SPATIAL DISTRIBUTION OF APPARENT NATIVE BROOK TROUT POPULATIONS AND THEIR CHARACTERISTICS IN SOUTHEASTERN MINNESOTA STREAMS[1]

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Abstract: Populations found at the edge of a species range are important in terms of range contraction, genetic divergence, and life history variants. Minnesota represents the western most part of the brook trout's native range. Because of historically degraded stream conditions, previous stockings of eastern origin brook trout, and abundant brown trout populations, it was assumed that native brook trout were extirpated from southeast Minnesota. Our objectives were to examine these peripheral brook trout populations to determine their spatial and genetic distribution, and quantify population characteristics. Information on presence or absence of brook trout was gathered from recent file data (<5 years) or electrofishing on 174 streams in southeastern Minnesota. Brook trout were present in 119 streams or 68%. Genetic data on 73 populations were analyzed to determine origin. Several clusters of populations were not associated with known hatchery sources, but were primarily composed of geographic groupings from Rush Creek, Zumbro River, and South Fork Root River tributaries. In all, 37 streams had brook trout populations that were unique to southeastern Minnesota. Given their proximity to each other and that they do not conform to know hatchery stocks, these populations could represent remnant populations. In six intensively studied streams, brook trout density was highly variable across years and streams, but some patterns were evident. Maple Creek, East Indian Creek, and Trout Valley Creek typically had the highest density of both recruits and adults. Spring 2008 had the lowest trout numbers, but recruitment was high in the fall. Growth was also variable across years, with 2009 having slower growth than 2008. Coolridge Creek and Trout Brook typically had the slowest growth rates. Maple Creek and Trout Valley Creek had larger brook trout than the other populations that appeared to be related to stream size. Brook trout matured at a small size across all streams with males maturing in their first year of life. Size at maturity was not related to genetic strain, but rather appeared to increase with the presence of larger fish in the population. Genetic strain did not appear to affect any of our population characteristics. We estimate that 68% of coldwater streams support brook trout populations in southeast Minnesota but only 21% of coldwater streams support populations native to the Driftless Area. These apparently remnant populations should be given conservation priority.

Populations found at the edge of a species range are important in terms of range contraction, genetic divergence, and life history variants. Peripheral populations are important in the evolutionary process because they are subject to more environmental limitations resulting in a divergence in population characteristics from those found in central populations (Lesica and Allendorf 1995). In terms of range, peripheral populations of cutthroat trout (*Oncorhynchus clarkii*) were less likely to persist than interior populations (Haak et al. 2010). Because Minnesota represents the western edge of the native range of brook trout (*Salvelinus fontinalis*), conservation measures are of added importance. Also, it is important to describe population characteristics of these populations given that they may differ from those of more central populations.

Coldwater streams in southeastern Minnesota are highly productive compared to mountainous eastern U.S. streams where numerous brook trout studies have been completed (Kwak and Waters 1997). We would expect brook trout in this agricultural area to experience higher growth rates, earlier maturation, and higher mortality than those found in the eastern US. Brook trout are the only native stream dwelling salmonid in southeastern Minnesota (MacCrimmon and Campbell 1969). During the mid-1800s logging and intense agriculture degraded many trout streams in southern Minnesota causing a precipitous decline in brook trout populations throughout the region (Thorn et al. 1997). By the late 1800s most native brook trout populations in southern Minnesota were presumed extirpated and stockings of eastern strain brook trout, brown trout, and rainbow trout *Oncorhynchus mykiss* were used to provide fishable populations (Thorn et al. 1997). Stream conditions improved greatly from the 1970s through the 1990s in part because of better soil conservation practices (Thorn et al. 1997). Currently, brown trout have naturally reproducing populations in most coldwater streams in southeastern Minnesota. Brown trout fingerlings are still stocked in some streams with poor natural reproduction. Rainbow trout are stocked as fingerlings and yearlings in areas with high fishing pressure, but they are not known to naturally reproduce.

Interest in brook trout management has been increasing in recent years from government agencies and private organizations (e.g., Trout Unlimited). Concern over low abundance and competition with non-native salmonids has given state and federal agencies a renewed interest in managing this native species. Numerous initiatives have recently been developed to address brook trout management in the eastern U.S. (American Fisheries Society's Southern Division Trout Committee, the Eastern Brook Trout Joint Venture). In the Driftless Area of southeastern Minnesota (an area missed by the last Wisconsin glaciation), the Trout Unlimited Driftless Area Restoration Effort (TUDARE) is a project designed to restore native brook trout habitat by improving land use practices. Likewise, the Minnesota Department of Natural Resources has developed a long range plan for trout management in the Driftless Area that calls for increased brook trout management.

Given the historically degraded stream conditions, previous stockings of eastern origin brook trout, and abundant brown trout populations, it was assumed that native brook trout were extirpated from southeast Minnesota (MacCrimmon and Campbell 1969; Thorn and Ebbers 1997). Brook trout stocking began in the late 1800s by public and private hatcheries. The source of these brook trout is unknown, but likely came from local stocks. Starting in the 1970s, origins of brook trout were recorded when they were brought into state hatcheries. Many of the brook trout brought into Minnesota hatcheries were from assorted domesticated stocks from hatcheries outside of Minnesota. Therefore, it is difficult to identify where the domesticated stocks originated from. One such example is the Owhi strain, stocked in Minnesota from 1983 to 1994. Minnesota received this strain from White Sulphur Springs Fish Hatchery in West Virginia. The fish held at White Sulphur Springs were from stock in

Owhi Lake, Washington. The Owhi Lake strain originated from a single introduction of domestic fish from the U.S. Bureau of Fisheries in the early 1900s from the Northeast US, though the exact source of these fish is unknown. Similarly, St. Croix Falls strain was stocked in southeastern Minnesota streams from 1983 to 1997 and was obtained from the St. Croix Falls hatchery in Wisconsin. The origins of these fish are from Nashua Fish Hatchery, New Hampshire. In 1982 and 1983, fish from Rome New York and North Attleboro Massachusetts were raised and stocked from Minnesota hatcheries. In the mid to late 1980s, brook trout from Phillips hatchery in Maine were raised and stocked from Minnesota hatcheries. The strain used in current reintroductions and supplemental stocking is referred to as Minnesota Wild (MNWILD) and has been stocked since 1995. This strain was developed by crossing brook trout from Spring Brook in Rice County Minnesota, and Coolridge Creek in Winona County Minnesota. Given the numerous strains that have been stocked, it is difficult to know what currently exists in Minnesota streams. While stocking records for the last 40 years indicate what strains were stocked, there are several reasons why there is a poor understanding of the genetic makeup of brook trout in the Driftless Area. First, sometimes the strain was not known or recorded. Second, multiple strains were stocked into the same stream. Third, connectivity among coldwater streams is high in the Driftless Area and brook trout can move among streams. Fourth, private coldwater hatcheries that raise brook trout are present in southeast Minnesota and origins of these fish are unknown. Finally, some streams in southeastern Minnesota that have no records of being stocked have reproducing brook trout populations.

Our objectives were to examine peripheral brook trout populations in southeastern Minnesota to 1) determine spatial distribution of brook trout populations to assess current status, 2) determine genetic stock to identify stocking source and possible remnant populations, and 3) quantify population characteristics to compare with other populations in their native range.

Methods

Study area

The Driftless Area of southeast Minnesota now consists of steep valleys dominated by hardwood forests with a mix of agriculture and forests on the flatter uplands or bottoms of valleys. Agriculture practices mainly include row crops and pasture. Coldwater streams in this region are a result of groundwater inputs often near the headwaters. Many streams warm as they reach downstream lower gradient portions of the valleys and are further away from groundwater inputs. Despite the relative stability of groundwater inputs, stream discharge can be highly variable due to overland flow from rain and snowmelt events. Most coldwater streams in this region are very fertile with high alkalinity. Brown trout are naturally reproducing in most of the areas coldwater streams, however some supplemental stocking of fingerling brown trout continues. Rainbow trout are stocked as fingerlings and yearlings in several popular streams but seldom reproduce in southeast Minnesota. Angling pressure varies by stream and season, with most of the effort targeted towards brown trout (Snook and Dieterman 2006). Catch rates for brown trout and rainbow trout combined are 1.1 trout/hr. Angler effort and harvest is highest during April and May, however, the release rate is high (82.7% release rate for brown trout; brook trout release rate not available).

Spatial distribution

Information on recent presence or absence of brook trout was gathered from Minnesota Department of Natural Resources (MNDNR) Division of Fisheries, Minnesota Pollution Control Agency, and the University of Minnesota from stream data collected within the last five years in the Driftless Area. If a stream had not been sampled within the last five years, we then conducted fish sampling by electrofishing. Sampling locations were based on whether brook trout were reported at a location more than five years previously, or on landowner/angler accounts of brook trout being present, if such information was available. In the absence of such information, we sampled headwater reaches and in areas of known spring sources. Warmwater streams were only sampled if there were previous reports of brook trout in a particular stream. Although brook trout are sometimes sampled in the larger warmwater rivers such as the Cannon, Zumbro, and Root Rivers, we considered these individuals as transients, and not year round residents of these larger streams.

Brook trout were sampled with either a backpack or barge electrofisher depending on stream size. Typically, a single pass was made upstream collecting all brook trout, while counting numbers of adult and young of year brown trout. The presence of sculpin and other fish species was also noted. Station length was a minimum of 35 times the mean stream width or until at least 25 brook trout were collected for genetic analyses. Some streams were sampled at multiple locations if brook trout were not found at the initial sampling site, or in order to collect enough samples for genetic sampling. GPS locations were taken at the beginning and end of each station to determine length. Brook trout were measured for total length and an adipose fin was collected for genetic analysis. Brook trout populations were classified based on numbers per mile collected on a single pass as none (0/mile), rare (<50/mile), common, (between 50-250/mile) or abundant (> 250/mile).

Additional information on a subset of streams was collected on the spatial distribution of gill lice (*Salmincola edwardsii*; n = 59 streams) and sculpin (n = 155). Gill lice are parasites that exclusively use brook trout as hosts. We wanted to document the presence or absence of gill lice to determine if any spatial patterns were evident. We checked for the presence of gill lice by visually examining the gills of all of the brook trout captured. Because slimy and mottled scuplin are also native to Driftless Area streams, we gathered presence /absence data on these two species to gain further insight on measures of historical stream quality. If sculpin were present, it would indicate that water quality is likely suitable for brook trout populations.

We assumed all coldwater streams in the Driftless Area of southeast Minnesota supported brook trout historically; therefore our estimate of percent decline is based on 174 streams recently or newly surveyed. We also compared our results to that of Thorn and Ebbers (1997). That study used available MNDNR file data to determine the presence and absence of brook trout. This data was not verified by field collections and was not always current (some streams had not been sampled in 10-15 years).

Genetics

Genetic samples were available from earlier MNDNR collections from 22 populations. We added to this database by collecting genetic samples from most of the remaining brook trout populations in southeastern Minnesota.

Samples were prepared for polymerase chain reaction (PCR) amplification using a simple DNA extraction based on Walsh et al. (1991). A small piece of fin tissue was placed in a 1.5 ml tube with 250 µL of a 5% solution of a chelating resin (Chelex®, Sigma Chemical, St. Louis, MO). Samples were incubated overnight in a 56°C water bath and boiled 8 min. Microsatellite amplification was performed in 15 µL reactions containing 1x polymerase buffer (10 mM Tris-HCl, 50 mM KCl, 0.1% Triton® X-100), 1.5 mM MgCl2, 0.2 mM each dNTP, 0.5 µM of the forward and reverse primers, with the forward primer labeled with a fluorescent dye 6FAM, VIC, NED or PET, and 0.5 units Taq DNA polymerase (Promega, Madison, WI). We used seven microsatellite DNA loci designed for brook trout: *Sfo*C24, *Sfo*C38, *Sfo*C86, *Sfo*C88, *Sfo*C113, and *Sfo*D105 (Tim King, USGS, Leetown, WV, unpublished data). Each set of samples included a water blank as a negative control to detect possible contamination of PCR solutions. Amplification was carried out in a thermocycler (Hybaid Omn-E, Thermo-

Hybaid U.S., Franklin, MA) with 35 cycles at 95°C for 30 s, 50°C for 30 s, and 72°C for 1 min; followed by a 20 min extension at 72°C. We submitted PCR products to the Biomedical Genomics Center (University of Minnesota, St. Paul) for electrophoresis on an ABI Prism 3130xl Genetic Analyzer (Applied Biosystems, Foster City, CA). Alleles were scored using the software program Genotyper v.2.1 and later Genemapper v.4.1 (Applied Biosystems).

We estimated measures of genetic diversity and evaluated genetic equilibrium within each population. We calculated allelic frequencies and expected and observed heterozygosities. The data were then tested for deviations from Hardy-Weinberg expectations and linkage equilibrium using exact tests in the software GENEPOP v.4 (Raymond and Rousset 1995).

We estimated genetic diversity among populations and displayed inter-population relationships using clustering methods. The measure of population differentiation Fst was estimated for all population pairs using FSTAT 2.9.3 (Goudet 1995). We calculated Cavalli-Sforza and Edwards' (1967) chord distances among populations and constructed neighbor-joining trees using the program Populations 1.2.30 (Langella 1999). A neighbor joining tree was constructed using TREEVIEW ver. 1.6.6 (Page 1996).

Population characteristics

To gain a better understanding of population characteristics we intensively examined six streams over a two year period. To encompass the range in potential variation, we chose brook trout populations from different watersheds, stream size, and genetic background. Study streams included East Indian Creek (MNDNR Kittle number, M-32), Maple Creek (M-9-10-8), Coolridge Creek (M-9-17-5-5), Trout Valley Creek (M-31-1), Trout Brook (M-48-7), and Garvin Brook (M-26-1). These streams are all spring fed coldwater trout streams with varying abundances of brook trout and brown trout. All of the streams have angling regulations which limit an angler to five brook trout per day with only one over 16 inches, except for Trout Valley Creek which has a limit of one brook trout over 12 inches per day.

Brook and brown trout population estimates were made from two-pass depletion techniques using a backpack electrofisher in Coolridge Creek, Garvin Brook, and Trout Brook, whereas a barge electrofisher was used in Maple Creek, Trout Valley Creek, and East Indian Creek. Lengths of sampling stations depended on mean stream width, and ranged between 165 and 311m. Sampling stations started and ended at shallow riffles to avoid trout leaving the area while sampling. Both brook trout and brown trout were measured (nearest mm) and weighed (nearest g). We removed otoliths from a subsample of brook trout for age determination. Otoliths were read in whole view under a dissecting microscope with reflected light on a black background. Other fish species were collected and counted, but not measured. Recruitment was measured in the fall as the abundance of age-0 brook trout.

Mean length at capture was estimated using mixed distribution models developed from length frequency histograms seeded with "known age" fish. Known age fish were those marked at age-0 and recaptured as age-1, and a subsample of fish aged with otoliths. Length frequency histograms were divided into 10-mm length groups. We used the mixdist package (Macdonald and Du 2010) in the software program R (R Development Core Team, 2009) to fit finite mixture distribution models to the length frequency histograms. Mixdist provides estimates for mixing proportions (π), mean lengths-at-age (μ) and standard deviations of length-at-age distributions(σ). Mixing proportions are described as the relative abundance of that age group as a proportion of the entire measured sample. We tested several different constraints and probability distributions and compared model results using minimum χ^2 values. The best models were used for mean length at age estimates. For Garvin Brook, we set π to 0.05 for the 2007 year-class given that this year-class was almost absent. We did not constrain π for any of the other populations given that we had enough known age fish in the model to identify the 2007 year-class as poor in some populations. Full details of model development are given in Hoxmeier and Dieterman (2011a).

Survival was estimated for each age group by using the proportion of each cohort remaining the following year. The number of brook trout in each cohort were obtained by multiplying total abundance from population estimate by the mixing proportions (π) for each cohort from the mixture distribution models described above. Data is presented as annual mortality for each age class.

A subsample of trout was sacrificed for internal examination of gonads to assess maturity. Maturation was determined by visual examination of gonads and scored as zero for immature and one for mature. For each population, we then used logistic regression with length as our dependent variable to calculate size-at-maturation for males and females. Equations derived from the logistic regression model were used to determine the length at which 50% of the population was mature. We combined data across years to increase sample size and to encompass annual variability.

We quantified trout habitat based on visual estimates of percent shade, pool type (i.e., deep or shallow pools with or without cover), stream bank erosion, abundance of five cover types and on measurements to estimate percent pool area, percent fine substrates, stream width, and width:depth ratio (Thorn and Anderson 2001). The five cover types we classified were woody debris, instream rock, overhanging vegetation, undercut banks, and instream vegetation. These measurements were used to develop a habitat quality index score for each stream reach. Habitat quality scores are classified as follows: poor (<18), fair (18-20), good (21-23) and excellent (>23). Habitat quality was measured in summer during low flow conditions. We measured discharge (m^3/s) near the most downstream boundary of each reach during baseflow conditions. Velocity was measured with a Marsh-McBirney model 2000 electromagnetic flow meter following standard cross-sectional methods (Gallagher and Stevenson 1999).

Results

Spatial distribution

We assessed 174 streams located in nine different river drainages for the presence of brook trout (Figure 1). Brook trout were present in 119 streams or 68%. There are 181 coldwater streams in southeastern Minnesota that could potentially support trout, not including the larger warmwater rivers. We did not sample the remaining seven streams due to access issues. Brook trout were found in all of the major watersheds except for the Cedar River Watershed, where only one stream was sampled. We sampled the most number of streams in the Root River watershed as well as the most brook trout populations. Most brook trout populations were found in the eastern half of the Root River watershed (Figure 1). Groundwater sources differ in this watershed from the eastern to western half. The western portion receives most of its groundwater from the Galena and Decorah Edge and the eastern half receives most of its groundwater from the St. Lawrence Edge and Prairie Du Chien. There were 40 brook trout populations that were categorized as abundant and of those only 17 were remnant populations (Figure 2). Twenty-one populations were rare with some samples only having one brook trout.

Gill lice were found in 40% of the brook trout populations we examined (24/60). Most of the brook trout populations with gill lice were in the Root River drainage (Figure 3); however, fewer attempts were made to examine for gill lice in the other watersheds.

Information on sculpin presence was gathered on 155 streams. Of those, 55 had either slimy or mottled sculpin present (Figure 4). Nine of those populations were the result of sculpin reintroductions by the MNDNR. All of the sculpin populations in the Mississippi River-Lake Pepin drainage were reintroduced.

Genetics

We collected genetic data on 51 streams from 2006-2009. Twenty-two streams had genetic data collected previously by MNDNR Fisheries in 2003 and earlier. These 73 populations were analyzed together for a more complete view of the genetic makeup of brook trout in southeastern Minnesota.

Most loci in most populations conformed to Hardy-Weinberg expectations. Of the 592 tests (locus x population), the number of tests per locus with P-values < 0.05 ranged from 2-11 and 4-14 for heterozygote deficits and excesses, respectively. Only five tests remained significant after sequential Bonferroni correction (Rice 1989) for multiple testing. Loci *Sfo38, Sfo113* and *Sfo115* showed significant heterozygote deficits in the Rome Hatchery sample and *Sfo88* had a heterozygote deficit in the Nashua Hatchery sample, while *Sfo24* had an excess in Camp Hazard Creek. Significant linkage disequilibrium was found in only 10 tests, with no locus-pair significant for more than two samples. Expected heterozygosities averaged 0.64 and but ranged from 0.19-0.77 in SEMN, Iowa and Wisconsin samples (Table 2). The very low heterozygosity was found in Pleasant Valley Tributary; the next lowest was Dakota Creek at 0.39. Heterozygosities in hatchery samples ranged from 0.39-0.73. Assinica and Rome were similar at 0.39 and 0.42 while all others exceeded 0.60.

Most population samples were significantly differentiated. Samples that were not differentiated generally were temporal replicates (two from Spring Brook Creek, two from Unnamed Riceford), from nearby tributaries (e.g., West Beaver Creek and Larson Creek) or associated with Minnesota Wild hatchery stocking (MNWILD).

Although most populations were differentiated, the clustering algorithm based on genetic distances grouped populations that were most similar into several distinct clusters. Several of the main clusters contained hatchery samples and varying numbers of southeastern Minnesota populations (Figure 5), indicating likely contributions of these hatchery strains to the current populations. The MNWILD hatchery sample and several recently stocked populations clustered together but near another cluster containing Coolridge Creek, one of the two source populations for MNWILD. Several clusters of populations were not associated with the known hatchery sources. These clusters were primarily composed of geographic groupings from Rush Creek, Zumbro River, and South Fork Root River tributaries (Figure 6). Rush and Zumbro clusters formed one major branch separated from all branches with hatchery samples. The South Fork Root River cluster incorporated the Iowa sample from South Pine Creek, the last putative remnant brook trout population in Iowa. In all, 37 streams had brook trout populations that were unique to southeastern Minnesota. Given their proximity to each other and that they do not conform to know hatchery stocks, these populations could represent remnant populations (Figure 6).

Population characteristics

The six populations studied intensively fell mostly into several genetic clusters. Trout Brook was in the same major cluster as the Nashua and St. Croix Falls hatchery samples, which are the same strain from two different locations. Garvin Brook is with the Marquette hatchery cluster, which is in the nearby cluster to Nashua/St. Croix Falls. Trout Valley Creek falls in a cluster with Spring Brook (MNWILD contributor) given that adult brook trout from Spring Brook were stocked into Trout Valley Creek in the past. Maple Creek is in the South Fork Root cluster. Finally, both Coolridge Creek and East Indian Creek fall in the Rush cluster. As noted previously, East Indian Creek falls in this cluster because of translocations from Hemmingway Creek, which is close to, and exchanges migrants with, Coolridge Creek.

Water temps were most seasonally variable in East Indian Creek and Maple Creek (Figure 7). These streams had the warmest summer temperatures and the coldest winter temperatures. Most of the dramatic spikes in water temperature could be traced back to heavy rainfall and storm events. Water temperatures did not exceed maximum limits (~68°F) for adult brook trout in any of the study streams. Habitat quality for adult brook trout ranged from poor to good across the six streams (Table 3). Coolridge Creek and Trout Brook were the smallest of the six streams in terms of discharge and stream width; whereas Maple Creek was the largest.

Brook trout density was highly variable across years and streams, but some patterns were evident. Maple Creek, East Indian Creek, and Trout Valley Creek typically had the highest density of both recruits and adults (Table 4). Spring 2008 had the lowest trout numbers, but recruitment was high in the fall. Trout Brook experienced a large decline in brook trout abundance between the spring and fall sample in 2009. Recruitment was poor in 2007 based on missing age1 year-class in several streams (Garvin Brook, Trout Valley Creek, Coolridge Creek). This missing year-class made it difficult in some situations to calculate growth and mortality (see below). All six streams had varying levels of brown trout. This was based somewhat on the location of the sampling stations. Most stations were in upstream reaches and there were abundant brown trout populations in the lower ends of most of these streams. Brown trout increased in Maple Creek during the study period and Trout Brook always had the lowest abundance of brown trout. No other patterns in brown trout abundance were apparent in the other streams. Other fish species were also sampled in all six streams. Coolridge Creek, Garvin Brook, and Trout Brook had the fewest fish species, whereas Maple Creek and Trout Valley Creek had numerous fish species including several warmwater species (Table 5). However, these species were not found in abundance.

Growth was variable across years, with 2009 having slower growth than 2008 (Table 6). Coolridge Creek and Trout Brook typically had the slowest growth rates. Growth was highly variable when examining known-age fish. Fish marked as age-0 were collected in 5 streams as age 1. Size of known age-1 brook trout collected in the fall ranged from147 to 234 mm. Maple Creek and Trout Valley Creek had larger brook trout than the other populations that was likely caused by the inclusion of older fish (Figure 8 and 9). Size structure appeared to be related to stream size with the larger streams having larger brook trout.

Mortality rates were difficult to estimate because of poor abundance estimates of the age-0 and age-1 cohorts. Age-0 brook trout were small in 2008 and not susceptible to our electrofishing gear. Therefore this age class was underestimated in terms of abundance as age-0 but not as age-1 when they were fully recruited into the sampling gear. This resulted in low mortality estimates for the 2008 age-0 cohort (Table 7). Mortality estimates were also low for the 2008 age-1 cohort. This was caused by very few fish being sampled in that cohort across most streams. Very few fish lived past age-3, resulting in estimates of 100% mortality from age-3 to age-4 (Table 7). The overall estimate of 49% mortality is likely a low estimate caused by the problems described above.

Brook trout matured at a small size across all streams (Figure 10 and 11). In general, males matured at a smaller size than females, with the exception of Maple Creek. Males often times matured in their first year of life. Maple Creek and Trout Valley Creek had the largest size at maturation for both males and females, with Coolridge Creek and Trout Brook having the smallest. Size at maturity was not related to genetic strain, but rather appeared to increase along with fish size.

Discussion

Spatial distribution

This study provides a much needed baseline about current brook trout distribution. This study should be repeated in the future to determine whether brook trout populations are increasing or decreasing.

We likely missed some brook trout populations in this effort, however, this effort is the most extensive and detailed distribution study to date. Although we found current brook trout populations in 68% of cold streams, an increase from the 55% reported by Thorn and Ebbers (1997), we presume the remaining 32% had brook trout prior to European settlement. The recent increase is likely due to reintroduction streams, and sampling additional streams. Thorn and Ebbers (1997) assessed 148 streams, whereas we assessed 174 streams. We did not attempt to determine why brook trout present and successful in certain watersheds but think that this is an important next step. Although brook trout were found in the majority of streams, and in more than previously recorded, the number of abundant remnant populations was low.

There did not appear to be any relationships between gill lice presence and brook trout abundance, nor was there any relationship with brown trout presence. The Root River drainage appeared to have a higher incidence of gill lice infestations. Gill lice are species specific affecting brook trout but not brown trout. There is little evidence that gill lice are harmful to brook trout populations in terms of growth and survival (Allison and Latta 1969); however, gill lice may reduce resistance of brook trout to high water temperatures (Vaughan and Coble 1975). It is unknown whether anglers are less likely to harvest brook trout with infestations of gill lice.

Information collected on sculpin distribution should provide useful information on locations for future reintroduction sites. It may also provide information on areas suitable for brook trout reintroduction, given that water quality in these sites is likely suitable for brook trout. Although brook trout stocking has a long history in Minnesota, sculpin reintroduction has only been done recently and in a few select streams.

Genetics

The unique genetic strains found in this study are most simply explained as a remnant of native brook trout in the Driftless Area, and its presence suggests stocking did not completely supplant native genetics. The remnant populations could be referred to as Driftless Area Brook Trout (DABT). These results are similar to recent genetic testing of brook trout in northeastern Minnesota Lake Superior tributaries that identified probable native populations (Burnham-Curtis 2000). Similarly, brook trout in the southern Appalachians also have unique genetic characteristics, and may represent remnant populations (Galbreath et al. 2001; Habera and Moore 2005). Similar to Minnesota, the streams in the southern Appalachians experienced extreme habitat degradation in the early 1900s from logging, causing a decrease in brook trout distribution and presumed extirpation of native stocks (Habera and Moore 2005). Our results confirm previous studies, in that despite stocking of non-native fish, remnant populations can still persist, and these should be given extra conservation attention.

Several associations of populations were inconsistent with geography but can be accounted for by recorded translocations rather than stocking of hatchery strains. The Rush Creek cluster contains East Indian Creek, East Burns Valley Creek, Swede Bottom Creek and Badger Creek Tributary, all outside of the Rush system. Records indicate that Hemmingway Creek fish were translocated to the first three streams in the 1970s, and the last, Badger Creek Tributary, has connectedness to Swede Bottom Creek. Similarly, records indicate translocations of Spring Brook fish to Miller Valley Creek, Trout Valley Creek, Deering Valley Creek, and Bullard Creek, which all clustered closely.

Population characteristics

Population characteristics were highly variable across streams and years. Although there were few differences across genetic strains, small sample size (6 streams) may have precluded detection. Also, habitat differences across streams may have masked any potential differences in growth, recruitment, and mortality. A common garden experiment, where remnant and non-native strains are monitored in the same stream may be needed. We found young age at maturity, which is similar to other reported populations. Older age at maturation may be possible in lightly exploited populations with good water quality and trout habitat.

Maple Creek and Trout Valley Creek both had high brook trout abundance and large brook trout present. These were the two largest stream reaches in our study and had the most fish species present. Although these two populations appeared similar in terms of population characteristics, they were not genetically similar.

Brook trout abundance was highly variable across streams and years. Temporal variation in trout abundance may have masked any differences across streams (Dauwalter et al. 2009). We would have expected low abundance given that these are peripheral populations (Lesica and Allendorf 1995). Also, native salmonid density is often less when in the presence of a non-native species, such as brown trout (Benjamin and Baxter 2010).

Growth rates of brook trout in southeastern Minnesota were similar to other brook trout populations reported elsewhere. In fall sampling in Lawrence Creek, Wisconsin, age-0 brook trout were 94 mm total length (TL), age-1 averaged 170 mm, and age-2 averaged 208 mm (Brasch et al. 1973). Growth was slightly higher in a southern Appalachian stream where mean TL for brook trout was 112 mm for age-0, 184 for age 1, and 268 mm for age-2 (Strange et al 2000). In other southern Appalachian streams, growth was much slower, with few brook trout ever reaching 200mm (Konopacky and Estes 1986). Determinants of growth and size have been related to prey, stream elevation, water temperature, and genetics. Our fastest growing brook trout were found in our larger study streams. In Wyoming, the proportion of quality-sized, non-native brook trout was associated with stream elevation, and with size-selective predation on smaller brook trout by brown trout where sympatric (Larscheid and Hubert 1992). Although we didn't see growth differences caused from genetic strain, native brook trout in the southern Appalachians had slower growth and lower survival than hatchery influenced populations (Wesner et al 2011). Slower growth of native brook trout is not necessarily a detriment, however, given that slower growing brook trout populations may have longer life spans and achieve larger size (Konopacky and Estes 1986).

The mortality rates in this study should be interpreted with caution given the difficulties in obtaining good estimates of age-0 and age-1 abundance as described in the results. Given that few trout sampled were over age-3, it appears mortality is high. Catch curve analysis is unlikely to give better results since only 3-4 age classes are present and recruitment is highly variable. More intensive methods such as mark and recapture modeling should produce better results. Estimates from Coolridge Creek made from mark and recapture models incorporating movement parameters and capture probabilities, estimated annual mortality of 91% from age-1 to age-2 and 87% from age-2 to age-3 (see Hoxmeier and Dieterman 2011b). Longevity of brook trout can vary across regions. Similar results were noted in Wisconsin and in the southern Appalachians, where few trout lived beyond three years (Brasch et al. 1973; Konopacky and Estes 1986). However, in a high elevation stream in Colorado, brook trout as old as 14 years were sampled (Kennedy et al. 2003). We did not identify sources of mortality in this study such as avian and mammalian predators, spawning stress, and angling, but future attempts should be made to determine the source of high observed mortality.

Both male and female brook trout matured at a small size across the six study streams. In Lawrence Creek, Wisconsin, about 80% of female brook trout matured as yearlings (127 mm TL; Brasch et al. 1973).

In two headwater streams in Colorado, the majority of female brook trout matured at age 4 in the high-elevation stream and age 2 in the mid-elevation stream (Kennedy et al. 2003). Because of this wide range in age at maturity (1 to 4 years) and its relationship to longevity, it is important to gain a better understanding of these relationships for brook trout in southeastern Minnesota. A delay in maturation could allow for larger brook trout in Minnesota streams.

Conclusions

This was the first comprehensive study of brook trout in southeastern Minnesota. As such, it provides a useful baseline for developing conservation strategies. We estimate that 68% of brook trout populations remain in southeast Minnesota but only 21% are native to the Driftless Area. These unique populations should be given conservation priority. Of these remnant populations, only 17 have abundant populations. Although we found few differences in population characteristics between remnant and introduced brook trout populations, more controlled studies are needed to determine whether differences exist.

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Table 1. A list of coldwater streams in southeast Minnesota used to determine the distribution of brook trout. The streams were previously classified as having brook trout present or absent in 1997 by Thorn and Ebbers from historical file data (Previous). The current study used electrofishing to determine presence or absence of brook trout (This study) and assigned a relative abundance value for each stream (Abundance). Streams listed as "Stocked" are currently receiving stocked brook trout and natural recruitment is unknown. Genetic samples were analyzed from some brook trout populations and are classified as follows: DABT= Driftless Area Brook Trout unique to southeastern Minnesota, Eastern = originating from northeastern US hatchery stock, MNWILD = originating from southeast Minnesota hatchery stock, Spring Br = originating from direct transfer from Spring Brook in Rice County Minnesota. The presence of gill lice, sculpin (Intro = introduced by MNDNR), and brown trout, was also recorded.

			UTM		Brook trout						Brown trout
Stream	Trib. Number	County	Easting	Northing	Previous	This Study	Abundance	Origin	Gill Lice	Sculpin	Abundance
Ahrensfeld	M-09-17-10	Winona	596383	4862747	No	No	None			No	Common
Anderson Spring	M-09-17-05-04	Winona	591286	4857857	Yes	Yes	Common		Yes	Yes	Common
Badger	M-09-10-02	Houston	615752	4841996	Yes	Yes	Common	DABT		No	Common
Badger trib-6	M-09-10-02-06	Houston	615989	4840959	Yes	Yes	Abundant	DABT		No	Rare
Ball Park Trib	M-04-07	Houston	631507	4829829	Yes	Yes	Rare		No	No	Abundant
Bear Cr	M-26-6	Winona			Yes						
Beaver	M-09-10-03	Houston	613388	4838267	No	Yes	Rare			Yes	Abundant
Beaver Cr	M-31-6	Wabasha	575854	4888530	No	No	None			Yes	Abundant
Beaver Cr, East	M-09-10-03-08	Houston	614470	4833047	Yes	Yes	Rare	Eastern	No	Yes	Abundant
Beaver Cr, West	M-09-10-03-09	Houston	611831	4831779	Yes	Yes	Common	Eastern		Yes	Common
Bee	I-06	Houston	614695	4819517	No	Yes	Rare	Eastern	No	Yes	Rare
Beetle Springs	M-09-27.5	Fillmore	579749	4849555		No	None			No	Rare
Belle Cr	M-48-4	Goodhue	521929	4932834	No	No	None				
Berg	M-01-10	Houston	629606	4821928	No	No	None			Yes	Common
Big Springs	M-09-30-06	Fillmore	568168	4845321	No	No	None			No	Rare
Big Springs	M-09-21	Fillmore	587623	4849991	Yes	Yes	Rare			No	Common
Blagsvedt	M-09-10-12	Fillmore	591966	4830396	Yes	Yes	Common	DABT			
Borson Spring	M-09-17-06	Winona	596548	4856997	Yes	Yes	Common	DABT			
Boynton Spring	Rush SPG #9	Winona	594022	4863279		Yes	Common	DABT	No	Yes	Common
Bridge	M-09-10-04	Houston	605748	4840314	Yes	Yes	Abundant	Eastern	Yes	No	Rare
Brush Valley	M-09-04	Houston	628489	4849912	Yes	Yes	Rare	DABT	No	No	None
Brush Valley trib	M-09-04-01	Winona	628903	4850148	No	Yes	Abundant	DABT	No	No	None

Table 1 continued…

Stream	Trib. Number	County	UTM Easting	UTM Northing	Brook trout Previous	Brook trout This Study	Brook trout Abundance	Origin	Gill Lice	Sculpin	Brown trout Abundance
Bullard Cr	M-45	Goodhue	541945	4930629	Yes	Yes	Abundant	Spring Br		No	None
Burfiend's Trib.	M-43-5	Goodhue	543097	4922344		Yes	Common	MNWILD		Intro	Rare
Burns Cr	M-24	Winona			No	No	None				
Butterfield	M-09-01-01	Houston	632650	4843568	Yes	Yes	Common	Eastern	No	No	Common
Camp	M-09-25-03	Fillmore	575423	4835584	No	No	None				
Camp Hayward	M-09-19	Fillmore	594019	4847655		Yes	Common	Eastern	Yes	Yes	Common
Campbell	M-09-11-02	Winona	615240	4857097	Yes	Yes	Abundant	Eastern	Yes	No	None
Canfield trib-1	M-09-25-10-01	Fillmore	562688	4828927		No	None			Yes	Abundant
Carter's	M-09-33-07	Fillmore	558528	4844014		No	None			No	Common
Cedar Valley	M-18	Winona	614357	4866477	Yes	No	None			No	Abundant
Chickentown	M-09-10-10-02	Fillmore	595773	4827856	Yes	Yes	Common	DABT			
Clear	M-04-01	Houston	637124	4826464	No	No	None			No	Rare
Clear Cr	M-43-6	Goodhue	540790	4921439		Yes	Common				
Cold Spring Br	M-34-48	Wabasha	545130	4904221	Yes	Yes	Abundant	DABT		Yes	Abundant
Coolridge	M-09-17-05-05	Winona	590341	4858415	Yes	Yes	Abundant	DABT	No	Yes	Abundant
Corey	M-09-11-05	Winona	612237	4859932	Yes	Yes	Common	Eastern	Yes	No	Rare
Crooked	M-04	Houston	625553	4832159	No	Yes	Abundant	Eastern		No	Rare
Crooked trib-4	M-04-04	Houston	635260	4830533	No	No	None			No	None
Crooked trib-5	M-04-05	Houston	633216	4831590	No	No	None			No	Common
Crooked, So. Fk.	M-04-09	Houston	626375	4829146	No	Yes	Abundant	MNWILD	No	Yes	Common
Crystal	M-09-07	Houston	622124	4842403	No	Yes	Stocked	MNWILD		No	Common
Crystal	M-09-25-04-04	Fillmore			No						
Dakota	M-14	Winona	629468	4864386	Yes	Yes	Common	DABT		No	
Daley	M-09-12	Houston	605102	4844998	Yes	Yes	Rare		Yes		Common
Deering Valley Cr	M-27	Winona	596044	4887142	No	Yes	Abundant	Spring Br	No	No	None
Diamond	M-09-23	Fillmore	590345	4842316	Yes	Yes	Common	Eastern	No	No	Abundant

Table 1 continued…

			UTM		Brook trout						Brown trout
Stream	Trib. Number	County	Easting	Northing	Previous	This Study	Abundance	Origin	Gill Lice	Sculpin	Abundance
Diamond, So.Fk.	M-09-23-01	Fillmore	591386	4841208	Yes	Yes	Abundant		No	No	Abundant
Dry Run Cr	M-34-52	Wabasha	538928	4894055	No	No	None			No	None
Duschee	M-09-25-01	Fillmore	582283	4835808	No	Yes	Stocked	MNWILD		No	Abundant
E Burns Cr	M-24-2	Winona	608744	4874539	Yes	Yes	Rare	DABT		No	Common
East Indian Cr	M-32	Wabasha	577844	4896291	Yes	Yes	Abundant	DABT	No	No	Common
Eitzen	M-01-11	Houston	627761	4821374	No	Yes	Stocked	MNWILD		Yes	Rare
Etna	M-09-25-14	Fillmore	552957	4827889	Yes	Yes	Stocked	MNWILD		Yes	Common
Etna, So. Br.	M-09-25-14-01	Fillmore	552902	4827842	No	Yes	Stocked	MNWILD			
Ferguson	M-09-17-12	Winona	593400	4861493	Yes	Yes	Rare	DABT	No	No	Abundant
Ferndale	M-09-14	Fillmore	603901	4848016	No	Yes	Abundant	DABT	Yes	Yes	Rare
Forestville	M-09-25-09	Fillmore	562833	4832192	No	No	None			Yes	Abundant
Frego	M-09-10-10-06	Fillmore	589627	4822966	No	No	None			No	None
Freheit Spring	M-09-33-10-02	Fillmore	554982	4839502		No	None			No	None
Garvin Br	M-26-1	Wabasha	595175	4872363	Yes	Yes	Abundant	Eastern	No	Yes	Abundant
Gernander	M-09-11-06	Winona	604117	4858751	Yes	Yes	Rare			No	None
Gilbert Cr	M-42	Wabasha	552115	4920765	No	Yes	Stocked	MNWILD		Intro	Common
Gilmore Cr	M-24	Winona	604811	4877534	No	No	None				Abundant
Girl Scout Camp	M-09-10-05.5	Houston	603475	4838690	Yes	Yes	Common	DABT		No	Rare
Goetzinger Trib	M-04-08	Houston	630748	4828100	No	Yes	Rare		No	No	Rare
Gorman Cr	M-33	Wabasha	574116	4902234	Yes	Yes	Rare		No	No	None
Gribben	M-09-24	Fillmore	587870	4839042	Yes	Yes	Common		No	No	Abundant
Gribben trib-3	M-09-24-03	Fillmore	587841	4839123		Yes	Common			No	Common
Hallum	M-09-10-06	Houston	602069	4837045	Yes	Yes	Common	DABT	Yes	No	Rare
Hamilton	M-09-33-08-06	Mower	544313	4845356		No	None			No	None
Hammond	M-34-41	Wabasha	550047	4896549	Yes	Yes	Common	DABT		No	Common
Hay Cr	M-46	Goodhue	534617	4927909	No	No	None			Intro	Abundant

Table 1 continued…

Stream	Trib. Number	County	UTM Easting	UTM Northing	Brook trout Previous	Brook trout This Study	Brook trout Abundance	Brook trout Origin	Gill Lice	Sculpin	Brown trout Abundance
Helbig Cr	M-34-13	Wabasha	568945	4904957	Yes	Yes	Common	DABT	No	No	None
Hemmingway	M-09-17-05-06	Winona	590810	4857404	Yes	Yes	Abundant	DABT	No	Yes	Abundant
Hippie Trib.	M-09-11-07	Winona	610126	4861254		No	None			No	None
Kedron	M-09-33-08-04	Fillmore	553018	4846795	No	No	None			No	Abundant
Klair's Cr	M-43-9	Goodhue	537878	4919792		Yes	Common	MNWILD		Intro	
Konkel Spring	M-01-15	Houston	625123	4823517		No	None			Yes	Rare
Latsch Cr	M-28	Winona	592718	4891738	No	Yes	Abundant	MNWILD		Intro	None
L Cannon R	M-48-12	Goodhue	507201	4928159	No	No	None			No	Rare
L Pickwick Cr	M-17-2	Winona	623754	4867698	Yes	Yes	Abundant			Intro	None
Larson Creek	M-09-10-03-09-06	Houston	612003	4831895	Yes	Yes	Common	Eastern		Yes	Abundant
Little Jordan	M-09-33-05	Fillmore	558866	4848647	No	Yes	Stocked	MNWILD		No	Abundant
Logan Cr	M-31-18-4	Olmsted								No	Common
Long Cr	M-34-22	Wabasha	560960	4897737	No	Yes	Common	DABT		No	Abundant
Looney	M-09-09-03	Houston	619287	4853760	Yes	Yes	Common	Eastern	Yes	No	None
Lost	M-09-33-02	Fillmore	558064	4852260	No	No	None			No	None
Lynch	M-09-31	Fillmore	570388	4852944	No	Yes	Stocked	MNWILD		No	Abundant
M B Whitewater	T-31	Olmsted	571144	4874826	No	Yes	Stocked	MNWILD		Yes	Abundant
Mahoods	M-09-33-10-01	Fillmore	556631	4840206		No	None			No	Common
Main Whitewater	T-31	Winona	579571	4889078	No	No	None				
Maple	M-09-10-08	Fillmore	597388	4836265	Yes	Yes	Abundant	DABT	Yes	Yes	Rare
Maple trib-2	M-09-10-08-02	Fillmore	597070	4838257	Yes	Yes	Abundant		Yes	Yes	None
Mazappa Cr	M-34-49-1	Wabasha	536310	4906063	Yes	Yes	Common	DABT		No	Abundant
MBr. Rollingstone	M-26-2	Winona									
Middle Cr	M-34-21	Wabasha	563576	4899281	Yes	Yes	Abundant	DABT		No	
Mill	M-09-34	Olmsted	564702	4855807	Yes	No	None			No	Abundant
Miller Cr	M-41	Wabasha	557551	4920009	No	No	None				

Table 1 continued…

			UTM		Brook trout						Brown trout
Stream	Trib. Number	County	Easting	Northing	Previous	This Study	Abundance	Origin	Gill Lice	Sculpin	Abundance
Miller Valley Cr	M-15	Winona	626758	4869358	Yes	Yes	Abundant	Spring Br	No	No	None
Money	M-09-11	Winona	607056	4863375	No	No	None			No	Common
Money trib-4.5	M-09-11-4.5	Winona	611063	4855364		No	None			No	None
Money, West	M-09-11-08	Winona	605354	4862089	No	No	None			No	
N B Whitewater	T-31-8	Winona	577306	4881872	No	No	None			Yes	Abundant
Nepstad	M-09-10-09	Fillmore	596240	4834093	Yes	Yes	Abundant	DABT	Yes	Yes	Common
NY Hollow	M-01-09	Houston	630513	4819934	Yes	Yes	Common	Eastern	No	No	Rare
Newburg	M-09-10-10-03	Fillmore	595210	4825896	Yes	Yes	Rare	DABT	No	Yes	Rare
Partridge	M-09-25-03-01	Fillmore	577263	4828091	No	No	None			No	None
Peterson Cr	M-26-1-8	Winona	595052	4872752	Yes	Yes	Rare	Eastern		Yes	Common
Pickwick Cr	M-17	Winona	619982	4868131	Yes	Yes	Stocked	MNWILD		Intro	Common
Pine	M-09-17-05	Winona	591392	4857796	Yes	Yes	Rare		No	Yes	Abundant
Pine Cr	M-48-11	Goodhue	510384	4930368	No	No	None				Common
Pine NH	M-11	Winona	624053	4857617	Yes	Yes	Abundant	MNWILD		No	Abundant
Pine NH, So. Fk.	M-11-21	Winona	622462	4859690	Yes	Yes	Abundant	MNWILD	No	No	Common
Pleasant Valley	M-24-1	Winona	612057	4872799	Yes	No	None				Common
Pleasant Vly trib	M-24-1-1	Winona	612250	4871851		Yes	Common	Eastern		No	Common
Rice	M-09-30	Fillmore	571232	4850173	No	No	None			No	Abundant
Riceford	M-09-10-05	Fillmore	604332	4828735	Yes	Yes	Rare			No	Common
Riceford trib-3	M-09-10-05-03	Fillmore	601811	4826590	Yes	Yes	Abundant	DABT	Yes	Yes	Rare
Riceford trib-4	M-09-10-05-04	Fillmore	602235	4823808	Yes	Yes	Common	Eastern	Yes	Yes	Common
Richmond Cr	M-16				No						
Rollingstone Cr	M-26	Winona			No						
Root River, So. Br.	M-09-25	Fillmore	561090	4830429	No	Yes	Stocked	MNWILD		Yes	Abundant
Root River, So. Fk.	M-09-10	Fillmore	592191	4830362	Yes	Yes	Common			Yes	Abundant
Rose Valley	M-11-09	Winona	628151	4857442	Yes	No	None			No	Rare

Table 1 continued…

Stream	Trib. Number	County	UTM Easting	UTM Northing	Brook trout Previous	Brook trout This Study	Brook trout Abundance	Brook trout Origin	Gill Lice	Sculpin	Brown trout Abundance
Rupprecht Cr	M-26	Winona	591427	4876909	Yes	Yes	Rare			Yes	Abundant
Rush	M-09-17	Winona	590366	4866028	No	No	None			Yes	Abundant
Rush trib-13	M-09-17-13	Winona	597544	4854809		No	None			No	Rare
Rush trib-3	M-09-17-03	Fillmore	597488	4855113		Yes	Abundant	DABT	Yes	Yes	Common
Rush trib-5.5	M-09-17-5.5	Winona	596632	4857020		Yes	Abundant	DABT	Yes	No	Common
S Br Whitewater	T-31-17	Winona	582171	4879305	No	Yes	Rare	DABT		Yes	Abundant
Schueler	M-09-17-01	Fillmore	598659	4854337	Yes	Yes	Common	DABT			
Schutz Spring	M-01-13	Houston	626391	4822724		No	None			Yes	Rare
Second Cr	M-40	Wabasha	560732	4919190	Yes	Yes	Common	DABT		No	Rare
Shady	M-09-33-01	Fillmore	564794	4848562		No	None			No	Common
Shamrock Trib	M-04-10	Houston	626439	4832693		Yes	Common	Eastern	No	No	Rare
Silver	M-09-09	Houston	619380	4853849	Yes	Yes	Abundant	Eastern	Yes	No	Rare
Silver Springs	M-34-37	Wabasha	552503	4896401		Yes	Common	DABT	No	No	Rare
Skunk Hollow	M-09-11-01	Houston			No						
Snake Cr	M-32.5	Wabasha	580203	4900146	Yes	Yes	Stocked	MNWILD		No	None
Sorenson	M-09-10-10-05	Fillmore	586097	4825118	Yes	Yes	Common	Eastern	Yes	Yes	None
Speltz Cr	M-26-3	Winona	592565	4884985	No	No	None			No	None
Sprau's Trib	M-09-34-04	Olmsted	564301	4856680		Yes	Stocked	MNWILD			
Spring Br	M-48-20	Rice	483254	4921457	Yes	Yes	Common	Eastern			
Spring Branch	M-07-02	Houston	634345	4838561	No	No	None			No	None
Spring Cr	M-47	Goodhue	526835	4930068	Yes	Yes	Stocked	MNWILD		No	Stocked
Spring Cr	M-34-20	Wabasha	559841	4905772	No	No	None			No	Common
Spring Valley	M-09-33-10	Fillmore	556752	4841906	No	No	None			No	Common
Stockton Val Cr	M-26-1-5	Winona	599935	4868651	Yes	Yes	Abundant	Eastern	No	No	Common
Storer	M-09-08	Houston	621967	4850167	Yes	Yes	Abundant	DABT	Yes	No	None
Straight Cr	M-26-5	Winona	590905	4882431	No	No	None				Common

Table 1 continued…

Stream	Trib. Number	County	UTM Easting	UTM Northing	Brook trout Previous	Brook trout This Study	Brook trout Abundance	Brook trout Origin	Gill Lice	Sculpin	Brown trout Abundance
Sullivan	M-09-01-02	Houston	629310	4839361	Yes	Yes	Abundant	Eastern	No	Yes	Rare
Swede Bottom	M-09-10-01	Houston	616712	4844145	Yes	Yes	Abundant	DABT	Yes	No	None
Thompkins Cr	M-34-56-4-12	Dodge	525995	4877735		Yes	Common	MNWILD	No	No	None
Thompson	M-09-01	Houston	626358	4842111	No	Yes	Common	MNWILD	No	No	Common
Torkelson	M-09-06	Fillmore	582242	4848138	Yes	Yes	Rare				Abundant
Trail Run	M-48-8	Goodhue	513454	4929888		Yes	Abundant	Eastern	No	No	Rare
T10 – Whitewater	M-31-10	Winona	581272	4884872		No	None			No	None
Trout Br	M-48-7	Dakota	513602	4934573	Yes	Yes	Abundant	Eastern		No	Rare
Trout Br	M-34-9	Wabasha	567306	4911126	No	Yes	Abundant	MNWILD	No	No	None
Trout Br	M-46-1	Goodhue	533888	4932320	No	Yes	Abundant	MNWILD		Intro	None
Trout pond Trib	M-11-16	Winona	623592	4856890		Yes	Common	Eastern	No	No	Rare
Trout Run	M-09-29	Winona	576387	4850304	No	No	None			Yes	Abundant
Trout Run	M-31-20	Winona	576413	4877632	Yes	Yes	Abundant	MNWILD	No	Yes	Abundant
Trout Valley Cr	M-31-1	Winona	585471	4890175	Yes	Yes	Abundant	Spring Br	Yes	No	Rare
Vesta	M-09-10-07	Fillmore	559194	4834227	Yes	Yes	Abundant	DABT	Yes	No	None
Voelker Brook	M-09-17-05-09	Fillmore	591042	4855632	Yes	Yes	Abundant	DABT	No	No	Rare
W Burns Cr	M-24-2-1	Winona	607799	4874775	Yes	Yes	Common			No	Common
W Indian Cr	M-34-17	Wabasha	568368	4898593	Yes	Yes	Rare			Yes	Abundant
Watson trib-2	M-09-25-02-2	Fillmore	565548	4838245		Yes	Stocked	MNWILD		No	Rare
Watson	M-09-25-02	Fillmore	565555	4838208	No	Yes	Stocked	MNWILD		Yes	Abundant
Wells Cr	M-43	Goodhue	536965	4919648		Yes	Common			Yes	Common
West Albany Cr	M-34-20-1	Wabasha	556414	4905188	No	No	None			No	Common
Wildcat	M-07	Houston	637982	4838945	No	No	None			No	Common
Willow	M-09-25-04	Fillmore	572984	4834517	No	No	None			Yes	Common
Winnebago trib-4	M-01-04	Houston	635685	4820712	No	No	None			No	Rare
Winnebago	M-01	Houston	621186	4824711	Yes	Yes	Stocked	MNWILD		Yes	Common

Table 1 continued…

Stream	Trib. Number	County	UTM Easting	UTM Northing	Brook trout Previous	Brook trout This Study	Brook trout Abundance	Brook trout Origin	Gill Lice	Sculpin	Brown trout Abundance
Wisel	M-09-10-10	Fillmore	594892	4828525	No	Yes	Common	DABT	Yes	Yes	Abundant
Woodson	I-27-09	Mower	502449	4831491	No	No	None			No	None
Wunderlich Spring	Rush SPG #7	Winona	594072	4860229		Yes	Rare		Yes	Yes	Common

Table 2. Stream ID for Figure 6 with year of sample collection, sample size, expected and observed heterozygosities (HZ), and source of data. Samples include Driftless Area streams from southeast Minnesota, Wisconsin, Iowa, and known hatchery strains

Sample	ID	Year	N	Unbiased Hz	Obs Hz
			Wisconsin/Iowa[1]		
Ash, WI	4WI	2003	50	0.50	0.50
Melancthon, WI	3WI	2003	50	0.62	0.63
Parfrey's Glen, WI	1WI	2003	50	0.52	0.54
S. Pine Creek, IA	IOWA	1999	54	0.62	0.60
Soper, WI	2WI	2003	50	0.71	0.72
			Southeast MN		
Badger Creek Trib	BCT	2003	29	0.67	0.71
Bee Creek	BEE	2008	16	0.64	0.64
Blagsvedt Creek	BLAG	2003	26	0.66	0.62
Borson Spring Creek	BRS	2003	30	0.69	0.73
Bridge	BDG	2008	24	0.61	0.62
Brush Valley	BRV	2009	24	0.65	0.70
Bullard Creek	BUL	2006	30	0.57	0.52
Butterfield	BUT	2006	24	0.66	0.64
Camp Hazard Creek	CHC	2003	31	0.66	0.82
Campbell	CAM	2008	26	0.74	0.75
Chickentown Creek	CKC	2003	29	0.61	0.62
Cold Spring Brook	CSB	2003	25	0.68	0.74
Coolridge Creek	CC	2001	46	0.68	0.69
Corey	COR	2006	25	0.75	0.71
Crooked Creek	CRK	2006	39	0.70	0.73
Crooked Creek, SF	CRC	2008	28	0.65	0.63
Dakota Creek	DKC	2003	32	0.63	0.60
Deering Valley Creek	DVC	2009	32	0.39	0.39
Diamond	DIA	2006	40	0.66	0.65
East Beaver Creek	EBC	2008	16	0.55	0.58
East Burns Valley Creek	EBVC	2003	27	0.56	0.59
East Indian Creek	EIC	2006	56	0.70	0.69
Ferguson Creek	FER	2007	26	0.64	0.77
Ferndale	FDL	2008	30	0.65	0.60
Garvin Brook	GAR	2006	27	0.64	0.66
Girl Scout Camp Creek	GSCC	2003	26	0.71	0.69
Hallum	HAL	2009	25	0.72	0.70
Hammond Creek	HMC	2003	30	0.69	0.63
Helbig Creek	HEL	2009	42	0.69	0.72
Hemmingway Creek	HEM	2001	34	0.69	0.64
Larson Creek	LAR	2006	24	0.70	0.69
Long	LNG	2006	30	0.67	0.70
Looney Creek	LVC	2003	30	0.65	0.67
Maple	MAP	2006	32	0.70	0.67
Mazeppa Creek	MAZ	2006	34	0.68	0.71
Middle Br Whitewater	MBW	2007	22	0.67	0.67
Middle Creek	MDC	2003	27	0.62	0.60
Miller Valley Creek	MVC	2009	37	0.55	0.54
Nepstad Creek	NEP	2003	30	0.73	0.73
Sample	ID	Year	N	Unbiased	Obs Hz

				Hz		
New Yorker Hollow	NYH	2007	17	0.62	0.58	
Newburg	NEW	2006	15	0.70	0.63	
Peterson Creek	PTC	2003	31	0.60	0.61	
Pine NH	PCR	2007	25	0.70	0.69	
Pine NH, S Fork	PINE	2008	28	0.77	0.76	
Pleasant Valley Trib	PVT	2009	14	0.19	0.18	
Riceford3 repeat	URCE	2008	27	0.69	0.70	
Rush trib- Fillmore	URUF	2008	29	0.69	0.70	
Rush trib- Winona	URUW	2008	26	0.62	0.59	
S Br Whitewater Trib	SBWTr	2003	29	0.68	0.68	
Schad trib - Boynton	SCD	2008	16	0.56	0.69	
Schueler Creek	SHC	2003	26	0.70	0.69	
Second Creek	SEC	2003	26	0.65	0.70	
Shamrock	SHA	2007	25	0.72	0.71	
Silver	SIL	2009	25	0.71	0.72	
Sorenson	SRN	2008	20	0.54	0.61	
Spring Brook	SBC	2001	32	0.47	0.46	
Spring Brook -Stott	SBWS	1999	29	0.51	0.44	
Stockton Valley Creek	SVC	2008	19	0.59	0.56	
Storer	STR	2006	29	0.72	0.72	
Sullivan Creek	SUL	2006	27	0.68	0.71	
Swede Bottom Creek	SWB	2003	26	0.68	0.69	
Thompson Creek	THM	2006	30	0.70	0.73	
Trail Run	TRN	2009	61	0.60	0.59	
Trout Brook	TRB	2007	33	0.68	0.69	
Trout Brook	TBW	2009	21	0.63	0.69	
Trout Pond trib	TPT	2008	27	0.46	0.56	
Trout Run	TTR	2009	27	0.71	0.79	
Trout Valley Creek	TVC	2007	25	0.57	0.56	
Unnamed Riceford3	3UN	2006	29	0.73	0.73	
Unnamed Riceford4	4UN	2006	26	0.61	0.59	
Vesta	VES	2009	27	0.60	0.65	
Voelker Brook	VKB	2003	28	0.64	0.72	
West Beaver Creek	BCW	2006	25	0.71	0.71	
Wisel Creek	WIS	2009	24	0.71	0.69	
			Hatchery Strains[2]			
Assinica	ASN	1998	51	0.38	0.41	Maine
Marquette	MARQ	2003	73	0.61	0.59	Mich - L Superior
MN Wild	MNW	1998	60	0.67	0.70	Coolridge x Spring Br
Nashua	NASH	1997	37	0.72	0.68	Bayfield
Owhi	OWHI	1998	52	0.73	0.73	Egan State UT
Rome	ROME	1998	50	0.42	0.33	NY
St. Croix Falls	SCF	1998	48	0.67	0.63	New Hampshire

[1]Data from Tim King, USGS, Leetown, WV, unpublished data.

[2]Data from W. Stott, USGS, Ann Arbor, MI, unpublished data

Table 3. Habitat characteristics of six streams used to describe population characteristics of southeastern Minnesota brook trout. Length and baseflow discharge of sampling station. Habitat quality index was calculated using methods from Thorn and Anderson (2001). For brook trout <18 is considered poor, 18-20 is fair, 21-23 is good, and >23 is excellent. Cover is the sum of five adult trout habitat features scored from 0-4 based on visual estimates of abundance.

Stream	Date	Length (m)	Discharge (m^3/s)	Habitat Quality Index	Percent Pool Area	Percent fines	Cover	Mean Width (m)	Width:Depth
Coolridge	7/23/2008	515	0.03	20	38.7	25	13	2.7	19.9
Maple	7/23/2008	180	0.19	22	67.1	45	13	5.3	16.6
East Indian	7/2/2008	209	0.11	23	91	63	15	5.7	13.0
Garvin	7/2/2008	311	0.08	17	66	30	11	5.6	26.8
Trout Valley	7/2/2008	278	0.11	18	78.8	55	11	4.8	14.1
Trout Brook	7/1/2008	165	0.05	19	87	80	10	3.4	12.6

Table 4. Number of brook and brown trout per mile in the spring and fall of 2008 and 2009 in six southeast Minnesota streams. Recruits are defined as young of year in the fall and yearlings in the spring. Standard errors could not be estimated in some cases (na) because no fish were collected in the second pass for the depletion estimate.

		Brook Trout (N/mile ±SE)					Brown Trout (N/mile ±SE)				
Stream	Date	recruits		Adult		total	recruits		Adult		total
Spring 2008											
Coolridge	5/23/2008	75	na	88	na	163	31	na	34	na	65
Maple	5/9/2008	161.1	(169.8)	565.4	(25.9)	726.5	0	na	3	na	3
East Indian	5/6/2008	371.1	(75.4)	1168.2	(164.1)	1539.3	4	na	277.4	(69.5)	281.4
Garvin	5/5/2008	2	na	93.2	(15.5)	95.2	0	na	69.9	(13.4)	69.9
Trout Valley	5/8/2008	2	na	598.4	(63.2)	600.4	0	na	144.3	(14.8)	144.3
Trout Brook	5/7/2008	183.6	(25.9)	466.2	(10.3)	649.8	0	na	1	na	1
Fall 2008											
Coolridge	8/29/2008	28.6	(5.3)	119.3	(9.9)	147.9	115.9	(5.9)	48.3	(11.4)	164.2
Maple	9/26/2008	2853.6	(458.8)	609	(118.5)	3462.6	40.3	(13.4)	35.8	(31.0)	76.1
East Indian	9/22/2008	4519.8	(125.7)	944.7	(45.3)	5464.5	389.7	(26.7)	186	(4.1)	575.7
Garvin	9/23/2008	1034.7	(185.0)	69.9	(13.4)	1104.6	1160.2	(255.4)	5	na	1165.2
Trout Valley	9/25/2008	2371.3	(31.4)	237.1	(13.0)	2608.4	1	na	98.8	(1.7)	99.8
Trout Brook	9/24/2008	3426.7	(89.0)	197.2	(59.8)	3623.9	1	na	0	na	1
Spring 2009											
Coolridge	6/3/2009	56	na	94	na	150	31	na	28	na	59
Maple	4/14/2009	3899.6	(71.1)	449.3	(09.2)	4348.9	72	na	35.8	(62.0)	107.8
East Indian	4/17/2009	2560.6	(61.0)	224.1	(07.2)	2784.7	177.9	(26.5)	34.6	(23.1)	212.5
Garvin	4/16/2009	646.6	(65.8)	73.9	(22.9)	720.5	902.3	(64.9)	139.8	(38.0)	1042.1
Trout Valley	4/15/2009	3268.1	(67.4)	174.6	(05.3)	3442.7	36.2	(08.9)	52.1	(155.3)	88.3
Trout Brook	4/13/2009	3452.1	(175.3)	122.2	(21.2)	3574.3	0	na	0	na	0
Fall 2009											
Coolridge	10/7/2009	327	na	97	na	395	2987	(86)	239	(2)	3226
Maple	9/23/2009	2871.2	(192.7)	4319	(58.8)	7190.2	107.4	(107.3)	126	(6.0)	233.4
East Indian	9/21/2009	3412.5	(277.2)	1400.2	(31.4)	4812.7	240.2	(13.2)	84.5	na	324.7
Garvin	9/24/2009	1039.5	(301.6)	335.9	(34.7)	1375.4	106.5	(52.3)	381.2	(73.5)	487.7
Trout Valley	9/25/2009	3471.9	(88.7)	1462.6	(10.2)	4934.5	1946.8	(67.9)	52.1	(155.3)	1998.9
Trout Brook	9/17/2009	19.6	na	344.8	(89.0)	364.4	2	na	0	na	2

Table 5. Fish species present in six southeastern Minnesota trout streams used to examine population characte-ristics of brook trout.

	Coolridge	Maple	East Indian	Garvin Brook	Trout Val-ley	Trout Brook
Brook trout	X	X	X	X	X	X
Brown trout	X	X	X	X	X	X
Sculpin spp.	X	X		X		
Brook stickleback			X		X	X
Longnose dace		X	X		X	
Blacknose dace		X			X	
White sucker		X	X		X	
Central stoneroller		X			X	
Creek chub		X			X	
Green sunfish					X	
Black bullhead		X				
Johnny darter		X				
Fantail darter		X				
Common shiner		X				

Table 6. Mean total length at capture (±SE) for brook trout caught in six southeastern Minnesota streams in fall of 2008 and 2009. Ages were determined from length frequency data combined with subsampled aged fish in MIXDIST.

Stream	Year	Age-0		Age-1		Age-2		Age-3		Age-4	
Maple	2008	102.9	(.8)	190.2	(6.2)	219.7	(8.7)	259.2	(9.3)	316.8	(6.9)
	2009	97.7	(1.1)	156.6	(1.4)	201.0	(3.5)	282.2	(4.9)	339.4	(13.5)
East Indian	2008	101.9	(.8)	192.1	(3.5)	225.3	(6.7)	230.4	(18.2)		
	2009	112.8	(.9)	184.5	(2.1)	214.0	(4.6)	267.4	(12.9)		
Garvin	2008	100.4	(1.3)	182.2	(15.8)	227.2	(8.3)	254.3	(7.8)		
	2009	99.5	(1.1)	177.69	(2.1)	202.3	(10.1)	238.7	(5.9)		
Trout Valley	2008	114.5	(1.1)	163.8	(22.5)	243.9	(13.3)	274.6	(5.2)	311.4	(19.4)
	2009*	124.1	(.8)	191.3	(2.3)	219.1	(4.2)	270.3	(11.4)		
Trout Brook	2008	106.6	(.8)	174.1	(20.6)	213.3	(4.7)	255.4	(6.9)		
	2009	103.5	(10.7)	165.4	(4.0)	172.5	(16.2)	203.8	(8.9)		
Coolridge	2008	95.35	(2.)	161.16	(10.5)	205.7	(4.7)	206.6	(14.3)		
	2009	91.2	(1.2)	166.3	(3.8)	196.3	(4.8)	228.2	(8.4)		

*There was not a good fit to the 2009 Trout Valley length histogram.

Table 7. Annual mortality rates of brook trout for six streams in southeastern Minnesota. Mortality was set to zero if there were more fish of a cohort caught in the second year.

	Age class				Stream
Stream	0-1	1-2	2-3	3-4	Mean
Coolridge	0.05	0	0.73	1.00	0.44
Maple	0	0	0.23	0.93	0.43
East Indian	0.73	0.15	0.96	1.00	0.71
Garvin	0.67	0	0	1.00	0.42
Trout Valley	0.54	0	0.35	1.00	0.47
Trout Brook	0.92	0	0.58	1.00	0.63
Cohort mean	0.49	0.03	0.48	0.98	0.49

Figure 1. Map with watershed names and sampling locations showing presence (●) or absence (○) of brook trout in southeast Minnesota coldwater streams. Streams without documented natural reproduction and are currently being stocked with brook trout are indicated as such (★).

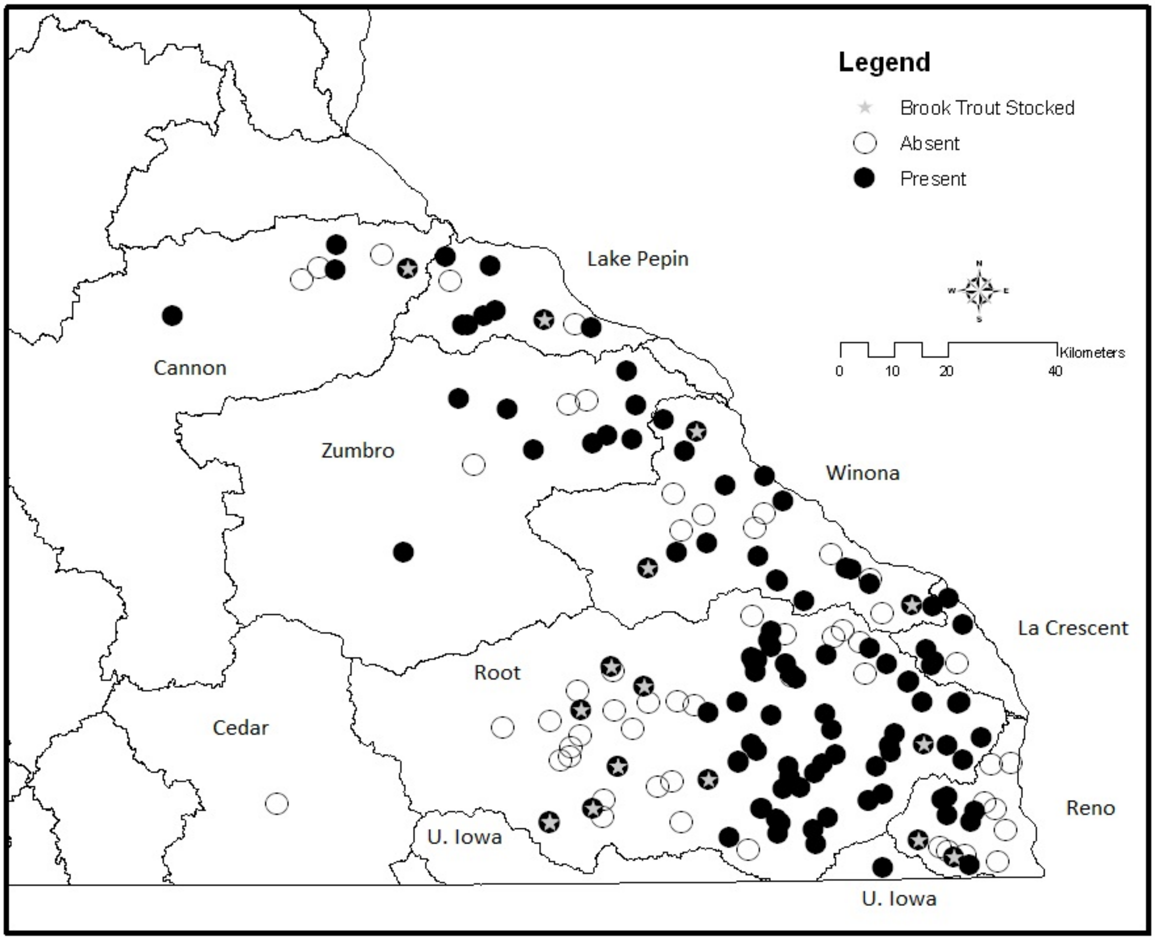


Figure 2. Relative brook trout abundance in coldwater streams in southeast Minnesota. Streams indicated as stocked are currently being stocked with brook trout and natural reproduction is not known.

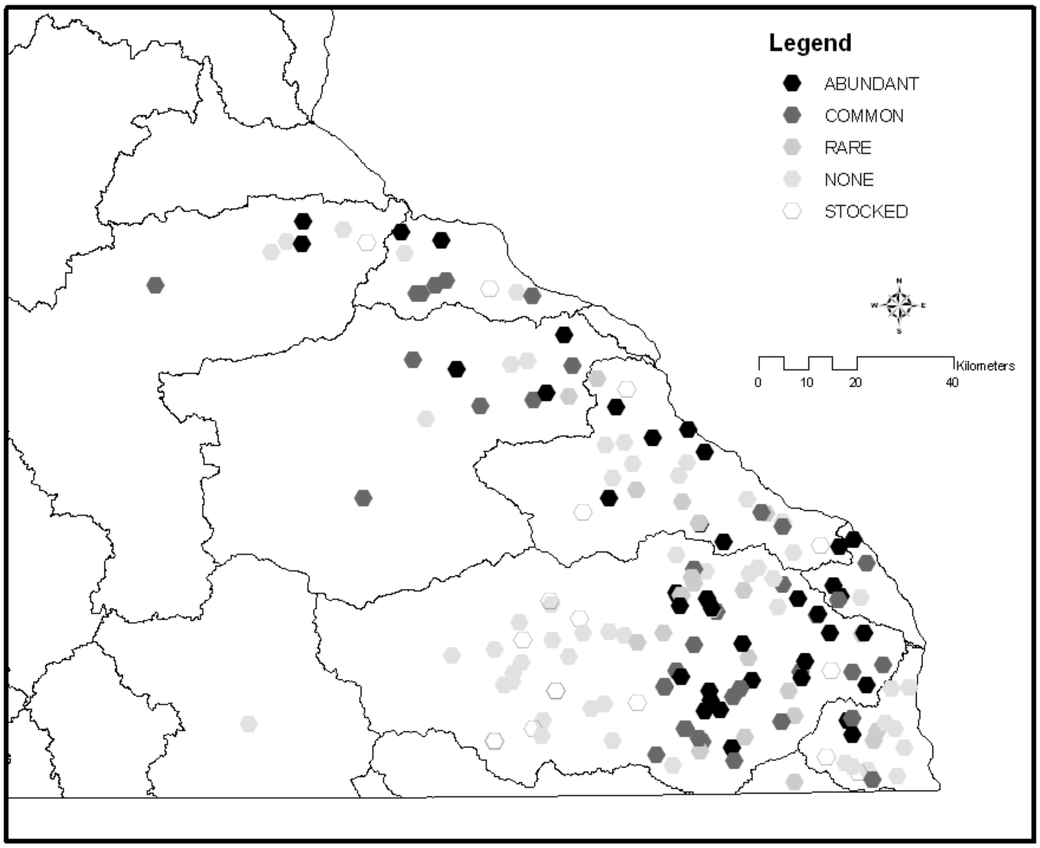


Figure 3. Distribution of gill lice infestations in brook trout populations in southeast Minnesota. Note that not all brook trout populations were examined for gill lice.

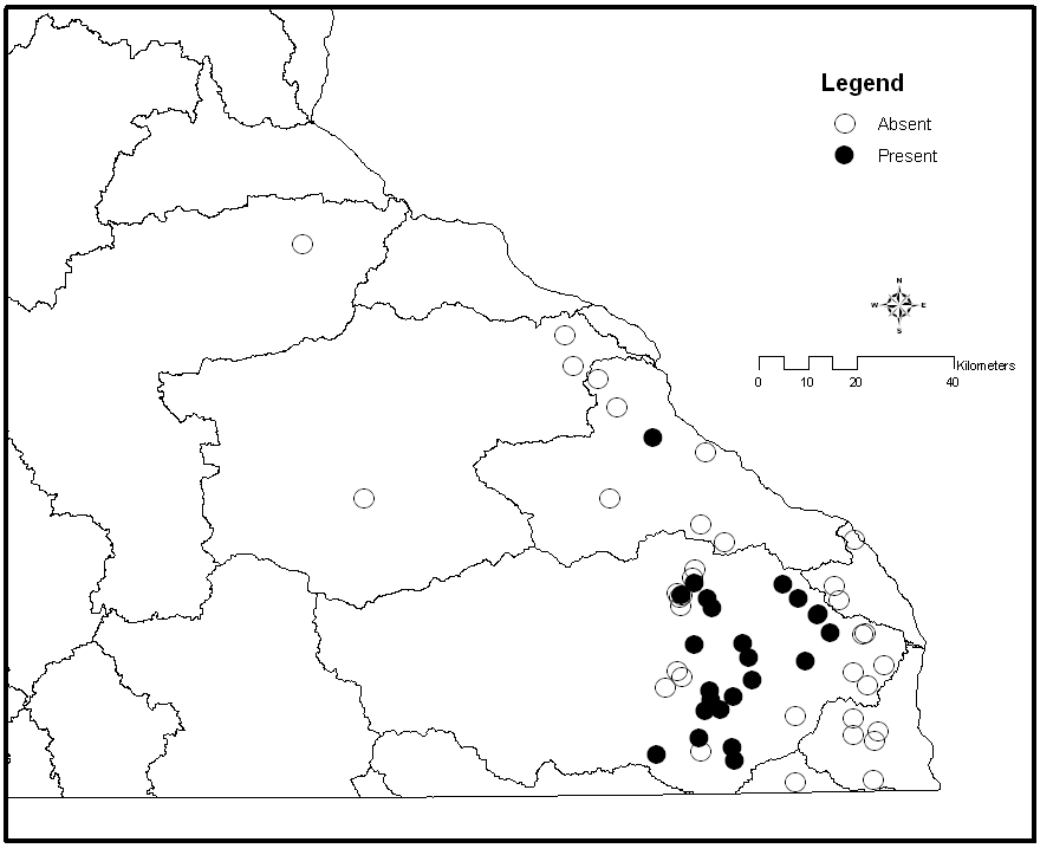


Figure 4. Presence (●) or absence (○) of mottled or slimy sculpin in southeast Minnesota coldwater streams.

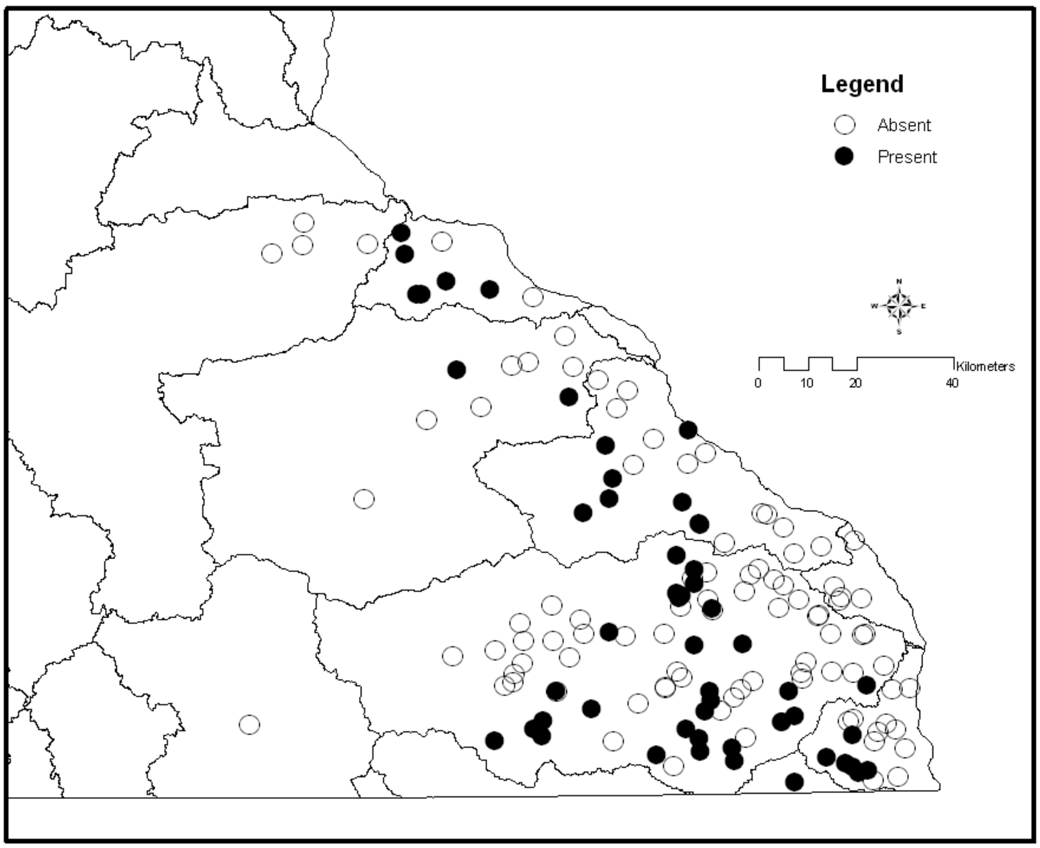


Figure 5. Radial tree diagram showing the genetic similarity among brook trout populations in southeastern Minnesota streams and known hatchery strains (n = 102). Suspected Driftless Area Brook Trout (DABT) in southeastern Minnesota are in bold and cluster according to watersheds (Zumbro, Rush Creek, South Fork Root). Hatchery strains included MNWILD, St. Croix Falls, Michigan, Owhi, and Northeast United States (NE US). Streams stocked with adult transfers from Spring Brook formed their own cluster. Stream ID is found in Table 2.

Figure 6. Genetic origins of brook trout populations in southeast Minnesota. Brook trout populations are classified as follows: DABT = unique to southeastern Minnesota, Eastern = originating from northeastern US hatchery stock, MNWILD = originating from southeast Minnesota hatchery stock, Spring Brook = originating from direct transfer from Spring Brook in Rice County Minnesota.

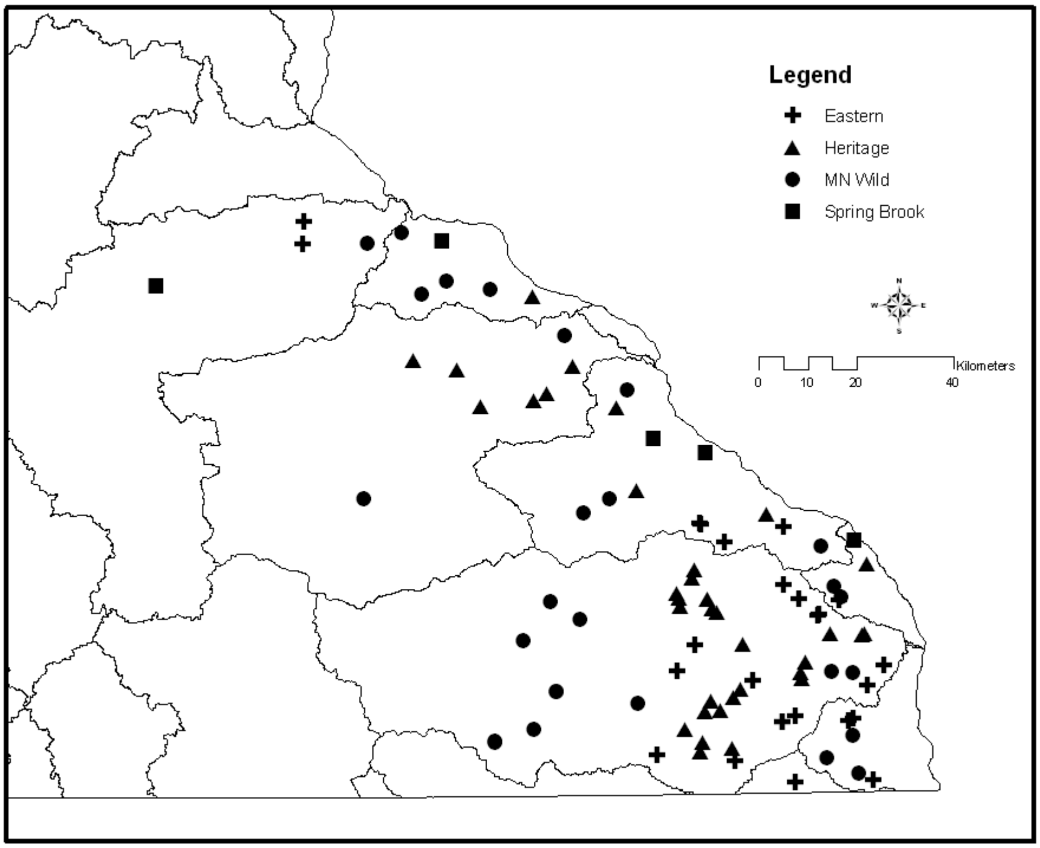


Figure 7. Mean daily water temperature for six streams in southeastern Minnesota from April 2008 through September 2009. Coolridge Creek, Trout Brook, and Trout Valley Creek had missing data during parts of the study.

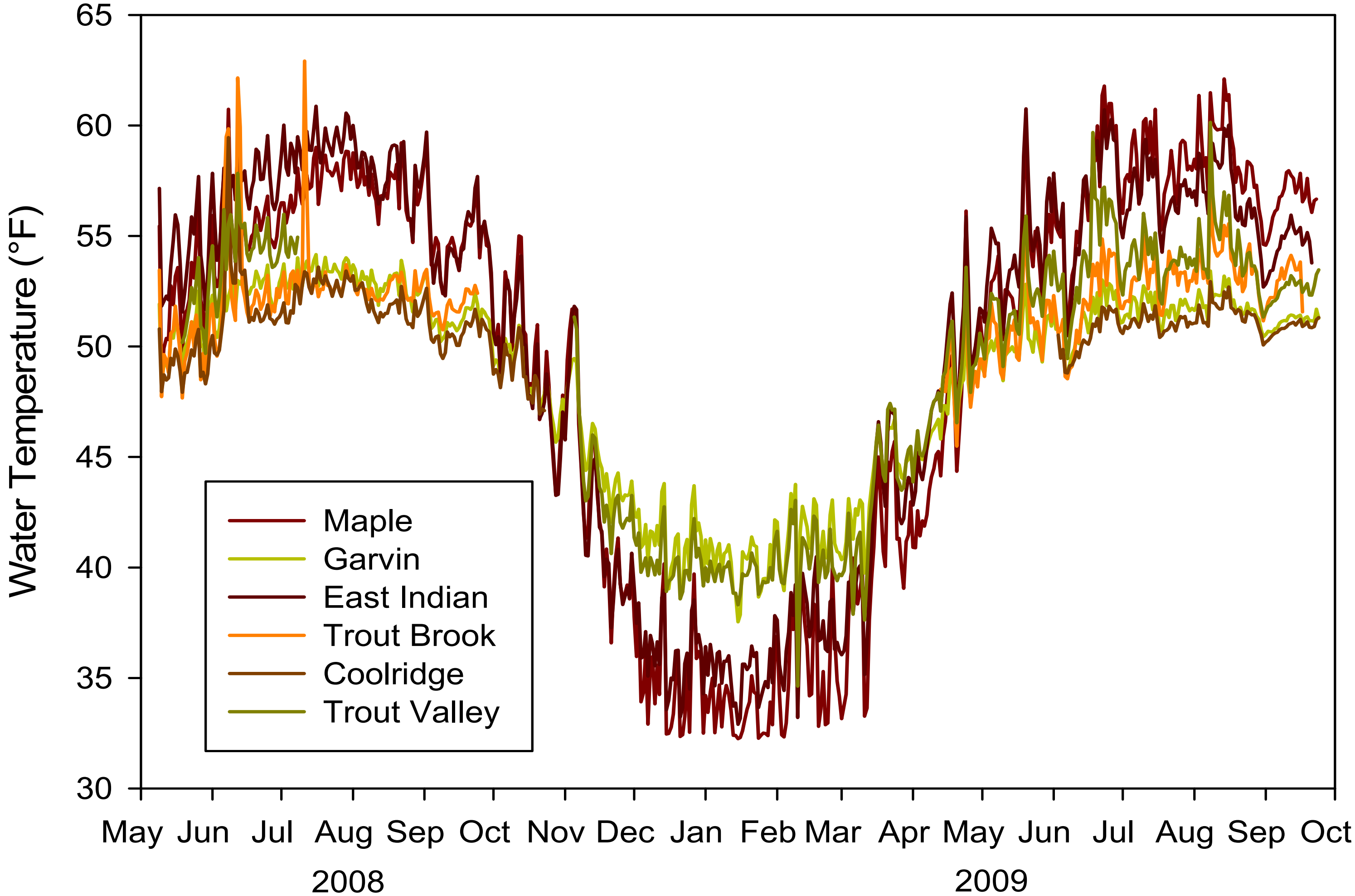


Figure 8. Size structures of brook trout collected in the fall 2008 for six streams in southeast Minnesota. Note scale difference for East Indian Creek.

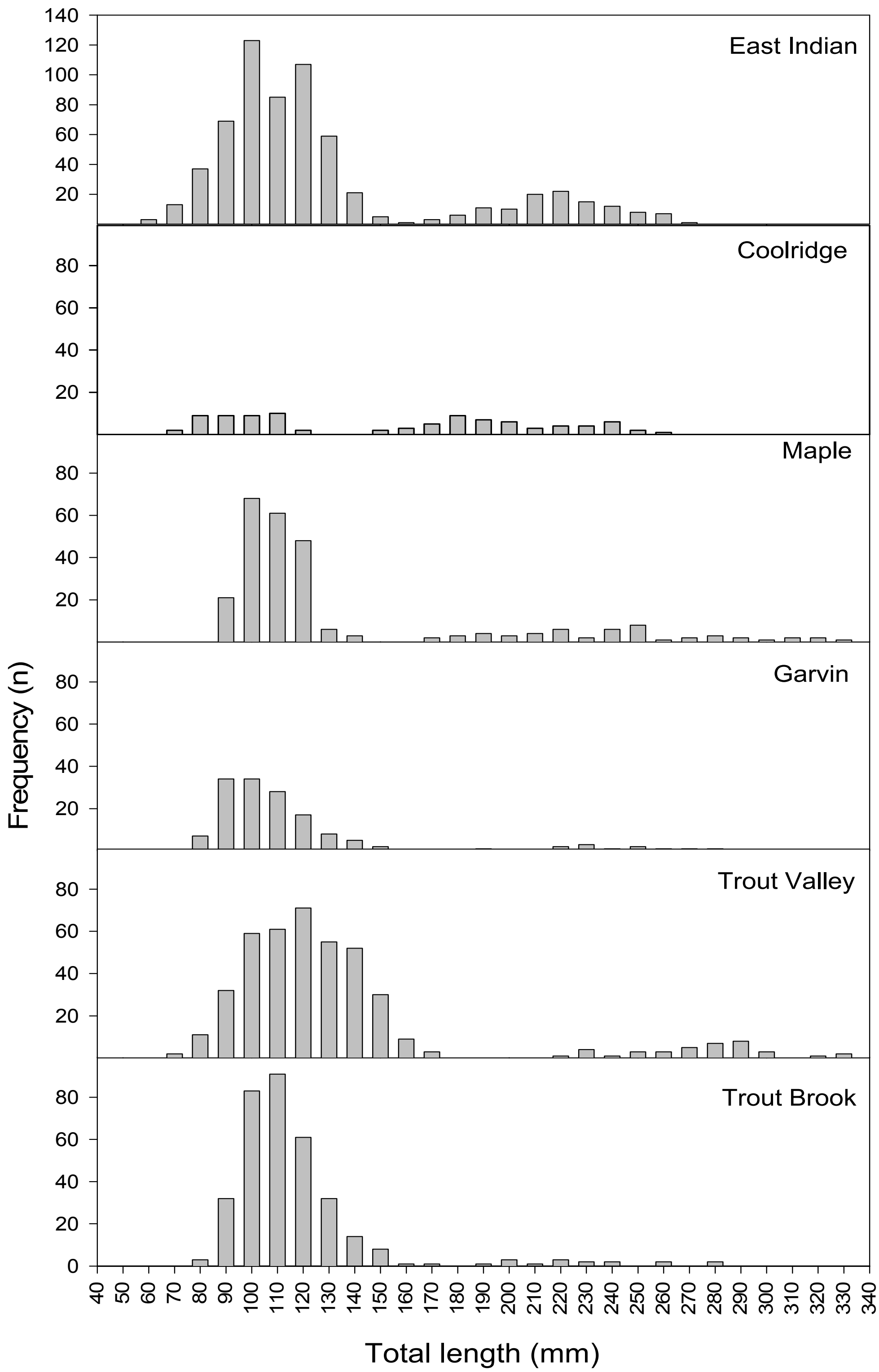


Figure 9. Size structures of brook trout collected in the fall 2009 for six streams in southeast Minnesota. Note scale difference for Trout Brook.

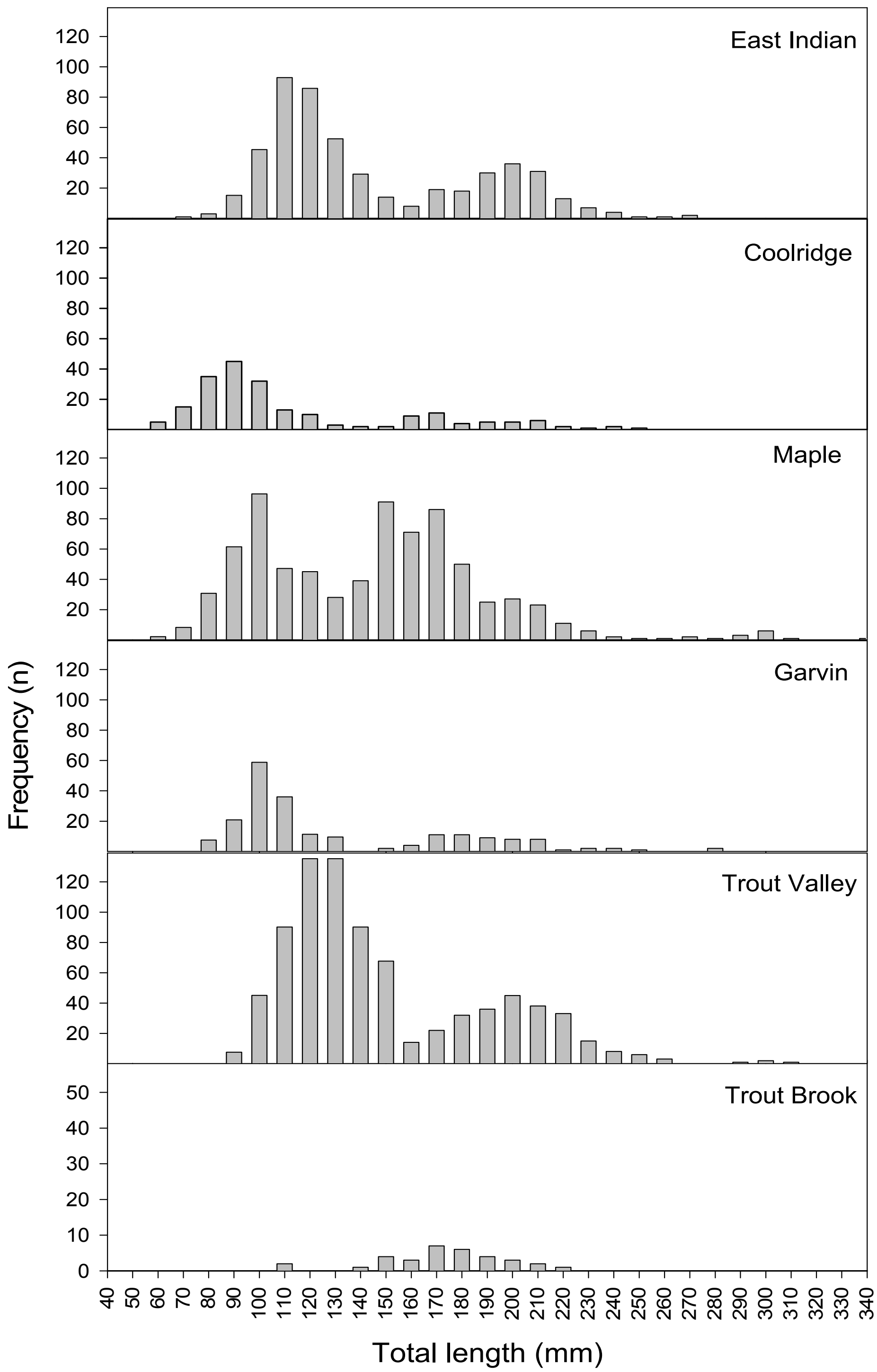


Figure 10. Logistic regression graphs of female brook trout size at maturity from six intensively sampled streams in Southeast Minnesota. 1 = mature; 0 = immature. L_{50} = the length at which 50% of the population is mature.

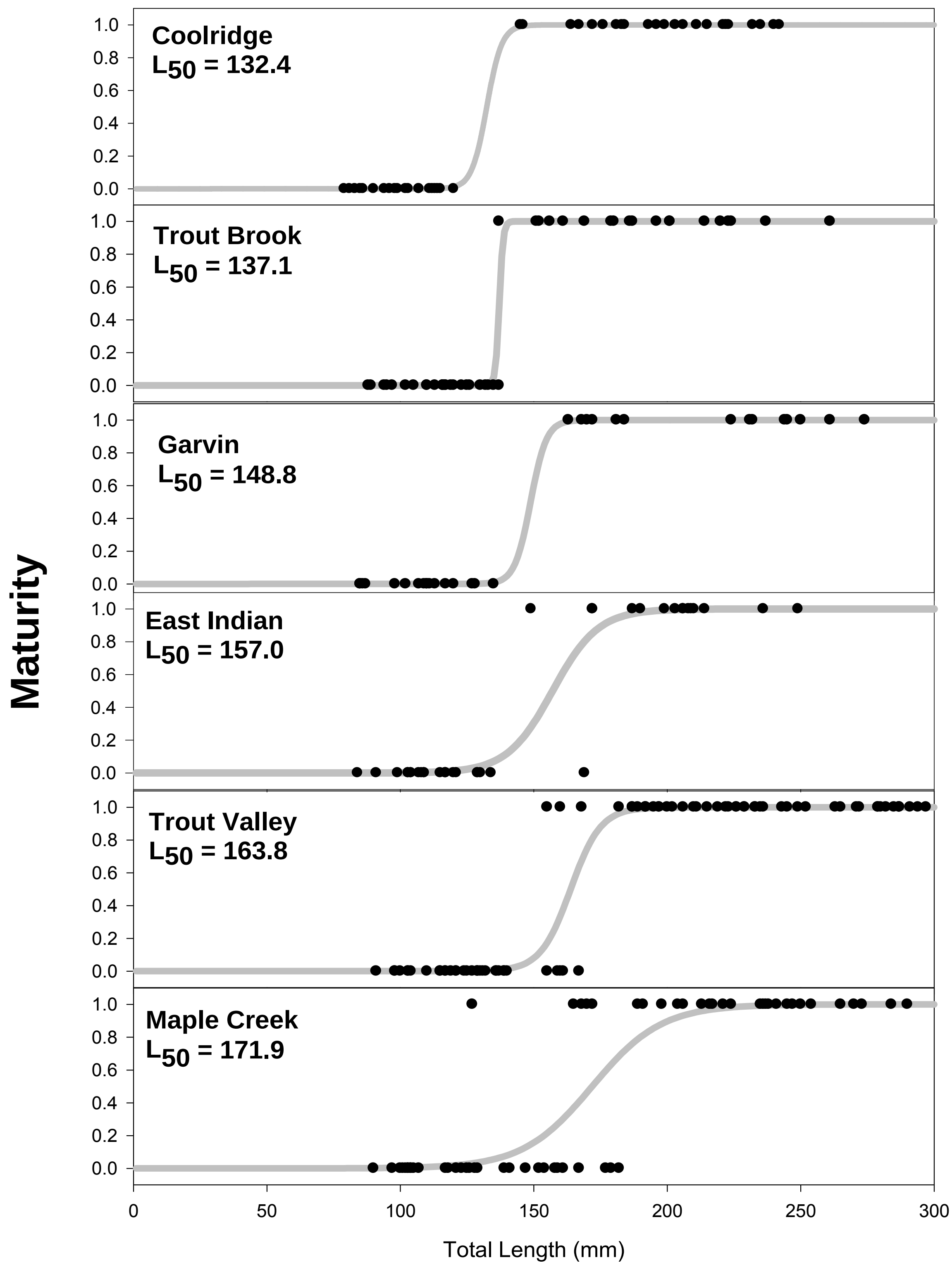
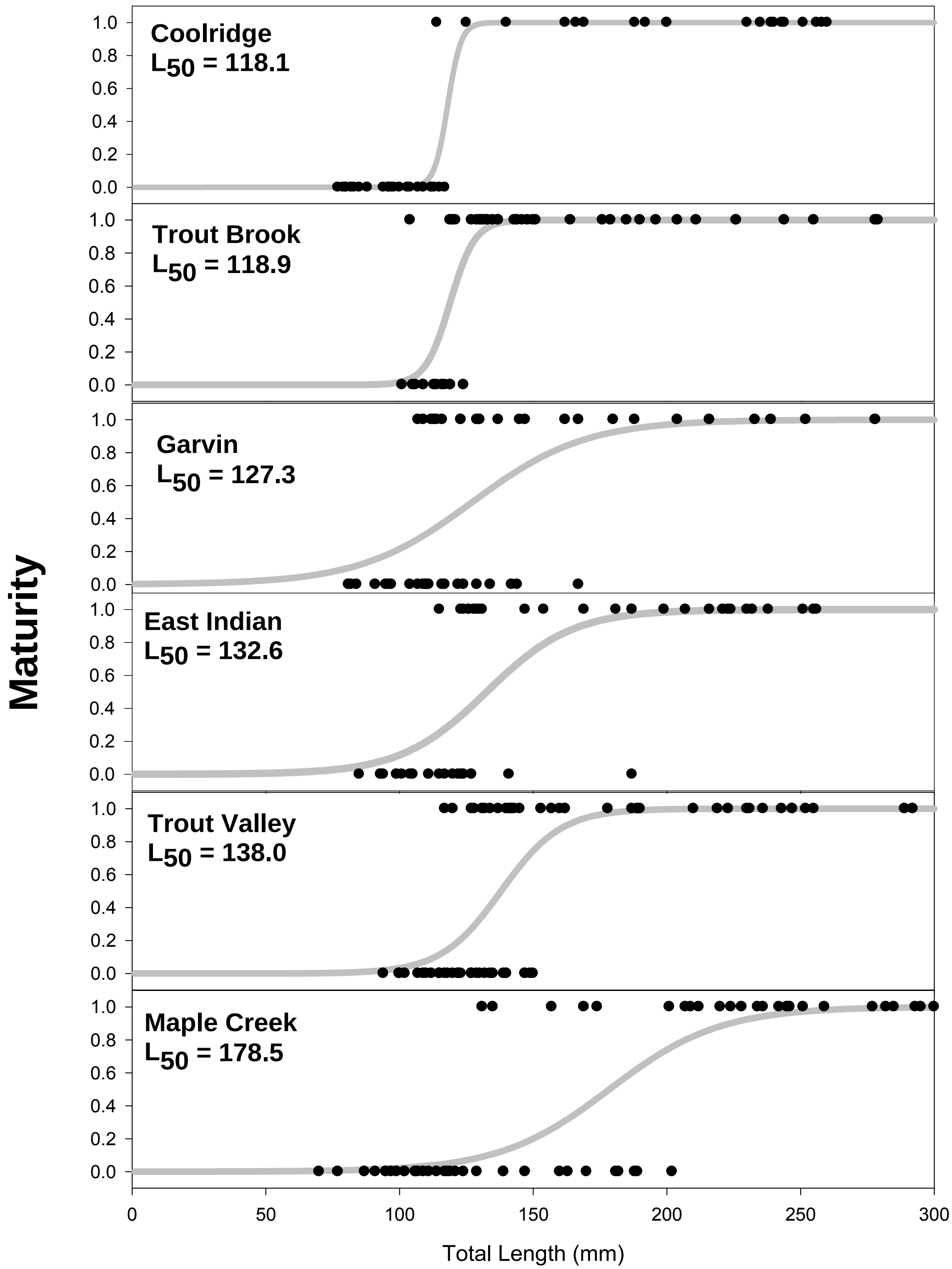


Figure 11. Logistic regression graphs of male brook trout size at maturity from six intensively sampled streams in Southeast Minnesota. 1 = mature; 0 = immature. L_{50} = the length at which 50% of the population is mature.



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