RIPARIAN LAND COVER CHARACTERISTICS OF BROOK TROUT STREAMS IN PENNSYLVANIA

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ABSTRACT: Cumulative anthropogenic impacts, including losses of riparian buffers, have contributed to the decline of North American fish species. The present day location of native brook trout *(Salvelinus fontinalis)* populations in Pennsylvania is thought to be a function of stresses commonly associated with urban and agricultural land use changes from forested cover. An extensive forested riparian zone which stabilizes water temperature and buffers pollutants is likely to represent suitable stream habitat for brook trout. For this study, land cover percentages within three separate riparian buffer distances for stream reaches that contain viable populations of brook trout were compared to riparian land cover percentages for non-brook trout headwater streams which met the minimum criteria outlined by 290 stream reaches designated as Class A Brook Trout streams in Pennsylvania; this criteria includes stream reaches possessing a drainage area $\leq$ 38mi^2, a stream classification $\leq$ 3 (Strahler method), and an elevation $\geq$ 56.5ft above sea level. Results indicate that average percent forest land cover within the all three riparian buffer distances were significantly greater in brook trout streams than in geographically similar non-brook trout headwater streams. 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. To conserve brook trout populations or consider reintroduction of brook trout in Pennsylvania, the results of this study suggest that percentages of riparian land cover for proposed streams should illustrate approximately 94.9% or greater forest cover, and less than 0.8% urban cover and 4.6% agricultural cover.

Keywords: *Land Use Change, Brook Trout, Salvelinus fontinalis, Riparian buffers*

INTRODUCTION

Humans are thought to drive alterations in fluvial systems which include watershed wide components of channel, riparian zone, floodplain, terraces, and hill-slopes (Wohl, 2006). Historically, alterations to aquatic landscapes have occurred to meet economic and social needs such as building roads, dredging waterways for travel and transport, and exploiting fisheries resources for food and recreation (Ardent and Carline, 2004). Specifically, land use changes within riparian areas such as urban and agriculture development have been correlated to the health of stream systems (Schweizer, 2005). According to U.S. EPA (2010), a riparian buffer is a "vegetated ecosystem along a waterbody through which energy, materials, and water pass". Marczak (2010) indicates that 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.

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). Deforestation practices have removed more than half of forested buffers in the United States (Teels, 2006), and has contributed to the loss of many beneficial ecological functions. In agricultural settings, adverse impacts on aquatic ecosystems can occur when soil becomes exposed from tilling or plowing fields or from overgrazing. Turbidity from soil erosion can damage gills of fish and aquatic insects, decrease suitable spawning habitat, and the reduce light that is needed for photosynthesis of algae and aquatic plants. Compacted soils from overgrazing or from urbanization can also increase surface runoff, limit baseflows, and increase sediment inputs to stream systems (EPA, 2010). Through dense root networks, riparian buffers can enhance infiltration and intercept sediment inputs (Sprague et al., 2006) and associated non-point source pollutants such as excess nitrogen and phosphorus (Teels, 2006) from agricultural land uses.

In urban settings, streambanks can erode due do lateral confinements and increased peak discharges due to increased runoff from impervious surfaces; such streams can become deeply incised and disconnected from their floodplain. Increased peak discharges in urban settings can be dissipated through infiltration through vegetated buffers and through increased roughness from woody debris within stream channels and on floodplains (Harmon et al. 1986). Streams that have become degraded from poor management practices in agricultural and urban settings have illustrated discontinuity of sediment supply and transport processes (Florsheim et al., 2011), unstable hydrologic and thermal regimes (Fleischner, 1994), poor water chemistry (Johnson et al., 1997), and modified aquatic food webs (Klein, 1979).

Given the above impacts associated with the removal of forested riparian areas, engineers and public work managers have sought to implement riparian plantings to mitigate human induced impacts and restore previously degraded streambanks (Osborne and Kovacic, 1993). Management plans aimed at restoring streams to a more natural state by implementing and protecting riparian forest buffers have been suggested by the EPA (2010). The Riparian Buffer Goal for the Chesapeake Bay states that forest buffers should exist on at least 70 % of all shorelines and streambanks in the Watershed (CBP, 2010). In addition to restoring and protecting riparian areas, EPA (2010) states that upland land uses that contribute to riparian systems should also be considered an important components of riparian restoration projects. In order for these buffer systems to reach their critical threshold of creating suitable biological habitats, they must be maintained for extended periods of time (EPA, 2010). Likewise, Keeton (2007) has illustrated a relationship between the age of the forest buffer and the amount of biocomplexity that it supports.

Riparian buffer systems have been noted to regulate stream temperatures (Poole and Berman, 2001), which maintains dissolved oxygen concentrations that many coldwater species depend on (Johnson. 2008), such as the brook trout, *Salvelinus fontinalis.* Within the last century, brook trout have declined or have been locally extirpated within the species' native range (Hudy, et al., 2008). The brook trout are native to lower temperature streams of the northeastern United States and Canada (Johnson, 2008). The historic range of brook trout 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 (Hudy et al., 2008). Due to their fondness for lower water temperatures, brook trout are typically found in higher elevation headwaters or near surface springs. Normally brook trout use points of ground water discharge as spawning points, but the introduction of fine sediments from agricultural or urban development may cause brook trout to spawn in faster flowing stream sections which can lead to increased mortality either by increased flow velocities or through enhanced visibility to predator species (Curry, 2004). Increased sediment loading to a stream can also cause increased mortality of brook trout embryos as they may become buried by fine sediment (Curry, 2004). Further, Jones (1999) states that with a lack of vegetated riparian zone, sediment-tolerant species will become more prevalent which can effectively push trout species into more stable headwater reaches with forest cover. Such studies have identified land use impacts to stream banks and riparian areas to fish distributions, including the brook trout (Armour et al., 1991). This study expands on the relationship between brook trout and land use changes by identifying the presence and absence of brook trout populations in relation to land over percentages of riparian zones within Pennsylvania. Increases in urban and agricultural land cover within riparian zones are assumed to be primary contributing factors on the presence or absence of brook trout in Pennsylvania.

PURPOSE AND SCOPE

According to Ardent and Carline (2004), the relative health of aquatic systems can be assessed by using fish as a metric due to their sensitivity 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 documented the movement of fish species from degraded areas to stable areas, which is thought to be reflective of the present day location of brook trout in Pennsylvania. Because brook trout rely on cooler water temperatures, it can be assumed that the presence of brook trout would translate to an extensive forested riparian zone. This assumption is tested by comparing land use percentages of urban, forest, and agriculture within riparian buffers for two separate stream groupings that (1); contain naturally sustaining brook trout populations (Class A brook trout streams) as identified by Pennsylvania Department of Conservation and Natural Resources (PA DCNR) (2011) and (2); for geographically similar non-brook trout headwater control stream reaches that illustrate comparable drainage area size, stream order, and elevation expressed by Class A brook trout streams. By determining the status of land use practices within riparian zones, in relation to the presence or absence of brook trout, this study potentially has implications regarding the future protection, restoration, and potential reestablishment of brook trout in Pennsylvania.

METHODS

To observe the presence of brook trout in Pennsylvania, stream reaches containing the species were extracted from a "Class A trout waters" dataset compiled from fisheries data by Pennsylvania DCNR (2011). The "Class A" designation represents streams that support a population of wild (naturally reproducing) trout of sufficient size and abundance. This dataset contains 290 separate stream segments (reaches) within 38 out of 67 Pennsylvanian counties that have been identified as containing solely brook trout and excluding non-native trout species such as brown or rainbow trout (Figure 1).

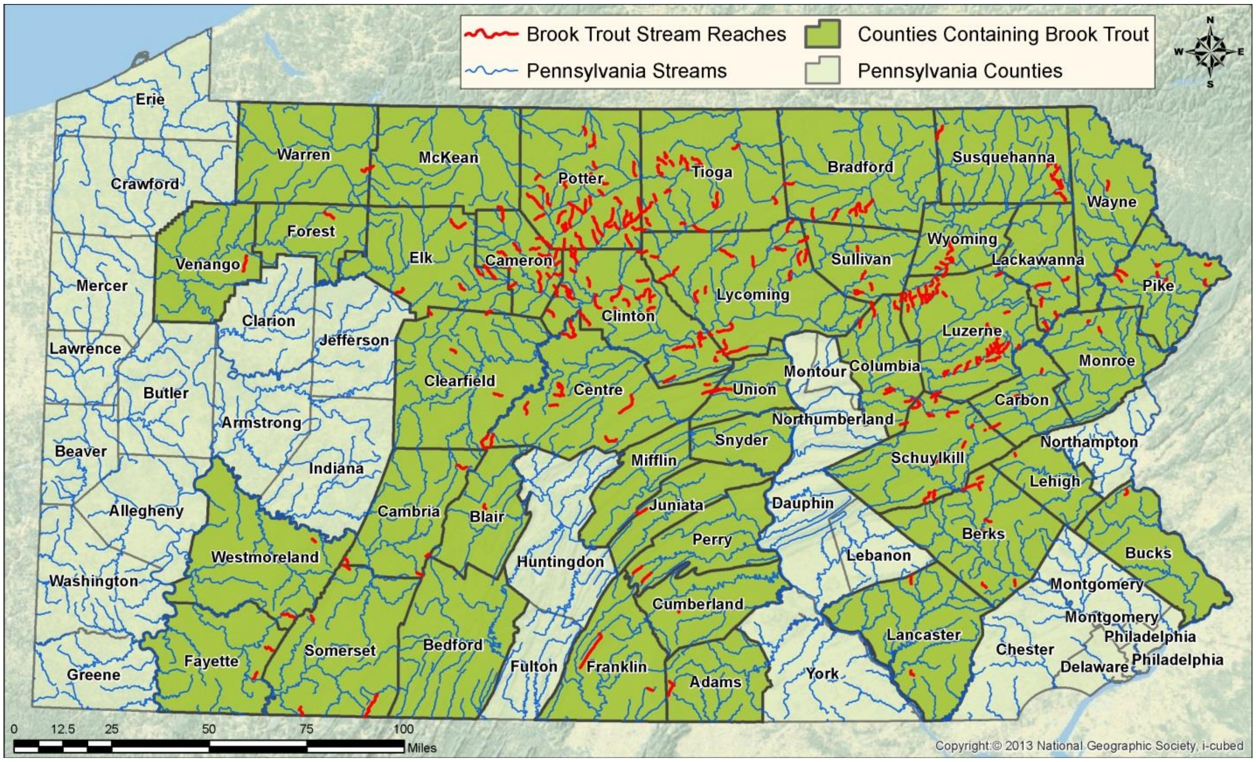

Figure 1: Brook trout (only) stream reaches in Pennsylvania within representative counties from the Class A Trout Waters dataset (PA DCNR, 2011). Most of the Class A streams are concentrated in the northern portion of the state. This generally coincides with major land covers of the state, with forested land cover being dominant in the north, and agriculture and urban being dominant in the south (n=290).

Approximately 85% of the Class A trout stream reaches were identified as headwater or source reaches (PA DCNR, 2011). By referencing an Aquatic Resources Classification dataset (Walsh, et al., 2007), brook trout in Pennsylvania exist at a maximum drainage area of 38mi^2 which consisted of streams at a stream classification level of three or less (Hughes et al. 2011). The lowest elevation in which brook trout were observed was at 56.5ft above sea level. Maximum drainage area, maximum stream order, and minimum elevation of Class A brook trout streams were used as delineative criteria for selecting the second control group of streams representing geographically similar non-brook trout headwater control reaches. A total of 24,146 additional stream segments representing these criteria were identified from a high-resolution National Hydrography (USGS, 2005) stream dataset (1:24,000/1:12,000 scale) (Figure 2). Land cover statistics within riparian zones were used to compare stream reaches containing brook trout and non-brook trout headwater reaches. A Pennsylvania land cover dataset (Pennsylvania State University, 2005) was analyzed to determine percentages of land cover classes within varying buffer widths for 290 Class A brook trout stream reaches and all other non-brook trout headwater stream reaches:

Given the minimum mapping unit (cell size) of 36.5m^2 for the Pennsylvania land cover dataset, 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. All GIS datasets were projected to a NAD 83 coordinate system in meter units. To create stream buffers for the three separate widths, a distance grid was calculated by setting the input source data for "Class A brook trout stream reaches" and "non-brook trout headwater reaches" with a maximum distance of 109.5m and an output cell size of 36.5m. The new raster layers were reclassified into three new grids at target buffer distances of 36.5, 73, and 109.5m. To observe broad land classifications, the Pennsylvania Land Cover Dataset was reclassified to the Anderson Level I (Anderson et. al., 1976), before land cover statistics were calculated. A total of six raster datasets containing three buffered distances for each stream grouping were transformed to vector polygons in which each land cover percentage was tabulated. The land cover percentages within the riparian zones of both, brook trout and non-brook trout datasets followed similar tendencies in distribution, as observed by land cover histograms for 109.5 meter buffer widths in Figure 3.

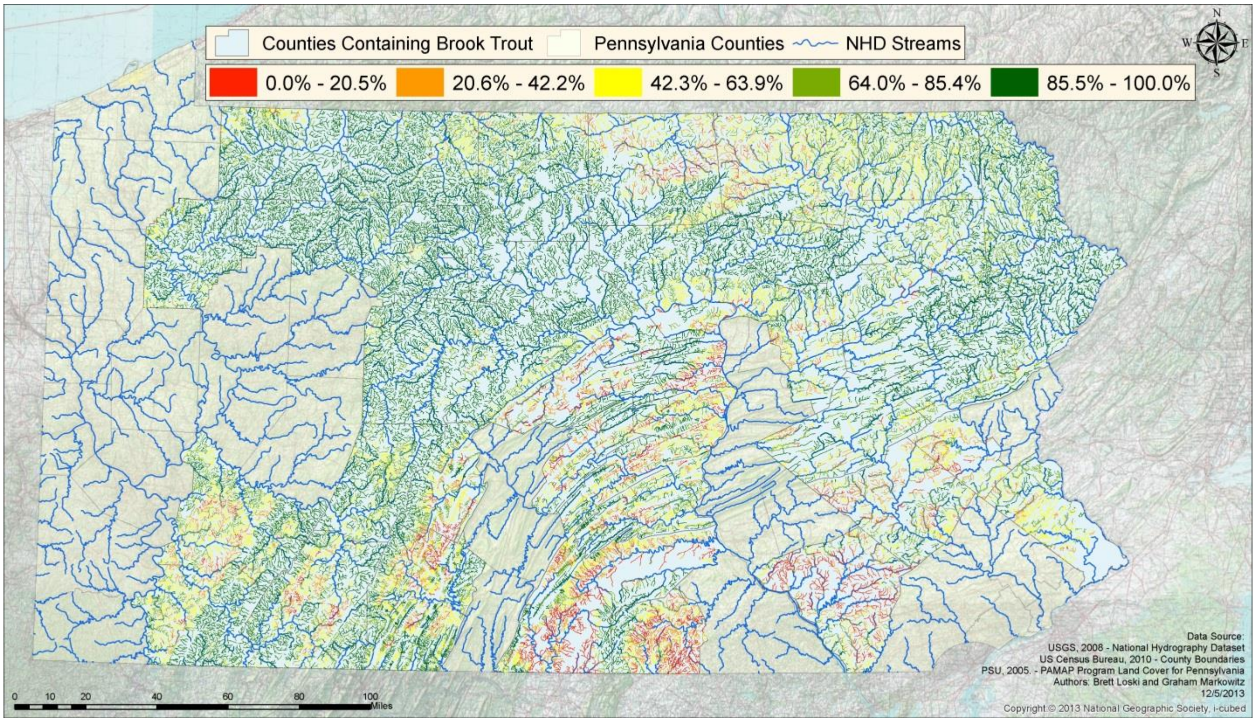

Figure 2: Percent forest cover for all headwater control streams; the major (NHD) streams are also shown for comparison of size, density, and location. Agriculture and urban land cover dominate in the southern portion of the state while forested land cover dominates northern Pennsylvania.

To interpret the differences in 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. For each percentage of land cover type, including forest, urban, and agricultural, within each riparian zone, the separation in sample means was described by the *t* statistic. The riparian land use percentages (percent urban, forest, and agriculture) of brook trout streams were compared to non-brook trout headwater control streams by the one sample t test. Significant differences were evaluated at <0.05. All statistics were analyzed using IBM's SPSS program (2011).

RESULTS

The average riparian land cover percentages for brook trout stream reaches ranged from 94.19 - 95.54% forested, 0.74 - 0.83% urban, and 4.20 - 4.98% agricultural land cover within the three buffer zones (Figure 4). 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 290 brook trout stream reaches, the highest forest cover percent was observed at 100% and the lowest at 31.9% within a 109.5m buffer width. The highest percent agriculture within the same buffer width was observed at 66.4%.

For the second stream grouping of non-brook trout headwater control reaches, which met the minimum-delineative criteria, results showed decreases in average forest percentages, and increases in average urban and agriculture percentages for all buffer widths (Figure 5). The average land cover percentages in the riparian buffers for non-brook trout headwater reaches ranged from 75.30-73.14% for forest, 2.60-2.88% for urban, and 24.26-21.81% agriculture land cover. 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.

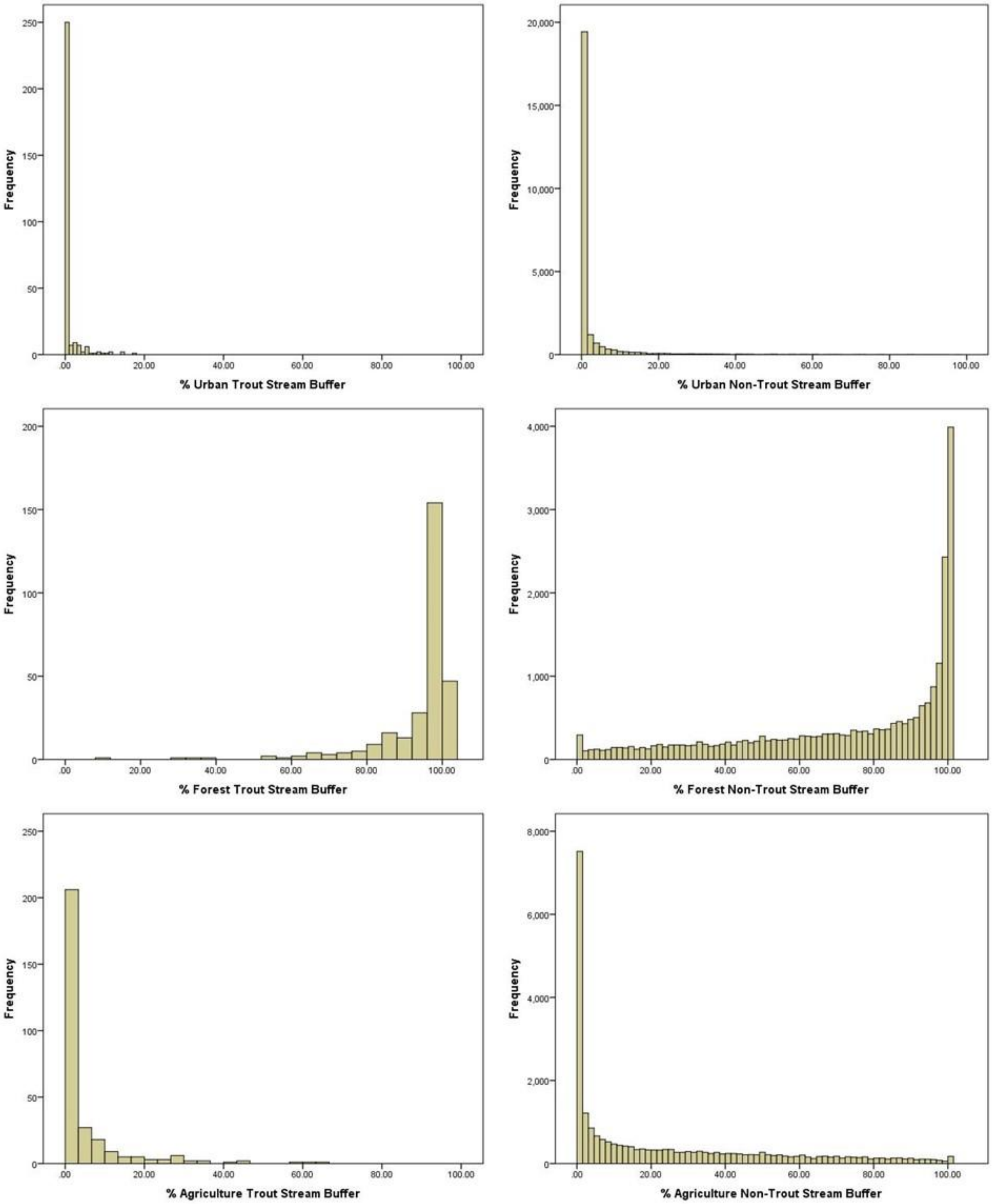

Figure 3: Histograms showing distributions of brook trout streams and non-brook trout streams various land covers within a 109.5 meter buffer. Histograms show similar shape and intensity across all three land cover classes. Trout stream n= 290, non-trout n= 24,146

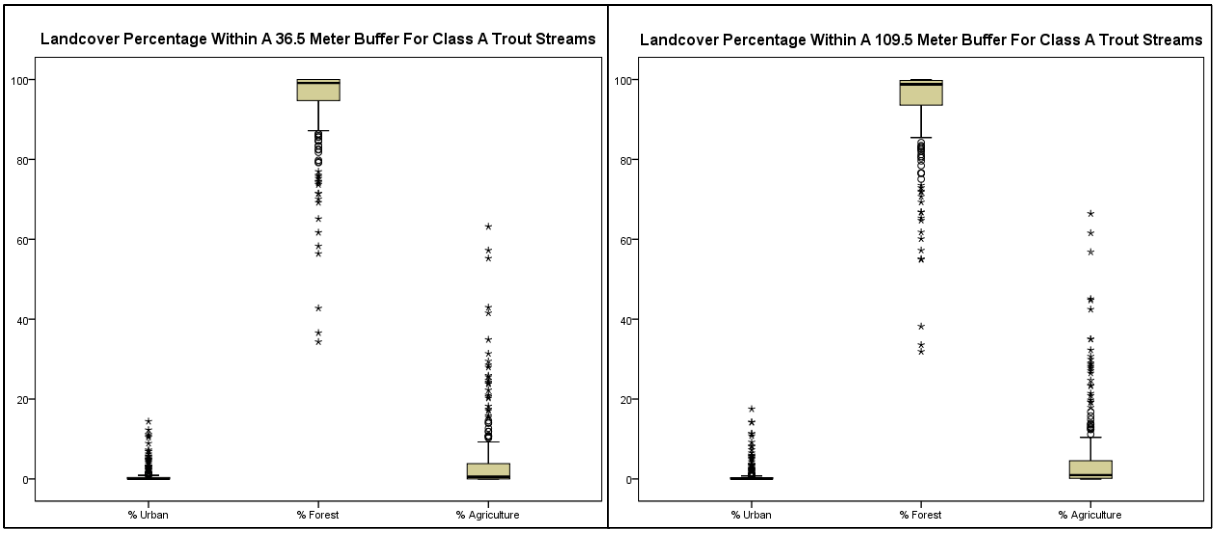

Figure 4: Percentage of land use cover for the Class A brook trout streams. Class A streams are dominated by forested land cover (over 90%), and reside in high density in the northern portion of PA. Agriculture and urban land covers are almost nonexistent with mean values being below 5% (n= 290).

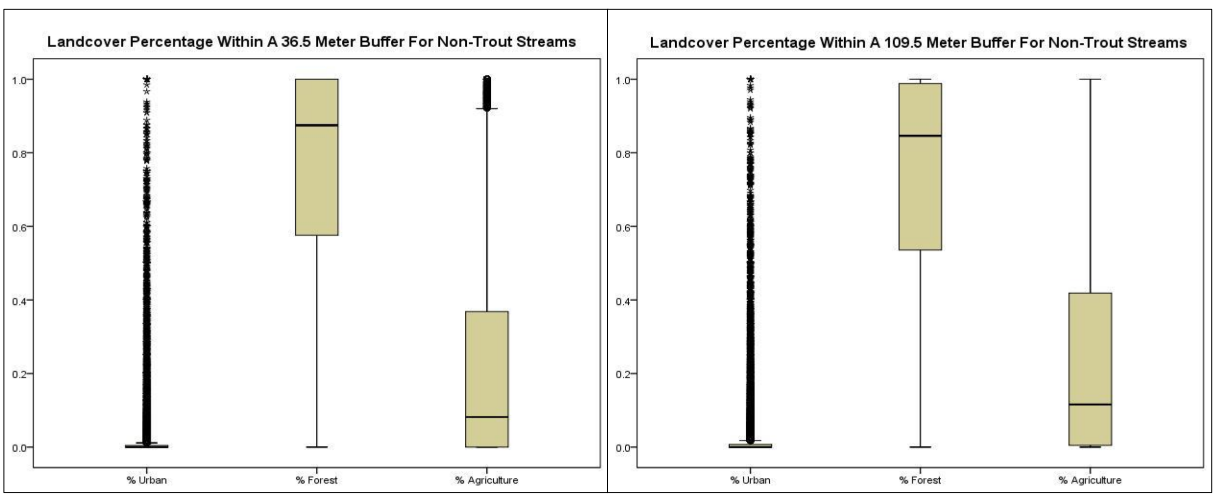

Figure 5: Percentage of land use cover for the riparian zones for headwater control streams. Non-trout streams show much more variability than the Class A streams. Forested land cover means reach ~75%, equating to a 20% loss from the Class A streams. Agricultural land cover rises to a mean of ~25% and urban rises from 0.8% to 2.8% (n= 24,146).

Results from the riparian land cover comparison of Class A brook trout streams to non-brook trout headwater streams showed statistically significant results in all land cover types for the three buffer widths (Table 1). Average percent forest land cover 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 ($p<0.001$).

Table 1: Statistical table of brook trout streams and non-brook trout headwater streams.

36.5 Meter Buffer					
Land Cover	t value	p value	Mean (decimal percent)	Mean Difference	Standard Error of Mean
Urban	-69.492	0.000	0.0074	-0.083	0.0012
Forest	37.909	0.000	0.9506	0.215	0.0057
Agriculture	-24.891	0.000	0.042	-0.132	0.0053
73 Meter Buffer					
Land Cover	t value	p value	Mean (decimal percent)	Mean Difference	Standard Error of Mean
Urban	-58.165	0.000	0.0079	-0.0744	0.0013
Forest	33.906	0.000	0.9454	0.2037	0.006
Agriculture	-22.934	0.000	0.0467	-0.1292	0.0056
109.5 Meter Buffer					
Land Cover	t value	p value	Mean (decimal percent)	Mean Difference	Standard Error of Mean
Urban	-50.004	0.000	0.0083	-0.0687	0.0014
Forest	32.521	0.000	0.9419	0.2039	0.0063
Agriculture	-22.964	0.000	0.0498	-0.1345	0.0059

DISCUSSION AND CONCLUSIONS

Given the criteria in which the control group of non-brook trout headwater streams were selected, significant increases in percent agriculture and urban land classes were not surprising as these “headwater streams” could still potentially exist within lower elevations and valleys more-suitable for human development. In general, the results of this analysis show a significant link between the percent of forest cover and the presence or absence of brook trout. By considering land use as the only explanatory variable, this analysis may risk oversimplification as many other influencing factors may be generalized by the presence of urban and agricultural land use. Hudy (2008) outlined additional statistically significant predictor variables of fish species in riparian areas; these include sulfate and nitrate deposition, percent mixed forest in riparian areas, and road density. The presence or absence of brook trout may also be associated with the introduction of naturalized exotic fishes (Hudy, et al., 2008). According to Argent (2000), a total of 42 introduced fish species have increased in distribution within the U.S. 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 state 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. In order to regain connectivity between isolated headwater reaches, higher stream order reaches (i.e. 3 and 4) should be considered for restoration and conservation, as these larger network reaches appear to be prone to increased human land use impacts.

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

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 buffer width of 109.5. Our study also suggests riparian buffers with forested area constituting more than 75% of all land use are possible indicators for the presence of brook trout. The results 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. Jones, et al (2006) noted that riparian management or restoration applications should consider riparian buffer width for stream temperatures, as brook trout prefer stream temperatures less than 68ºF. The study by Jones et al. (2006) indicated 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.

According to Wang et al. (1997), aquatic habitat within the stream channel is related to agricultural and urban land uses at a watershed scale and therefore, habitat suitability may not be directly relatable to riparian land cover statistics. However, Richards et al. (1996) demonstrated that stream buffers are better-able to predict sediment-related habitat variables such as channel substrate and bank erosion than watershed characteristics could predict. 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 contain 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 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. Brook trout restoration or conservation applications for streams exceeding these percent land cover within the riparian zones illustrate reduced potential and less prioritization should be placed upon those locations. This statistically based information, specific to Pennsylvania stream systems, may be used to better-prioritize conservation efforts or guide reintroduction efforts of brook trout through the replenishment of riparian buffer zones.

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