, NC, USA), water temperature and conductivity was recorded (C66 Sharp meter, Milwaukee Instruments, Inc., Rocky Mount, NC, USA.).

Suspended Sediment Concentration

Suspended sediment concentration analysis of the water samples were analyzed as outlined by Guy (1969), the standard USGS method of measuring SSC and the American Society's Testing and Materials standard method for sediment concentration (ASTM Method D 3977-97 2000). The filtration method was used because it is the preferred method for water samples with less than 10,000 mg/L of sand (Gray et al. 2000). The water samples were filtered using Whatman 934 AH glass fiber filters in a Buchner funnel and flask attached to an aspirator (Gray et al. 2000, Guy 1969; Smith and Greenberg 1963). Whatman 934 AH glass filters are equipped to filter solids greater than 1.5 µm. Suspended sediment concentration were calculated in ppm and converted into mg/L using the following equation,

$$SSC\left(\frac{mg}{l}\right) = C(ppm) = c\left(\frac{Net\ Wt.of\ Sediment}{Net\ Vol.of\ Sediment + Water} \times 10^6\right)$$

where *c* is the conversion coefficient that converts from ppm to mg/l. The value of *c* is dependent upon the calculated ratio and fluid density, but is typically 1.0 (Guy 1969).

Grain Size Analysis

Grain size analysis was performed on the collected bank samples using the Mastersizer 3000 manufactured by Malvern Instruments. The Mastersizer 3000 determines particle size by laser diffraction where the intensity of light scatter is measured as the laser beam passes through a dispersed sample; I used distilled water as my dispersant (Kadouche et al. 2012). The scattering pattern of the laser is used to indicate particle size (Kadouche et al. 2012).

Prior to analysis each bank sample was disaggregated and the coarse fraction (> 2mm) was sieved out and weighed. From the bulk soil sample, 10 g were taken and mixed with a 15 % solution of sodium hexametaphosphate, a deflocculant, and put in a sonicator for an hour. Each bank sediment sample was pipetted and measured five times by the Mastersizer and the procedure was repeated three times for a total of 15 measurements. Those 15 measurements were averaged with outlier measurements (determined by the output trend graphs or high r^2 values) were omitted from the average.

Land Use Change Analysis

Land use was determined using multi-temporal ISODATA classification of satellite imagery from when the bio-surveys were performed, June 2011 and December 2015. For Osborn Creek and Jones Creek the land use was classified into Conifer, Deciduous Forest, and Grass/Clear-cut; For Ropes Creek and Clara Creek were classified into six categories Conifer, Deciduous, Developed/Barren, Grass/Urban-Open, Open Water, and Shrub/Scrub. Grass/Urban-Open is defined as open urban spaces such as golf courses, athletic fields, and parks, with some recently cut-over forest land and suburban-type housing; so essentially urban-open is grassy areas with some structures mixed in. Developed/barren is defined as high density development where areas are mostly covered with man-made surfaces such as asphalt, or bare rock/soil.

Correlation Analysis

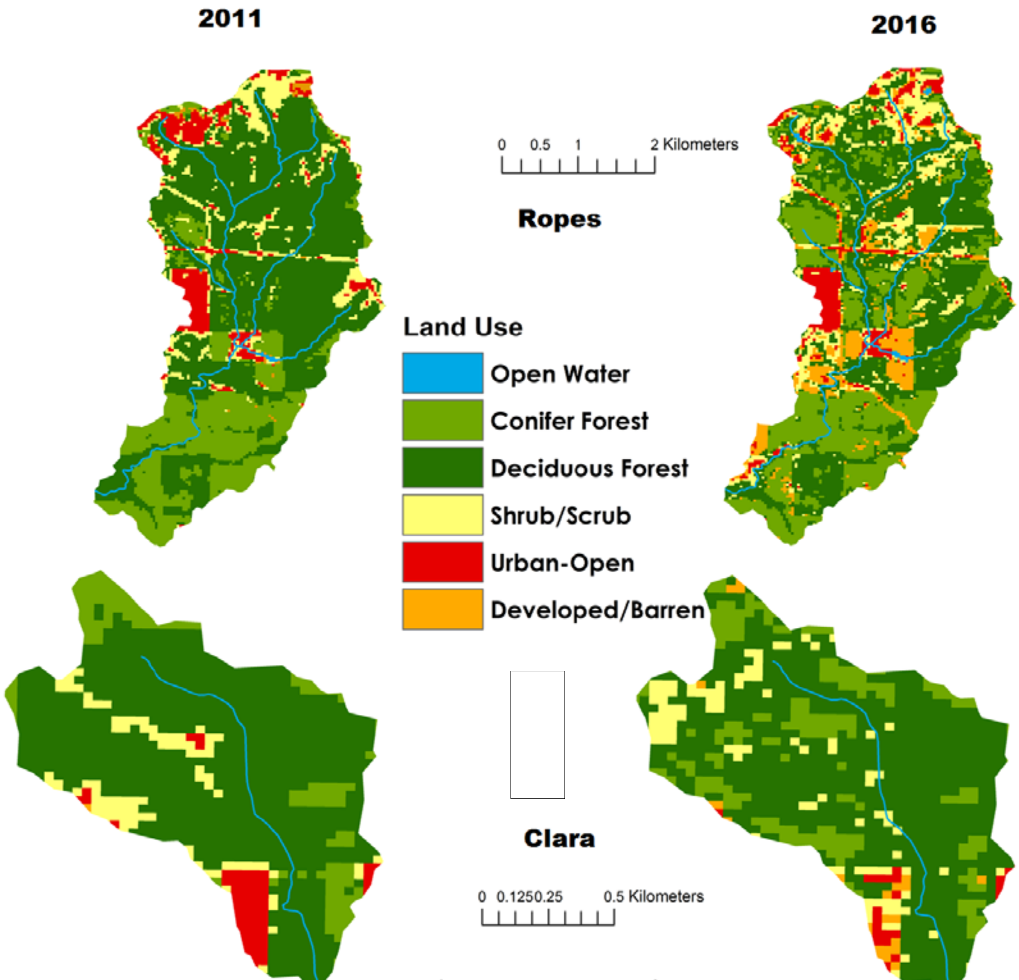
Correlational statistics were run on all the variables involved in this study in Microsoft Excel. Correlation values (R) that were greater than ± 0.85 and with a p-value less than 0.05 were only included in the results.

RESULTS

Land Use Change Analysis

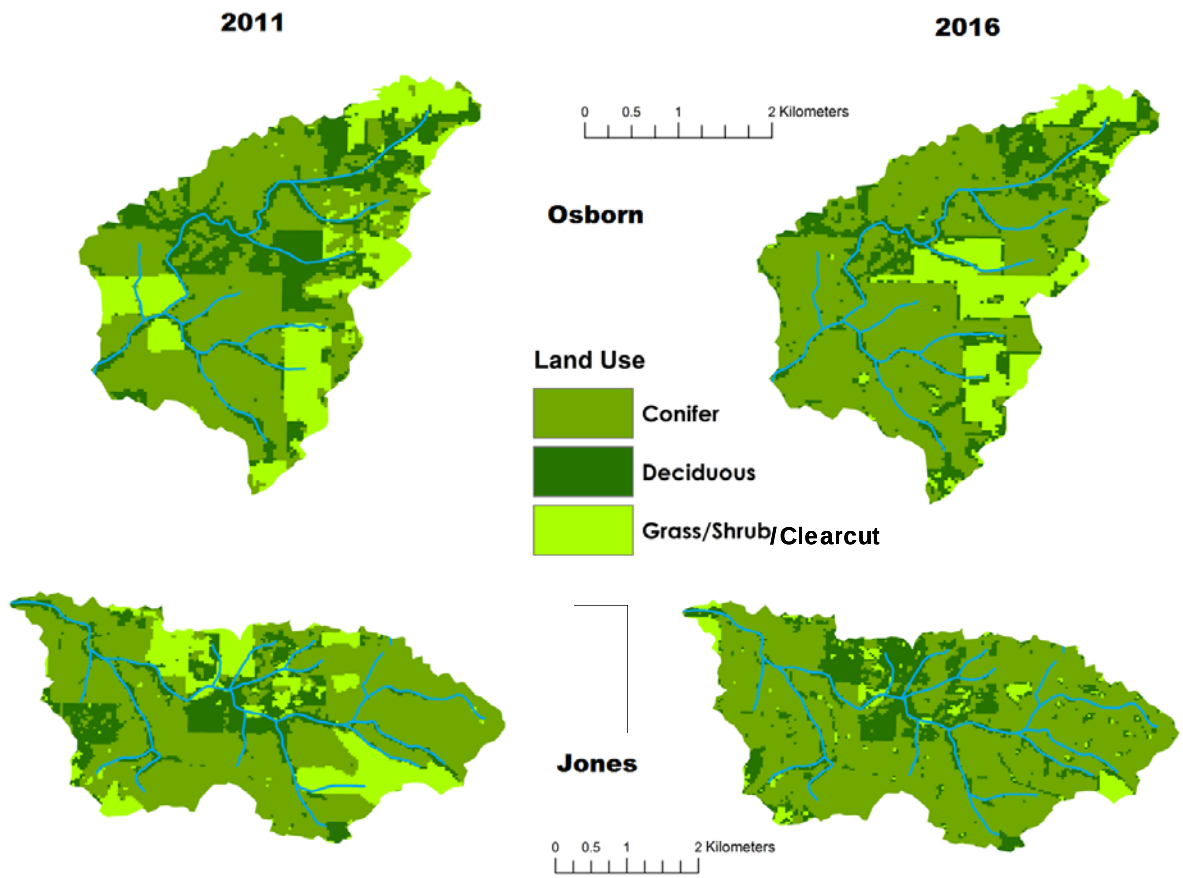
From 2011-2016 native deciduous forest was converted to conifer forest, cleared, or developed, averaging a 9.2 % loss of native forest, with Ropes Creek having the greatest loss of deciduous forest at 16 % (Figures 9a. and 9b.). At Osborn and Jones Creek there has been an increase (>10 %) in conifer forest since 2011, and at Clara and Ropes Creek there has been an increase in development, conifer forest, and shrub/scrub with a decrease in deciduous forest (Figures 9a. and 9b.). Ropes Creek has had the most marked change in land cover of all the sites with a ~9 % increase in developed area (Figure 9a.). Notably there was recent clearing that has occurred at Jones and Osborn Creek by silviculture operations, shown in Plate 1.

Plate 1: Clearcutting of forest for forestry operations at Jones Creek taken in June 2016.



	Ropes		Clara	
Land Use Cover	**2011 (%)**	**2016 (%)**	**2011 (%)**	**2016 (%)**
Conifer Forest	23.0	27.8	10.1	16.5
Deciduous Forest	59.7	43.7	78.2	72.5
Developed / Barren	0.6	9.3	0.0	1.8
Grass / Urban-Open	7.0	6.5	4.7	1.7
Open Water	0.1	0.3	0.0	0.0
Shrub/Scrub	9.6	12.4	7.0	7.5

Figure 9a: Land use map and land use percentages in 2011 and 2016 of Clara and Ropes Creek. Land use designations are open water, conifer forest, deciduous forest, shrub/scrub, urban-open, and developed/barren.



	Osborn		Jones	
Land Use Cover	**2011 (%)**	**2016 (%)**	**2011 (%)**	**2016 (%)**
Conifer Forest	54.6	63.9	65.2	77.4
Deciduous Forest	24.1	18.3	17.5	18.4
Grass/shrub	21.3	17.8	17.2	4.2

Figure 9b. Land use map and land use percentages in 2011 and 2016 of Osborn and Jones Creek. Land use designations are conifer forest, deciduous forest, and grass/clearcut.

Bio-Assessment

Fish, crayfish, and benthic invertebrate results are reported below. Table 2 shows physicochemical properties of the streams at sampling. A total of 560 fish specimens were collected comprising of 6 families and 18 species at the study stream reaches (Tables 3 and 4).

Site	Drainage Area (km²)	Width (m)	Average Depth (m)	Max Depth (m)	pH	Conductivity (μS/m)	Temperature (°C)	Flow (m/s)	Q(m³/s)
Clara	0.96	1.91	0.10	0.28	7.3	55	20.2	0.02	0.003
Jones	12.39	4.88	0.10	0.25	7.6	19	21.2	0.11	0.068
Osborn	8.06	3.88	0.17	0.7	7.5	16	19.7	0.09	0.034
Ropes	10.80	3.71	0.14	0.38	7.6	56	23.9	0.08	0.047

Table 2: Streams sampled for biotic assemblages and associated mean physicochemical conditions at time of sampling.

Cyprinidae was the most taxa rich across all sites (6 spp.), followed by Percidae (5 spp.), Centrarchidae (4 spp.), and with Castostomidae, Cottidae, and Ictaluridae being represented by one species each (Appendix 1). Total fish catch ranged from 64 to 242, fish species richness ranged from 2 to 19, CPUE ranged from 0.13 to 0.42 fish/m^2, and species diversity (Shannon's H') ranged from 0.33 to 2.06 (Table 3). The percent of fish assemblages as complex nest-guarding breeders (%C) ranged from 0 to 45%, generalist non-guarding breeders (%G) ranged from 20 to 100%, and lithophilic spawners (%L) ranged from 0 to 62% (Table 4). No species of the assemblages were endemic (%E) to the basin, while narrow-endemics (%NE) ranged from 0 to 62%, and widespread species (found in multiple large basins, %WS) ranged from 38 to 100%. Only Jones Creek had any herbivore species at 3.72%, while omnivores (%O) ranged from 0 to 92%, invertivores (%I) ranged from 0 to 93%, and piscivores (%P) ranged from 5 to 8% (Table 4).

Site	Richness	Catch	Diversity (H')	CPUE
Clara	3	64	0.31	0.29
Ropes	9	72	1.96	0.13
Osborn	11	242	1.99	0.42
Jones	16	182	2.03	0.25

Table 3: Fish richness, catch, diversity and CPUE (fish/m^2) in 2016.

Site	%C	%G	%L	%E	%NE	%WS	%H	%I	%O	%P
Clara	0	100	0	0	0	100	0	0	92	8
Ropes	32	33	35	0	39	61	0	93	0	7
Osborn	19	20	62	0	27	73	0	86	7	7
Jones	45	21	33	0	62	38	4	86	5	5

Table 4: Percent breeding, feeding, and distribution for all sites in 2016. Look above for explanation on abbreviations.

Crayfish count ranged from 7-36, with Osborn having the least crayfish and Jones with the highest (Table 5). Crayfish richness ranged from 1-4, and M:F ratios ranged from 0.40-0.79 (Table 5). Overall six species of crayfish were identified in these streams, with *Procambarus spiculifer* being the most abundant (Appendix 2).

Site	Catch	Richness	Carapace Length	CPUE	M:F Ratio
Clara	25	3	21.64	0.11	0.79
Ropes	32	3	20.47	0.04	0.52
Osborn	7	1	31.64	0.01	0.40
Jones	36	4	21.04	0.05	0.50

Table 5: Crayfish catch, richness, carapace length, CPUE, and Male:Female Ratio for all sites in 2016.

Roughly 3400 macroinvertebrate specimens representing 12 orders, 33 families, and 54 genera were collected during sampling (Table 6). The most diverse orders were Coleoptera (12 genera), Plecoptera (10 genera), and Tricoptera (8 genera; Table 6 and Appendix 3). Abundance ranged from 711- 1012 specimens. Diversity was fairly consistent across sites ranging from 2.08-2.62 while richness ranged from 29-47 (Table 6). Ephemeroptera, Plecoptera, and Tricoptera assemblage (EPT) richness varied little across sites ranging from 12-16 (Table 6). Functional group richness showed little variability across sites with collector/filterers richness (CF) ranging from 3-4, collector/gatherers (CG) ranging from 4-7, predators (PR) ranging from 12-14, scrapers (SC) ranging from 4-6, and shredders (SH) ranging from 4-5 (Table 6). The composition of the insect assemblage with the percentage as collector/filterers ranging from 5-30 %, collector/gatherers ranging from 34-54 %, predators ranging from 10-23 %, scraper ranging from 8-24 %, and shredders ranging from 1-8 % (Table 6). Clara had the highest percentage (58 %) of Chironomidae, Ropes Creek and Jones had elevated abundances of Chironomidae at 45 % and 48 % respectively. Osborn had the lowest abundance of Chironomidae at 28 %.

Site	H'	Richness	EPT	CF richness	CF %	CG richness	CG %	PR richness	PR %	SC richness	SC %	SH richness	SH %
Clara	2.10	29	12	4	5	4	54	12	23	6	10	4	8
Ropes	2.08	30	16	4	30	5	47	12	14	4	8	5	1
Osborn	2.62	47	15	3	16	7	34	13	20	5	24	5	7
Jones	2.13	31	14	4	19	4	50	14	10	6	13	4	8

Table 6: Benthic invertebrate diversity (H'), richness, EPT, and functional feeding groups in 2016.

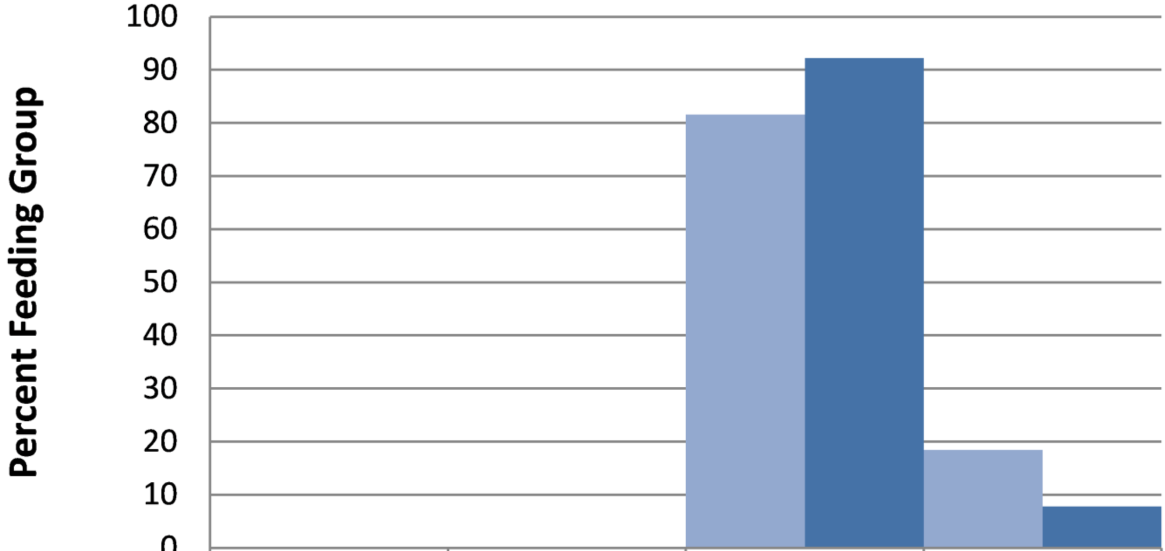
Population Response

Fish Response

From 2011 to 2016, fish catch increased only at Jones Creek, but at all other sites there was a decrease in fish catch, richness, diversity, and Catch per Unit Effort (CPUE, organisms/m^2; Table 7). Fish functional feeding guild distributions have changed minimally since 2011(Figures 10a., 10b., 10c., and 10d.).

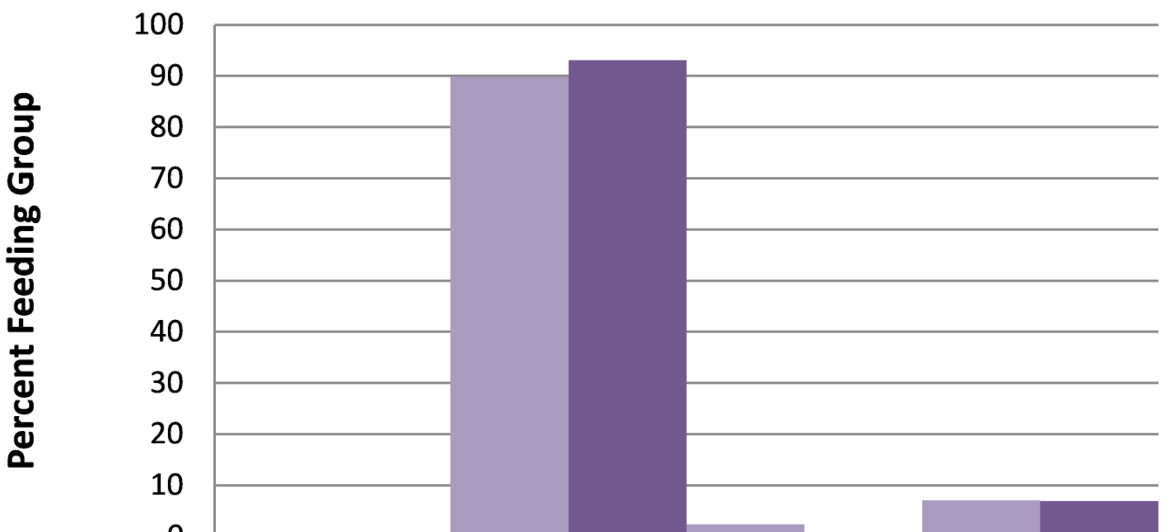
	Fish Richness		Fish Catch		Diversity (Shannon's H')		CPUE (organisms/m²)	
Site	2011	2016	2011	2016	2011	2016	2011	2016
Clara	2	3	117	64	0.48	0.31	0.42	0.29
Ropes	10	9	130	72	1.89	1.96	0.43	0.13
Osborn	13	11	286	242	2.21	1.99	0.55	0.42
Jones	19	16	173	182	2.36	2.03	0.36	0.25

Table 7: Changes in fish richness, fish catch, diversity, and CPUE for all sites from 2011-2016.



	Herbivore	Invertivore	Omnivore	Piscivore
Clara 2011	0	0	81.6	18.4
Clara 2016	0	0	92.19	7.81

Figure 10a.: Percent functional fish feeding guild distribution at Clara Creek for 2011 and 2016.



	Herbivore	Invertivore	Omnivore	Piscivore
Ropes 2011	0	89.9	2.4	7.1
Ropes 2016	0	93.06	0	6.94

Figure 10b.: Percent functional fish feeding guild distribution at Ropes Creek for 2011 and 2016.

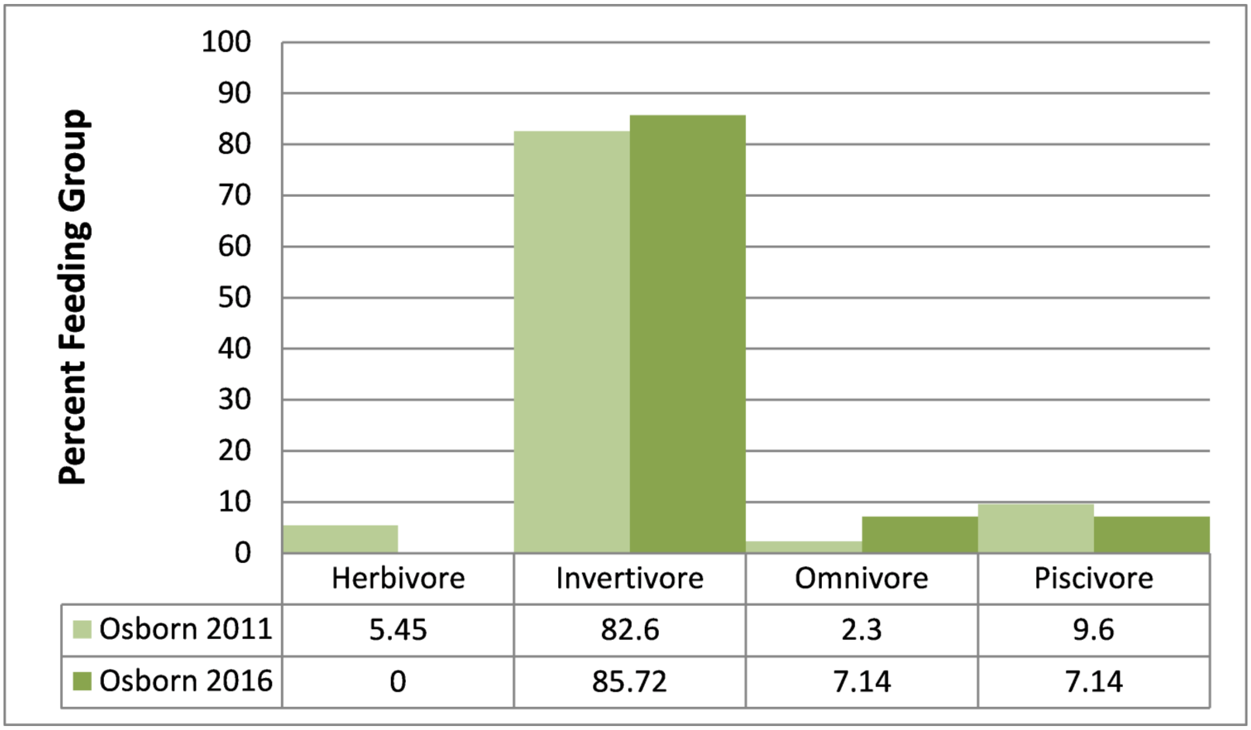


Figure 10c.: Percent functional fish feeding guild distribution at Osborn Creek for 2011 and 2016.

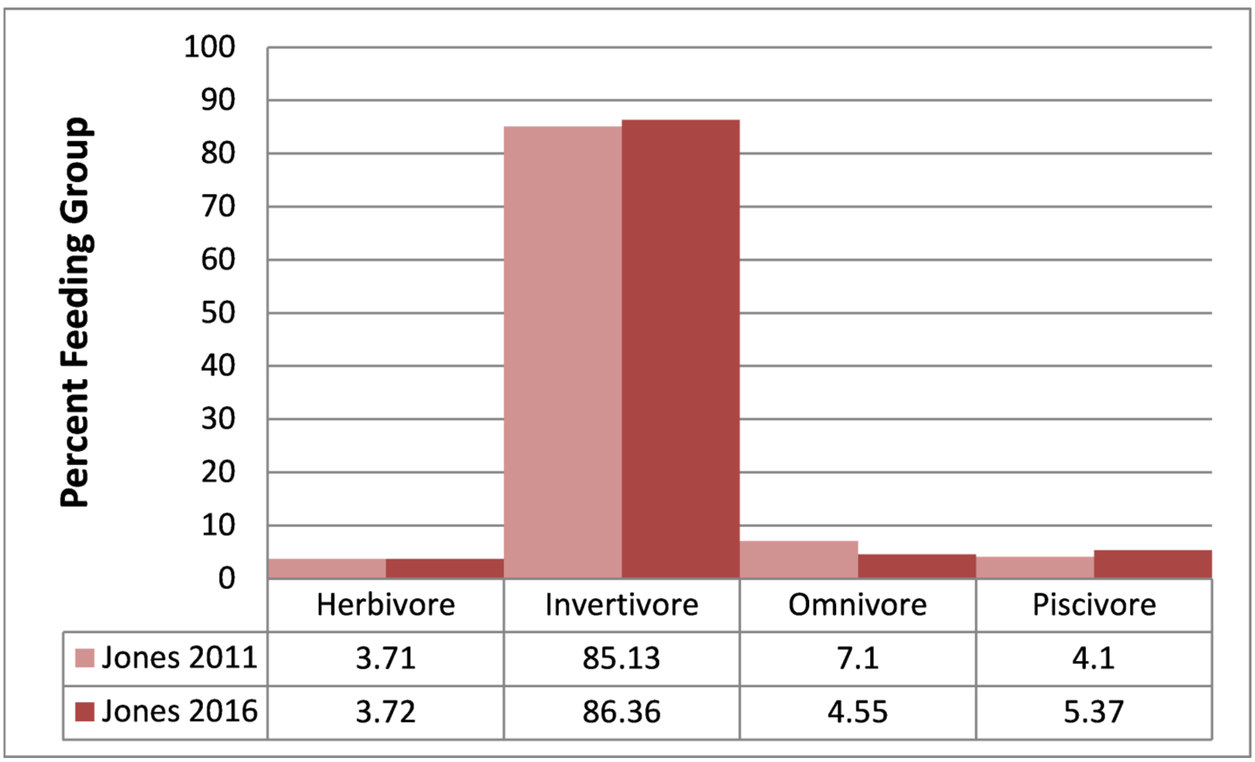


Figure 10d.: Percent functional fish feeding guild distribution at Jones Creek for 2011 and 2016.

Since 2011, the breeding fish guild distributions at Ropes, Osborn, and Jones Creek have only changed slightly, and at Clara the breeding guild distribution did not change (Table 8). At Ropes and Osborn Creek there was increase in complex (guarders) breeders as generalist species decreased, with a slight increase in lithophilic spawners (Figure 11a. and 11b.). At Jones, since 2011, there has been an increase in complex breeders, with a decrease in lithophilic spawners, and generalist breeders (Figure 11c.). No species were collected that were endemic to the Tallapoosa in 2016, but in 2011 Jones had 7.02 % endemic species. Narrow endemic (% NE) and widespread species (% W) species have increased at Ropes and Jones Creek. Narrow endemics have decreased and widespread species have increased at Osborn, and no change has occurred at Clara Creek (Table 9).

CLARA	Breeding Group	2011	2016
	% C	0	0
	% G	100	100
	% L	0	0

Table 8: Breeding guild distribution of Clara Creek, no changes have occurred since 2011.

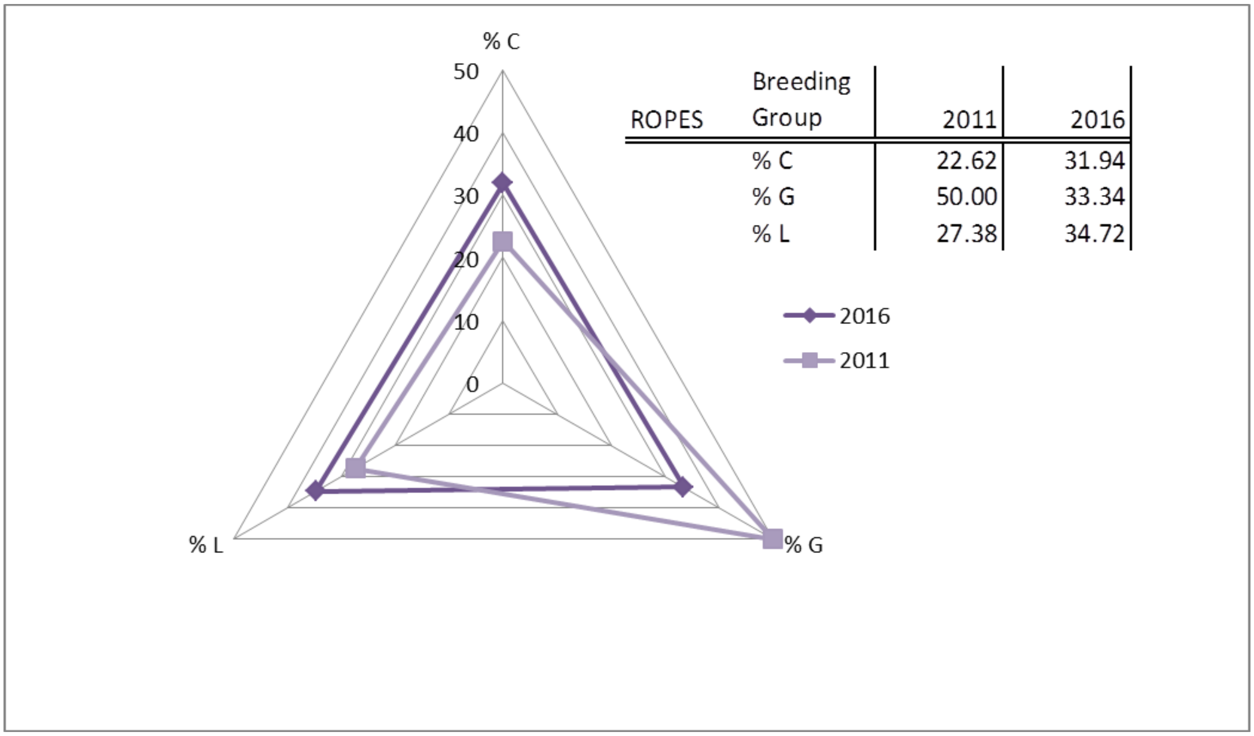


Figure 11a: Breeding guild distribution of complex nest-guarders (%C), generalist non-guarders (%G), and lithophilic spawners (%L) of Ropes Creek in 2011 and 2011.

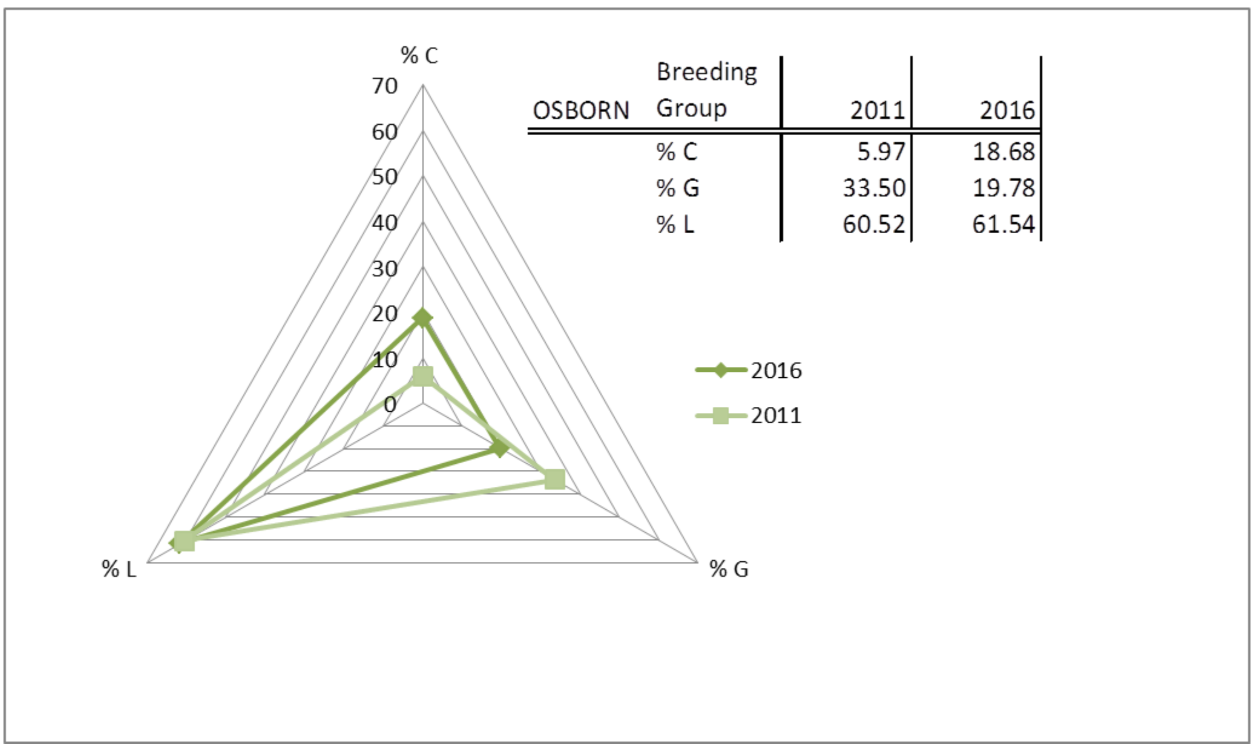


Figure 11b: Breeding guild distribution of complex nest-guarders (%C), generalist non-guarders (%G), and lithophilic spawners (%L) of Osborn Creek in 2011 and 2011.

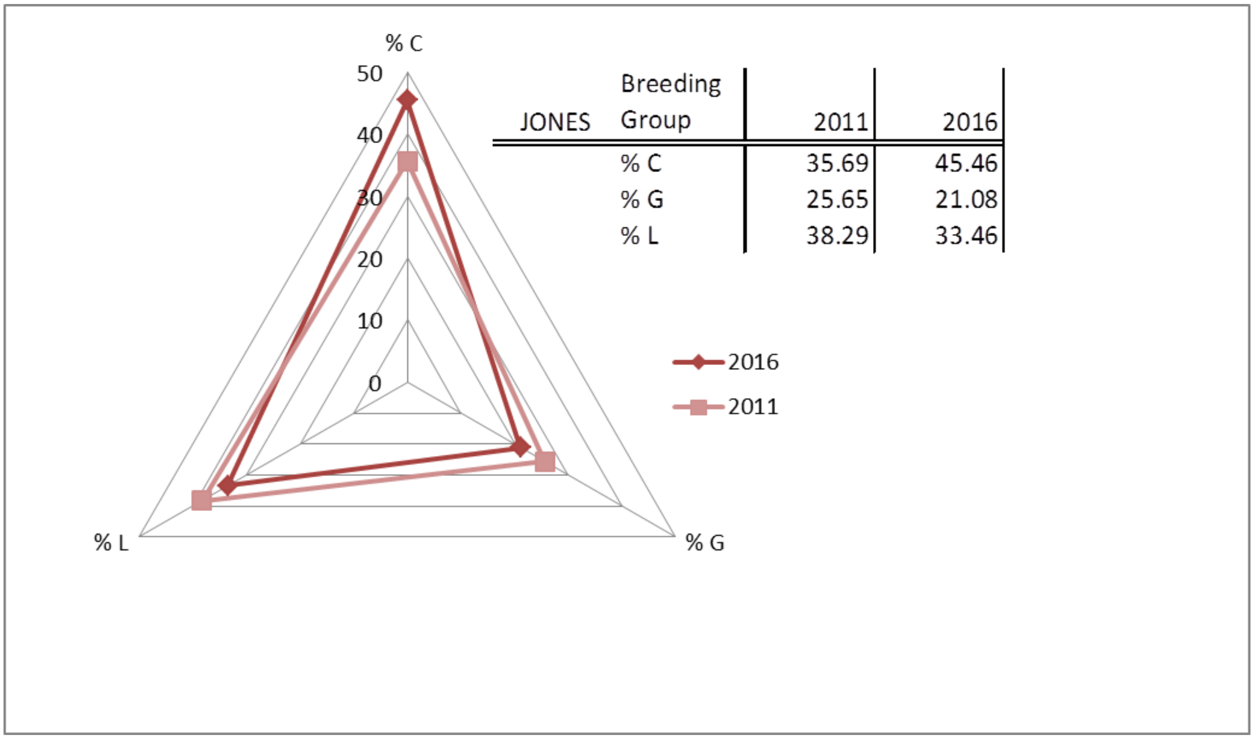


Figure 11c: Breeding guild distribution of complex nest-guarders (%C), generalist non-guarders (%G), and lithophilic spawners (%L) of Jones Creek in 2011 and 2011.

	Clara		Ropes		Osborn		Jones	
Distribution	2011	2016	2011	2016	2011	2016	2011	2016
% E	0	0	0.00	0	0.00	0	7.02	0
% NE	0	0	33.33	38.89	41.81	26.92	45.72	61.98
% WS	100	100	66.67	61.11	58.18	73.08	47.21	38.02

Table 9: Range distribution category changes at all sites from 2011-2016.

Crayfish Response

Similar results to the change in fish populations occurred with the crayfish and benthic populations. Crayfish richness and catch decreased at all sites with the exception of Jones Creek (Table 10). Carapace length increased at all sites since 2011. The M:F has decreased at Clara (slightly), Jones, and Osborn and increased, slightly, at Ropes Creek (Table 10).

	Crayfish Catch		Crayfish Richness		Carapace Length		CPUE		Male:Female Ratio	
Site	2011	2016	2011	2016	2011	2016	2011	2016	2011	2016
Clara	98	25	4	3	16.12	21.64	0.35	0.11	0.81	0.79
Ropes	58	22	4	3	18.40	20.47	0.19	0.04	0.49	0.52
Osborn	66	7	4	1	18.48	31.64	0.13	0.01	0.69	0.40
Jones	54	36	2	4	17.36	21.04	0.11	0.05	0.59	0.50

Table 10: Total catch, CPUE (crayfish/m2), species richness, diversity (Shannon's H'), carapace length (CL), and male:female ratios (M:F) for crayfishes in 2011 and 2016 for all sites.

Benthic invertebrate Response

Diversity (H’) and EPT have decreased at all sites minimally (Table 11). Richness has decreased at all sites, except at Osborn Creek (Table 11). Functional feeding assemblages varied since 2011 (Figures 12a.-12d.). At Clara Creek, there was an increase in scraper and shredders, and a decrease in collector/gatherers (Figure 12a.). Ropes Creek had a decrease in collector/filterers coupled with an increase in collector/gatherers (Figure 12b.). Osborn shifted from predominantly scraper to collector/gatherers (Figure 12c.). Lastly, Jones Creek increased in collector/gatherers and decreased in collector/ filterers and predators (Figure 12d.).

	H'		Richness		EPT		CF				CG				PR				SC				SH			
	2011	2016	2011	2016	2011	2016	2011		2016		2011		2016		2011		2016		2011		2016		2011		2016	
Site							Rich	%	Rich	%	Rich	%	Rich	%	Rich	%	Rich	%	Rich	%	Rich	%	Rich	%	Rich	%
Clara	2.13	2.10	39	29	15	12	3	4	4	5	6	63	4	54	12	24	12	23	8	23	6	10	9	5	4	8
Ropes	2.41	2.08	38	30	17	16	7	44	4	30	7	33	5	47	15	12	12	14	5	14	4	8	2	0	5	1
Osborn	2.75	2.62	32	47	15	15	2	11	3	16	5	25	7	34	11	16	13	20	6	20	5	24	5	8	5	7
Jones	2.76	2.13	49	31	17	14	11	33	4	19	5	22	4	50	17	15	14	10	8	10	6	13	4	13	4	8

Table 11: Diversity, richness, Ephemeroptera-Plecoptera-Tricoptera richness (EPT), and percent/richness functional feeding guilds for all sites in 2011 and 2016.

Clara

Feeding Group	2011	2016
CF	4.5	5.5
CG	63.0	54.4
PR	23.6	22.7
SC	4.1	9.9
SH	4.8	7.6

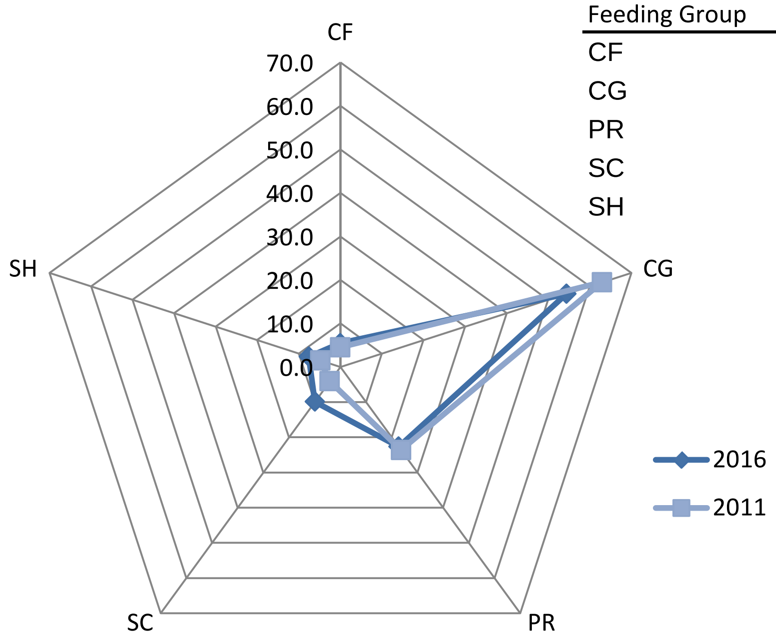


Figure 12a: Functional Feeding Groups collector/gatherer (CG), collector/filterer (CF), predator (PR), scraper (SC), and shredder (SH) distribution at Clara Creek in 2011 and 2016.

Ropes

Feeding Group	2011	2016
CF	44.4	29.6
CG	33.2	47.1
PR	11.7	14.4
SC	10.2	7.6
SH	0.5	1.2

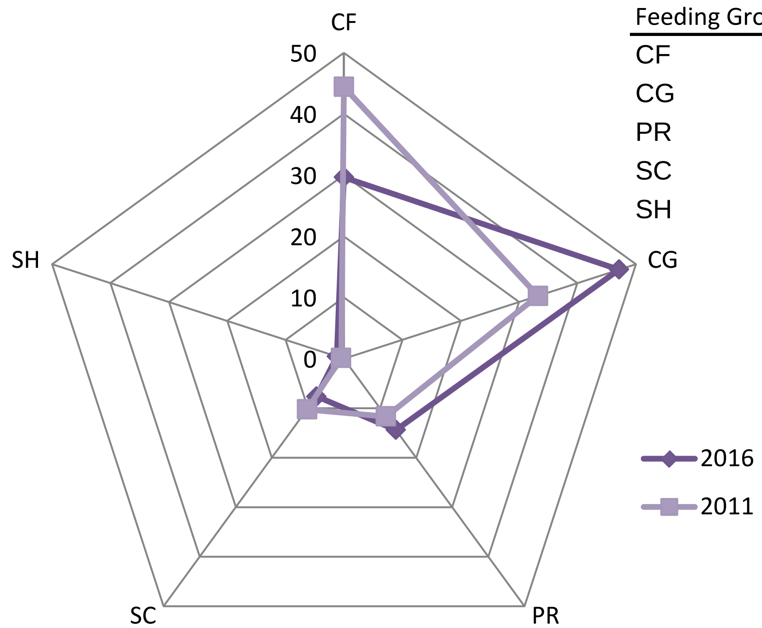
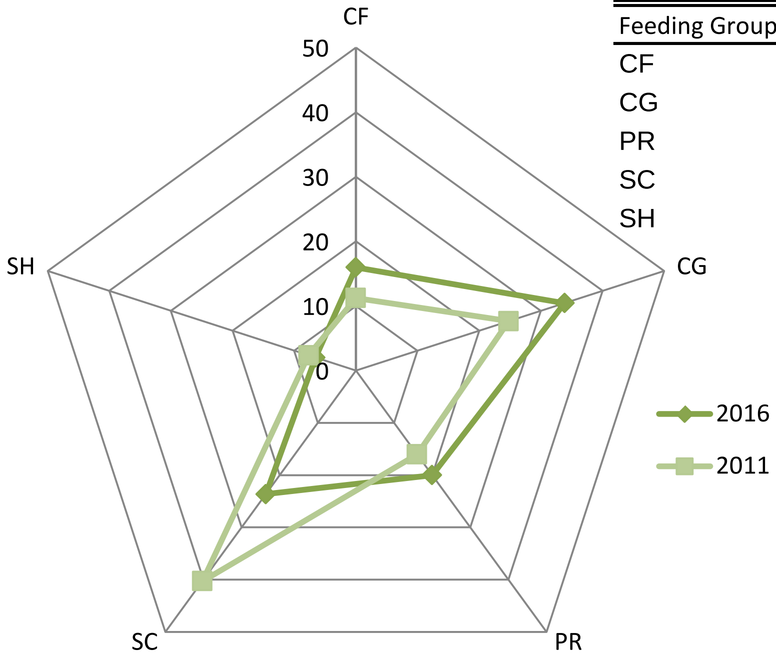


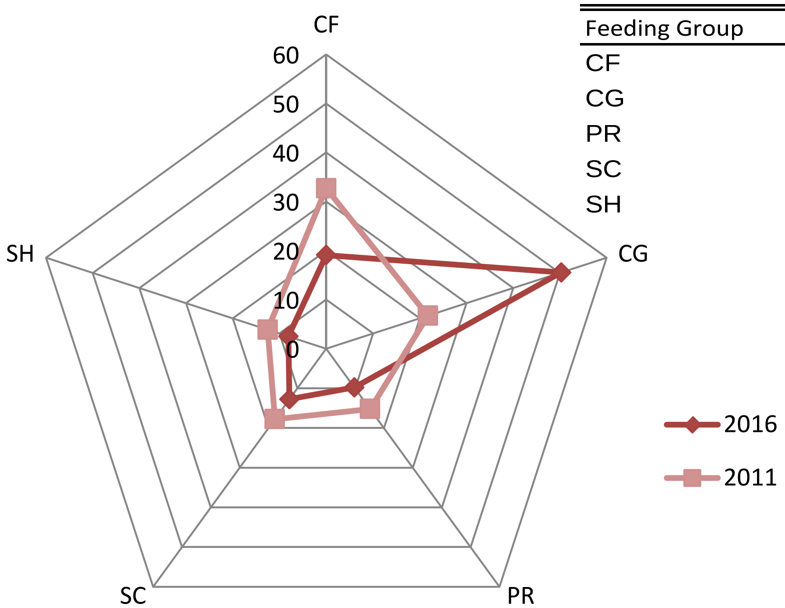
Figure 12b.: Functional Feeding Group Distribution of Ropes Creek in 2011 and 2016.



Osborn

Feeding Group	2011	2016
CF	11.2	16.0
CG	24.8	33.8
PR	16.0	20.0
SC	40.3	23.6
SH	7.7	6.5

Figure 12c.: Functional Feeding Group Distribution of Osborn Creek in 2011 and 2016.



Jones

Feeding Group	2011	2016
CF	32.7	19.1
CG	21.8	50.3
PR	15.2	9.8
SC	17.8	12.7
SH	12.5	8.1

Figure 12d.: Functional Feeding Group Distribution of Jones Creek in 2011 and 2016.

Geomorphic/Sedimentologic Results

Width to depth ratios (WDR, m/m) are a common measure used for Rosgen classification of streams and help to understand the distribution of energy within a stream channel to move sediment (Simon et al. 2007). Since 2011, all width to depth ratios (WDR, m/m) increased at all sites with the exception of Clara Creek (Table 12). These ratios indicate that there has been widening at Osborn, Jones, and Ropes Creek; and at Clara Creek there has been greater down-cutting as shown by Table 15, Plates 2a.-2c., and Figure 9. WDR ranged from 7.01-18.98, with the most dramatic change in WDR at Osborn Creek and Clara Creek. Bankfull Cross-sectional area ranged from 5.10-7.00 m^2 increasing at Clara and Osborn Creeks, and decreasing at Ropes and Jones Creeks since 2011 (Table 12).

Stream power is the rate of energy expended on the bed and banks of a stream per unit downstream length (Bagnold 1966). There was an increase in stream power (N/s), at all sites since 2011 and an increase in shear stress at all sites, except Clara (calculated by the Ohio DNR Stream's Module, Table 13). Overall, Osborn and Clara Creek had the most marked change in the aforementioned geomorphic characteristics. Figure 13 shows the change in geomorphology at Clara Creek. Also, the average bank height was 1.71 m, and at other sites their bank height's averaged 0.94-1.36 m, showing that even though Clara Creek is the smallest drainage erosional processes are enhanced at Clara.

	Bankfull Width (m)		Bankfull Mean Depth (m)		Bankfull Cross-sectional Area (m^2)		Width to Mean Depth Ratio (m/m)		Hydraulic Radius (m)		Bankfull Discharge (m^3/s)	
Site	2011	2016	2011	2016	2011	2016	2011	2016	2011	2016	2011	2016
Clara	3.9	6.1	0.41	0.87	1.60	5.30	9.45	7.01	0.40	0.70	3.30	10.40
Ropes	7.9	7.3	0.86	0.69	6.80	5.10	9.19	10.58	0.80	0.60	16.80	12.70
Osborn	6.3	11.2	0.47	0.59	3.00	6.60	13.40	18.98	0.40	0.60	2.70	11.20
Jones	8.7	7.8	1.05	0.9	9.10	7.00	8.29	8.67	0.90	0.80	16.40	13.20

Table 12: Geomorphic characteristics and bankfull dimensions of all sites from 2011-2016 calculated from Ohio DNR's STREAMS Module.

	Shear Stress (N/sq.m)		Stream Power (N/s)	
Site	2011	2016	2011	2016
Clara	64	40	576	612
Ropes	23	37	599	745
Osborn	9.5	26	253	529
Jones	23	37	610	956

Table 13: Shear stress and stream power in 2011 and 2016 for all sites.

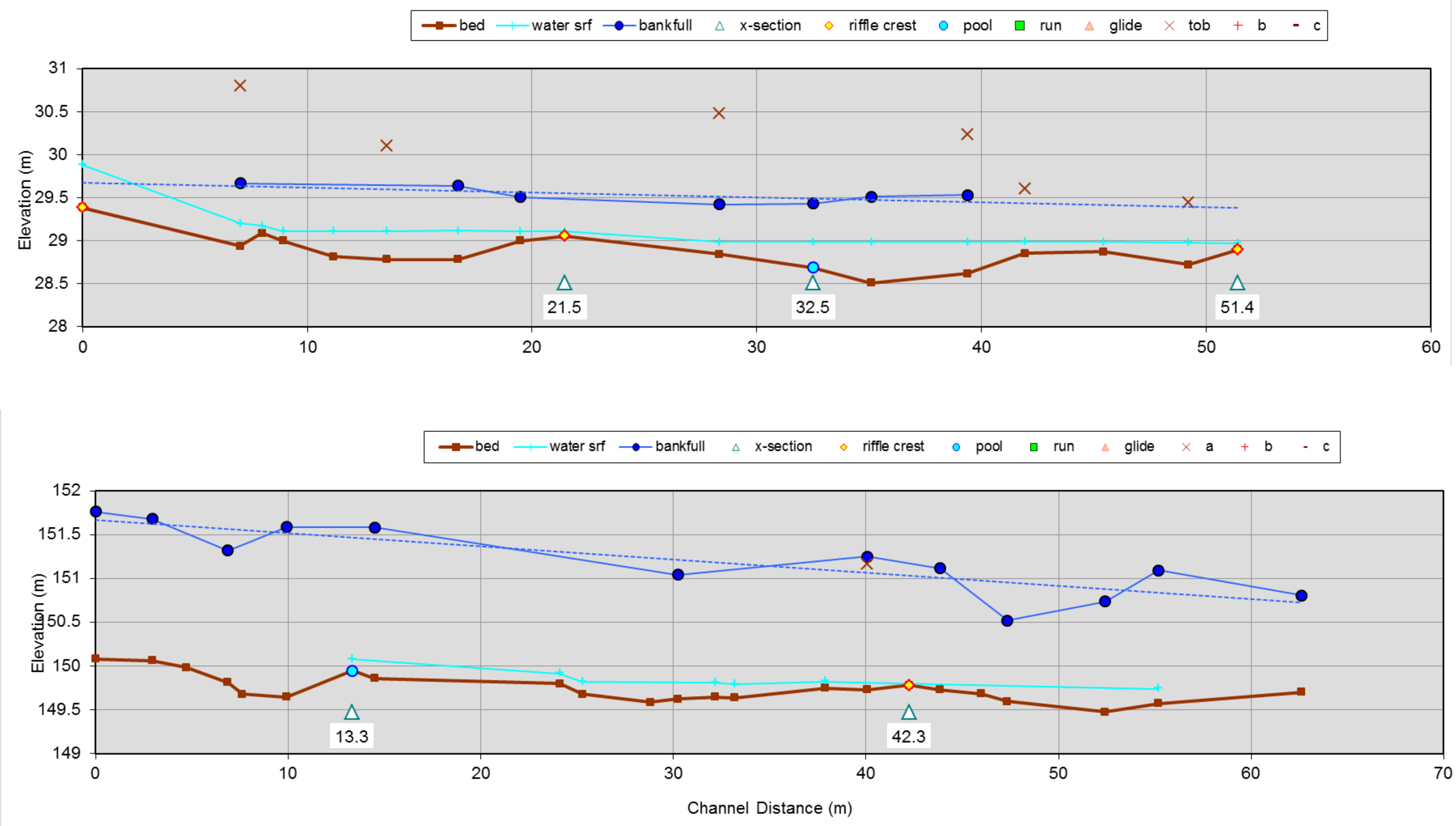


Figure 13: Longitudinal profiles of Clara Creek in 2011 (top) and 2016 (bottom).

The bed substrate at Jones Creek, Ropes Creek, and Clara Creek coarsened since 2011, but Osborn Creek had fining of the substrate (Table 14). Bed D50 (mm) ranged from 1-42 mm for 2016, and ranged from 0.45-9.3 mm in 2011 (Table 14 and Figures 14a.-14d.). In 2011 the substrate at Clara Creek was classified as very fine gravel and in 2016 it was classified as medium gravel, at Ropes Creek in 2011 the substrate was predominantly medium sand, and in 2016 it is coarse sand, at Osborn Creek in 2011 the substrate was mostly coarse gravel and in 2016 it is fine gravel, and at Jones Creek the substrate was medium gravel and in 2016 it is very coarse gravel with a lot of bedrock exposure (Wentworth 1922).

Site	**Clara**		**Ropes**		**Osborn**		**Jones**	
	2011	**2016**	**2011**	**2016**	**2011**	**2016**	**2011**	**2016**
Bed D50 (mm)	3.8	11	0.45	1	26	8.3	9.3	42
Bed D95 (mm)	63	100	12	100	83	59	170	190

Table 14: D50 and D90 (mm) grain size of the bed substrate for all sites in 2011-2016.

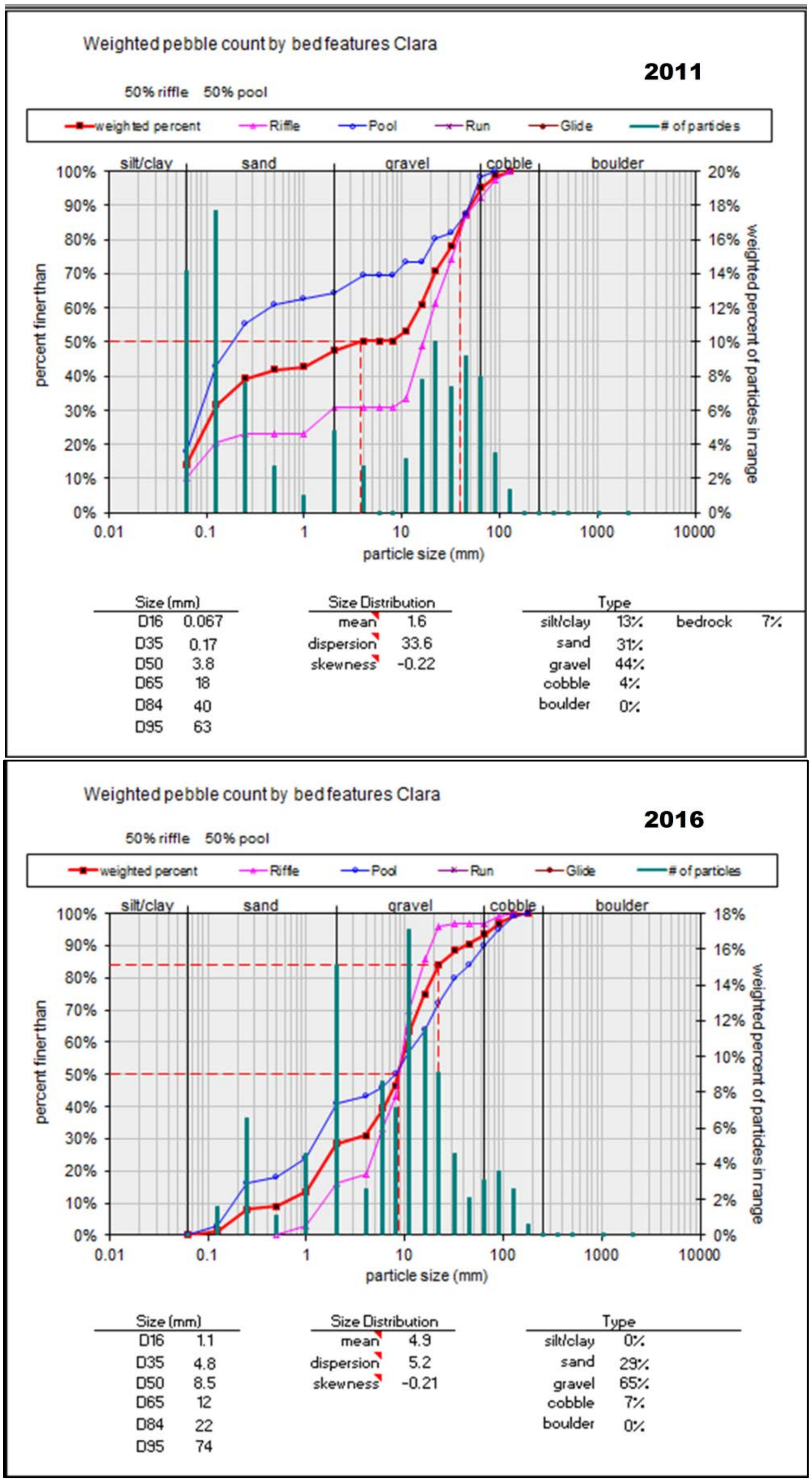
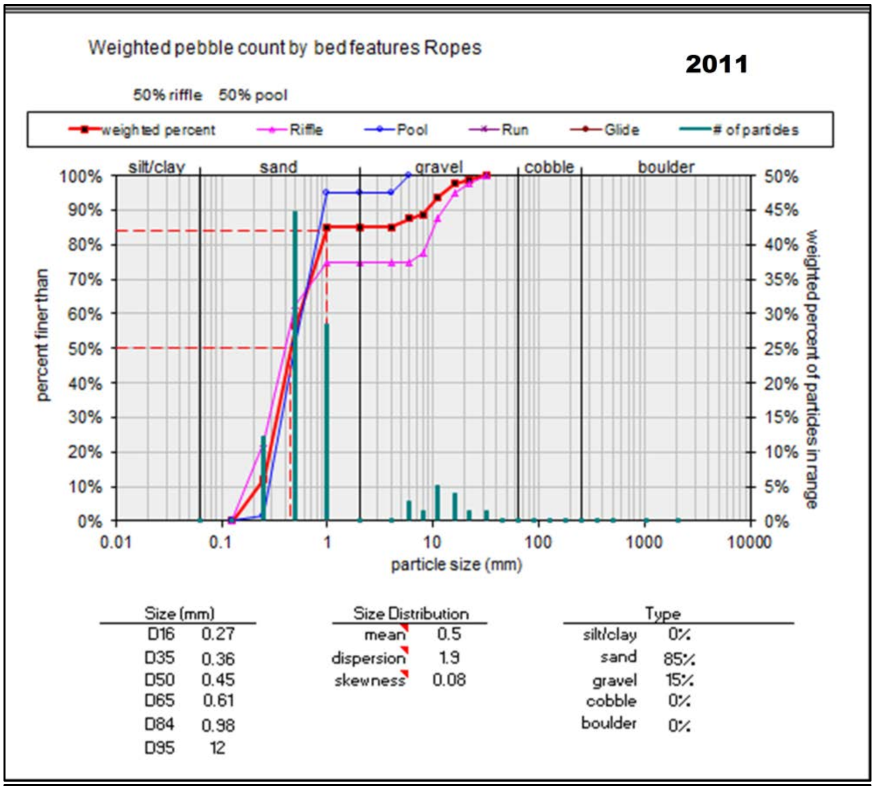


Figure 14a.: Pebble count grain size distribution of the surveyed pool and riffle at Clara in 2011 and 2016.



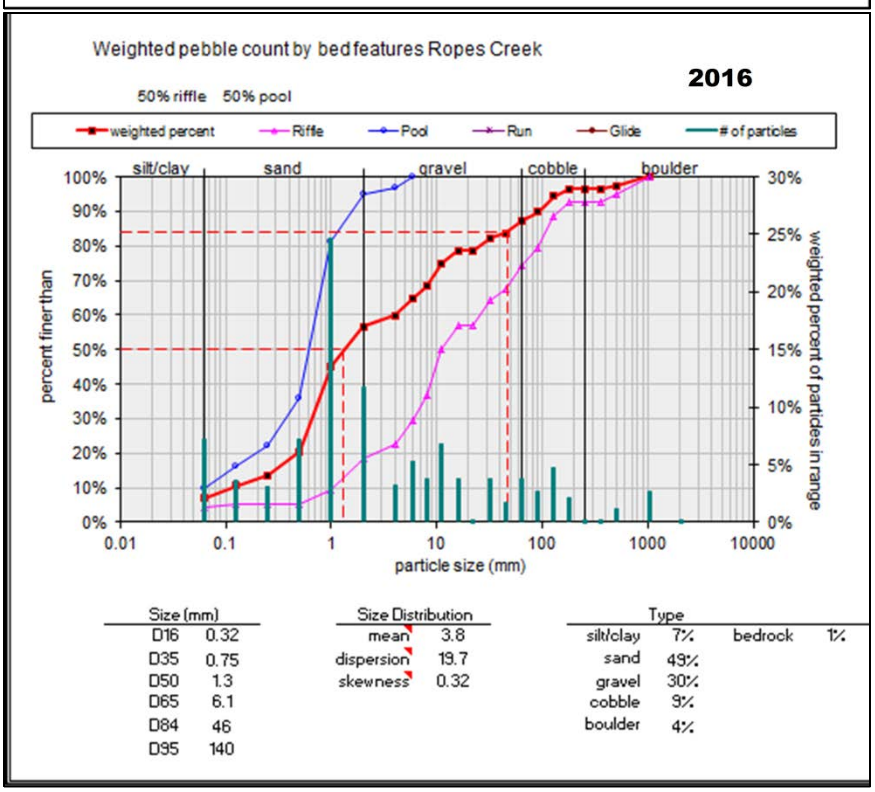
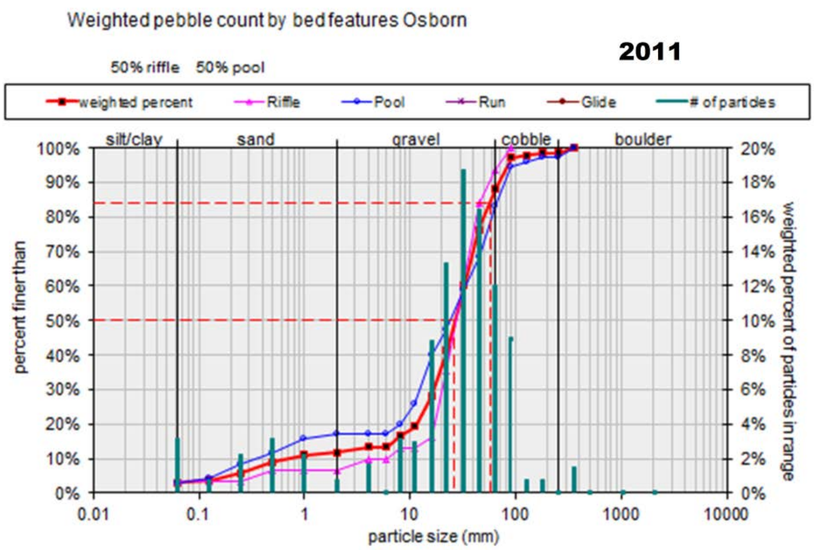


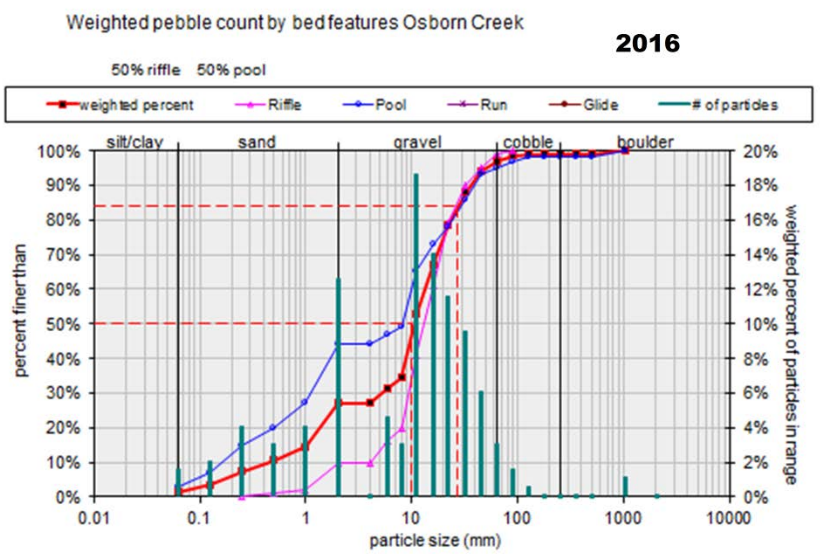
Figure 14b.: Pebble count grain size distribution of the surveyed pool and riffle at Ropes Creek in 2011 and 2016.



Size (mm)	
D16	7.7
D35	19
D50	26
D65	36
D84	57
D95	83

Size Distribution	
mean	20.9
dispersion	2.8
skewness	-0.10

Type			
silt/clay	3%	bedrock	1%
sand	9%		
gravel	75%		
cobble	10%		
boulder	1%		

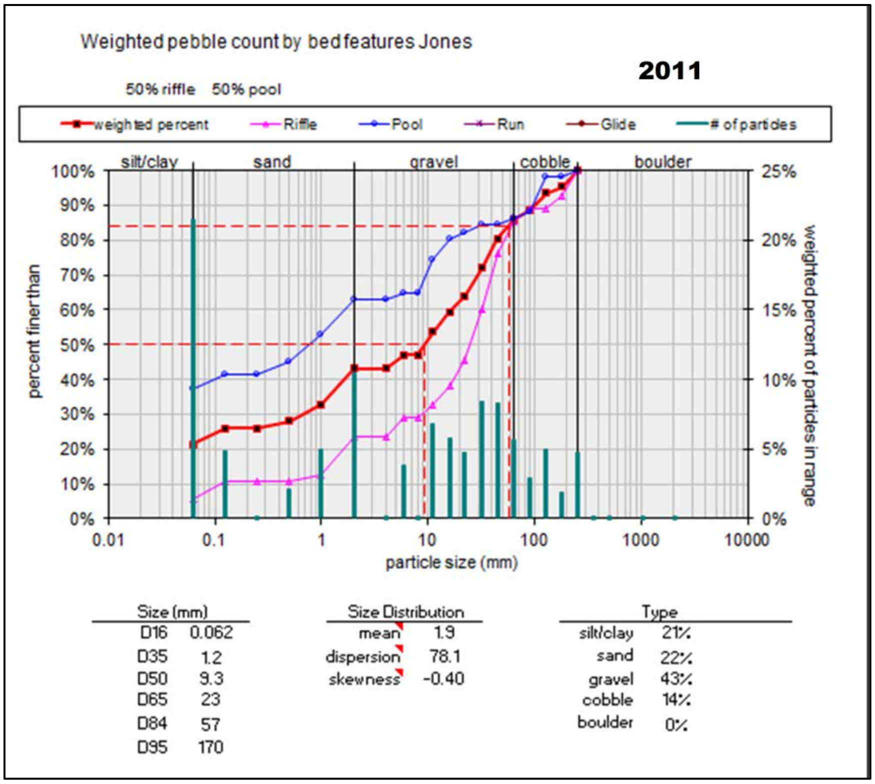


Size (mm)	
D16	1.1
D35	8.1
D50	10
D65	15
D84	27
D95	51

Size Distribution	
mean	5.4
dispersion	5.9
skewness	-0.22

Type	
silt/clay	2%
sand	26%
gravel	70%
cobble	2%
boulder	1%

Figure 14c.: Pebble count grain size distribution of the surveyed pool and riffle at Osborn Creek in 2011 and 2016.



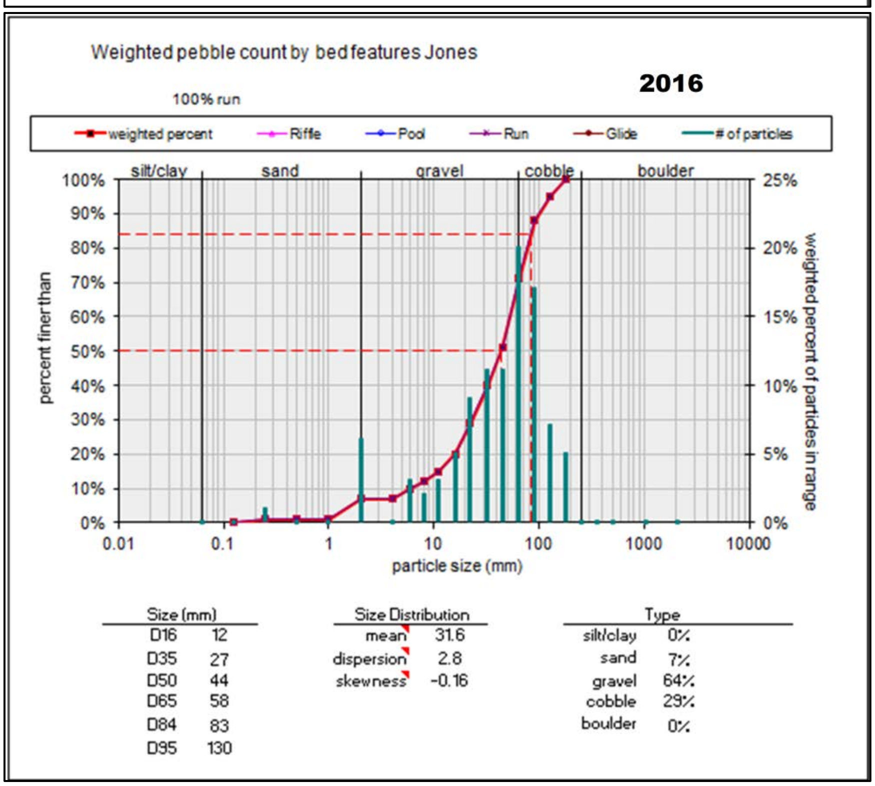


Figure 14d.: Pebble count grain size distribution of the surveyed pool and riffle at Jones in 2011 and 2016.

Bank D50 grain size (µm) with the >2 mm fraction removed ranged from 9.58-37.85 at Ropes Creek, 9.66-36.62 at Clara Creek, 13.28-24.11 at Jones Creek, and 12.69-22.67 at Osborn Creek (Table 15). The average of all sites ranged from 17.33-23.07 µm, which all classify as medium silt based on the Wentworth Scale (Table 15; Wentworth, 1922). Clara Creek had the coarsest Bank D50 based on the Mastersizer grain sizing and with the > 2mm (%) correction and Osborn had the finest bank composition (Table 15).

Erosion Pin	Dx (10) (µm)	Dx (50) (µm)	Dx (90) (µm)	Bank Sample > 2mm (%)
Ropes Pin 1	1.96	12.39	201.00	0.03
Ropes Pin 2A	2.97	24.86	312.27	0.29
Ropes Pin 2B	1.37	9.58	280.45	0.00
Ropes Pin 3A	3.33	37.85	681.18	0.00
Ropes Pin 3B	3.28	28.01	191.17	0.00
Average	2.58	22.54	333.21	0.06
Clara Pin 1A	1.31	9.66	61.99	2.37
Clara Pin 1B	1.69	28.70	202.82	3.07
Clara Pin 2A	2.57	36.62	251.40	0.83
Clara Pin 2B	1.06	25.06	75.78	11.79
Clara Pin 3	2.82	15.30	80.38	2.15
Average	1.89	23.07	134.47	4.04
Jones Pin 1	4.39	23.15	226.13	0.29
Jones Pin 2	3.85	24.11	135.42	1.09
Jones Pin 3	2.96	13.28	108.18	0.69
Average	3.73	20.18	156.58	0.69
Osborn Pin 1	3.38	20.98	83.93	0.00
Osborn Pin 2A	3.06	12.97	67.48	0.05
Osborn Pin 2B	3.55	12.69	74.99	0.00
Osborn Pin 3	3.98	22.67	90.67	0.00
Average	3.49	17.33	79.27	0.01

Table 15: Bank grain size distribution for all sites. Dx(10), Dx(50), and Dx(90) represent percent finer than values and % >2mm represents the % weight of the total sample sieved >2mm.

Overall, suspended sediment decreased at all sites from October 2015 - September 2016 (Figure 15 and Table 16). Throughout the water year the suspended sediment ranged from 2.21-16.16 ppm at Ropes Creek, 0.43-4.44 ppm at Clara Creek, 1.55-22.62 ppm at Osborn Creek, and 0.92-11.97 ppm at Jones Creek (Table 16). The averages of suspended sediment concentration across all sites ranged from 2.41-7.24 ppm; Ropes Creek having the overall highest average of suspended sediment and Clara Creek with the lowest concentration of suspended sediment (Table 16).

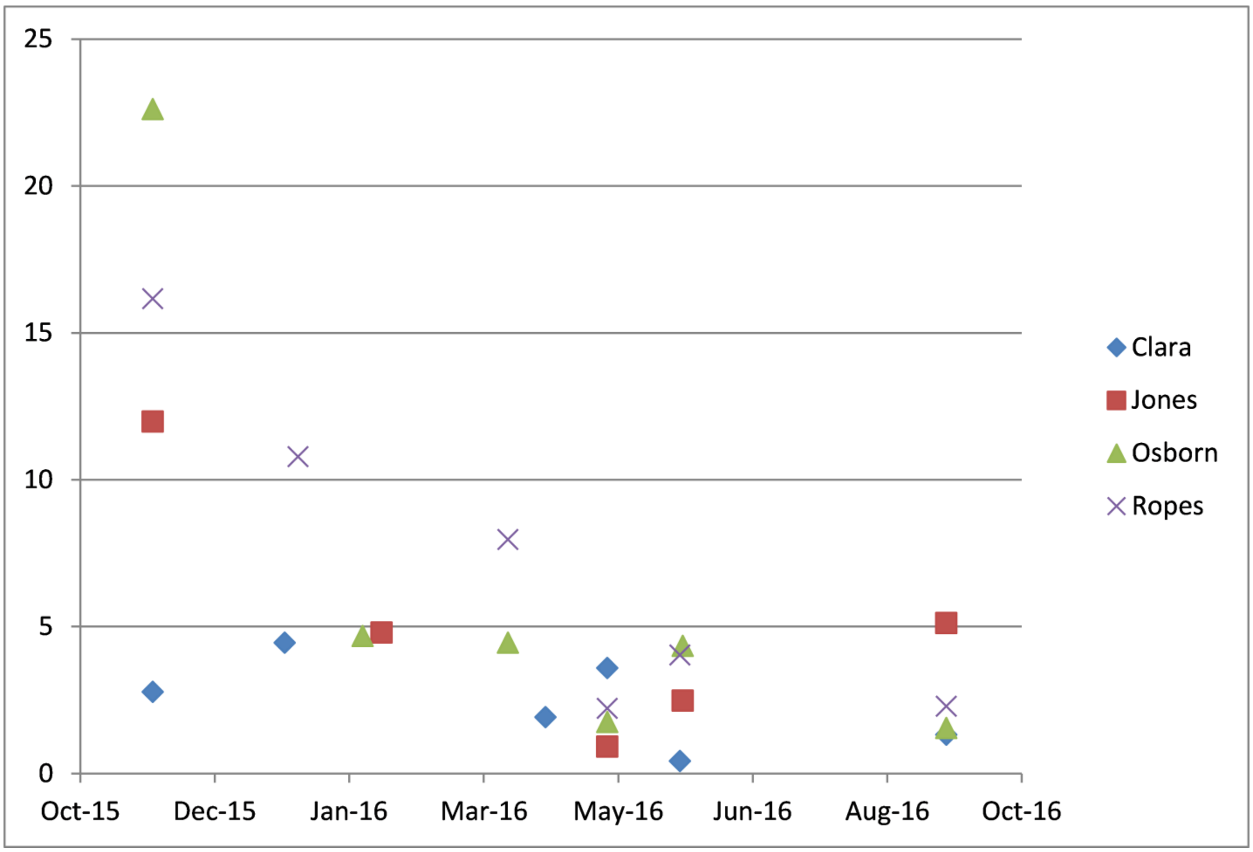


Figure 15: Suspended sediment concentration for the 2016 Water Year.

Site	Date	ppm
Clara	11/19/2015	2.78
	1/7/2016	4.44
	4/13/2016	1.92
	5/6/2016	3.59
	6/2/2016	0.43
	9/9/2016	1.32
average		2.41
Ropes	11/19/2015	16.16
	1/12/2016	10.78
	3/30/2016	7.96
	5/6/2016	2.22
	6/2/2016	4.03
	9/9/2016	2.29
average		7.24
Osborn	11/19/2015	22.62
	2/5/2016	4.67
	3/30/2016	4.44
	5/6/2016	1.75
	6/3/2016	4.34
	9/9/2016	1.55
average		6.56
Jones	11/19/2015	11.97
	2/12/2016	4.79
	5/6/2016	0.92
	6/3/2016	2.48
	9/9/2016	5.12
average		5.05

Table 16: Suspended sediment concentration from November 2015- September 2016.

Change in erosion pin exposure ranged from -4.17 to 5.22 cm. Ropes Creek had the greatest bank erosion, with significant erosion at Ropes Pin 1 to cause the loss of the pin. Jones had the least amount of erosion, but that could be due to potential burial of a pin due to erosional processes (Jones Pin 1, Figure 16 and Table 17). Additionally, there was a trend of increasing average suspended sediment with increased bank erosion (Table 17). Plate 2a.-c. shows bank erosion typical of these sites. Bank erosion within these streams occurs in incising channels with steep banks or undercutting banks where the upper portion sloughs onto the lower part of the bank because it is stabilized by vegetation.

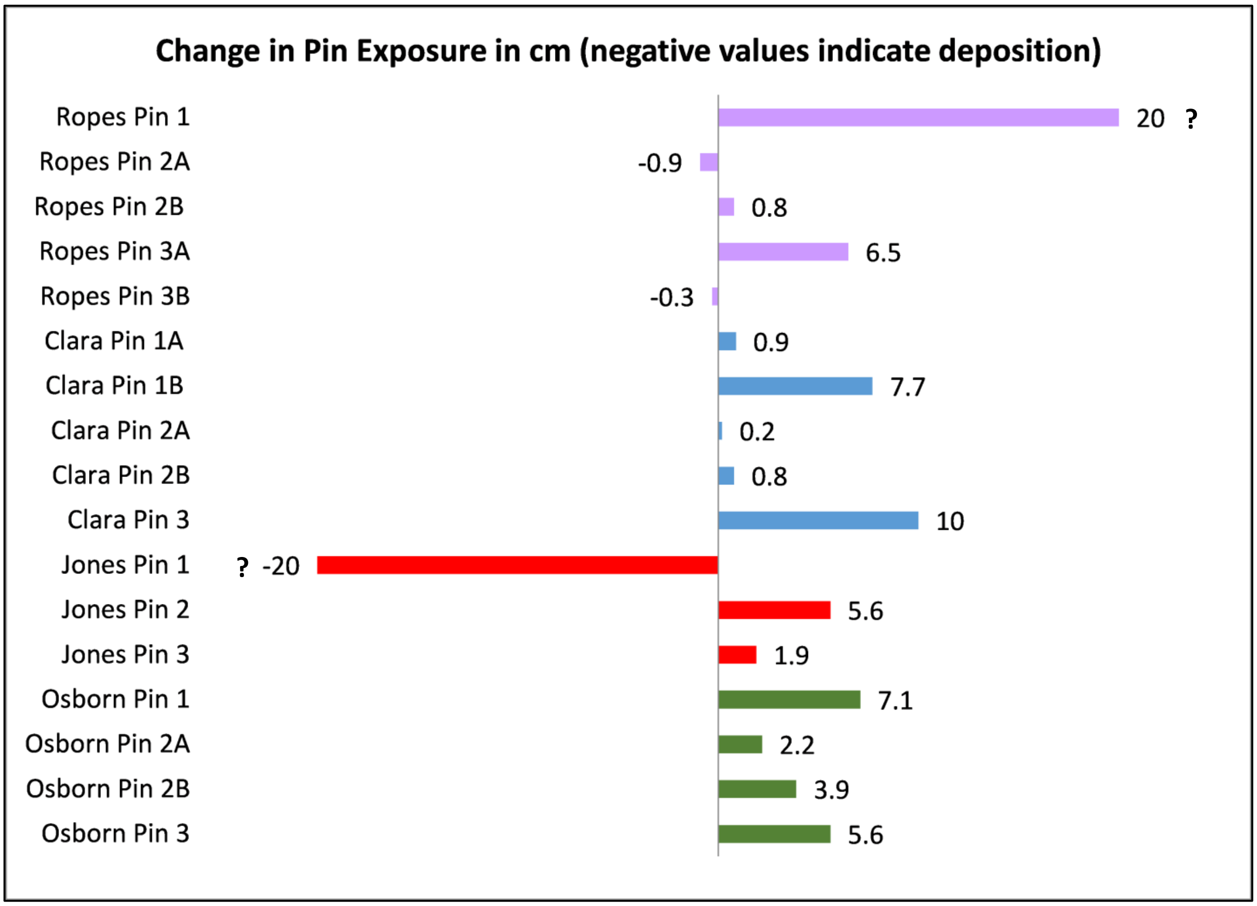


Figure 16: Total change in erosion pin exposure for the 2016 Water Year at all sites, question marks are where pins were buried (Jones Pin 1) or eroded away (Ropes Pin 1).

Site	Avg. Change in Pin Exposure (cm)	Avg. Suspended Sediment (ppm)
Clara	3.92	2.41
Ropes	5.22	7.24
Osborn	4.70	6.56
Jones	-4.17	5.05

Table 17: Average change in pin exposure compared to the average suspended sediment concentration for all sites.

Plate 2 a.), b.), and c.), bank erosional processes/ morphology at Clara and Osborn Creek. Osborn and Clara had the greatest change in geomorphology and also have elevated bank erosion. Both pictures were taken where erosion pins were installed. Plates a.) and b.) are at Clara Creek, c.) was taken at Osborn Creek.

When this original study was conducted Helms et al. were trying to use reference condition sites, but had trouble finding sites that were reference/unimpaired (2016). They found that many streams in the Alabama Piedmont are incised, lack floodplain connectivity, and unstable (Helms et al. 2016). The difficulty of finding reference streams in the Alabama Piedmont is due to the land use history of the area that included extensive clearing for agriculture causing aggradation of fine grained legacy sediment in the banks that re-suspends during storm events (Helms et al. 2016; Hupp et al. 2013). Typical of the Piedmont is a basal gravel layer overlain by fine grained legacy sediment representing the natural pre-colonial substrate overlain by sediment eroded from agricultural practices (Plate 3; Hupp et al. 2016). As previously mentioned, past and present land use is important when assessing watershed morphology and ecology.

Plate 3: Changes in bank material at Clara Creek. Notice the fining upwards and changes in soil horizons due to historical land use.

Correlation Results

Fish and crayfish assemblages showed several significant relationships with reach-scale geomorphic features and physiochemical characteristics. Generally fish CPUE, richness and diversity increased with drainage area, although the most significant differences were due to Clara drainage area being an order of magnitude smaller than the other watersheds (Table 18). Complex nest guarders significantly increased with pH, channel width, and fish diversity (Table 18). Fish Catch decreased with increasing conductivity and bank grain size, and crayfish richness/catch decreased with depth and channel size (Table 18). Furthermore bankfull width decreased as bank grain size increased and surprisingly the greater the shear stress the narrower the bankfull width (Table 18). Benthic invertebrate diversity and richness was negatively related to the D50 bank grain size and WDR. As percent conifer increased, pH decreased and the WDR increased (Table 18). Lastly as percent urban and percent barren increased, bankfull velocity increased.

Correlation Results ($p<0.05$)

Measure 1	Measure 2	Correlation Value R
Fish Catch	Conductivity	-0.972
	D50 Bank	-0.984
Fish Diversity	Max Bankfull Depth	-0.983
% C	pH	0.945
	Channel Width	0.994
	Max Bankfull Depth	-0.993
	Fish Diversity	0.953
% G	Fish Diversity	-0.991
% L	Shear Stress	-0.896
Crayfish Richness	Max Depth	-0.961
	WDR	-0.896
Crayfish Catch	Max Depth	-0.943
	Reach Slope (%)	0.983
D50 Bank	Macrobenthic Diversity	-0.904
	Macrobenthic Richness	-0.917
WDR	Macrobenthic Diversity	0.949
	Macrobenthic Richness	0.969
% Conifer	pH	-0.953
	Bankfull X-Sectional Area	0.969
% Urban	Bankfull Velocity	0.970
Bankfull Width	D50 Bank	-0.960
	Shear Stress	-0.992

Table 18: Significant ($p<0.05$) relationships between measures of biota assemblages and geomorphic characteristics for the four sites.

DISCUSSION

I found that there are strong biota and watershed relationships linked to differences in land cover across sites and land use alteration through time. Based on my knowledge of land use within the region and data from the original Eco-Geomorphological study (Helms et al. 2016) I selected Osborn and Jones Creek to act as my reference sites because they were mostly forested and Clara and Ropes Creek as the impaired streams because they had more developed/impervious area, but what I found is that although primarily forested, Osborn Creek is dynamic and may not be as stable as I expected. Outlined in detail below, geomorphology and biota greatly changed over a short term period of 5 years, Osborn Creek and Clara Creek had the greatest changes in geomorphology since 2011, Ropes and Clara Creek had the greatest change in biota populations since 2011.

Land use change

Overall, the conversion of deciduous forest has potentially affected the stream's sites geomorphology and habitat. This is evidenced by Osborn Creek, where changes in geomorphology have occurred since conifer conversion has increased, despite that forested area at Osborn Creek has not changed greatly, geomorphology and aquatic populations have. Riparian buffers are important to maintaining stream health, but what vegetation comprises the buffer and whether it is native forest or plantation growth is important as well. Significantly, conversion of forested watersheds from hardwood species to conifer species causes a marked decrease in streamflow as soon as six years post conversion and causes as much as a 20 % decrease in streamflow under the same climatic conditions (Burt 1989; Swank et al. 1988; Swank and Miner 1968). These potential decreases in streamflow due to conifer conversion could have considerable effects on geomorphology and available habitat. Moreover, in forests managed for timber harvest, there is a reduction in habitat complexity as the number of pools decrease, and mass soil movements increase; these effects of managed forest land could be occurring at Osborn Creek where bank slumping is common and Jones Creek where there is a lack of pools (Allan 2007).

Urban land use and stream health has been well studied (Simpson et al. 2014; Hupp et al. 2013; Gangloff and Feminella 2007; Wang et al. 1997). These effects of urban development are readily seen at the more developed watersheds where bank erosion is magnified and biological populations are reduced. These differences could also be due to differences in lithology as well, where the underlying gneisses at Clara and Ropes Creek are more susceptible to erosion and have more active elements when weathered affecting bio-populations. Furthermore, urban development limits soil capability to function as a sink for potential nutrients and sediment, as well as limits rainfall interception causing more erosion (Pope and Odhiambo 2014). Also, Clara and Ropes Creek have increased in stream power since 2011 potentially linked to increases in impervious area. Likewise, as impervious surfaces increase the competence of a stream for carrying more sediment as well as the stream's erosive ability increases (Pope and Odhiambo 2014).

Bio-assessment

It is well documented that fish assemblages increase in richness and diversity as drainage systems increase in size, but the effect of drainage area may not be a controlling factor because three of the four sites' have relatively equal drainage size eliminating the effects of stream drainage differences on fish assemblages (Helms et al. 2016; Matthews and Robison 1998; Barila et al. 1981). Smaller drainages typically have the lowest species richness, but can also be a result of degraded habitat as shown by elevated bank erosion and down cutting at Clara Creek, my smallest drainage. Furthermore, Ropes Creek had the second highest drainage area (10.8 km^2), but the second lowest richness and catch, and lowest CPUE suggesting that land cover differences rather than drainage area is limiting the fish populations in these Alabama Piedmont drainages. Osborn and Jones Creek had higher fish richness, catch, and diversity suggesting they are the least disturbed of the sites.

Additionally, conductivity and bank grain size were negatively correlated to fish catch. These significant relationships suggest that fish populations are responding to differences in conductivity and bank grain size. In the more developed watersheds where bank grain size is coarser (not bedrock) and conductivity is higher, potentially due to higher bank erosion and suspended sediment concentrations, could be constraining fish populations.

With the exception of Jones Creek, at all sites fish assemblages contained primarily widespread species, but narrow-endemic species did account for a ~1/3 of the population at the most altered watersheds, and are potentially threatened if deciduous removal continues. Tallapoosa River Basin endemics (narrow-endemics) are confined geographically, but are found in significant numbers locally and in these streams (Helms et al. 2016). These findings suggest small streams harbor these distinct narrow-endemic species that contribute to biodiversity of the Tallapoosa River Basin, which although small are important to study for restoration efforts for larger watersheds and could be detrimentally affected if land use disturbance continues.

Complex breeders were the most abundant at these sites (except Clara). Fishes with this reproductive strategy build and protect nests and are generally more common on coarse substrates (Allan 2007). These streams had coarse substrates, which may partially drive the high relative abundance of complex breeders. Generalist breeders were more abundant in watersheds with smaller drainage area and potentially habitats that are degraded. Generalist breeders can spawn on sand, silt, or vegetation; and fish assemblages shift to generalists when habitats are degraded (Allan 2007; Helms et al. 2005). Lithophilic spawners are very sensitive to sedimentation and need clean gravel/cobbles free of silt to spawn. Osborn Creek had the highest percentage of lithophilic spawners suggesting that sedimentation is not affecting fish populations as expected since there has been a fining of the substrate at Osborn Creek since 2011.

Benthic invertebrate diversity, richness, and EPT did not vary greatly across streams. Clara, Ropes, and Jones Creek had the lowest values and were almost equal for benthic invertebrate diversity and richness. Osborn Creek had the highest diversity and richness suggesting higher habitat quality for benthic invertebrates at Osborn Creek than at the other sites. EPT richness, a measure of orders that are sensitive to pollution, was relatively similar at each site. Ropes Creek had the highest EPT richness, but all other benthic invertebrate metrics were lower than the other sites, suggesting habitat degradation at Ropes Creek. Benthic invertebrate metrics suggest that finer substrate is less suitable for benthic invertebrates and Allan (2007) found that benthic invertebrate abundance and diversity increases with mean particle size because fine grained substrates are too tightly packed limiting oxygen delivery and detritus trapping efficiency. These findings suggest that benthic invertebrate populations in watersheds are reduced because of the finer bed substrate and possibly greater land development limiting benthic invertebrate populations. Watersheds with high abundances of Chironomidae may reflect degraded benthic invertebrate habitat and streams had overall lower benthic invertebrate metrics, than watersheds with less Chironomidae (Pinder 1986).

Bioassesment Conclusions

The watersheds with the most forested area were the most biologically abundant for fish and benthic invertebrates, while the more disturbed watersheds were less biologically abundant and rich. No notable trends were evident for crayfish populations in 2016. These differences in biological populations could be due to land use differences across sites, bank erosion rates, suspended sediment concentrations, and hydrological regimes of these four streams.

Temporal Response

Habitat degradation and restructuring has occurred since 2011 because biotic signatures are responding to land use change. The data collected in 2016 shows the same trends as 2011, with Osborn Creek having the highest fish population metrics and Clara Creek with the lowest fish population metrics. Fish catch and richness has only increased at Jones Creek, slightly, which could be a result of conversion from grass/scrub to forest since 2011, where areas that were once cleared are now forested (17.2 % clear-cut in 2011 to 4.2 % clear-cut in 2016) improving the floodplain's trapping efficiency for runoff.

There have been slight changes in feeding guilds since 2011. Omnivorous species may be most abundant where drainage area is small and habitat is potentially degraded. Overall, the shift to complex breeders may be due to coarsening of the substrate from changes in energy of these systems since 2011. Complex nest-guarding breeders need gravel-cobble-pebble substrates to construct their nests (Helms et al. 2005). Range distribution categories transitioned since 2011. Where there was greater conifer conversion narrow-endemic species decreased, and where clear-cut area decreased narrow-endemics increased. A decline in narrow-endemic species may indicate a decline in habitat quality. The decline of narrow-endemic species is consistent with the decline in diversity at Osborn Creek which has decreased more since 2011 than the other sites. The increase in near-endemics at Jones is consistent with the increase in fish catch since 2011.

Crayfish metrics have declined since 2011, specifically catch and CPUE. These declines in crayfish populations suggest that there has been an overall decline in habitat quality since 2011. Osborn Creek had the lowest crayfish population in 2016 and declined the most since 2011, this change in crayfish populations is probably due to the large increase in shear stress (2011 shear stress 9.2 N/s, 2016 shear stress 26 N/s). Simpson et al. (2014) found that crayfish metrics were significantly related to the shear stress since crayfish live and feed on the bottom of the stream.

Benthic invertebrate diversity and richness have decreased at all sites except Osborn Creek. Increases in bedrock exposure, or deciduous conversion to clear-cut or conifer, coupled with increases in shear stress could be attributed to these declines in benthic invertebrate/crayfish metrics since 2011. Benthic invertebrates live on the streambed and are highly sensitive to changes in substrate, hydrology, and shear stresses. Where functional feeding groups have changed, (Ropes, Osborn, and Jones Creek) there has been a shift from collector/filterer to collector/gatherer. This shift in functional feeding groups could be because there is now more organic matter present on the streambed than suspended in the water column. At Osborn Creek there has also been a shift away from scrapers that feed on algae/periphyton on the surfaces of the substrate, indicating a decrease in algae productivity and possibly linked to the fining of the substrate.

Temporal Response Conclusions

Since 2011, fish, benthic invertebrate, and crayfish populations are on the decline as evidenced by dramatic decreases in catch and changes in functional feeding/breeding guilds and range distribution categories. At all sites declines in population metrics with concomitant increases in impervious surface, clear-cutting, forest conversion, and bank erosion suggests that declines in population metrics is due to land use change. Biota declines at the four sites are possibly due to geomorphological adjustments to land use alteration and changes in hydrological regimes suggesting deciduous conversion to clear-cut or conifer is adversely affecting the populations of these streams.

Geomorphic/Sedimentologic Results

Since 2011, geomorphological adjustments to land use alteration have been widening, except at Clara Creek where down-cutting is the primary geomorphic adjustment. Bedrock dominated watersheds (Jones Creek) has the least change in WDR when land use is altered because lateral migration of the stream is constrained because bedrock is resistant to erosion. Where streams have been incising, and have cut into bedrock as shown by Plate 4, the steam has reached the threshold of incision and will adjust geomorphically by widening. Furthermore, at incising creeks banks are higher than widening streams as shown by the geomorphic conditions at Clara Creek. Geomorphic disequilibrium can cause intense incision which may eventually correct itself through a negative feedback loop.

Plate 4: Bedrock exposure downstream of survey reach at Clara Creek.

Osborn Creek's dramatic increase in WDR reflects greater bank erosion which caused a fining of the bed substrate since 2011. As streams widen typically, the silty banks erode and deposit finer grained sediment on the streambed. Osborn is a dynamic system and as shown by Plate 5 trees and debris have been piling along this road-cut causing the water to back up and flood which affects the geomorphology of the stream and may enhance the fish habitat because of subsequent larger pool formation. When I performed the surveys this flooding was absent, and when the first survey was conducted in 2011 beavers had dammed the stream and caused a rise in water level as well. These findings suggest that Osborn is dynamic and constantly evolving from either human or animal induced changes in water level and geomorphology.

Plate 5: Culvert backup at a road-cut in Osborn Creek.

The changes in geomorphology have also caused an intense increase in bankfull discharge. Higher bankfull discharge can cause greater bank erosion and habitat degradation because of its capacity to carry and erode greater amount of sediments during stormflow. During stormflow when bankfull discharge is achieved, populations can be reduced because of the increase in stream power and shear stress.

Since 2011, changes in energy regimes potentially linked to land use alteration has caused an increase in stream power and shear stress. Stream power has increased at all sites and is highest at Ropes and Jones Creek. Ropes Creek has the greatest bank erosion which could be due to increases in stream power and although Jones Creek has the highest stream power there is less bank erosion because it is bedrock controlled which is fundamentally more resistant as a stream boundary condition than at the other drainages. The increase in stream power and bankfull velocity could also have caused the coarsening of the bed substrate because finer grained sediments are entrained and suspended within the water column and deposited in lower energy environment downstream.

These hydrological and energy regime changes since 2011 may also be attributed to changes in the bed substrate. The bed substrate has changed considerably at Jones and Osborn

Creek. Jones has had a coarsening of the substrate which may have caused the reduction in biological populations as Jones is a relatively shallow, rocky (mostly bedrock), straight and swift stream. The substrate at Osborn has gotten finer which could be an indication of more bank erosion and suspended sediment than present in 2011.

With the greater than 2 mm fraction removed from the bank samples they all fell under the grain size category of medium silt (0.016-0.031 mm; Wentworth 1922). Despite the similar bank grain size, each site had varying amounts of bank erosion indicating that bank grain size may not be a controlling factor in bank erosion. Additionally, because bank grain size was similar at all sites and bank erosion was not, similarly suspended sediment is also not controlled by the bank grain size. Clara Creek did have the coarsest bank soil which is also evident in Plate 3; Clara has coarser banks increased bedrock exposure due to incision. At Jones Creek where bedrock is prevalent, the bedrock is schist or gneisses which typically (if loose) are imbricated, shielding finer grained deposits from being eroded. Also, it is expected that as you travel downstream there should be a fining of sediment because these are headwater streams and because of transport of eroded bank sediment to lower reaches of the stream.

More disturbed watersheds had elevated suspended sediment concentrations because it has the most altered surface area than the other watersheds. Bolstad and Swank (1997) found in an Appalachian watershed that as building density increased, turbidity increased, positing that the more developed land, the greater suspended sediment in the stream. Furthermore, in the same study, sediment deposited from land use alterations such as logging, construction, and farming could be re-suspended during stormflow and that increases in turbidity during storm flow could be a result of current and past land use (Bolstad and Swank 1997). Additionally this resuspension of sediment deposited from past land use alteration, also known as legacy sedimentation, is common in the Piedmont region and could very likely be happening in these streams (Hupp et al. 2013).

Although I did not collect samples during stormflow the same trends are evident, the greater the land use alteration, the greater the suspended sediment loads. Also, the suspended sediment concentrations at all sites for my first sampling on November 19th, 2015 are significantly higher than my other values because the previous day it had rained 60 mm in Lee County, AL (NOAA). Osborn had the highest concentration when I first sampled, which could indicate that during rainfall events Osborn has the greatest overland input of sediment to the stream from poor forest management or the sediment could come from bank erosion. Seasonal variations in suspended sediment followed a broad trend of more suspended sediment in the winter and spring and decreasing into the summer and fall.

Ropes, Clara, and Osborn could be suffering from flashiness, a hydrological phenomenon of land use disturbance where streams rise and fall quickly in response to precipitation (Fongers et al. 2012). Land use modification most commonly results in increases in stream flashiness and decreases in baseflow (Walsh et al. 2005; Baker et al. 2004). Non-flashy streams have steadier flow and the flow is mostly from groundwater than overland flow (Fongers et al. 2012). Flashiness or intensified variations in flow has serious consequences for the health and stability of streams' ecosystem, morphology, and quality compounding the symptomatic effects of urbanization (Poff et al. 2006). I posit that this phenomenon of flashiness is prevalent in Ropes and Osborn Creek due to their high suspended sediment concentration collected from samples the day after it rained. And from previous study of the Hillabee and Saugahatchee watersheds, flashiness has been increasing in both watersheds for the last decade and Saugahatchee, the more urbanized watershed, has higher flashiness.

Contributing to suspended sediment loads is bank erosion, the greater the average change in pin exposure, the greater concentration of suspended sediment. So the most likely source of suspended sediment in these streams is bank erosion. Bank erosion at these sites happened in 1 of 2 ways, as evidenced by Plates 2 a.-c.; bank erosion occurred either through incision creating or undercutting of the banks where eventually the bank sloughs onto itself. And noted as before, differences in bank composition does not seem to control bank erosion rates, rather could be attributed to land use differences across sites.

The most altered watersheds since 2011, (Ropes Creek and Osborn Creek) had the most bank erosion because of land use alteration converting natural forest/soils/vegetation to plantation forest or clear-cut/paved areas enhancing the flow of runoff to the stream which carries nutrients and sediments to the stream (Pope and Odhiambo 2014). This storm runoff from impervious surfaces and storm management systems also reaches the stream at an accelerated rate exacerbating bank scour during storm flow (Ricker et al. 2008). Conversely percent conifer and bankfull cross-sectional positively correlated ($p<0.05$) supporting that the managed forest has had an effect on channel dimensions. In bedrock dominated systems (Jones and Clara Creek) bank erosion is lessened because bedrock is more resistant to erosion.

Geomorphic/Sedimentologic Conclusions

The more urban drainages have had the highest declines in biological metrics, but in general there has been a decline in all bio-metrics since 2011. The decline of the habitat is reflective of the land use change since 2011 that involves loss of deciduous forests to managed conifer forests or to development of vegetated areas, each watershed having a reduction in deciduous forest. Geomorphological adjustments to land use disturbance include channel widening and incision, manifesting as failing and steepening banks. The above-mentioned geomorphological adjustments contribute to suspended sediment in the stream and degradation of habitat quality in these streams' ecosystems. Changes in energy and hydrological regimes have altered morphology and substrate potentially contributing to erosive processes and consequent suspended sediment concentrations in the stream potentially causing the decline in population metrics.

Habitat and geomorphology adjustments to land use alteration can either function on a positive or negative feedback loop and this study illuminates how quickly streams respond to changes in land use, as this study is only covering stream response over a five year period. This study supports the need for greater interdisciplinary research of watersheds for better inferences about stream response to land use change and can hopefully inform stream restoration efforts for other streams of the Alabama Piedmont.

Sources of error

Pebble counts are biased towards coarser particles because the person measuring is more likely to grab the larger rock than the smaller particles. Likewise due to user error, catch could have decreased at all sites since 2011 partially due to collection differences. Moreover, as evidenced by Plate 1, using satellite imagery is not always enough, or the most accurate for land use change modelling. The nuances of changing land use cover are further complicated because it cannot always be captured in satellite imagery, ground-truthing is necessary to support one's findings.

CONCLUSIONS

Land use alteration has caused a decline in the biological populations and geomorphic change of these four headwater streams in the Alabama Piedmont since 2011. Loss of deciduous forest has intensified bank erosion as well as greater sediment delivery to the stream. Not only are there differences among sites because of difference in land use cover, but regional variations in geology and soil erosivity have baseline controls on geomorphology as well. Overall, land use alteration has serious implications on the health of a watershed, and these changes can be rapid and occur on numerous scales.   Further research is necessary to relate these biogeomorphic concepts and get known, verified trends in biogeomorphic response to watershed disturbance.

SIGNIFICANCE

Sedimentation is the most pervasive pollutant of streams in the US and is common in the Tallapoosa Watershed (ADEM-IWQAR 2014). Sediment dynamics and geomorphologic surveys of altered watersheds is necessary as policy-makers address channel incision and channel widening threatening to undercut bridges, and aggrading channels overloaded with sediment increasing flood risk in populated areas (Kondolf et al. 2000). Additionally, as Rapid Bioassessment Protocols (RBP's) for assessing water quality were implemented in 1989, and continuously evolving practices and metrics improve, a greater understanding of interactions between biota and geomorphology is necessary for restorative efforts (Barbour et al. 1999). New base-line transportation, geomorphologic, and hydrologic data will also allow statistical and spatial analysis on the relationships and dependence among different variables. The effort of this study was to further understand habitat quality variations in response to morphologic alterations and sediment flux, to enhance the growing database of interdisciplinary research on biology, land use, soils, geology, and geomorphology and improving restorative efforts on degraded streams.

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APPENDIX:

ROPES 2016

Family	Species	Common Name	Count
Catostomidae	*Hypentelium etowanum*	Alabama hogsucker	5
Centrarchidae	*Lepomis macrochirus*	Bluegill	4
	Micropterus coosae	Redeye bass	5
Cyprinidae	*Cyprinella gibbsi*	Tallapoosa shiner	23
	Luxilus chrysocephalus	Striped shiner	11
	Nocomis leptocephalus	Bluehead chub	12
	Hybopsis lineapuntata	Lined chub	4
Ictaluridae	*Noturus nocturnus*	Freckled madtom	3
Percidae	*Estheostoma tallapoosae*	Tallapoosa darter	5
total:			72

CLARA 2016

Family	Species	Common Name	Count
Centrarchidae	*Lepomis cyanellus*	Green sunfish	1
	Micropterus coosae	Redeye bass	4
Cyprinidae	*Semotilus atromaculatus*	Creek chub	59
total:			64

JONES 2016

Family	Species	Common Name	Count
Catostomidae	*Hypentelium etowanum*	Alabama hogsucker	5
Centrarchidae	*Lepomis auritus*	Redbreast sunfish	2
	Micropterus coosae	Redeye bass	3
Cottidae	*Cottus tallapoosae*	Tallapoosa sculpin	10
Cypinidae	*Campostoma oligolepis*	Largescale stoneroller	9
	Cyprinella gibbsi	Tallapoosa shiner	110
	Luxilus chrysocephalus	Striped shiner	24
	Nocomis leptocephalus	Bluehead chub	18
	Hybopsis lineapuntata	Lined chub	10
	Semotilus atromaculatus	Creek chub	11
Ictaluridae	*Noturus nocturnus*	Freckled madtom	8
Percidae	*Estheostoma chuckwachattee*	Lipstick darter	5
	Etheostoma stigmaeum	Speckled darter	2
	Estheostoma tallapoosae	Tallapoosa darter	4
	Percina smithranizi	Muscadine darter	3
	Percina palmaris	Bronze darter	18
total:			242

OSBORN 2016

Family	Species	Common Name	Count
Catostomidae	*Hypentelium etowanum*	Alabama Hog Sucker	8
Centrarchidae	*Lepomis auritus*	Redbreast Sunfish	6
	Micropterus coosae	Redeye Bass	6
Cottidae	*Cottus tallapoosae*	Tallapoosa Sculpin	7
Cypinidae	*Cyprinella gibbsi*	Tallapoosa Shiner	34
	Luxilus chrysocephalus	Striped Shiner	31
	Nocomis leptocephalus	Bluehead Chub	9
	Hybopsis lineapuntata	Lined chub	58
	Semotilus atromaculatus	Creek Chub	13
Ictaluridae	*Noturus nocturnus*	Freckled Madtom	2
Percidae	*Estheostoma tallapoosae*	Tallapoosa Darter	8
total:			182

Table A1: Taxa list of fish species and count of all sites.

CLARA			
Crayfish Species	Count	M	F
Cambarus latimanus	10	4	6
Procambarus versudes	12	5	7
Procambarus lopholes	3	2	1
	25	**11**	**14**

ROPES			
Crayfish Species	Count	M	F
Procambarus spiculifer	29	10	19
Cambarus halli	1	1	0
Cambarus latimanus	2	0	2
	32	**11**	**21**

OSBORN			
Crayfish Species	Count	M	F
Procambarus spiculifer	7	2	5

JONES			
Crayfish Species	Count	M	F
Cambarus halli	26	6	20
Cambarus englishi	5	3	2
Cambarus latimanus	4	3	1
Procambarus spiculifer	1	0	1
	36	**12**	**24**

Table A2: Taxa list, total count, and M/F count of crayfish species collected at all sites.

Order	Family	Genus
Coleoptera	Dryopidae	*Helichus*
	Dytiscidae	*Hydaticus*
	Elmidae	*Ancyronyx*
		Dubiraphia
		Macronychus
		Microcylloepus
		Optioservus
		Oulimnius
		Stenelmis
	Gyrinidae	*Dineutus*
	Psephenidae	*Ectopria*
		Psephenus
	Ptilodactylidae	*Anchytarsus*
Diptera	Certopogonidae	*Probezzia*
	Chironomidae	Non-Tanypodinae
		Tanypodinae
	Simuliidae	*Simulium*
	Tipulidae	*Hexatoma*
		Tipula
Ephemeroptera	Baetidae	*Baetis*
	Ephemerellidae	*Eurylophella*
	Heptigeniidae	*Stenonema*
	Leptophlebiidae	*Habrophlebiodes*
		Leptophlebia
		Paraleptophlebia
	Leptohyphidae	*Leptohyphes*
Gastropoda	Pleuroceridae	*Elimia*
Hemiptera	Gerridae	*Trepobates*
	Veliidae	*Rhagovelia*
Hirudinea		
Isopoda	Asellidae	*Lirceus*
Megaloptera	Corydalidae	*Chauliodes*
		Corydalus
		Nigronia
Odonata	Gomphidae	*Gomphus*
		Dromogomphus

Table A3: Taxa list of macroinvertebrate families and genera collected at Clara, Ropes, Osborn, and Jones.

Order	Family	Genus
Plecoptera	Leutricidae	*Leuctra*
		Leutricidae
	Perlidae	*Acroneuria*
		Agnetina
		Attaneuria
		Beloneuria
		Eccoptura
		Perlinella
	Peltoperlidae	*Tallaperla*
	Pteronarcyidae	*Pteronarcys*
Trichoptera	Brachycentridae	*Brachycentrus*
	Calamoceratidae	*Anisocentropus*
	Hydropsychidae	*Cheumatopsyche*
		Homoplectra
		Hydropsyche
	Odontoceridae	*Psilotreta*
	Philopotamidae	*Chimarra*
	Polycentropodidae	*Polycentropus*
	Rhyacophilidae	*Rhyacophila*
Trombidiformes	Trombiculidae	

Table A3 (continued) : Taxa list of macroinvertebrate families and genera collected at Clara, Ropes, Osborn, and Jones.