Analyzing Riparian Land Cover Statistics of Brook Trout Streams in Pennsylvania

GEO 533: Science of Land Use Change

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Contents

Introduction

Riparian buffer systems have great importance in the health of natural systems. These buffers play a variety of roles in the stabilization of stream systems as they regulate temperatures, control erosion, reduce pollution effects, and are beneficial for a variety of ecological purposes. According to the U.S. EPA (2010), a riparian buffer is a “vegetated ecosystem along a waterbody through which energy, materials, and water pass. Riparian areas characteristically have a high water table and are subject to periodic flooding and influences from the adjacent waterbodies”. Forested buffers consist of trees, shrubs and other plants that grow next to streams and rivers. Due to deforestation practices in the United States, less than half of the forested buffers are gone (Teels, 2006). Losing these systems translates to the loss of beneficial ecological functions. Cumulative anthropogenic impacts, including losses of riparian buffers, have been cited as contributing to the decline of 73% of North American fish species (Miller et al., 1989).

This research explores the idea of identifying the current state of riparian areas in headwater streams that sustain brook trout populations in Pennsylvania. Because brook trout are considered a key biological indicator of water quality, this study addresses the presence or absence of brook trout in relation to land cover metrics including percentages of forest, urban, and agriculture within riparian zones. The land cover percentages within the riparian zone of stream reaches that contain viable populations of brook trout have been compared to land cover percentages for a wide range of non-brook trout stream reaches within headwater settings, given similar measures of drainage area, elevation, and stream order. Brook trout populations have declined from their historical range in Pennsylvania; identifying specific land use cover that support brook trout populations may lead to future management and conservation efforts of the species.

Review of Literature

Riparian Buffers

Riparian buffers are identified as vegetated strips of approximately 30 meters on either side of a stream bank that run parallel to a stream system (Marczak, 2010) (Figure 1). These natural buffers provide a variety of beneficial functions that contribute to the health of stream ecosystems and surrounding human populations. Vegetated buffers intercept nutrient run off occurring from surrounding land uses as non-point source pollution (Teels, 2006). Land use changes, including urban development and agriculture have been correlated to the degradation of stream health and buffer systems (Schweizer, 2005).

Riparian buffer systems also help reduce the amount of sediment entering the stream system, as function of dense root networks that bind soil particles along the streambanks which consequently decreases sediment inputs from erosion (Sprague et al 2006). In an urban setting, increased peak discharges can initiate streambank erosion due to reduced roughness provided by streamside buffers. The presence of riparian buffers help mitigate human induced changes by keeping the system more stable, and closer to its natural state. If the riparian zone is largely forested, the floodplain can dissipate higher peak flows by increased roughness once water levels exceed bank heights (Harmon et al. 1986). There is also a feedback geomorphic process that occurs when riparian buffers contain forests; this occurs as large woody debris such as branches, logs, and root wads make their way into the stream. The presence of large woody debris stability within the channel by creating roughness in addition to trapping polluted sediments.


Figure 1: An example of riparian buffer zone vegetation.

Forested buffers contribute to the biodiversity and virility in stream ecosystems throughout a variety of natural processes. A vegetated buffer creates streamside habitat which also provides cover from predators. The overhanging vegetation also provides shade from solar radiation, keeping temperatures cool and stable, and in turn, increases the amount of dissolved oxygen within the water (Johnson. 2008). With the presence of a vegetated riparian buffer, organic matter falls into or near the stream, which creates a food source for any first order consumers, mainly macro invertebrates (Marczak, 2010). From this feedback process, Keeton (2007) has illustrated a relationship between the age of the forest buffer and the amount of biocomplexity that it supports. In order for these buffer systems to reach their critical threshold of creating suitable biological habitats, these buffers must stay in place for extended periods of time before sufficient biological improvements are noted. Such studies have addressed this issue as a function of land-use impacts and fish distribution which has been related to stream bank and riparian area health (Armour et al., 1991). Streamside buffers are especially beneficial to the biological function of brook trout, *Salvelinus fontinalis*, with which this study considers.

Brook Trout

The brook trout is a popular sport fishery species found in lower temperature streams (Johnson, 2008). They are identified as smaller trout species, as compared to rainbow and brown trout, and are known for the red and white coloration that can be found on ventral fins (Figure 2). Due to their fondness for lower water temperatures, brook trout are typically found in higher elevation headwaters or near surface springs.

Figure 2: A brook trout, these species are thought to be indicators of colder stream systems.

Brook trout depend on a diet that mainly consists of macro invertebrate species. In an environment where there is an increase in macro invertebrate populations, there is also an increase in brook trout populations (Jones, 2006). As previously mentioned, macro invertebrates thrive on organic matter found in decomposing plant material found in the water. The presence of riparian buffers increases organic matter within the stream, which in turn, increases macro invertebrate populations. From this relation, brook trout, which consume primarily macro invertebrate species, are dependent upon healthy riparian buffer systems. Conflicting studies have shown that macro invertebrates populations have increased in areas of logging (organic inputs) close to streams (Jones, 2006), which have also increased brook trout populations, although these populations are relatively short lived due to temperature fluctuation, sediment loading, and improper breeding locations at the site.

Brook trout are dependent upon stream temperature in addition to fine sediment loading and subsequent stream channel substrate for spawning. Sediment loading in a stream can cause increased mortality of brook trout embryos as they may become buried by fine sediment (Curry, 2004). Normally the brook trout uses points of ground water discharge as spawning points, but the presence of sediment may cause them to use faster flowing stream sections (Curry, 2004). This can cause increased mortality either by increased flow velocities, or through enhanced visibility to predator species. Areas with increased loss in riparian zones will be heavily populated by more sediment tolerant species (Jones, 1999), which effectively pushes the trout species into higher reaches with more forest cover.

Anthropogenic Impacts

Anthropogenic influences to streams have altered both the terrestrial and aquatic landscape to meet needs including building roads, dredging waterways for travel and transport, and exploiting fisheries resources for food and recreation (Ardent and Carline, 2004). Additional impacts including agriculture, deforestation, and urbanization, alter the natural structural and functional of a landscape. Transformations of forest to urban or agriculture can lead to stream channel destabilization and loss of aquatic habitat as impervious surfaces or compacted soils can generate increases runoff and consequent streambank erosion.

If the land cover adjacent to streams is primarily agriculture, implications exist when soil is exposed from tilling or plowing fields, overgrazing or between growing seasons, and increased surface runoff and sediment inputs associated with impervious surfaces and compacted soils. In an agricultural setting, aquatic ecosystems and stream systems may experience impacts including (EPA, 2010):

- Destroying beneficial channel structures such as pool and riffles
- Damaging gills of fish and aquatic insects
- Filling in pore spaces on the stream bed and suffocating benthic biota
- Interfering with fish spawning habitat, and egg and larval survival
- Reducing light penetration and interfering with algae and aquatic plant photosynthesis

In an urban setting, streambanks can erode due do lateral confinements and increased peak discharges from runoff, the stream can become incised and completely disconnected from its floodplain. Because of these impacts, natural processes of erosion, transport, and deposition of various-sized soil particles within a watershed can become imbalanced due to human activities such as urban development and agriculture (EPA, 2010). Conversely, stream channel stability may be regained if urban and agricultural land cover in riparian zones is converted to forested cover. If stream systems were left in their natural state, current implications such as increased sediment delivery to streams, altering hydrologic and thermal regimes (Fleischner, 1994), influencing water chemistry (Johnson et al., 1997), and modifying the aquatic food web (Klein, 1979) may not occur.

Reinstituting riparian buffers in areas where they have been removed in the past would seemingly lead to the reestablishment of a brook trout population as riparian buffers reduce temperatures and contributing to the overall health of the stream. Management plans aimed at restoring streams to a more natural state by implementing and protecting riparian forest buffers (EPA, 2010). The Riparian Buffer Goal for the Chesapeake Bay states that forest buffers should exist on at least 70 percent of all shorelines and streambanks in the watershed (CBP, 2010). In addition to restoring and protecting riparian areas, upland land uses that contribute to riparian degradation is also an important component of a successful riparian restoration project (EPA, 2010). If the lands surrounding waterways were not protected or restored, land cover would exist for other purposes such as cropland, pastureland, lawns, parkland, which may lead to other potential problems. As described in *Riparian Forest Buffer Design and Maintenance* (MDNR FS 2005), those could include the following:

- Soil compaction – Dense soils that do not allow for infiltration around areas of construction and overgrazing would limit baseflows and increase runoff and peak stormflows.
- Noxious or invasive weeds—Weeds can and often will outcompete and kill young trees. Present and future generations of noxious or evasive weeds might reside at the site.
- Human damage—Riparian buffers are sometimes damaged by the actions of well-meaning residents. Mowing, clearing, and other landscaping improvements can limit ecological functions,

Purpose and Scope

According to Ardent and Carline (2004), fish are useful for assessing the relative health of aquatic systems because they are sensitive to anthropogenic influences. The structure of fish communities are dependent upon direct and indirect effects of stress on the entire aquatic ecosystem (Plafkin et al., 1989). Studies by Gagen et al. (1993) have also monitored the movement of fish species from degraded to healthy areas, which is assumed to have influenced the present day location of brook trout in Pennsylvania. Such fish species, including the brook trout, depend upon various environmental conditions over broad spatial areas for their survival (Fausch et al., 1990). Because brook trout rely on cooler water temperatures, and riparian zones are able to stabilize stream temperature; it can therefore be assumed that brook trout within a stream would translate to a large, healthy, forested riparian zone. This assumption will be tested by comparing land use percentages (ie. urban, forest, agriculture) for three separate stream groupings with varying buffer widths. These groups include the following:

- Class A Brook Trout streams as classified by PA DCNR (2011)
- Non-Brook Trout headwater control stream reaches
- Network (major) control streams of Pennsylvania drawn at 1:1,000,000 scale (USGS, 2012)

By determining the status of land use practices in relation to the presence or absence of Brook trout, this study would potentially have implications on the future protection and restoration of brook trout habitat.

Study Area

The historic range of brook trout, as described by Hudy et al. (2008), covered the majority of the northeastern United Sates, including Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, Ohio, Pennsylvania, New Jersey, West Virginia, Maryland, Delaware, Virginia, Tennessee, North Carolina, and South Carolina (figure 3). Within the last century, brook trout have declined or have been locally extirpated within the species' native range in the eastern USA (Hudy, et al., 2008). Given the timeframe of our study and the accessibility to state-level fisheries and land cover datasets our study area is confined to Pennsylvania. The scale of the study will incorporate all stream reaches containing brook trout within Pennsylvania, which have been identified in 38 out of 67 counties in Pennsylvania.

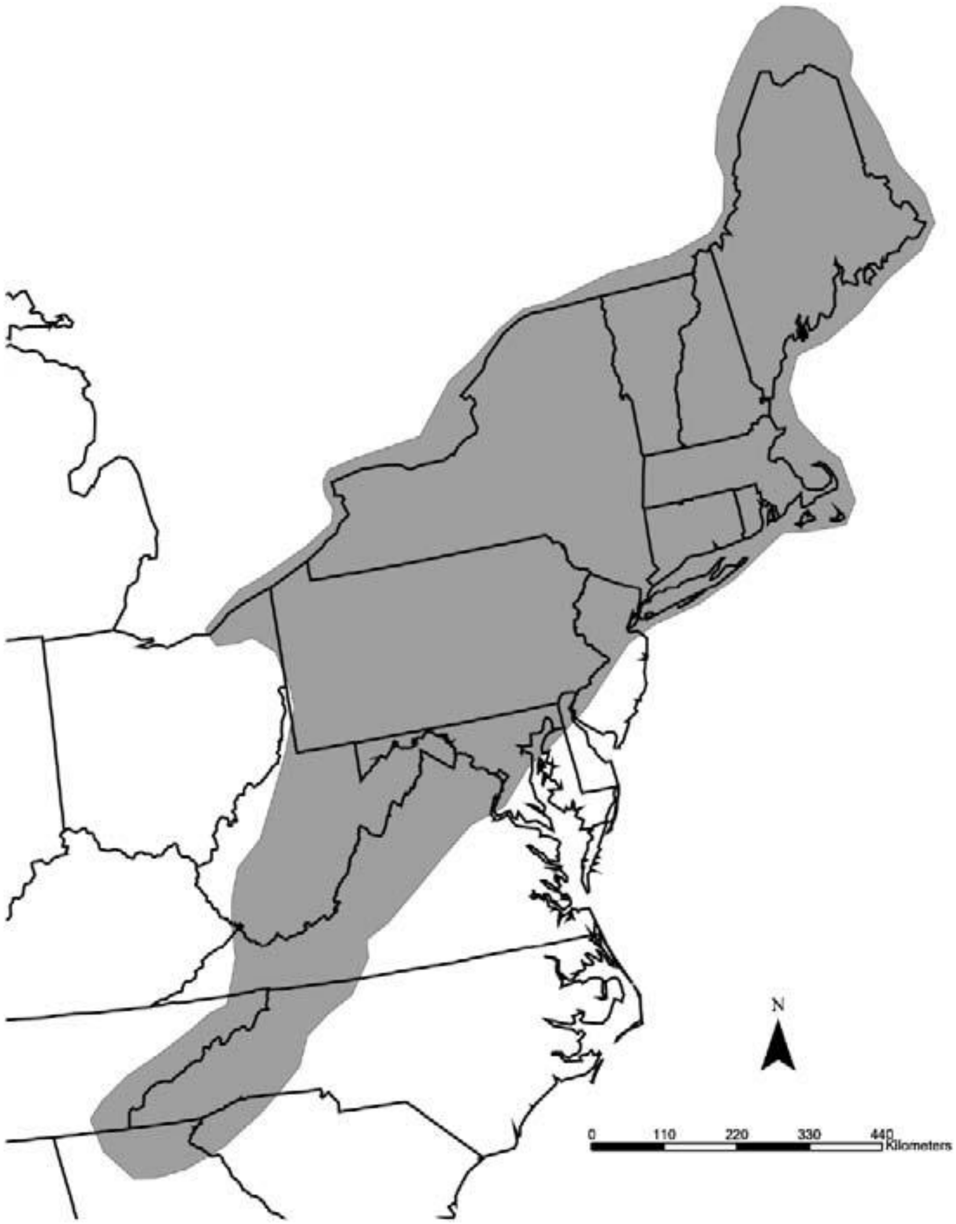

Figure 3: Historic range of brook trout in the northeastern United States.

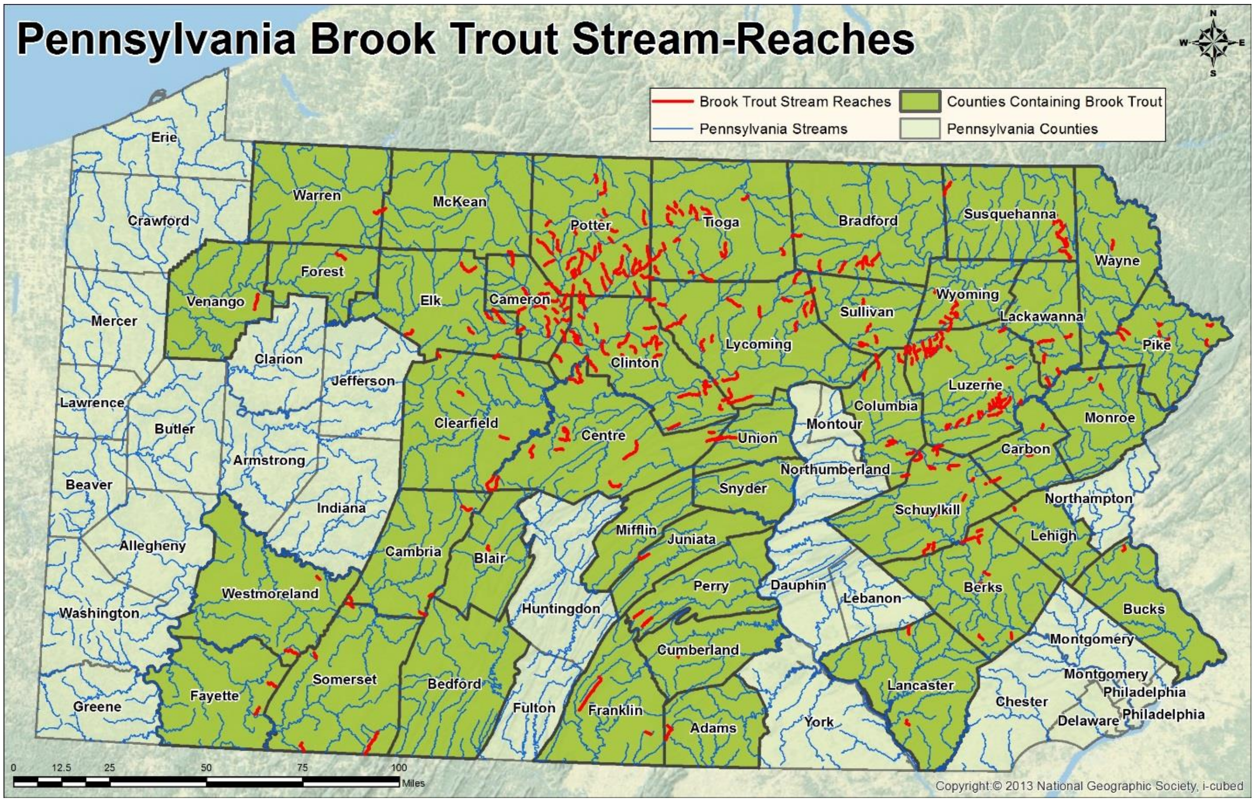

Figure 4: Study area map illustrating all brook trout stream reaches in Pennsylvania within representative counties.

Methods

Stream Reach Selections

To observe the presence of brook trout in Pennsylvania, stream reaches containing the species have been extracted from a “Class A trout waters” dataset compiled from fisheries data by Pennsylvania DCNR (2011). This dataset contains 290 separate stream segments (reaches) that have been identified as containing brook trout only and not containing other non-native trout species such as brown or rainbow trout. A stream reach is defined as a section of stream with consistent or distinctive basin and channel morphology characteristics. The “Class A” designation represents streams that support a population of wild (natural reproduction) trout of sufficient size and abundance.

A second selection has been completed for counties within Pennsylvania that contain brook trout streams to further define the study area. From a brief interpretation of the Class A trout stream dataset, approximately 85% of the stream reaches have been identified as headwater or source reaches (PA DCNR, 2011). From an analysis of the Aquatic Resources Classification dataset (Walsh, et al., 2007), brook trout in Pennsylvania exist at a maximum drainage area of 38mi^2 which consisted of a stream classification 3 or less (Strahler method). The lowest elevation in which brook trout were observed was in Berks County at 56.5ft above sea level. Maximum drainage area, maximum stream classification, and minimum elevation were used as delineative criteria for selecting similar non-brook trout headwater control reaches. The remaining stream reaches were identified from a high-resolution NHD stream dataset developed at 1:24,000/1:12,000 scale. Given these criteria a total number of 24,146 stream reaches exemplified drainage areas less than 38mi^2, a stream classification less than 3, and an elevation greater 56.5ft above sea level.

Additional riparian statistics, not following the above delineative criteria, were calculated for a separate stream grouping that was derived from major streams of Pennsylvania drawn at 1:1,000,000 scale (USGS, 2012). This dataset was used to compare the significance of average land use percentages of major network drainages to non-brook trout headwater stream reaches.

Derivation of Riparian Land Cover Statistics

Land cover statistics within riparian zones have been used to compare stream reaches containing brook trout and non-brook trout stream reaches. The following data sets have been analyzed to determine percentages of land cover classes within varying buffer widths for 290 brook trout stream reaches and non-brook trout stream reaches:

- Pennsylvania Land Cover Data , 2005 data through PASDA
- Class A Trout Waters (PA DCNR, 2011)
- Aquatic Resources Classification (Walsh, et al., 2007)
- National Hydrography Dataset (USGS, 2005)
- Major streams of Pennsylvania drawn at 1:1,000,000 scale (USGS, 2012)

Given the minimum mapping unit (cell size) of $36.5m^2$ for the Pennsylvania Land Cover map (2005), the buffer widths were determined to be 36.5, 73, and 109.5m. Specific GIS techniques used in this research include raster reclassification, euclidean distance calculations, raster to vector transformations, and tabulate areas. To create the stream buffers for the above distances, a distance grid was calculated by setting the input source data for "Class A Trout Waters", "Non-Brook Trout headwater reaches", and "Major streams of PA" with an maximum distance of 109.5m and an output cell size of 36.5m. The new raster layers were reclassified into 3 new grids at target buffer distances of 36.5, 73, and 109.5m. To observe broad land classifications, the PA-LCD file was reclassified to the Anderson Level I, before land cover statistics were calculated. A total of 9 buffered distances (rasters) were transformed to vector polygons in which each land cover percentages were tabulated.

Statistical Analysis

To interpret the differences in percent forest, urban, and agriculture land cover within the riparian buffers for the three stream network groupings, a One-Sample T-Test for Means was employed. This statistical test is used to compare one sample mean to another and allows the researcher to determine whether the mean of a sample data set is significantly greater or smaller than another separate data set. For each percentage of land cover type, including forest, urban, and rural, within each riparian zone, the separation in sample means was described by the *t* statistic. *t* is the distance between the two means, in standard deviation units, taking into consideration sample size, as described by equation 1.

Equation 1.

$$t = \frac{x - \mu}{s / \sqrt{n}}$$

Where:

x= sample mean,
u= true mean,
s= sample standard deviation
n= sample size.

All statistics were analyzed using IBM's SPSS program (2011). The riparian land use percentages (percent urban, forest, and agriculture) of brook trout streams were compared to both network and headwater control stream groups by the one sample t test. Significance was determined by the p-value and the direction of difference was observable by the sign of the t statistic. The control groups were also compared to each other in the same fashion to identify similarities and statistically significant differences between the controls. By determining the significance of control groups, the greatest contributing factor influencing the presence or absence of brook trout could therefore be determined.

Results

Riparian Land Cover Percentages

The average riparian land cover percentages for brook trout stream reaches ranged from 95.54-94.19% for forest cover, 0.83-0.74% for urban, and 4.98-4.20% for agriculture within the three buffer zones (Figure 5). The shortest buffer width of 36.5m illustrated the highest average forest cover percent. Conversely, the widest buffer width of 109.5m illustrated the lowest average forest cover percent with the highest urban and agriculture land cover percentages. Out of the 290 brook trout stream reaches, the highest forest cover percent was observed at 100% and the lowest at 31.9% within the 109.5m buffer width. The highest percent agriculture within the same buffer width was recorded at 66.4%.

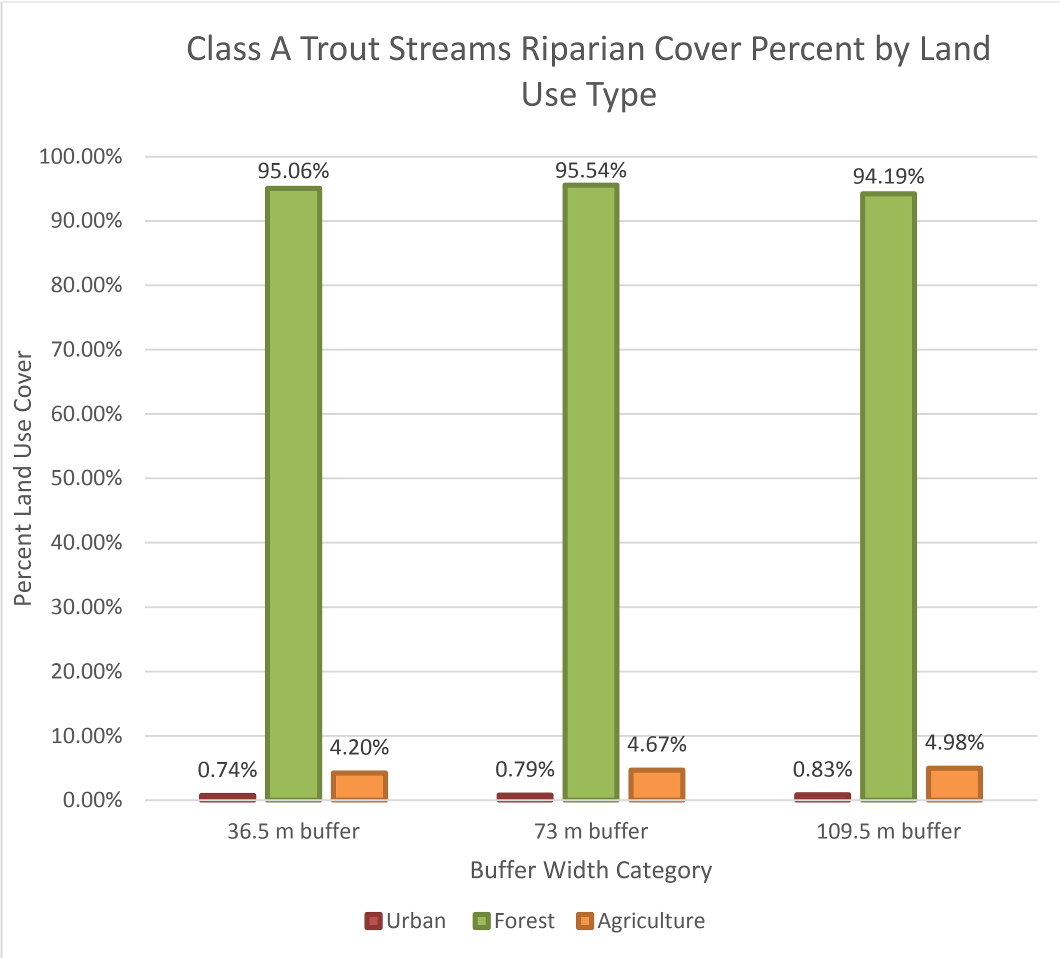

Figure 5: Percentage of land use cover for the Class A brook trout streams.

For the second stream grouping of non-brook trout headwater control reaches, which met the criteria of having a drainage areas less than 38mi^2, a stream classification less than 3, and an elevation greater 56.5ft above sea level, results showed decreases in average forest cover percentages, and increases in average urban and agriculture percentages for all buffer widths (figure 6). The spatial distribution of all 24,146 non-brook trout stream reaches is illustrated by figure 7. The average land cover percentages in the riparian buffers for non-brook trout headwater reaches ranged from 75.30-73.14% for forest cover, 2.60-2.88% for urban cover, and 24.26-21.81% agriculture cover. The non-brook trout headwater streams illustrated an average decrease of 20.8% forest cover and an average increase of urban and agriculture at 1.94% and

18.52% respectively. The most considerable differences were observed at a buffer width of 109.5m.

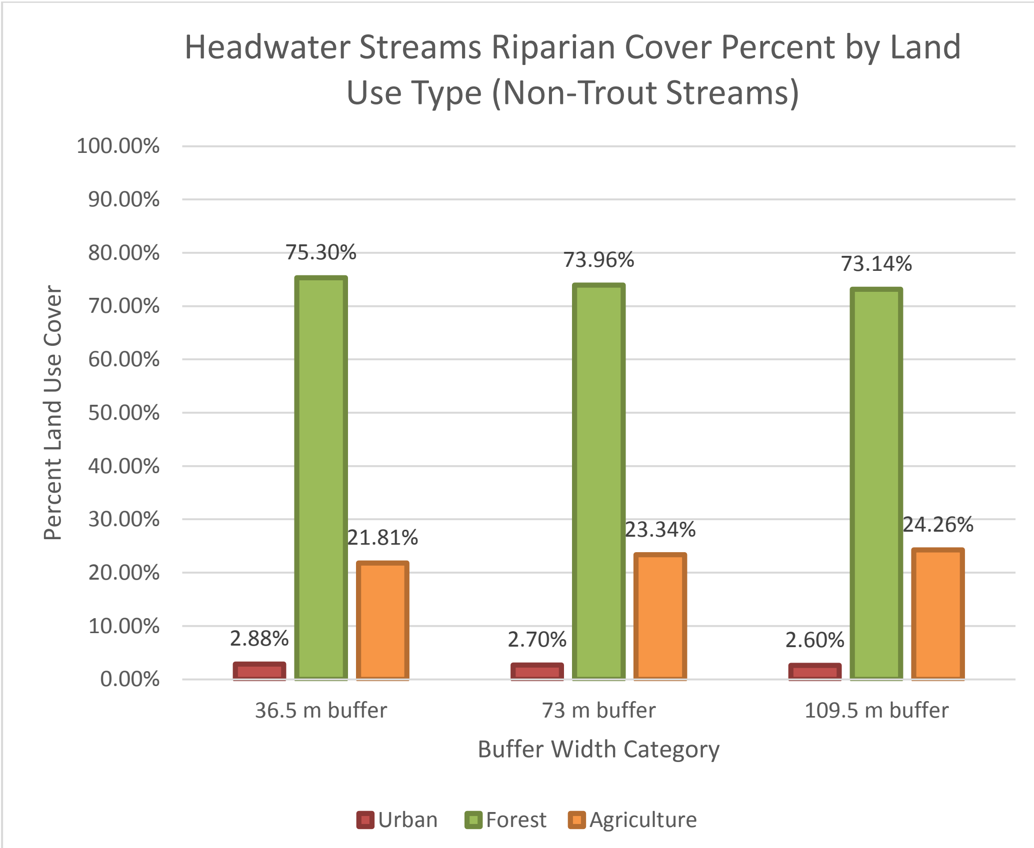

Figure 6: Percentage of land use cover for the riparian zones for headwater control streams.

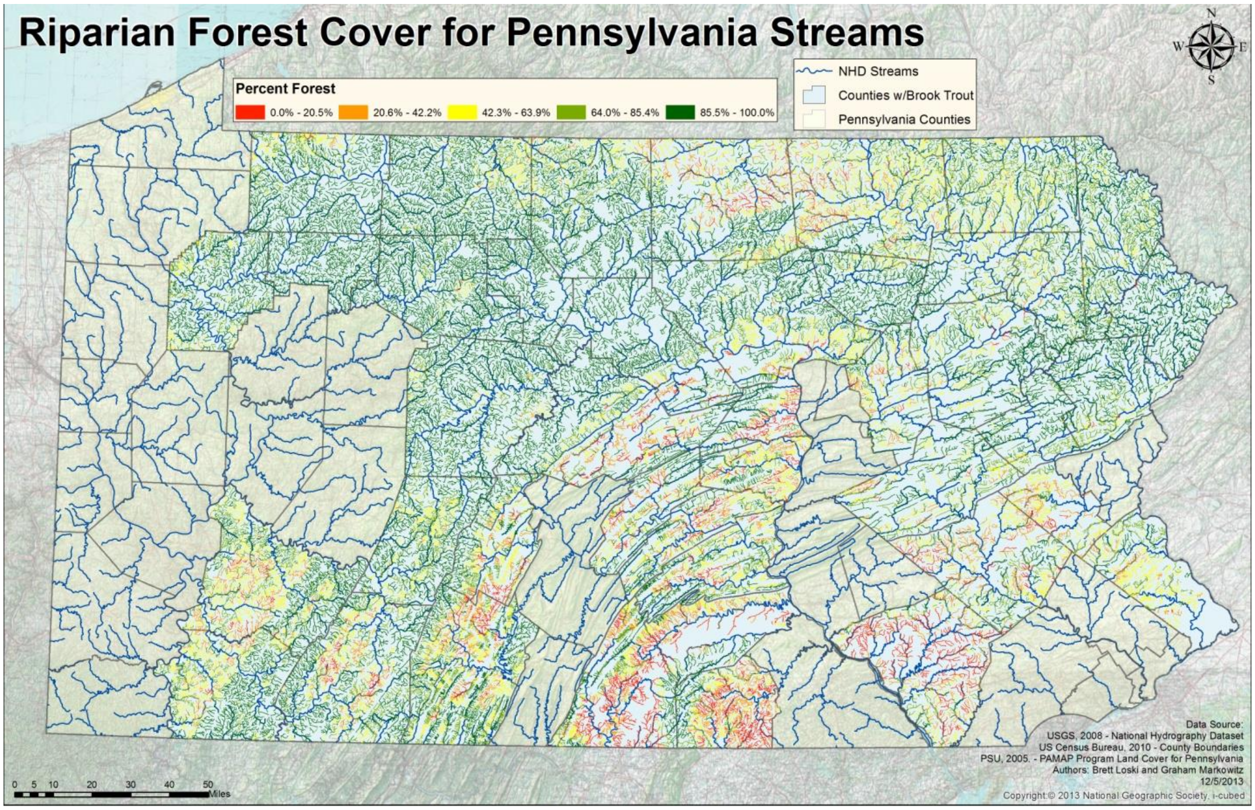

Figure 7: Map of study area showing the percent forest for all headwater control streams; the network control streams are also shown for comparison of size, density, and location.

To observe significant changes in land uses percentages within the control groups, riparian land cover percentages were also observed for major streams of Pennsylvania drawn at 1:1,000,000 scale (USGS, 2012). Similarities between the non-brook trout headwater reaches and the major-network streams existed within average percent forest cover in the riparian zones, which ranged from 74.17%-73.56%. Considerable differences were observed from an increase of 5.61% average percent urban cover and a decrease of 5.33% average percent agriculture cover.

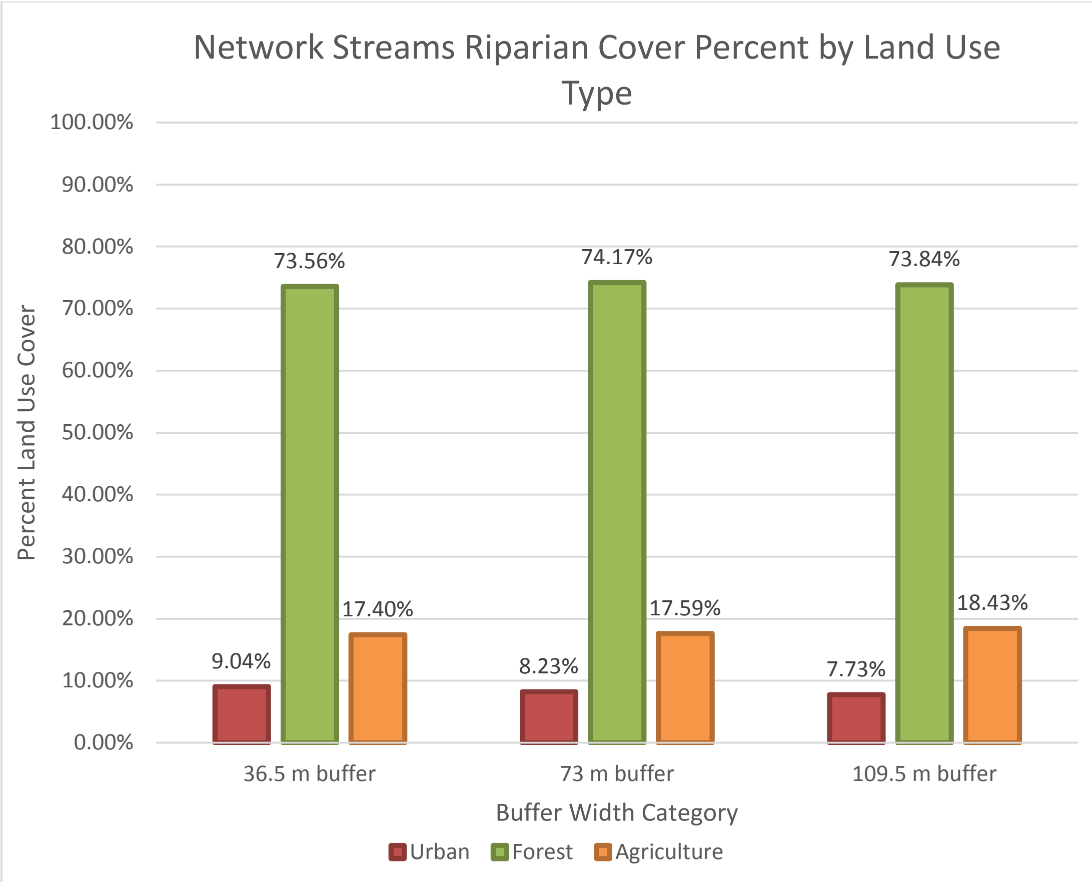

Figure 8: Percentage of land use cover for riparian zones along network stream control group.

Statistical Relationships

The results from the one-sample t-test for the non-brook trout headwater reaches and the major-network streams showed a significant increase in urban cover and a significant decrease in agriculture cover within the riparian zones of the major-network streams ($p<0.05$). Differences in forest cover between control groups were not statistically significant for all riparian widths, illustrated by p-values ranging from 0.897-0.428. Results from the riparian land cover comparison of brook trout streams to non-brook trout headwater streams showed statistically significant results in all land cover types for the three buffer widths. Average forest land cover percent in the riparian zones was significantly greater in brook trout streams than in non-brook trout headwater streams ($p<0.001$). Average urban and agriculture land cover percentages in the riparian zones were significantly less in brook trout streams than in non-brook trout headwater streams ($p<0.001$). In comparison, the *t* statistic, which is the distance between the two means in standard deviation units, ranged from -19.03 to -14.93 for urban land cover, 35.37 to 33.80 for forest cover, and -33.57 to -32.47 for agricultural land cover.

Comparison of Non-Brook Trout Headwater and Major-Network Stream Controls					
36.5 Meter Buffer					
Land Cover	t value	p value	Mean (percent)	Mean Difference	Standard Error of Mean
Urban	3.949	0.000	9.04%	6.04%	0.0153
Forest	-0.795	0.428	73.56%	-1.44%	0.0181
Agriculture	-3.123	0.002	17.40%	-4.60%	0.0147
73 Meter Buffer					
Land Cover	t value	p value	Mean (percent)	Mean Difference	Standard Error of Mean
Urban	4.226	0.000	8.23%	5.53%	0.0131
Forest	0.13	0.897	74.17%	0.21%	0.0165
Agriculture	-4.098	0.000	17.59%	-5.74%	0.014
109.5 Meter Buffer					
Land Cover	t value	p value	Mean (percent)	Mean Difference	Standard Error of Mean
Urban	4.219	0.000	7.73%	4.73%	0.0112
Forest	0.564	0.573	73.84%	0.84%	0.0149
Agriculture	-4.19	0.000	18.43%	-5.57%	0.0133

Table 1: Statistical table of t and p values for non-brook trout control groups.

Comparison of Brook Trout Streams to Non-Brook Trout Headwater Control Streams					
36.5 Meter Buffer					
Land Cover	t value	p value	Mean (percent)	Mean Difference	Standard Error of Mean
Urban	-19.03	0.000	0.74%	-2.26%	0.0012
Forest	35.365	0.000	95.06%	20.06%	0.0057
Agriculture	-33.57	0.000	4.20%	-17.80%	0.0053
73 Meter Buffer					
Land Cover	t value	p value	Mean (percent)	Mean Difference	Standard Error of Mean
Urban	-14.935	0.000	0.79%	-1.91%	0.0013
Forest	34.263	0.000	94.54%	20.58%	0.006
Agriculture	-33.143	0.000	4.67%	-18.67%	0.0056
109.5 Meter Buffer					
Land Cover	t value	p value	Mean (percent)	Mean Difference	Standard Error of Mean
Urban	-15.778	0.000	0.83%	-2.17%	0.0014
Forest	33.797	0.000	94.19%	21.19%	0.0063
Agriculture	-32.472	0.000	4.98%	-19.02%	0.0059

Table 2: Statistical table showing t and p values between brook trout streams and non brook trout headwater streams.

Discussion

From the results of non-brook trout headwater streams and major-network streams, it has been determined that agriculture is more prevalent than urban in the riparian areas of the headwater streams as opposed to major-network streams. Because significant difference in average percent forest cover within the riparian zones of both non-brook trout control groups were not observed, percent forest cover was considered an important variable when assessing riparian cover for brook trout stream reaches. From this comparison, forest land use was determined to be the most likely variable to contribute to suitable brook trout environments, as both urban and agricultural land use were statistically different between the two control groups.

In relation to the non-brook trout headwater streams, significant increases in percent agriculture and urban land classes were not surprising since these headwater streams could still potentially exist within lower gradient areas such as valleys. Given the criteria in which the non-brook trout headwater streams were selected (DA $\leq$ 38mi^2, stream classification $\leq$ 3, and an elevation $\geq$ 56.5ft above sea level), the resulting stream reaches provided meaningful results as additional influencing variables (correlated to the criteria-variables) may have been ruled out, leaving percent land use as a primary explanatory variable. The results of our analysis show that there is a significant link between the percent of forest cover and the presence or absence of brook trout in a system, although, Hudy (2008) has outlined additional statistically significant predictor variables in riparian areas; these include sulfate and nitrate deposition, percent mixed forest in riparian areas, and road density. Other contributing variables may also be associated with local geology, low flow conditions, stream temperature, fish passage barriers such as check dams, and introduction of non-native species. In relation to the above variables potentially influencing brook trout habitat, management interpretations are discussed within the following section.

In regards to land cover percentages, Garman (1994) and Wang et al., (1997) found that as developed land use increased from 10 to 20%, fish communities were affected. From an analysis of brook trout streams in our study, brook trout are non-existent in stream reaches exceeding 17.5% urban cover within a buffer width of 109.5. The results of our study suggest that a mean percent urban cover within a 109.5m riparian zone of 0.74-0.83% would provide suitable brook trout habitat, given that additional influencing factors were not present. Additional factors in lower gradient and elevation streams may include stream temperature. In riparian management or restoration applications, results from Jones, et al. (2006) show that riparian buffer width is an important consideration for stream temperatures, as brook trout prefer stream temperatures less than 68^{o}F. This study showed that stream segments with 15-m wide buffers had higher peak temperatures by 2.0°C when compared to stream segments having 30-m wide buffers; it can therefore be assumed that a forested riparian buffer exceeding 30m would provide optimal stream temperatures.

The presence or absence of brook trout may also be associated with the introduction of naturalized exotic fishes (Hudy, et al.). According to Argent (2000), a total of 42 introduced species have increased in distribution; the brown trout (Salmo trutta), which is both widely stocked and naturally reproducing in Pennsylvania has become the most widespread. Therefore, the presence or absence of brook trout may be largely related to out-competition with non-native species; more site specific research is required to further depict such relations. Hudy, et al. (2008), also states that many of the existing subwatersheds classified as having reduced brook trout populations contained only one or two small populations that were restricted to isolated headwater habitats. Such locations are limited by factors influencing connectivity required to reestablish populations. In order to regain connectivity between isolated headwater reaches, higher stream order reaches (ie. 3 and 4) should be considered for restoration and conservation, as these larger network reaches appear to be prone increased human land use impacts.

In addition to current human land use impacts, historical land use practices have influenced the present-day diversity of stream invertebrates and fish populations (Harding, et al., 1998); findings indicate that past land-use activity, particularly agriculture, may have resulted in long-term modifications and reductions in aquatic diversity. From a study of Argent and Carline (2000), watersheds containing greater than 40%agriculture experienced the largest declines in trout populations. In our study, a total of 6 brook trout stream reaches, out of 290, illustrated agriculture percentages greater than 40% with a riparian buffer width of 109.5m. Given our mean value of 4.6% agricultural cover in the riparian zones of brook trout streams, restoration or conservation of riparian buffers consisting of 4.6% or less agriculture would seemingly provide suitable brook trout habitat.

According to Wang, et al. (1997), aquatic habitat within the stream channel is related to agricultural and urban land uses at a watershed scale, which may not be directly relatable to riparian land uses. Although, Richards et al. (1996) demonstrated that stream buffers are better able to predict sediment-related habitat variables such as stream substrate characteristics and bank erosion better than watershed characteristics could predict. In total, Naiman et al. (1993) argues that, to conserve the connectivity of functions within a watershed, the river corridor should be managed as an entire system, from well-buffered headwaters to downstream floodplains. To preserve brook trout habitat, our results suggest that restored or conserved riparian areas should strive for land cover percentages of approximately 0.8% or less urban cover, 94.9% or greater forest cover, and 4.6% or less agricultural cover. The results of our study show that brook trout in Pennsylvania do not exist in stream reaches with agriculture and urban land cover within the riparian zone exceeding 66% and 17.5% respectively. In regards to brook trout restoration or conservation applications, streams exceeding these percent land cover within the riparian zones illustrate reduced potential and status and less prioritization should be placed upon those locations.

Conclusion

Within the last century, brook trout have declined or have been locally extirpated within the species' native range in the eastern U.S. (Hudy, et al., 2008). Cumulative anthropogenic impacts, including losses of riparian buffers, have been cited as contributing to a decrease of 73% of North American fish species (Miller et al., 1989). Given these scenarios, this research has identified primary contributing factors, including percentages of land classes surrounding existing brook trout streams, which have been thought to significantly influence the presence or absence of brook trout. By identifying the current state of riparian buffers surrounding brook trout streams, the results point to specific land cover characteristics (percentages of forest, urban, and agriculture) that are indicative of good water quality. The land cover percentages within the watershed and riparian zone of stream reaches that contain viable populations of brook trout have been compared to riparian land cover percentages for non-brook trout headwater streams which have met the minimum criteria outlined by brook trout streams including drainage area $\leq 38mi^2$, stream classification ≤ 3, and an elevation $\geq$ 56.5ft above sea level. Comparisons between the datasets were completed through a one sample t-test.

Results from the riparian land cover comparison of brook trout streams to non-brook trout headwater streams showed statistically significant results in all land cover types for the three buffer widths. Average forest land cover percent in the riparian zones was significantly greater in brook trout streams than in non-brook trout headwater streams ($p<0.001$). Average urban and agriculture land cover percentages in the riparian zones were significantly less in brook trout streams than in non-brook trout headwater streams ($p<0.001$). Riparian buffers with forested area constituting more than 75% of all land use are possible indicators for the presence of brook trout. With this knowledge it may be possible to make more complete datasets on brook trout populations, increase efficiency efforts of trout introduction or population sustainability, or both. This research allows for a more complete picture on brook trout environment in Pennsylvania and provides statistically based information that may be used to prioritize conservation efforts of brook trout through the replenishment of riparian buffer zones.

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