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Longitudinal Differences in Brook Trout Density and Mean Length in Headwater Streams of Western Massachusetts

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Abstract: Brook trout (*Salvelinus fontinalis*) face many threats throughout their native range in the eastern United States including climate change, invasive species, and recreational angling. Understanding the habitat requirements and distribution of young of the year and adult brook trout in small headwater streams is essential for the conservation of the species. With this research, we sought to better understand the distribution pattern of young of the year, detect seasonal movement of adults before and during the spawning season, and determine if young of the year and adults preferentially inhabit stream reaches of different sizes. To explore these fish-habitat relationships, we electrofished 30 meter reaches with catchment areas ranging from 0.09 km^2 to 4.90 km^2 in the headwater systems of two western Massachusetts watersheds. Sampling was conducted during the spring and fall of 2014. We used generalized linear mixed models to evaluate young of the year density and linear density, adult density and linear density, and mean length of all fish sampled. The results for young of the year indicate that their distribution is quadratic or increases with stream size. We found no seasonal differences in adult densities. We also did not find a longitudinal difference in mean length. These results lead us to believe that the catchment sizes included in this study are equally important for brook trout persistence and should all be considered conservation priorities. This study demonstrated a need for additional research in the upper reaches of headwater streams since our models did not explain a significant proportion of the variability in the data. Additional landscape variables should be measured to better understand how brook trout population dynamics vary longitudinally in headwater streams and how the streams should be managed in the future.

Introduction:

Brook trout (*Salvelinus fontinalis*) are stream-dwelling fish native to the Eastern United States. Brook trout depend on cold, oxygenated water for suitable habitat and have a narrow thermal limit (10-19°C: Hillman et al. 1999), and thus are likely to be impacted negatively by increasing water temperatures associated with climate change. In addition to decreased habitat availability due to warming waters, the distributions of warmer water stream species such as smallmouth bass (*Micropterus dolomieu*), brown trout (*Salmo trutta*), and rainbow trout (*Oncorhynchus mykiss*) are shifting upstream and putting additional pressure on native brook trout (EBTJV 2006).

Populations of brook trout are declining over much of their native range with many isolated to the headwaters of stream systems (Hudy 2008). These isolated populations are particularly vulnerable to habitat degradation and changes in stream connectivity (Mollenhauer et al. 2013). It is thus important to understand how these populations are distributed throughout streams and how habitat use changes longitudinally. Although considerable research has

examined brook trout ecology and movement patterns (Ficke et al. 2009), there is still uncertainty on how movement and habitat use varies spatially and temporally.

The distribution of young of the year (YOY; age-0) brook trout has received limited attention despite its ecologically important consequences. The abundance of age-0 trout may be limited by substrate composition, because brook trout prefer to spawn on gravel substrate (Brasch et al. 1973). Another factor that has been studied is the influence of aquatic vegetation on brook trout density. Aquatic vegetation is important for age-0 trout because they depend on it for cover. Aquatic vegetation has been positively correlated with trout density (Maki-Petays et al. 1997). A study by McRae et al. (2011) found that water temperature was also an important variable related to age-0 brook trout density in the Au Sable River watershed of Michigan.

Another important aspect of brook trout ecology is the seasonal shift in adult movement and habitat use. However, much of the research on brook trout movement has examined non-native populations in the western United States (Gowan and Fausch 1996). It has been found that adults move upstream in the fall to spawn (Ficke et al. 2009; Gowan and Fausch 1996; Petty 2005), but these seasonal movements have not been quantified in small headwater streams. Movement during this time is an important indicator of habitat characteristics for redd-site selection and can be used to identify critical spawning habitat areas. Fall movement may also be related to decreasing water temperatures downstream that allow for increased distribution as lower reaches return into the thermal range of brook trout (Mollenhauer et al. 2013). In this case, brook trout may move downstream in the fall to spawn instead of upstream due to increased stream velocity, rocky substrate, and woody debris.

The analysis of mean length of fish in stream reaches may indicate the age structure of fish and their distribution in the stream. This may also provide a better understanding of the habitat use of different age classes. Fish size may also influence stream-dwelling fish movement and habitat use (Quinn and Kwak 2011; Bunnell et al. 1998). Petty et al. (2005) found that large adults inhabited larger stream reaches in the summer months due to increased resource availability but in the fall, large adult density trends were highest in areas with large amounts of suitable spawning habitat.

One aspect of brook trout habitat use that hasn't been researched extensively is the relationship between brook trout density and catchment area. Catchment is defined as the land area that contributes runoff to a given hydrologic system (Lawlor 2004). As catchment area increases, stream bankfull width, velocity, and depth also tend to increase. A study by Mason (2009) found that mean wetted width and drainage area were significantly correlated with brook trout density in central Pennsylvania streams. Mason (2009) found that mean wetted width was negatively correlated with brook trout density, indicating that brook trout density decreased as stream size increased. Catchment area was also found to be negatively correlated in this study, indicating that smaller reaches had a higher density of brook trout. In a study by Petty et al. (2005), nearly 80% of observed spawning of brook trout in the central Appalachian Watershed occurred in tributaries with a catchment area less than $3km^2$.

In this study, we hypothesized that catchment area and mean bankfull width would be correlated with age-0 density, adult changes in seasonal density, and mean length of brook trout. We chose to include bankfull rather than wetted width because we feel that it better describes stream channel morphology and maximum discharge levels in stream reaches. This analysis tested that brook trout disproportionately occupy stream reaches of a particular size. We predicted that age-0 brook trout density would be negatively correlated with catchment area and mean bankfull width. This would result in higher age-0 densities in smaller stream sizes where there is potentially more aquatic vegetation. Secondly, we predicted that adult brook trout densities would shift upstream during the fall in response to the spawning season. We also predicted that mean length would be positively correlated with catchment area and bankfull width. This would result in larger adult fish inhabiting larger stream reaches.

Methods:

Study Site Selection

This study was conducted in two watersheds near the University of Massachusetts Amherst. The Amethyst Brook watershed is located in the towns of Amherst and Pelham, east of the university campus. We selected four streams for sampling in the Amethyst Brook watershed: Buffam (B), Buffam Tributary (BT), Heatherstone (H), and Nurse (N). The West Brook watershed is located in the town of Whateley, northwest of the university campus. We selected five streams for sampling in the West Brook watershed: Avery (A), Jimmy Nolan (JN), Obear (O), Sanderson (S), and Sinkpot (Si). These sites were sampled in two seasons. Spring sampling occurred from May 19-June 27 and fall sampling occurred from September 4-September 26.

We used the National Hydrography Dataset Plus Version 2.1 (NHDPlus) dataset and ArcGIS v10.1 (Esri, Redlands, CA, USA) to identify potential study sites. Using the NHDPlus flow accumulation layer, we identified sites with catchment areas ranging from 0.1 km^2 to 1.0 km^2 in 0.1 km^2 increments and 1.0 km^2 to 5.0 km^2 in 0.5 km^2 increments for all streams sampled. In the field, we used a handheld GPS unit (GPSmap 62sc; Garmin, Salem, OR, USA) to locate sampling sites. In most cases, the GPS coordinates were used to determine the downstream limit of each study reach. However, in some instances it was necessary to shift sites slightly upstream or downstream in order to sample them adequately. The number of sites sampled per stream ranged from three sites (Si) to 18 sites (O). As this research was part of a related study examining the upstream limit of brook trout distributions, we sampled sites with catchment areas less than 1.0 km^2 more intensively than sites with catchment areas greater than 1.0 km^2. Although brook trout was the only species present at most sites, other species encountered during sampling included brown trout, slimy sculpin (*Cottus cognatus*), and blacknose dace (*Rhinichthys atratulus*).

Field Methods

We sampled brook trout in 30 m stream reaches with a Smith-Root LR-20B backpack electrofisher (Smith-Root, Vancouver, WA, USA). The electrofisher was set to constant direct current and the lowest effective voltage in order to minimize harm to fish. To prevent

immigration and emigration during sampling, we deployed block nets at the upstream and downstream limits of each reach (Peterson et al. 2005). In a few instances, natural barriers were used in place of block nets. We used standard 2- or 3-pass removal-depletion methods to estimate brook trout abundance (Zippin 1958, Seber and Le Cren 1967). We anesthetized fish using clove oil and measured fork length to the nearest mm. All fish were allowed to recover fully before being returned to the stream. During the spring sample, we did not collect YOYs, as they were not fully recruited to the electrofishing gear and were also extremely fragile due to their small size. Following fish sampling, we measured wetted width systematically at five locations approximately evenly spaced throughout each reach. Midway through the spring sample, we also began measuring bankfull widths at the same locations as wetted widths. We sampled 96 sites during the spring and fall samples, for a total of 192 sites sampled.

Statistical Methods

We used length frequency histograms to assign fall sample brook trout to YOY and adult (age-1 and older) age classes (Appendix 1). Brook trout of intermediate lengths that could not be identified confidently as YOY or adult were excluded from analyses. We analyzed density (n 100 m^{-2}) and linear density (n 10 m^{-1}) separately for the two age classes, using YOY data from the fall sample and adult data from both seasons. Mean length analysis was conducted using both age classes from the fall sample only.

For each site sampled, we estimated brook trout abundance using the Seber-Le Cren method when two passes were conducted (Seber and Le Cren 1967) and the Zippin method when three passes were conducted (Zippin 1958). Each time we sampled a site, we calculated total area sampled using mean wetted width and reach length. Abundance estimates and total area sampled were then used to calculate brook trout densities, and reach length was used to calculate linear densities. Linear densities were calculated to better represent the availability of habitat suitable for age-0 brook trout. In headwater reaches, the entire area may be suitable habitat for YOY with aquatic vegetation and ample hiding spots. However, reaches with larger catchment areas may not necessarily provide greater amounts of suitable YOY habitat, as YOYs tend to aggregate along the banks where there is more vegetation to provide cover and they can avoid the faster current of the thalweg (Nislow personal communication). Therefore, although the relative area of available brook trout habitat may differ between upstream and downstream reaches, the area of habitat utilized by age-0 brook trout may be comparable. Densities and linear densities were rounded to integers before modeling. Mean bankfull widths were calculated using five widths for sites that were measured only during the fall and ten widths for sites that were measured both spring and fall. We used the R statistical software and RStudio (Version 0.98.1073 – © 2009-2014 RStudio, Inc.) for all subsequent statistical analyses.

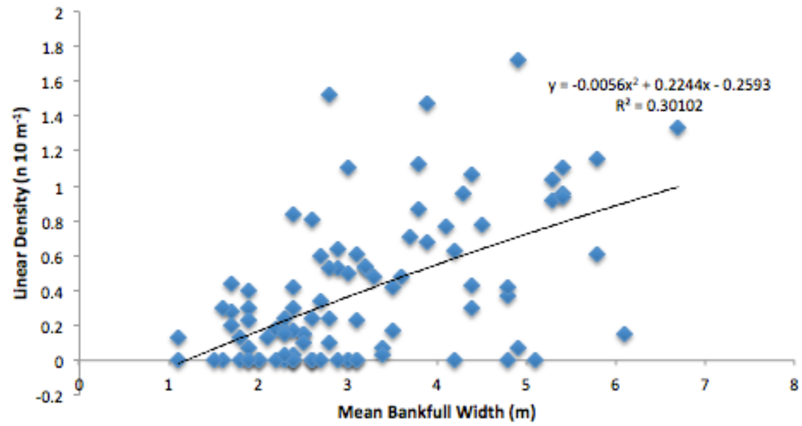

Figure 1: Brook trout YOY linear density as a function of mean bankfull width. A quadratic trendline provided the best fit for the data.

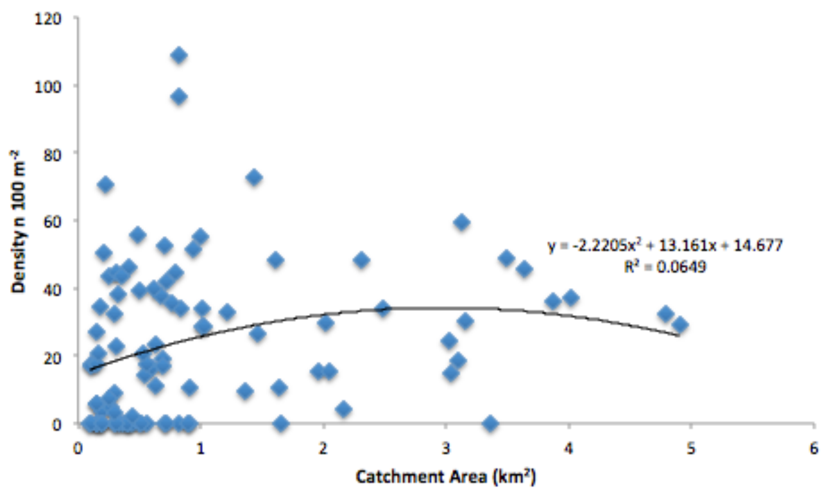

Figure 2: Brook trout YOY density as a function of catchment area. A quadratic trendline represented the best fit for the data.

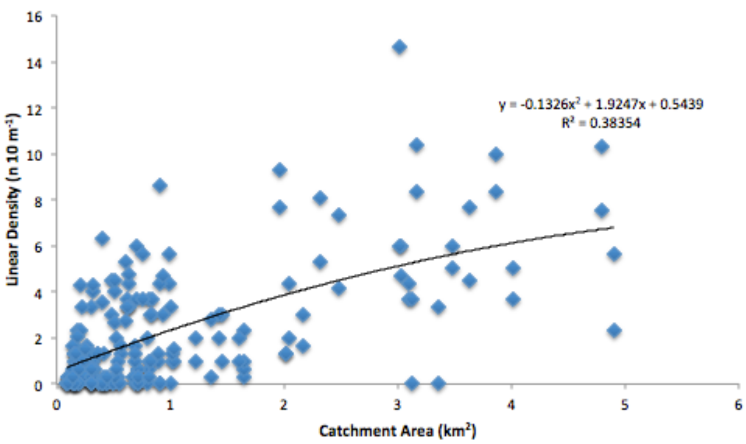

Figure 3: Brook trout adult linear density as a function of catchment area. A quadratic trendline represented the best fit for the data.

We used generalized linear mixed models and the glmer function in the lme4 R package to examine the relationships between YOY brook trout density or linear density, with watershed, mean bankfull width, and catchment area as fixed effect covariates. Stream was included in all models as a random effect. We used generalized linear mixed models and the glmer function in the lme4 R package to examine the relationships between adult brook trout density or linear density with watershed, mean bankfull width, catchment area, and season as fixed effect covariates. Stream was included in all models as a random effect. Exploratory data analysis suggested a quadratic relationship might best explain some of the variables (Figures 1-3), so quadratic models were also included for bankfull width and catchment area. We used linear mixed effects models and the lmer function in the lme4 R package to examine the relationship between mean length with watershed, mean bankfull width, and catchment area as fixed effect covariates. Stream was included in all models as a random effect.

We used Akaike's information criterion corrected for small sample sizes (AIC_c) for model selection. Models were considered to be significantly different if ΔAIC_c values were greater than 2. We evaluated model performance using marginal R^2 and conditional R^2. Marginal R^2 describes the proportion of variance explained by the fixed factors alone, while conditional R^2 describes the proportion of variance explained by both the fixed and random factors (Nakagawa and Schielzeth 2013).

Results:

Analysis of length frequency histograms yielded maximum YOY sizes ranging from 67-84 mm and minimum adult sizes ranges from 75-112 mm (Table 1). The minimum separation between age-0 and adult brook trout was 8 mm (H, A) and the maximum separation was 38 mm (Si). Overall, only 2% of the total length data collected in the fall was discarded due to intermediate lengths. At most, this represented 6% of the length data for a single stream sampled in the fall.

Table 1: Maximum YOY lengths, minimum adult lengths, and YOY-adult age class separation determined from length frequency histograms. Total brook trout collected and number of fish discarded due to unassignable age class are also provided for each stream.

Stream	Max YOY Length (mm)	Min Adult Length (mm)	YOY-Adult Separation (mm)	Total Fish Collected	Number Discarded
Buffam	72	81	9	118	6
Buffam Tributary	67	77	10	87	0
Heatherstone	67	75	8	248	1
Nurse	73	82	9	164	3
Avery	79	87	8	223	5
Jimmy Nolan	84	99	15	212	2
Obear	73	88	15	223	6
Sanderson	78	95	17	247	6
Sinkpot	74	112	38	62	4

Table 2: AIC_c, ΔAIC_c, marginal R^2, and conditional R^2 values for all models. Stream was included as a random effect in all models. Models are considered significantly different if ΔAIC_c values are greater than 2.

Varibles	AIC_c	ΔAIC_c	Marginal R^2	Conditional R^2
Age 0 Density				
Bankfull, Catchment, Catchment^2, Watershed	2235.7	0	0.1514747	0.1514747
Bankfull, Bankfull^2, Catchment, Watershed	2270.0	34.3	0.1046293	0.1046293
Bankfull and Catchment	2273.3	37.6	0.0938602	0.09386091
Bankfull, Catchment, Watershed	2274.2	38.5	0.09946151	0.09946151
Bankfull^2, Catchment, Watershed	2279.7	44	0.1006838	0.1006838
Catchment	2284.3	48.6	0.09341303	0.09341303
Catchment and Watershed	2284.5	48.8	0.09910035	0.09910035
Bankfull, Catchment^2, Watershed	2298.1	62.4	0.06764581	0.06764581
Bankfull	2303.8	68.1	0.05527352	0.05527352
Bankfull and Watershed	2305.3	69.6	0.0556023	0.05560238
Watershed	2431.1	195.4	0.002641504	0.002641764
Age 0 Linear Density				
Bankfull, Bankfull^2, Catchment, Watershed	512.5	0	0.309359	0.3094021
Bankfull, Catchment, Catchment^2, Watershed	517.9	5.4	0.3153174	0.3153174
Bankfull and Catchment	522.7	10.2	0.2754419	0.2754419
Bankfull, Catchment, Watershed	523.5	11	0.2751391	0.2751391
Bankfull, Catchment^2, Watershed	530.3	17.8	0.2626311	0.2626311
Bankfull	531.3	18.8	0.2612366	0.2612366
Bankfull^2, Catchment, Watershed	531.9	19.4	0.2540369	0.2540369
Bankfull and Watershed	533.4	20.9	0.263572	0.263572
Catchment and Watershed	540.3	27.8	0.2352194	0.2352194
Catchment	543.0	30.5	0.2157767	0.2157767
Watershed	636.3	123.8	0.01100567	0.01100567

Adult Density

Catchment, Bankfull, Season, Watershed	2438.4	0	0.1072136	0.2147739
Bankfull, Catchment, Watershed	2438.5	0.1	0.1065684	0.2141604
Bankfull, Catchment, Catchment^2, Season, Watershed	2438.6	0.2	0.1256597	0.2255144
Bankfull, Catchment, Season	2438.6	0.2	0.09358682	0.21595275
Bankfull, Catchment, Catchment^2, Watershed	2438.7	0.3	0.1250538	0.2249341
Bankfull and Catchment	2438.7	0.3	0.09287816	0.21535104
Bankfull, Bankfull^2, Catchment, Season, Watershed	2439.1	0.7	0.1100286	0.2211753
Bankfull, Bankfull^2, Catchment, Watershed	2439.1	0.7	0.1093775	0.2205528
Catchment and Season	2439.2	0.8	0.09113669	0.20844324
Catchment	2439.3	0.9	0.09039276	0.20777503
Catchment, Season, Watershed	2439.4	1	0.1018574	0.2095961
Catchment and Watershed	2439.5	1.1	0.101172	0.2089441
Bankfull, Season, Watershed	2451.8	13.4	0.08335741	0.19986492
Bankfull and Watershed	2451.8	13.4	0.0827469	0.1992977
Bankfull and Season	2452.7	14.3	0.06888967	0.21640838
Bankfull	2452.8	14.4	0.06821625	0.2158704
Season	2500.5	62.1	0.000847928	0.158454313
Season and Watershed	2500.9	62.5	0.008970466	0.156511728
Watershed	2501.0	62.6	0.008164842	0.155808289

Adult Linear Density

Bankfull, Catchment, Catchment^2, Season, Watershed	720.2	0	0.3427212	0.4066796
Bankfull, Catchment, Catchment^2, Watershed	720.5	0.3	0.3369158	0.4011156
Bankfull, Catchment, Season, Watershed	724.1	3.9	0.3209142	0.3928373
Bankfull, Catchment, Watershed	724.5	4.3	0.3147818	0.3869862
Bankful, Bankfull^2, Catchment, Season, Watershed	724.8	4.6	0.3300965	0.4023815
Bankfull, Catchment, Season	725.0	4.8	0.2875065	0.4049395
Bankfull, Bankfull^2, Catchment, Watershed	725.1	4.9	0.3242792	0.3968275
Bankfull and Catchment	725.4	5.2	0.2809819	0.3979286
Bankfull, Season, Watershed	734.2	14	0.3107649	0.3840655
Bankfull and Watershed	734.6	14.4	0.3046347	0.3781523
Bankfull and Season	737.1	16.9	0.2707915	0.4205159
Bankfull	737.5	17.3	0.2650115	0.4144204
Catchment and Season	740.6	20.4	0.2440065	0.3403039
Catchment	741.0	20.8	0.237171	0.3334981
Catchment, Season, Watershed	742.2	22	0.2590113	0.3433158
Catchment and Watershed	742.5	22.3	0.2519851	0.3364481
Season	843.3	123.1	0.007711481	0.18625737
Season and Watershed	844.9	124.7	0.01945555	0.1838233
Watershed	845.3	125.1	0.01066013	0.1779229

Fall Mean Length				
Watershed	681.4	0	0.008608744	0.008608744
Bankfull	681.8	0.4	0.003108847	0.003108847
Catchment	682.0	0.6	0.000849624	0.000849624
Catchment, Catchment^2	682.4	1	0.0234593	0.0234593
Bankfull, Bankfull^2	683.4	2	0.01092288	0.01092288
Catchment and Watershed	683.5	2.1	0.00979648	0.00979648
Bankfull and Watershed	683.6	2.2	0.009338751	0.009338751
Catchment, Catchment^2, Watershed	683.8	2.4	0.0353179	0.0353179
Bankfull and Catchment	684.1	2.7	0.003307356	0.003307356
Bankfull, Bankfull^2, Watershed	685.3	3.9	0.01745748	0.01745748
Bankfull, Catchment^2, Watershed	685.8	4.4	0.01111397	0.01111397
Bankfull^2, Catchment, Watershed	685.8	4.4	0.01046732	0.01046732
Bankfull, Catchment, Watershed	685.9	4.5	0.009797637	0.009797637
Bankfull, Catchment, Catchment^2, Watershed	686.0	4.6	0.0384927	0.0384927
Bankfull, Bankfull^2, Catchment, Watershed	687.6	6.2	0.01844265	0.01844265

Of 96 sites sampled during the fall, 26 were not occupied by age-0 brook trout. For the remaining sites, YOY densities ranged from 2.1 100 m^{-2} (Si, 0.4472 km^2 catchment area) to 108.7 100 m^{-2} (Si, 0.8154 km^2 catchment area). Linear YOY densities ranged from 0.03 10 m^{-1} (Si: 0.4473 km^2, JN: 0.3024 km^2, and N: 0.2016 km^2) to 1.7 10 m^{-1} (JN, 0.3024 km^2). There were 17 of 96 sites sampled in the spring that were not occupied by adult brook trout. Adult densities ranged from 0.94 100 m^{-2} (A, 1.3644 km^2) to 57.6 100 m^{-2} (N, 0.4086 km^2). Adult linear densities ranged from 0.3 10 m^{-1} (B: 0.4122 km^2, 0.54 km^2, 1.6497 km^2, N: 0.3339 km^2, 0.6822 km^2, A: 1.3644 km^2, JN: 0.1008 km^2, 0.2466 km^2, 0.3024 km^2, O: 0.1008 km^2, 0.0999 km^2) to 10.3 10 $^{m-1}$ (A, 4.7925 km^2). There were 24 of the 96 sites that contained no adult brook trout in the fall. Adult densities ranged from 1.2 100 m^{-2} (A, 0.5166 km^2) to 60.9 100 m^{-2} (H, 0.9108 km^2). Adult linear densities ranged from 0.3 10 m^{-1} (Si: 0.8154 km^2, 0.4473 km^2, O: 0.1008 km^2, and JN: 0.7173 km^2) to 14.7 10 m^{-1} (S, 3.0204 km^2). Mean brook trout length ranged from 49.7 mm (N, 0.8154 km^2) to 136.7 mm (JN, 0.8217 km^2).

The model that best described age-0 density included catchment area, mean bankfull width, watershed, and a quadratic for catchment area. The ΔAIC_c value for this model was far superior to all other models explored and the model explained 15.1% of the variance in the data (Table 2). Age-0 linear density was best described by a model including mean bankfull width, a quadratic for bankfull width, catchment area, and watershed. The ΔAIC_c value for this model was significantly smaller than all other models and the model explained 30.9% of the variance (Table 2).

For adult density, the best model included the variables of catchment area, mean bankfull width, season, and watershed, with no quadratic variables. However, the ΔAIC_c value indicates that the model was not significantly better than eleven other models. The fixed variables only explained 10.7% of the variance while the combination of both fixed and random variables explained 21.5% of the variance (Table 2). Adult linear density was best explained by a quadratic model including mean bankfull width, catchment area, season, and watershed with a quadratic variable of catchment area. This model was not significantly different from one other

model. It described 34.3% of the variance explained by the fixed factors and 40.7% of the variance explained by the fixed and random variables (Table 2).

The model best explaining fall mean length included a single fixed variable of watershed. The model was not significantly different from four other models and only explained 0.86% of the variance. Both the marginal and conditional model evaluations explained the same proportion of the variance (Table 2).

Discussion:

YOY density tended to be greater at intermediate catchment areas (Figure 2), although the trendline did not describe a significant portion of the data due to the high degree of variability in YOY density among sites with catchment areas less than 1 km^2. Mean bankfull width was also a significant predictor of YOY density (Table 2). YOY linear density was positively correlated with mean bankfull width (Figure 1), however the best model suggested that there was a quadratic relationship between these variables. This quadratic relationship was not evident in the figure because we could not extrapolate beyond the bankfull widths sampled. Catchment area was also a significant predictor of YOY linear density (Table 2). Our prediction of YOY density and linear density increasing at smaller stream sizes was not supported. It appears that there is either a quadratic relationship where some intermediate stream size has the highest density or densities increase with increasing stream size.

Adult density was best described by mean bankfull width, catchment area, season, and watershed. However, eleven other models with varying combinations of fixed effects were not significantly different. The only constant variable in all twelve models was catchment area. Adult linear density had two suitable models that had the same variables with the exception that one contained season and one did not. Catchment area was a quadratic variable but larger catchment areas needed to be sampled to observe the entire curve (Figure 3). Our prediction that adult density would shift upstream during the fall was not supported. For both YOYs and adults, our linear density models explained twice the variation in our data compared to our density models (Table 2). Mean length models described very little of the variability in the data and we found no significant longitudinal trend. This suggests that YOY and adult brook trout are not utilizing different catchment sizes as we predicted.

The density of young of the year brook trout is an important indicator of good spawning habitat because YOY have limited mobility and stay in the vicinity of the spawning area. Adults may move throughout the entire watershed with higher densities indicating seasonally important resources (Petty 2005). Although seasonality of adult density was included in our best models, not all models with an ΔAIC_c less than 2 included season. We did not find a significant seasonal change in adult density or linear density that would indicate adults moving upstream in the fall to spawn. Mean length may not be a good characteristic to use when analyzing such small streams and may offer better results when applied to larger streams to detect a difference in YOY and adult preferred habitats. In addition, we did not find a strong relationship between adult and YOY densities. Due to the more sedentary behavior of YOYs, this suggests that although adults

might have preferred spawning areas, they utilize the entire length of headwater streams during other times of year.

Although we were unable to identify specific catchment areas or mean bankfull widths with significantly higher YOY or adult densities, we feel that all catchment areas in the study are important for brook trout conservation because there are still many uncertainties about how YOYs and adults use the habitat. Headwater reaches will become increasingly important as climate change causes waters to warm and brook trout habitat to shrink (Hudy 2010). Further research on the habitat use of brook trout in cold headwaters may be the key to brook trout survival as their southern boundaries are pushed upstream.

Increased understanding of habitat use and seasonal movement of brook trout will help researchers identify important stream habitats that need to be protected to mitigate the effects of climate change and invasive species. More needs to be known about brook trout ecology in small headwater streams before management activities can be implemented. Once there is a better understanding of the fish-habitat relationships, direct conservation efforts and restoration programs can be done to critical areas for sustaining brook trout populations (Mollenhauer 2013). Understanding these ecological interactions can also help predict the consequences of habitat changes.

Our results provide a preliminary look at how catchment area and mean bankfull width can be used to analyze fish densities and lengths. However, even our best models only accounted for 40% of the variation in the data. Future studies should be done to identify other landscape variables that influence YOY and adult distributions. Also, since this study was a subset of another project, the sites were sampled unevenly throughout the watershed. A disproportionate number of sites had catchment areas less than 1 km^2, and future research would benefit by more even sampling of larger catchment areas throughout the watershed.

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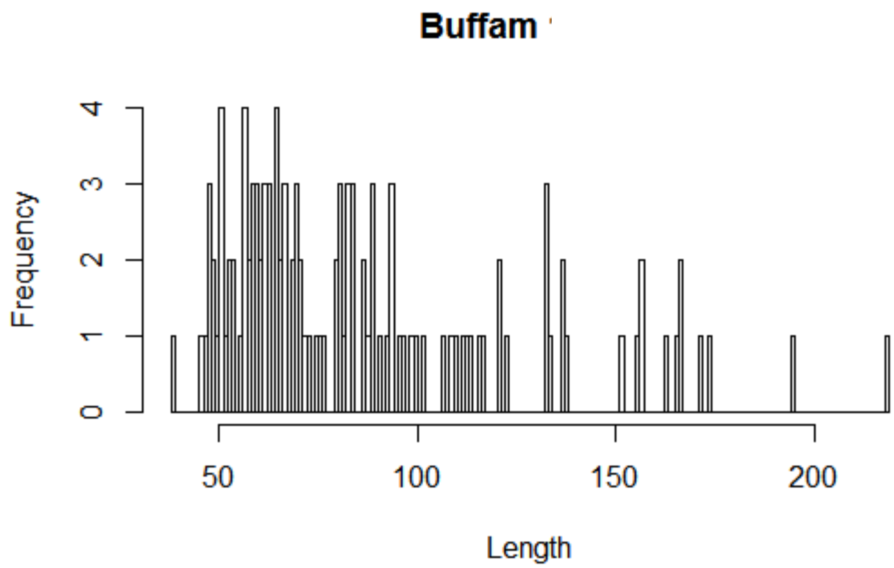
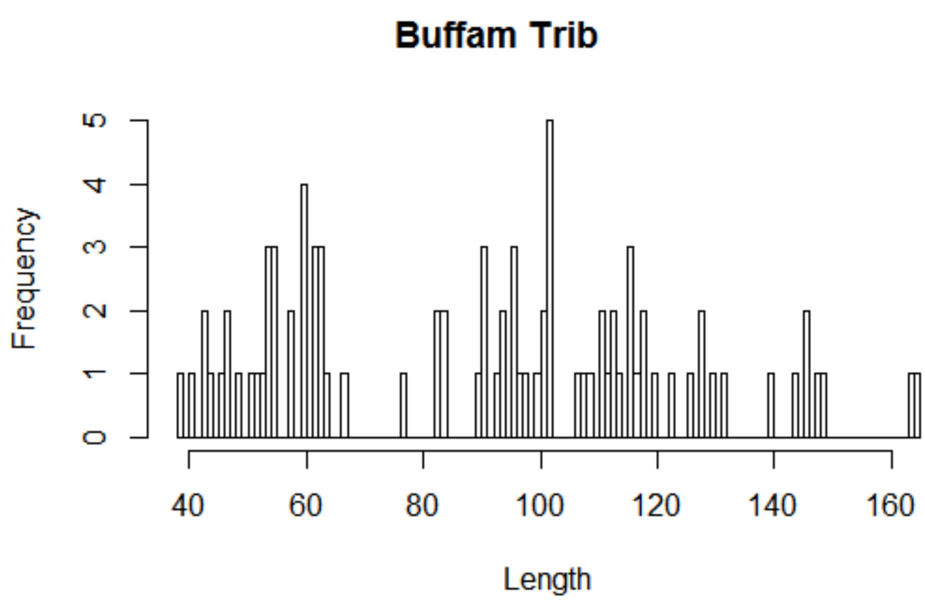
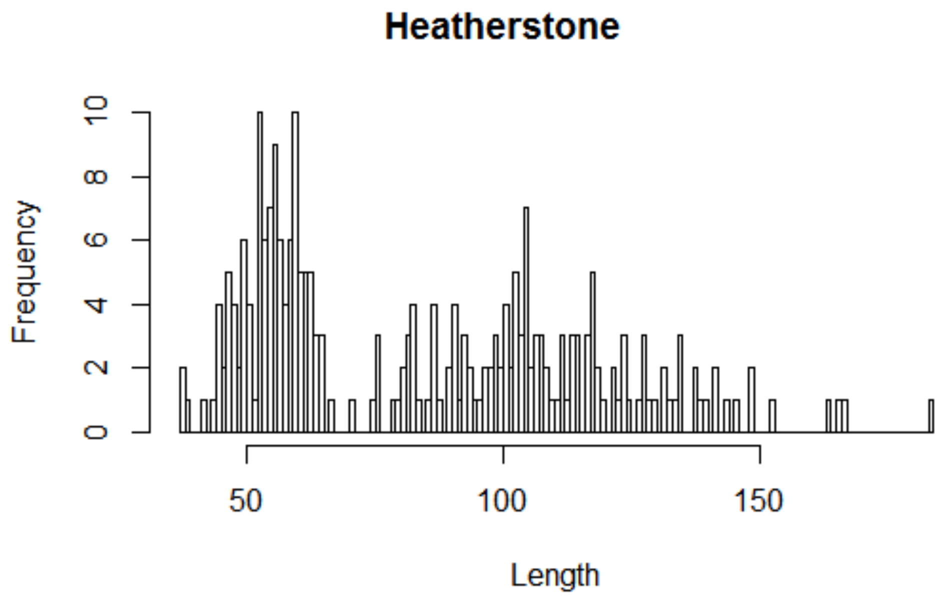
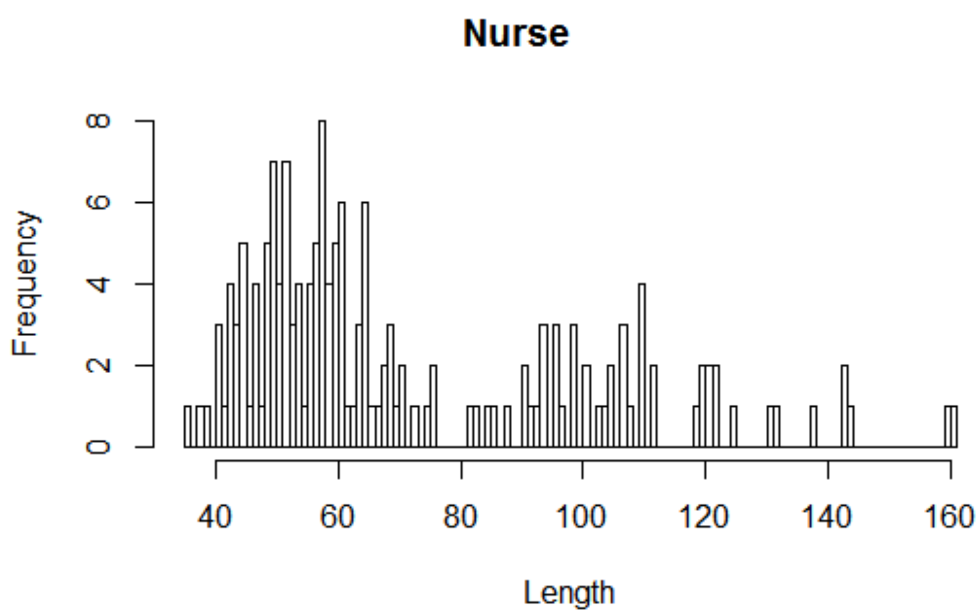
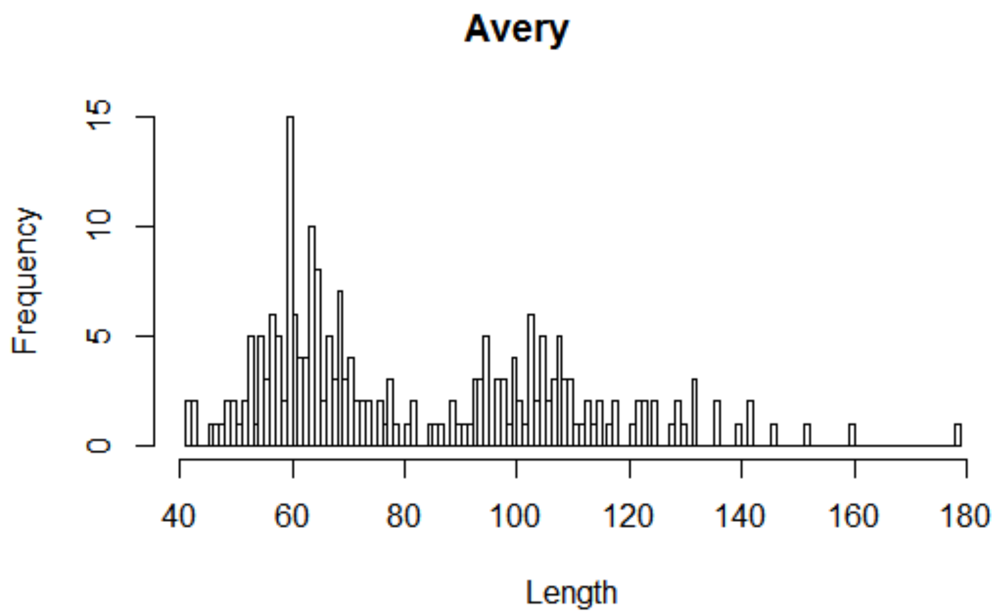
Appendix 1: *Length frequency histograms for each of the nine streams sampled. Each histogram has 1mm bin widths.*

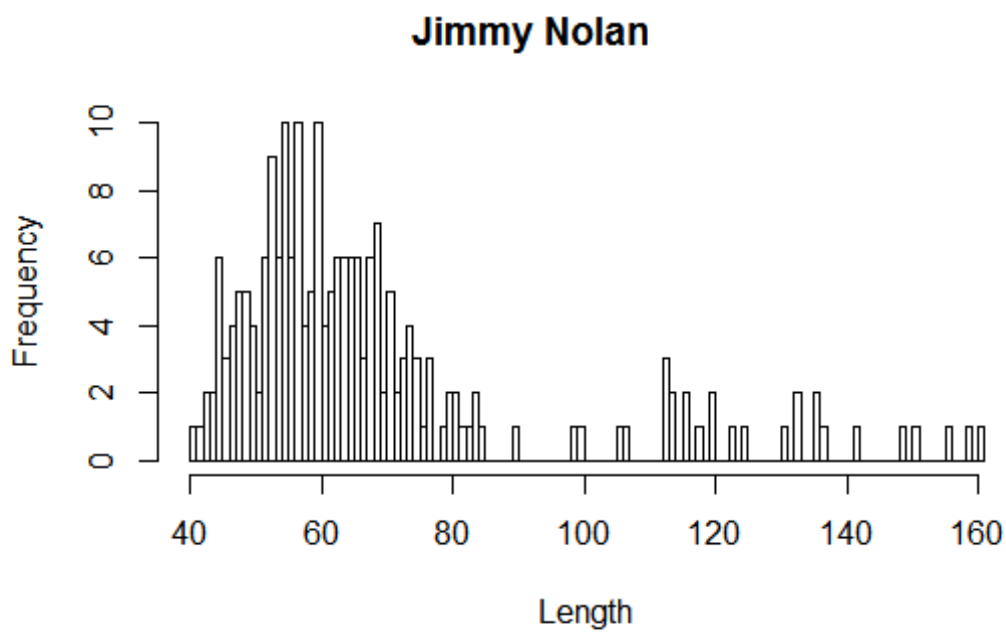


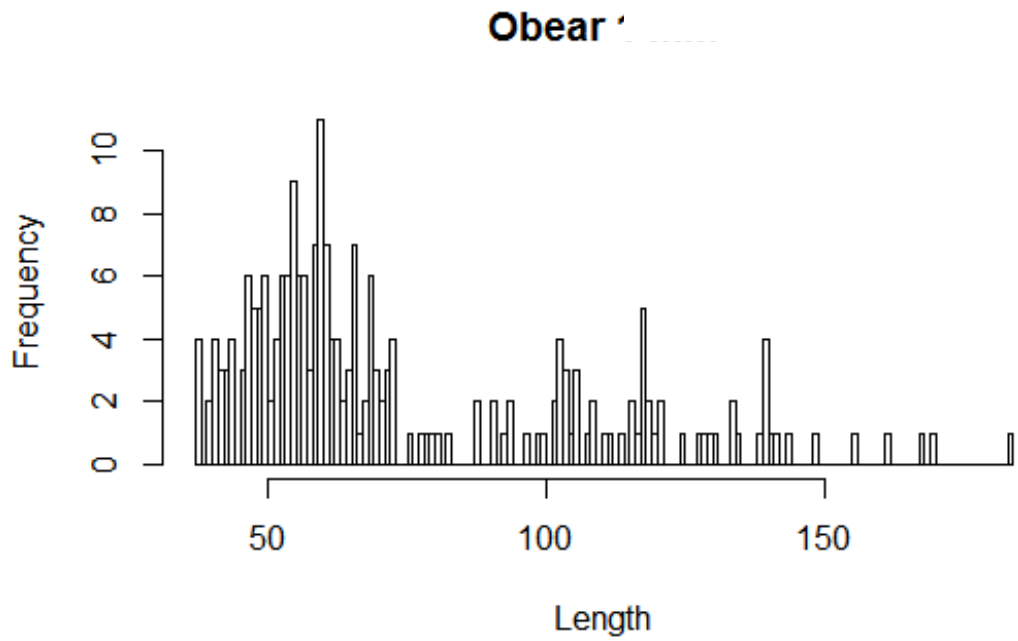


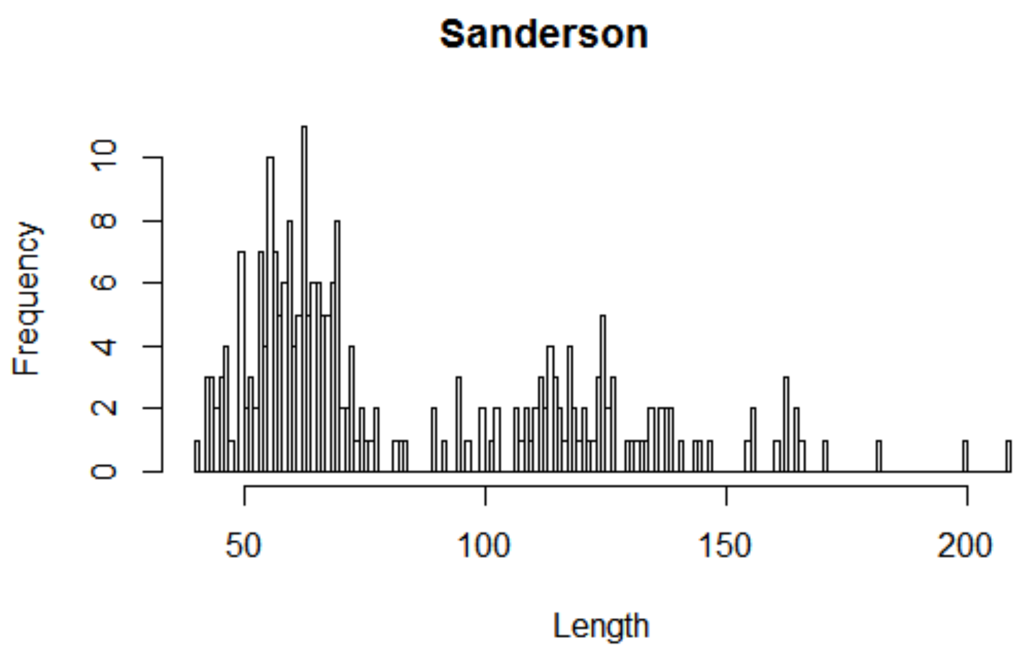

Heatherstone
Frequency
0
2
4
6
8
10
50
100
150
Length

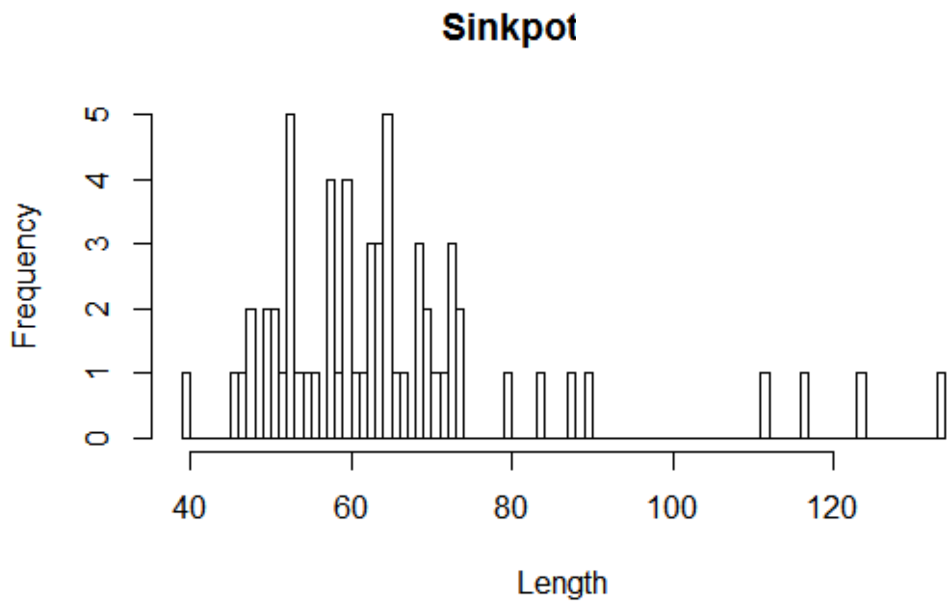

Nurse
Frequency
0
2
4
6
8
40
60
80
100
120
140
160
Length


Avery
Frequency
0
5
10
15
40
60
80
100
120
140
160
180
Length


Jimmy Nolan
Frequency
0
2
4
6
8
10
40
60
80
100
120
140
160
Length


Obear '
Frequency
0
2
4
6
8
10
50
100
150
Length


Sanderson
Frequency
0
2
4
6
8
10
50
100
150
200
Length



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