STATE OF MICHIGAN
DEPARTMENT OF NATURAL RESOURCES

2080
October 2005

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FISHERIES DIVISION
RESEARCH REPORT

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SPORT FISH RESTORATION

Printed under authority of Michigan Department of Natural Resources
Total number of copies printed 160 — Total cost $572.96 — Cost per copy $3.58

Suggested Citation Format

Wills, T. C. 2005. Field performance of one wild and two domestic brown trout strains in seven Michigan rivers. Michigan Department of Natural Resources, Fisheries Research Report 2080, Ann Arbor.

Michigan Department of Natural Resources
Fisheries Research Report 2080

Field Performance of One Wild and Two Domestic Brown Trout Strains in Seven Michigan Rivers

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Abstract.—In 1995–96, Michigan obtained a wild broodstock of brown trout from Gilchrist Creek (GC) in hopes that progeny of this stock would exhibit better survival and returns to anglers after stocking than the domesticated strains then available, Wild Rose (WR) and Seeforellen (SF). I evaluated the relative survival, growth, and return to anglers of the three brown trout strains in seven Michigan rivers where paired plantings of yearling fish were made from 1997 to 2000. The results of this study, with the exception of the Muskegon River, indicated that the wild GC strain brown trout greatly outperformed the domesticated SF and WR strains, despite being smaller at the time of stocking. The total density of GC strain brown trout was significantly higher ($P < 0.001$) than that of the other strains. GC brown trout survived to age 2 over 100 times better than the SF strain and over six times better than the WR strain. In addition, initial growth of the GC fish from stocking to the time of first sampling was nearly an inch higher than the SF brown trout and over ¾ of an inch higher than the WR brown trout. However, on average, the densities and biomass of all stocked brown trout were lower than the densities and biomass of unclipped resident brown trout. Relative angler returns of the stocked wild and domestic brown trout strains varied in two of the study systems for which creel data were available. GC brown trout appear better suited to stocking into streams with minimum size limits >10 inches because they survive better to older ages, grow faster, and consequently are more likely to reproduce, whereas WR fish may be better suited to streams with 8-inch minimum size limits where most of the angler harvest occurs during the year they are stocked. SF brown trout exhibited the lowest survival and immediate post-stocking growth of the three brown trout strains and should be stocked with caution. Fisheries managers must consider the performance of stocked brown trout strains, the performance of stocked brown trout in general, and returns to the angler when implementing or reviewing brown trout stocking programs.

Introduction

Michigan has a long history of stocking trout into rivers where low natural reproduction or some habitat feature limits the quality of trout fisheries. Traditionally, domesticated strains have been selectively bred to improve survival, growth, maturity, fecundity, and disease resistance in the hatchery. Such selection may be an intentional or an unintended consequence of hatchery rearing conditions. Many fisheries managers believe that the poor post-stocking survival and return to anglers frequently exhibited by domesticated trout strains are the direct result of years of inbreeding and forced selection to achieve these attributes (Vincent 1960; Avery et al. 2001). Such selective processes leave the domesticated strains unprepared to handle severe environmental variation, adapt to ecological conditions, and avoid predation (Fraser 1981; Avery et al. 2001). Accordingly, the introduction of wild salmonid strains into hatchery systems is common practice by fisheries managers hoping to improve poor post-stocking survival and angler returns of stocked salmonids.

There is a wealth of evidence in the literature that suggests wild salmonid strains outperform their domestic equivalents (Avery et al. 2001). For example, Greene (1952), Vincent (1960), Flick and Webster (1964, 1976), Fraser (1981), Webster and Flick (1981), and Lachance and Magnan (1990) all documented greater survival of wild brook trout *Salvelinus fontinalis* strains compared to domestic brook trout strains in natural and semi-natural environments. Vincent (1960) also noted comparable or higher growth of wild brook trout compared to domestic brook trout in an experimental stream, while Gowing (1978) found that the growth of a wild brook trout strain was superior to that of domestic trout in four small Michigan lakes.

Other studies comparing wild and domestic trout strains have focused on the brown trout *Salmo trutta*, an ecologically important and economically significant sport fish in Michigan rivers. Several studies conducted in Michigan have shown that domestic brown trout stocked into rivers exhibited substantially lower survival than naturalized brown trout reared in the same system (Alexander and Peterson 1983; Dexter 1991). Studies in Michigan lakes and natural systems elsewhere (Alexander 1987; Berg and Jørgensen 1991; Skaala et al. 1996; Weiss and Schmutz 1999; Avery et al. 2001) have documented higher survival rates of wild brown trout strains when compared to domestic strains. Alexander (1987) and Avery et al. (2001) also found higher growth of wild brown trout strains compared to domesticated strains.

The Gilchrist Creek (GC) strain of brown trout was transferred from the wild into Michigan's hatchery system in 1995 in hopes that their progeny would survive better and produce better recreational fisheries in stocked rivers. Although there is no record of brown trout stocking into GC, these non-native fish undoubtedly were derived from either unrecorded fish plantings or historic fish plantings elsewhere in the watershed. Alexander (1987) demonstrated that GC brown trout grew faster than other wild strains and a domestic brown trout strain studied in four experimental lakes in northern Michigan, but the Michigan Department of Natural Resources (MDNR) has not previously conducted an evaluation of paired plantings in rivers.

The MDNR presently stocks approximately 700,000 yearling brown trout into the state's streams and rivers annually. Current MDNR stocking policy (Dexter and O'Neal, 2004) states that fish may be stocked to maintain or improve fisheries, or to supplement self-sustaining populations, provided at least one of these criteria are met: 1) natural reproduction and survival are inadequate to maintain the fishery, 2) there is reasonable biological expectation that the quality of the fishery or fish community will not be diminished, and 3) the fishery produced justifies the cost of the program. The wild GC strain and the domestic Wild Rose (WR) and Seeforellen (SF) strains are the only brown trout strains presently divided among approximately 80 streams and rivers supplemented by stocking.

Given the substantial monetary and human resources invested into raising these fish, it is of utmost importance to determine the success of the MDNR's stocking efforts in meeting fisheries management goals and the criteria defined in its stocking policy. Poor performance of stocked fish limits the management options available to fisheries managers and increases associated costs (Flick and Webster 1976). Therefore, the objectives of this study were to: 1) evaluate the performance of wild GC strain brown trout in comparison to other domesticated hatchery strains (WR and SF) in Michigan rivers, 2) assess the contribution of stocked brown trout strains to brown trout populations and angler fisheries in Michigan rivers, and 3) provide information to guide management and policy decisions on the use of stocked brown trout in Michigan rivers.

Methods

Study Rivers

Fisheries managers identified Michigan rivers with historically poor performance of stocked brown trout as potential systems for strain evaluations. Priority for inclusion in this study was given to systems that provided easy access to fish planting trucks and were amenable to sampling by field personnel. Geographic location was also considered so that all study sites were not in the same region of the state. Seven rivers that fit these criteria were chosen for brown trout strain comparisons upon consultation with fisheries researchers (Table 1; Figure 1).

Brood Stock and Production Culture

GC brown trout.—Fisheries researchers selected GC, a tributary to the Thunder Bay River in northern Lower Michigan's Montmorency County, as the source for the wild brown trout used in the strain evaluation. Approximately 1,200 YOY brown trout were collected in fall 1991 and transferred into 15-acre Fuller Pond at the Hunt Creek Fisheries Research Station where they grew to maturity. A total of 681 adults in a 1:1 sex ratio were collected from Fuller Pond and transferred to the MDNR Oden State Fish Hatchery between October 1995 and May 1996. All GC brown trout stocked as part of this study were progeny of the original brood stock brought to the Oden Hatchery in 1995 and 1996.

SF brown trout.—The Oden Hatchery received 250,000 eyed SF eggs from the New York State Department of Environmental Conservation's (NYDEC) Caledonia State Fish Hatchery in 1989. Although the initial lot of 250,000 eggs was treated as a production lot and subsequently planted, an unknown number of yearlings were kept as brood stock. In 1992, the Oden Hatchery received three additional shipments of SF eggs for brood stock (157,000 eggs total) from the NYDEC. Records indicate that the 1992 shipment of eggs was taken from New York's 1985 brood lot, a lot originally received from Germany. A third brood stock lot obtained from the 1989 year class was produced in 1994. Although detailed records are not available, all SF brown trout stocked as part of this study were presumably progeny of either the 1989, 1992, or 1994 brood stock lots.

WR brown trout.—The Oden Hatchery obtained 507,000 eyed eggs from the Wisconsin Department of Natural Resources' (WDNR) WR State Fish Hatchery in 1987. Records held by WDNR give no indication as to the origin of this strain. All eggs were originally intended for use solely as production fish, but part way through the rearing cycle MDNR hatchery personnel decided to keep an unknown number of the yearlings as a future brood stock lot. No records are available to describe a second brood stock lot produced in 1990. MDNR hatchery personnel produced a third brood stock lot in 1994 from an unknown number of eggs taken from the 1990 and 1987 brood lots. Although detailed records are not available, all WR brown trout stocked as part of this study were presumably progeny of either the 1987, 1990, or 1994 brood stock lots.

Culture of production fish.—Oden Hatchery personnel spawned the brood stock brown trout annually between October and December, depending upon strain. The fertilized eggs were then transferred to egg trays and incubated at 45°F for 85 to 90 days. After 90 days, hatchery personnel transferred the brown trout fry from the egg trays to indoor tanks, and later to outdoor raceways after annual plant-out of yearling production fish. All stocked GC, WR, and SF brown trout were given a unique fin clip each year prior to stocking to distinguish strain and year class. Hatchery personnel estimated mean length prior to stocking for each strain from a random subsample of yearling fish (Table 2).

Stocking

In the spring of 1997, paired plantings of yearling brown trout (equal numbers of both GC and WR or SF strains) were initiated at survey stations in six of the seven study rivers (Table 2). Paired plantings did not begin in the Muskegon River until 1999. Survey stations ranged in size from 0.32 to 5.33 acres, and were physically or geographically separated from other stocking locations in the same system to minimize the possibility of immigration of fish from other stocking sites (Table 3). Paired plantings continued in each river through 2000 to provide for replicated observations of the performance of the three brown trout strains.

Population Assessment

Field personnel estimated brown trout populations by electrofishing in the late summer or early fall of each year of planting, from 1997 to 2000, at most stations (Table 3). Population estimates were made by either depletion or mark-recapture methods. Field personnel shocked each survey station on wadeable streams with a 240-V DC stream shocking unit equipped with 2 or 3 anode probes, beginning at the downstream end of the station and moving upstream, covering the entire width of the channel. Depletion surveys were completed the day that the survey was initiated, while mark and recapture survey passes were separated by a minimum of 24 hours. Trout captured on each electrofishing run were measured to the nearest inch group, examined for fin clips, recorded, given a temporary caudal fin clip for identification, and released (or held in a live well for the depletion method).

Population estimates were not feasible on the Muskegon River because of its larger size. Brown trout relative abundance there was determined from catch-per-effort (CPE) data on a single downstream pass with a boat-mounted 240-V DC electrofishing unit in 1999–2001.

Angler Data

Volunteer anglers provided catch rate data for five river segments in the Manistee River for the duration of the brown trout strain evaluation (Table 4). Before each fishing season, the Upper Manistee River Association, a local conservation organization, supplied cooperating anglers with fishing log cards. Anglers were asked to complete one card for each fishing outing and record time spent fishing, number of brown trout caught, total length of each fish, and fin clips. A diagram describing fin clip locations was included on the log cards to assist the volunteer anglers in proper identification of clips. The volunteer anglers returned an average of 375 log cards per year for 1997–2000.

The MDNR conducted an on-site creel census on the Muskegon River during all years when paired plantings were made (1999–2000), and again in 2001–2003. Trained creel clerks roamed the public access sites in the survey station from Croton Dam to Thornapple Road at randomly selected times during the trout fishing season (the last Saturday of April to September 30) each year. Creel clerks were instructed to interview as many angling parties at the end of their fishing trip as possible, record their harvest, and collect biological data (including length and fin clip) from a random subsample of fish. Creel supervisors distributed a diagram describing fin clip locations to the creel clerks to aid in identification of clips.

Data Analysis

Fisheries management unit and research personnel archived brown trout population and angler catch rate or harvest data from the seven study rivers during the 4 years when paired plantings were made. Angler catch rate and harvest data for several years after the paired plantings ceased were also archived. I used the archived fisheries data to summarize the performance of the three different stocked brown trout strains, in comparison to each other and to unclipped resident (presumably naturally reproduced) brown trout.

Depletion estimates.—I used the MicroFish 3.0 software package (Van Deventer and Platts 1989) to estimate the densities of unclipped resident, GC, and WR or SF brown trout at survey stations where depletion methods were used. For each year and survey station, I combined all brown trout captured (regardless of strain) to determine a total brown trout population estimate. To do this, I calculated separate maximum-likelihood population estimates for inch groups with similar catchability (visually estimated from the data) and added these population estimates together to derive the total estimate. Since larger individuals are more susceptible to capture than smaller individuals (Libosvarsky 1962), stratifying by inch groups helps to avoid size-related heterogeneity in capture probability (Riley and Fausch 1992). I calculated the total population estimate, then converted to density (number/acre), and apportioned this total into strain and inch groups based upon the proportion of new (once-caught) fish captured on all depletion passes combined. I summed all fish equal to or exceeding 8.0 inches (abbreviated as

“>8 inches”) in total length (TL) to approximate the number of legal-sized fish per acre, as most of the study rivers had an 8-inch minimum size limit for the duration of the study (Table 3). I converted numbers/acre to lbs/acre and calculated total biomass of all inch groups and total biomass of fish >8 inches using the length-weight relationships presented in Schneider (2000).

Mark-recapture estimates.—I used the Chapman modification of the Petersen mark-recapture formula (Ricker 1975) to estimate the densities of unclipped resident, GC, and WR or SF brown trout at survey stations where field personnel collected data for mark-recapture population estimates. For each year and survey station, I combined all brown trout captured (regardless of strain) to determine a total brown trout population estimate. Similar to the depletion estimates, I calculated separate population estimates for inch groups with similar catchability (visually estimated from the data) and added them together to derive the total population estimate. Then I converted to density (number/acre), and apportioned this total into strain and inch groups based upon the proportion of unmarked (i.e., no temporary caudal clip) fish captured on both the marking and recapture runs combined (Avery et al. 2001). Density of fish >8 inches and biomass of all inch groups and fish >8 inches were calculated as described above for depletion estimates.

Survival and growth.—Individual ages of stocked fish were known since all hatchery fish were given a unique fin clip prior to stocking. I calculated weighted mean length-at-age by strain from all new fish captured on all depletion passes combined for depletion estimates, or on both the marking and recapture runs combined for mark-recapture estimates. Since field personnel measured fish to inch group, I multiplied the midpoint of each inch interval by the number of fish of a particular age within the inch interval, summed the products by age, and then divided the sum of the products by the total number of fish within the age group. I computed annual survival estimates for each cohort (x) by dividing the density of age (x+1) fish present in a subsequent year by the density of age (x) fish present in the previous year. I derived yearly growth increments in a similar fashion as the difference in the mean length-at-age from year-to-year for each strain and cohort. Because weight measurements were not recorded, and I assumed that differences in weight were possible between strains, I did not use standard brown trout length-weight regressions to estimate differences in weight gain or total biomass among strains.

Angler data.—I summarized the total catch of brown trout, by strain and length, and the total number of hours spent fishing by volunteer anglers across all five stations for each year in which creel data were available for the Manistee River. I calculated angler CPE as the number of fish caught per 100 hours of fishing for unclipped resident, GC, and SF brown trout. I also calculated angler CPE of all unclipped resident, GC, and SF brown trout >8 inches to estimate the number of legal-sized brown trout, by strain, caught per 100 hours of angler effort. Since the detail of length measurements reported by the volunteer anglers varied, I could not report length information in any greater detail.

I summarized the total number of brown trout >8 inches (by strain) in the creel of interviewed anglers on the Muskegon River and calculated the percentage of the total recorded brown trout catch comprised of unclipped resident, GC, and WR fish. I also calculated the percentage of stocked fish in the total brown trout catch. Data for calculating angler CPE were not available for the Muskegon River.

Statistical Analyses

Population assessment.—I used mixed-effect analysis of variance (ANOVA) to determine if the performance of stocked brown trout varied predictably as a function of strain in river systems where population estimates were made. To determine differences among the three stocked strains of brown trout, I excluded unclipped resident fish from the initial analyses. For these analyses, I used total density, density of trout >8 inches, survival, and annual growth increment (adjusted by using initial length as a covariate to account for differences in length among strains) as metrics of performance. I included unclipped resident fish in a subsequent analysis to compare the contribution of stocked fish to the total population. Since many of the unclipped resident fish were presumably youngof-year (<4 inches TL), I used total density as well as total biomass as metrics of performance. For all mixed-effect models, I treated river, year, and strain (or origin in the case of comparisons between stocked and unclipped resident brown trout) as fixed effects and site (nested within river) as a random effect. When appropriate, I transformed the data to meet the necessary distributional assumptions. I used Bonferroni-adjusted P-values for multiple comparisons and set rejection criterion at $\alpha = 0.05$ for all analyses. All data were analyzed with SPSS version 11.5 (SPSS 2002).

I did not conduct statistical analyses on the CPE data from the Muskegon River due to the difference in format (CPE versus population estimates) and relatively low brown trout catches compared to the other study rivers. Instead, I present a brief summary of the Muskegon River CPE data strictly for generalization and comparison purposes.

Angler data.—I used a paired t-test to determine if angler CPE of stocked brown trout varied as a function of strain in the Manistee River. Since no stocked brown trout were reported in 2002 or 2003, I excluded these years from subsequent analyses. I compared catch per 100 hours of all GC and SF brown trout, regardless of size, and of all GC and SF brown trout >8 inches. I also compared the catch per 100 hours of all stocked and unclipped resident brown trout, regardless of size, and of all stocked and unclipped resident brown trout >8 inches. I set rejection criterion at $\alpha = 0.05$ for all paired t-tests. All data were analyzed with SPSS version 11.5 (SPSS 2002).

Since creel clerks on the Muskegon River recorded relatively few brown trout, I did not conduct statistical analyses on the Muskegon River creel survey data. Similar to the electrofishing CPE, I present a brief summary of the Muskegon River creel data for generalization and comparison purposes.

Results

Population Assessment

Density of stocked trout.—Based on 96 separate population estimates (generated from a combination of rivers, sampling stations, and years), the total density of stocked brown trout varied significantly by strain (Table 5). Mean total density was significantly higher for GC brown trout than for either WR or SF brown trout (Table 6; Figure 2). No significant difference was detected between WR and SF strains. Mean total density of stocked trout also varied significantly by river, with the highest densities of stocked fish occurring in the Coldwater River, followed by Fish Creek, Paint Creek, the Rogue River, the Indian River, and the Manistee River (Figure 3). However, a significant river*year interaction was present, indicative of yearly variation in the total density of stocked trout across all study rivers, regardless of brown trout strain (Table 5; Appendix A).

Population estimates of stocked brown trout >8 inches also varied significantly by strain (Table 5). Mean density of fish >8 inches was significantly higher for GC brown trout when compared to SF brown trout, but not for GC brown trout compared to WR brown trout or WR brown trout compared to SF brown trout (Table 6; Figure 2). Population estimates of stocked trout >8 inches also varied significantly by river, with the highest densities occurring in the Coldwater River, followed by Fish Creek, the Indian River, the Manistee River, the Rogue River, and Paint Creek (Figure 3). Variability in the density of trout >8 inches occurred across strains and years as indicated by a significant strain*year interaction. Point estimates of the density of GC brown trout were less than the density of WR brown trout during the first 2 years of the study, while in the final 2 years of the study the density of GC brown trout increased to a level higher than WR brown trout (Figure 4). The density of SF brown trout >8 inches remained relatively stable through all years of study, and was generally lower than estimates of the densities of GC or WR brown trout >8 inches.

Survival of stocked trout.—Since the density of age-1 stocked brown trout at some study sites exceeded the prescribed stocking density (indicating uneven dispersal of stocked yearlings throughout the entire system 4–5 months after planting), I could not calculate meaningful survival estimates from the time of stocking to the time of sampling after the first summer in residence for age-1 fish. Therefore, I assumed that the stocked fish would distribute themselves in a similar manner in subsequent years, and carried on survival analysis beginning with age-2 fish.

Gilchrist Creek brown trout displayed significantly higher mean survival to age 2 across rivers and years when compared to both the WR and SF brown trout strains (Table 6). No significant difference in survival to age 2 was detected between WR and SF brown trout (Table 6; Figure 5). Mean survival to age 3 or age 4 was low for all stocked brown trout and prevented statistical comparisons of survival to age 4. Survival to age 3 did not vary significantly by strain (Table 5). However, some GC brown trout did survive to age 3 (eight instances) and age 4 (three instances), while few age-3 WR or SF (one instance each) and no age-4 WR or SF brown trout were sampled during this study (Appendix B).

Growth of stocked trout.—Differences among strains presented a significant source of variability in the growth of stocked brown trout during their first summer after stocking (Table 5). Although smaller at the time of stocking, the GC fish grew faster in the first summer after stocking and in general were of comparable length to the WR or SF fish after 1 year (Table 7). The GC brown trout had a significantly higher mean growth increment from the time of initial stocking in spring to the time of sampling in late summer for all age-1 fish when compared to WR and SF brown trout. Initial growth of SF brown trout was not different than WR brown trout (Table 6; Figure 6). However, a significant river*strain interaction was present, indicating variability in age-1 growth across rivers and strains (Table 5). Point estimates of the initial growth after stocking of GC brown trout were higher than those of WR or SF brown trout across all rivers, while the initial growth of WR and SF brown trout varied considerably among rivers (Figure 7). Year was also a significant source of variability in initial growth after stocking for age-1 fish. On average, and regardless of strain, growth of stocked age-1 trout was highest in 1999, followed by 2000, 1997, and 1998, but this fluctuated among rivers as indicated by a significant river*year interaction (Table 5).

Growth from age 1 to age 2 did not vary significantly by strain (Table 5), although the point estimate of the mean growth increment from age 1 to age 2 was slightly higher for GC brown trout when compared to both WR and SF brown trout (Figure 6). Since SF and WR brown trout survival to age 3 and 4 was very low, I did not have sufficient data to statistically compare growth increments of either strain to the GC strain. Mean length of the GC strain was comparable to that of the WR or SF strains at age 3 (Table 7; Appendix C).

Density of stocked trout versus resident trout.—The total density of stocked brown trout was significantly lower than the total density of unclipped resident brown trout when averaged across all years and systems of study (Table 8). The total density of stocked fish was nearly half that of unclipped resident fish (Figure 8). The density of all brown trout, regardless of origin, varied significantly by river with the highest densities occurring in the Coldwater River, followed by the Manistee River, the Rogue River, Fish Creek, Paint Creek, and the Indian River (Table 8; Figure 9). However, significant variability in the densities of stocked and unclipped resident brown trout occurred across rivers as indicated by a river*origin interaction (Table 8). Point estimates of total density were highest for unclipped resident fish in all rivers, with the exception of the Coldwater River in which the total density of stocked fish was 4.5 times higher than unclipped resident fish (Figure 10).

Although the point estimate of total biomass was slightly higher for unclipped resident brown trout compared to stocked brown trout, the difference was not significant (Table 8; Figure 8). Similar to total density, the total biomass of all brown trout (stocked and unclipped) varied significantly by river (Table 8). Estimates of total brown trout biomass, regardless of origin, were highest in the Coldwater River, followed by the Rogue River, Paint Creek, the Manistee River, Fish Creek, and the Indian River (Figure 9). Significant variability in the biomass of stocked and unclipped resident brown trout occurred across rivers as indicated by a river*origin interaction (Table 8). Estimates of total biomass were higher for resident fish in all rivers except the Coldwater River and Fish Creek, in which the total biomass of stocked fish was more than 4.9

and 1.7 times that of unclipped resident fish, respectively (Figure 10).

Although point estimates of the density and biomass of stocked brown trout >8 inches were lower than that of unclipped resident brown trout, only biomass was significantly different between origins (Table 8; Figure 8). River was a significant source of variability for both the density and biomass of brown trout >8 inches (Table 8), with the greatest estimates of density occurring in the Coldwater River, followed by the Rogue River, Paint Creek, the Manistee River, Fish Creek, and the Indian River; and the greatest estimates of biomass occurring in the Coldwater River, followed by Paint Creek, the Rogue River, the Manistee River, the Indian River, and Fish Creek (Figure 11). The biomass of all brown trout >8 inches also varied significantly by year (Table 8). On average, the total biomass of all brown trout >8 inches was highest in 2000, followed by 1998, 1999, and 1997. The presence of a significant river*origin interaction for both the density and biomass of brown trout >8 inches indicates variability of both metrics across rivers and origin (Table 8). Estimates of the density and biomass of brown trout >8 inches were highest for unclipped resident fish in all rivers except the Coldwater River. Differences in the point estimates of density and biomass were most notable in the Coldwater River, where the density and biomass of stocked brown trout >8 inches was 4.4 and 3.9 times higher, respectively, than that of unclipped resident brown trout >8 inches (Figure 12).

Muskegon River CPE data.—Mean CPE of brown trout in the Muskegon River was highest for WR brown trout (12 fish/mile), followed by GC and unclipped resident brown trout (10 fish/mile each). All stocked brown trout captured were greater than 8 inches TL. Unlike the population estimate data from the other six rivers, total catch, and accordingly CPE, was very similar among the two stocked brown trout strains and unclipped resident brown trout. Catch-per-effort of unclipped resident brown trout greater than 8 inches was 9 fish/mile. In general, GC brown trout ranged from 8 to 15 inches TL, and were slightly smaller than the WR brown trout, which ranged from 8 to 20 inches TL. Unclipped resident fish ranged from 7 to 24 inches TL.

Angler Data

Manistee River.—The total numbers of GC and SF brown trout captured in 1997–2001 were very similar (Table 9). Volunteer anglers reported a total catch of 140 GC brown trout compared to a total of 129 SF brown trout during the same period. Accordingly, I found no significant difference in angler CPE between GC and SF brown trout across all years of study (Figure 13). The majority of volunteer angler catch was comprised of age-1 fish (Table 10). Summed over all years, the total catch of GC brown trout > 8 inches (48) was higher than the total catch of SF brown trout (27), but angler CPE for the two strains was not significantly different (Figure 13).

Volunteer anglers reported a total of 3,888 brown trout captured between 1997 and 2001, out of which only 269 fish (6.9 %) were of hatchery origin. Angler CPE across all years was significantly higher for unclipped resident brown trout compared to stocked brown trout (t = 5.91, df = 4, P = 0.004; Figure 14). Nearly all (97 %) of the 2,462 brown trout >8 inches reported by volunteer anglers were unclipped resident fish. Angler CPE across all years was significantly higher for unclipped resident brown trout >8 inches compared to stocked brown trout (t = 5.51, df = 4, P = 0.005; Figure 14).

Muskegon River.—Creel clerks recorded a total of 130 brown trout captured between 1999 and 2003 (Table 11). Wild Rose brown trout comprised the majority of the total recorded catch (60.0 %), followed by unclipped resident (31.5 %) and GC (8.5 %) fish. Angler catch of stocked brown trout older than age 2 was low, although creel clerks did record two GC brown trout in 2002 and three GC brown trout in 2003, indicating some survival of the GC fish to older age classes (Table 12). No clipped WR brown trout were recorded in either 2002 or 2003. Age-1 and age-2 GC brown trout were generally smaller than the WR fish, and the length of age 3 and age 4 GC brown trout was variable (Table 13).

Discussion

My results complement the results of previously published studies. Weiss and

Schmutz (1999) observed a substantial decline in the survival of hatchery brown trout in comparison to wild fish after 1 year in an Austrian stream, while Berg and Jørgensen (1991) noted that post-stocking mortality of wild brown trout was lower than that of hatchery-origin brown trout in a Denmark river. Avery et al. (2001) documented much higher survival of a stocked wild brown trout strain compared to domesticated brown trout in two Wisconsin river systems. The survival of the wild strain was substantially greater than that of the domestic strains in all years of their study. Alexander (1987) found that the 2-year survival rates for wild brown trout strains were nearly twice those of a domesticated brown trout strain in four Michigan lakes. Alexander and Peterson (1983) documented that the survival rate of hatchery-reared brown trout was significantly lower for ages 1 to 3 than for wild brown trout in a Michigan stream. Similar to the results of these studies, I found that the wild GC brown trout demonstrated higher survival than both the domestic SF and WR strains. On average, survival of GC fish during the first year after stocking was more than 100 times higher than SF brown trout and more than 6 times higher than WR brown trout. In addition, some GC brown trout survived up to 3 years after stocking to ages 3 and 4, while few SF or WR brown trout survived past age 2. Accordingly, the densities of all GC fish, as well as legal-sized GC fish, were noticeably higher than those of the SF and WR strains throughout the study.

The initial growth of GC strain brown trout during the first summer after stocking in my study was nearly 2 times that of SF brown trout and more than 1.5 times that of the WR brown trout strain when adjusted for initial length. Other studies have noted that wild brown trout strains exhibit higher growth rates than domestic strains. Avery et al. (2001) found that the growth of wild spring yearlings in a Wisconsin river exceeded the growth of domestic spring yearlings, thereby reducing the initial size advantage of the domestic strain over the 2 years of study. Alexander (1987) concluded that the GC strain brown trout displayed superior growth to other wild strains and a domestic strain in four Michigan lakes. In my study, the growth of GC fish also exceeded that of either domestic strain during the first year after stocking, up to a maximum of nearly twice that of SF brown trout. Although few SF or WR brown trout survived more than 2 years after stocking (i.e., to ages 3 and 4), the GC brown trout that did survive to these ages were usually larger than the minimum size limit in effect for the particular river of study.

The higher survival and growth displayed by the wild GC brown trout strain when compared to the domestic SF and WR brown trout strains are extremely relevant to stocking strategies and fisheries management. The minimum size limits in the majority of study rivers changed from 8 inches to 10 or 12 inches in 2000. The low survival and slow growth of the domestic brown trout strains may prohibit them from reaching the minimum size limit in these and similar systems, thereby decreasing the amount of fish available for angler harvest. Although the GC brown trout are far below the legal harvest size at the time of stocking, their high survival and growth rates afford them a chance to meet or exceed the minimum size limits in subsequent years. In addition, the presence of age 3 and 4 GC brown trout allows the chance for natural reproduction to occur; as such fish will probably be sexually mature.

In my study systems (with the exception of the Muskegon and Coldwater rivers), the densities of stocked brown trout on average were much lower than the densities of unclipped resident fish. Although some unclipped resident fish may have been carry-over of stocked fish from previous years, the low survival of the domestic strains in this study suggests that this may be minimal. Also, the presence of unclipped resident fish less than 4 inches TL indicates that natural reproduction is occurring. Fisheries managers should judge if such natural reproduction is enough to sustain the fishery, and if it is, consider making more efficient use of resources by reducing or discontinuing stocking.

The return of stocked fish to the angler should also be a consideration for fisheries managers. Avery et al. (2001) found that domestic brown trout provided a greater return to the angler during their second summer in a Wisconsin river because few of the wild brown trout had reached the 12-inch minimum size limit, but noted that the significantly higher survival of wild trout provided the opportunity for similar or increased angler returns in the following years. The creel data available for this study offers contrasting results. In the Manistee River, volunteer angler creel information suggested that angler returns were very similar between the wild GC brown trout and the domestic SF strain. In this river, most legal-sized (>8 inches) SF were caught the year they were stocked whereas legal-sized GC fish were usually caught the next year (A. J. Nuhfer, MDNR, unpublished data). In contrast, the proportion of domestic WR brown trout in the creel of interviewed anglers on the Muskegon River was much higher than that of the wild GC strain. Fisheries managers should weigh such information in regards to management objectives when considering which strain to stock.

It should also be noted that electrofishing CPE of the wild GC brown trout was very similar to that of the WR brown trout in the Muskegon River. Although this is only a single case, it offers some contrast to the results of the population estimate data available for the other six rivers of study. The Muskegon River is substantially larger than the other study rivers. In addition, the study site in this system was located directly below a hydropower facility, possibly increasing environmental variability. Perhaps characteristics of the river and study site leave a strain with a larger size at stocking better suited to meeting the needs of the fisheries manager and angler. Future research in the Muskegon and other large river systems would assist in answering this question.

Variability due to river and year and their interactions with origin (stocked versus unclipped resident fish) was also present in the six systems with population estimate data available. Significant river effects may account for the different characteristics of the study systems, such as stocking densities, available habitat, and thermal regimes. Significant year effects indicate yearly environmental variability or differences in hatchery production lots. The presence of significant interactions, especially in comparisons between the densities and biomass of stocked and unclipped resident fish, complicated data interpretation. Such interactions may indicate that the variety of environmental conditions present in the study rivers had variable effects on stocked fish, as well as on the natural reproduction of unclipped resident fish.

It is important to recognize the limitations of this study. The ability of field personnel, creel clerks, and volunteer anglers to distinguish stocked brown trout strains from each other and unclipped resident fish relies on the quality of the fin clips given to the stocked fish at the hatchery, and the familiarity of all personnel with the clips. If the fin clips were unrecognizable, bias in the population, survival, growth, and angler harvest estimates could occur. I assumed that the fin clips given to the stocked brown trout at the hatchery were quality clips, the trained MDNR field personnel and creel clerks responsible for sampling recognized the clips, and any unrecognizable clips were present in equal proportion among all strains. Although some error in clip recognition was apparent with the volunteer anglers (clips that did not correspond to stocking years or strains were reported), I again assumed that this was equal across strains and years. I also assumed that the stocked trout distributed themselves equally and consistently throughout the study sites across all years of study and were equally vulnerable to capture. Any unequal distribution of stocked trout throughout the study sites would again subject the population, survival, growth, and angler harvest estimates to bias.

Management Implications

Fisheries managers should consider the results of this and other studies that have demonstrated the superior performance of wild salmonid strains in comparison to domestic salmonid strains when determining stocking strategies. I found that the wild GC brown trout strain outperformed the domestic SF and WR brown trout strains in the majority of study systems. I also found that in general, the density and biomass of stocked brown trout was lower than that of unclipped resident fish.

Angler catch rates between the GC strain and the SF strain brown trout were similar in the Manistee River, while in the Muskegon River the majority of the total recorded angler catch was WR rather than GC fish. Such differences in the performance of brown trout strains, stocked fish as a whole, and angler catch reinforce the need for fisheries managers to consider which strains to stock, if any, to achieve management objectives for a particular river system.

By judging the necessity to stock a river system, and the best strain to stock, fisheries managers can more successfully and economically use stocking as a tool to meet desired management objectives. Gilchrist Creek brown trout appear to be the best strain to stock into streams where higher size limits require that fish survive well for a year or more after stocking to grow to the minimum size limit.

Acknowledgements

This study was originally conceived by the MDNR Fisheries Division, Trout Committee and would not have been possible without the efforts of numerous MDNR field crews who assisted in data collection. J. Braunscheidel, J. Dexter, S. Hanshue, A. Harrington, J. Jonas, A. Nuhfer, R. O’Neal, M. Phillips, and D. Wessander of the MDNR and C. Bassett of the United States Forest Service all provided archived data. E. Eisch and D. Sampson of the MDNR provided information regarding the history of the brown trout strains used in this study. Drs. D. Hayes of Michigan State University and Z. Su of the MDNR Institute for Fisheries Research provided statistical consultation. J. Wesley provided helpful comments on an earlier version of this manuscript. This research was supported with funds from the Federal Aid in Sport Fish Restoration Act (Study 230735, Project F-80-R, Michigan), MDNR Fisheries Division.

Figure 1.–Location of rivers selected for brown trout strain evaluation.

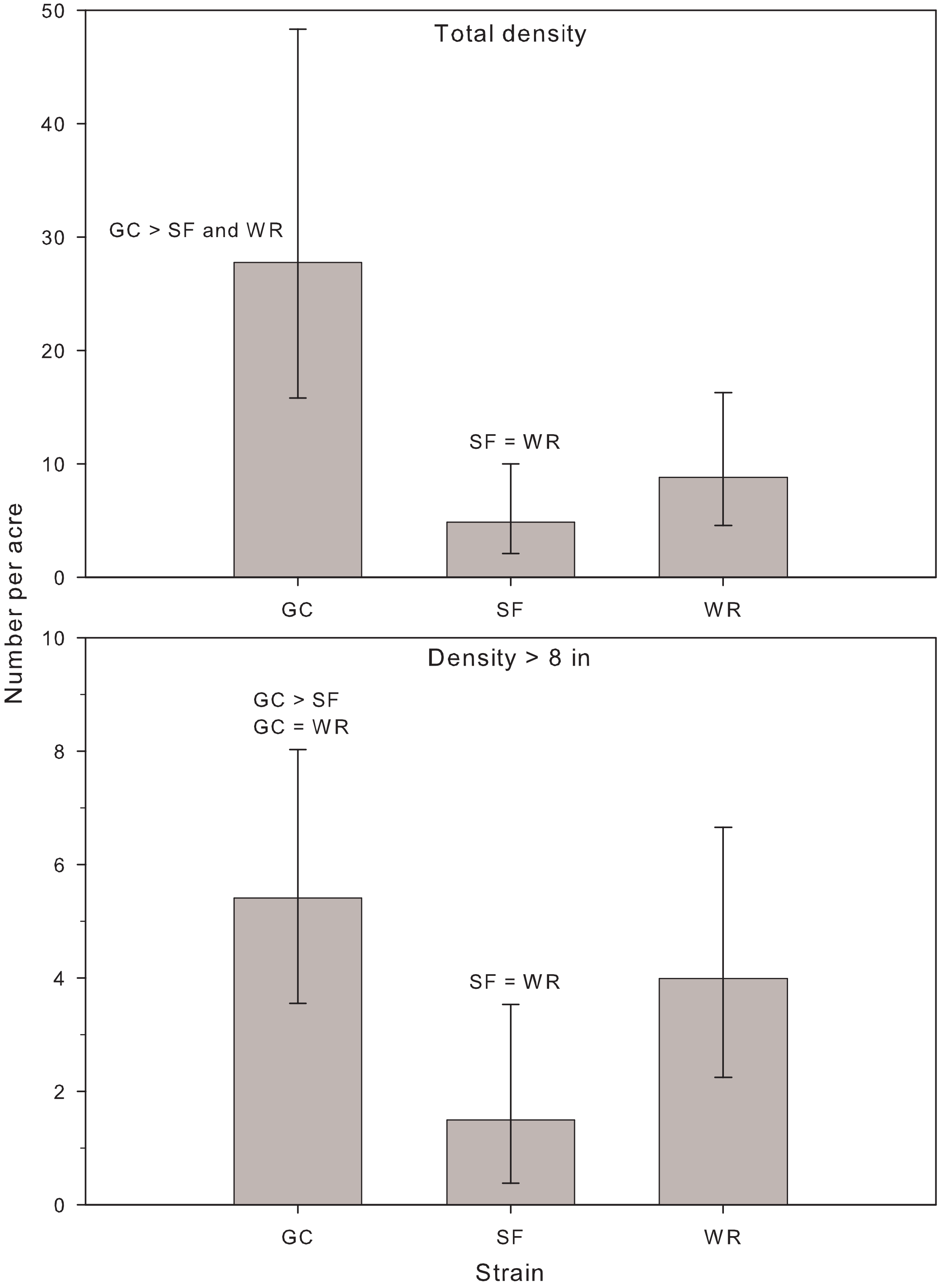

Figure 2.–Mean back-transformed total density (top) and density >8 in (bottom) of stocked brown trout, by strain, across all years and six rivers of study. Note the difference in y-axes. The thin vertical lines represent the 95% confidence intervals. GC = Gilchrist Creek, SF = Seeforellen, WR = Wild Rose.

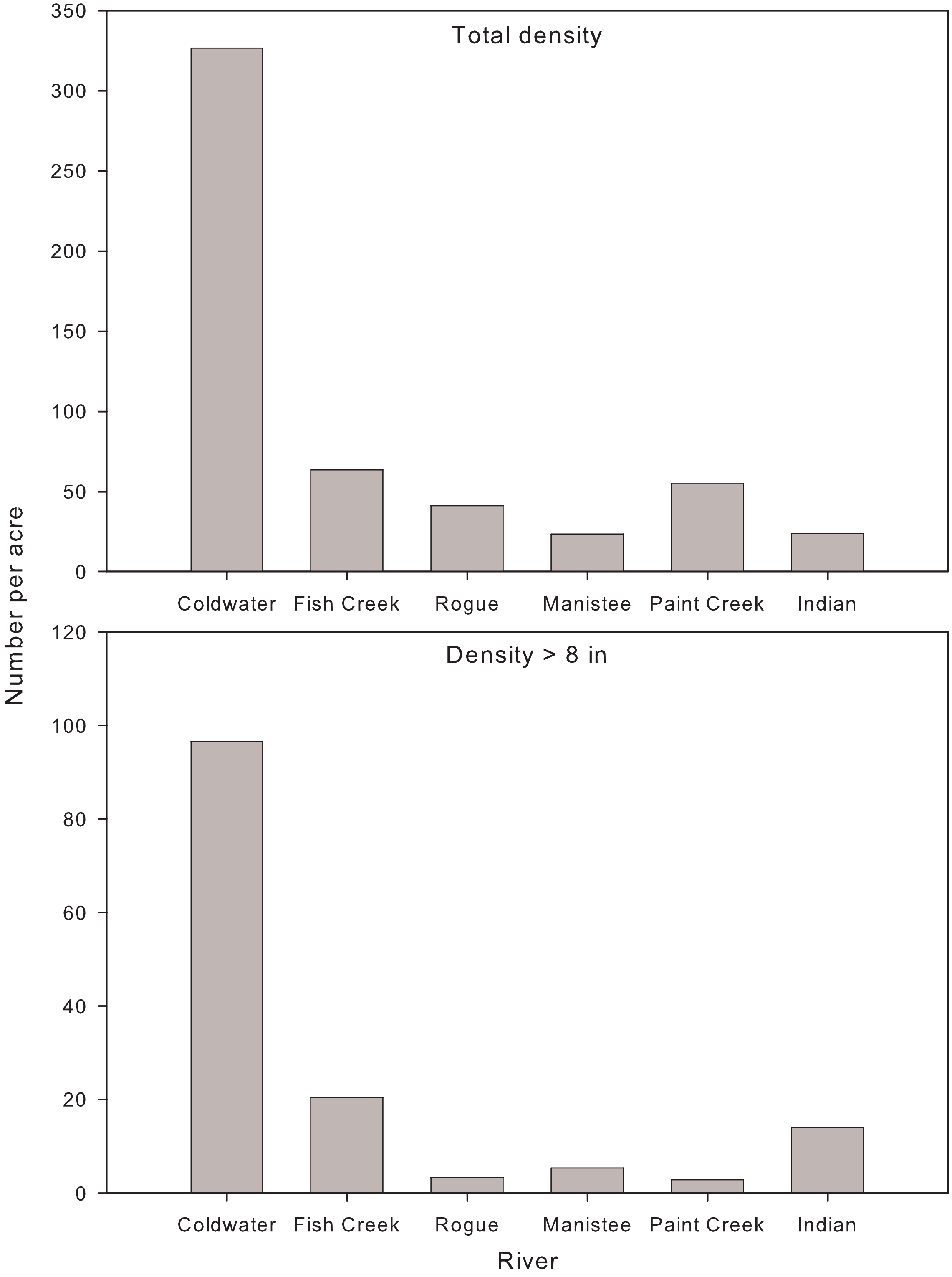

Figure 3.–Mean total density (top) and density >8 in (bottom) of stocked brown trout by river. Note the difference in y-axes. Confidence intervals have been omitted for clarity.

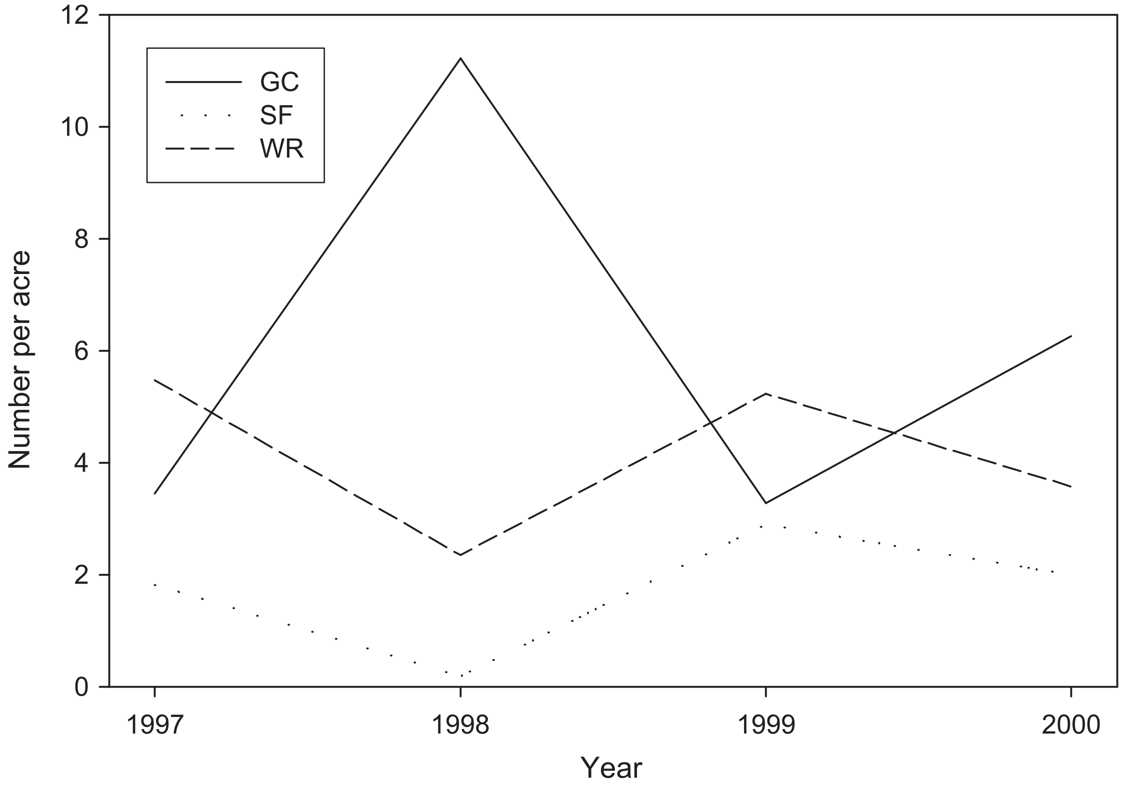

Figure 4.–Mean back-transformed density of stocked brown trout strains >8 in by strain and year for six rivers. Confidence intervals have been omitted for clarity. GC = Gilchrist Creek, SF = Seeforellen, WR = Wild Rose.

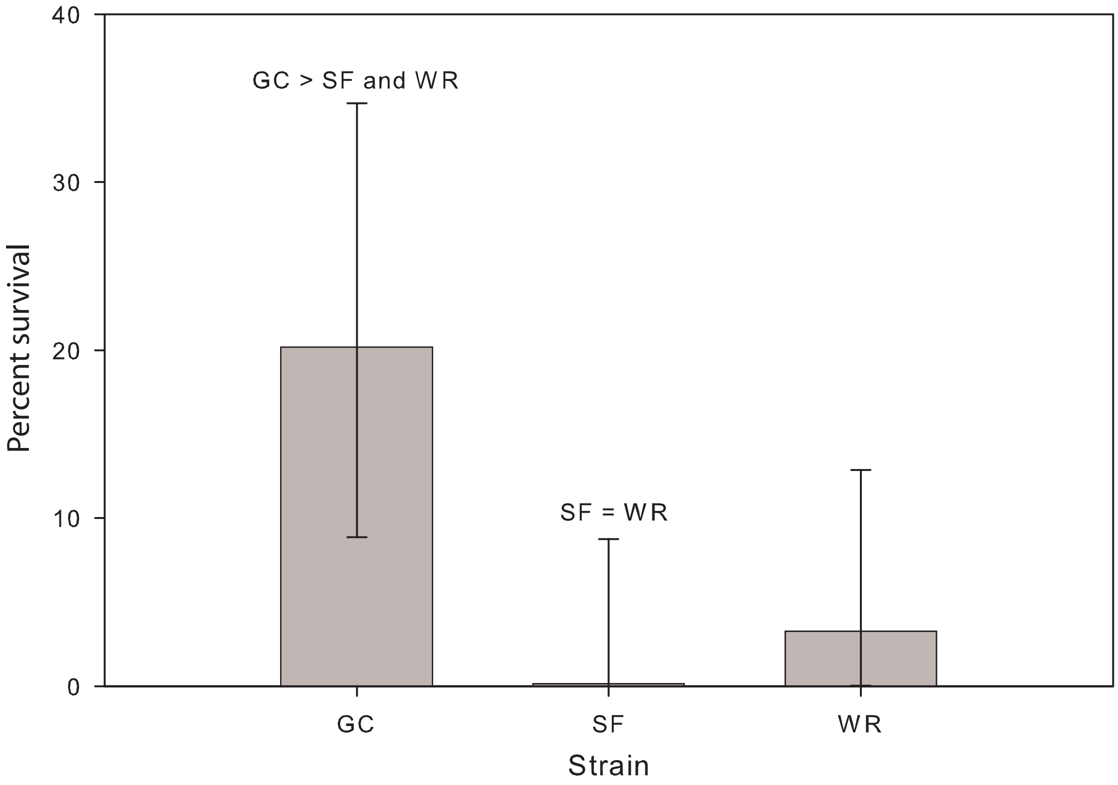

Figure 5.–Mean back-transformed survival to age 2 of stocked brown trout, by strain, across all years and six rivers of study. The thin vertical lines represent the 95 % confidence intervals. GC = Gilchrist Creek, SF = Seeforellen, WR = Wild Rose.

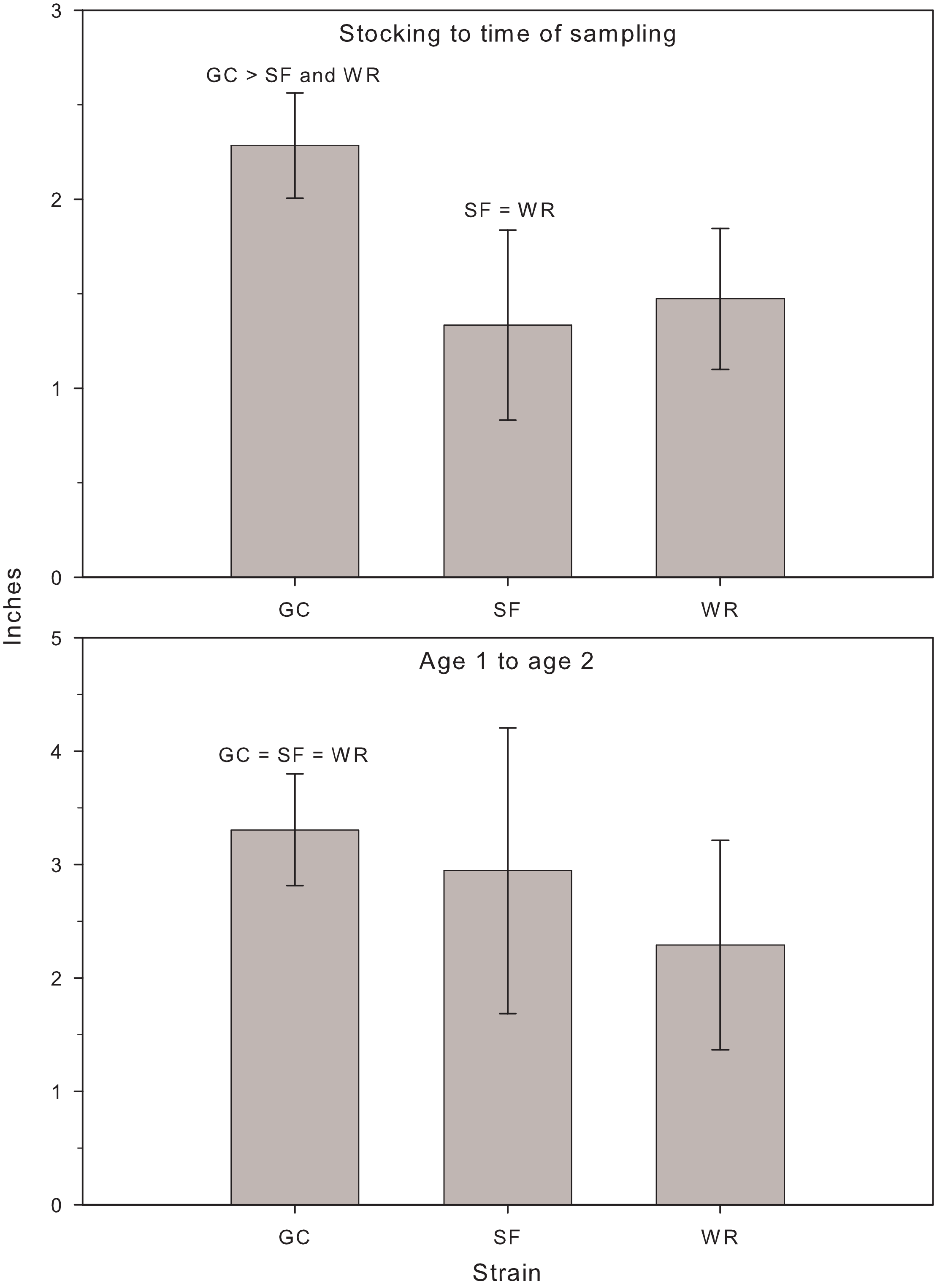

Figure 6.–Mean growth increment from stocking to time of sampling (top) and from age 1 to age 2 (bottom) for three stocked brown trout strains across all years and six rivers of study. Note the difference in y-axes. The thin vertical lines represent the 95% confidence intervals. GC = Gilchrist Creek, SF = Seeforellen, WR = Wild Rose.

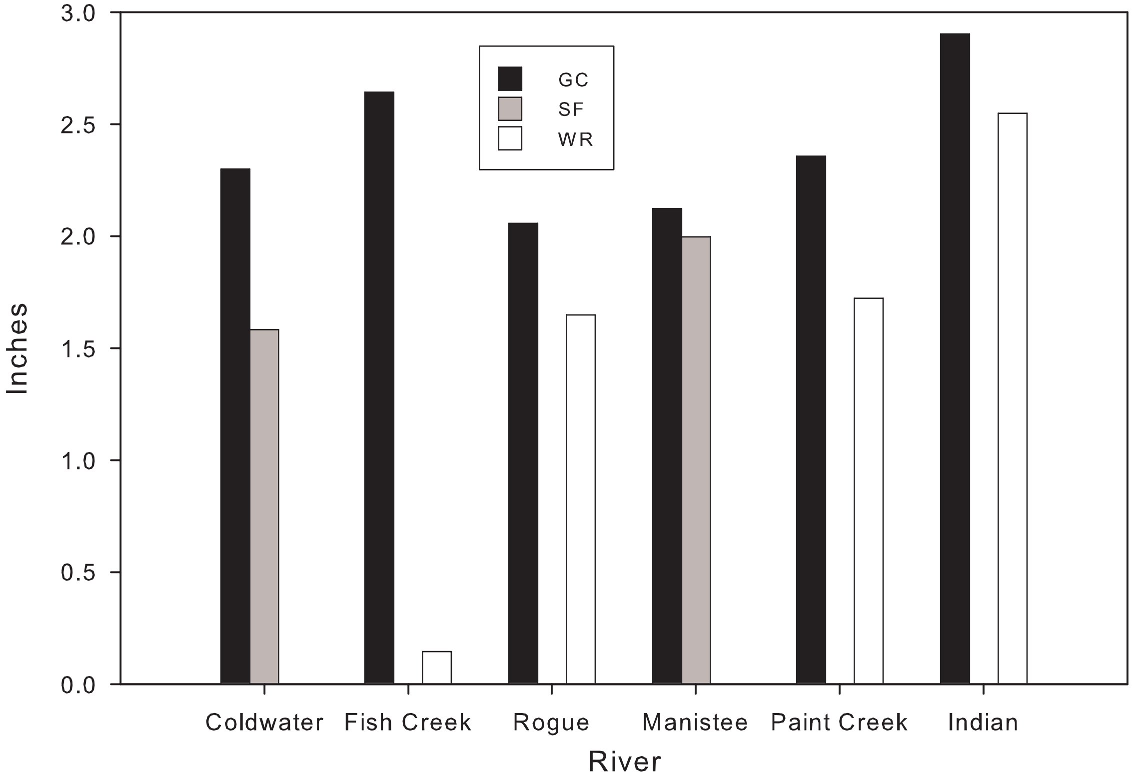

Figure 7.–Mean growth increment from stocking to time of first sampling for three stocked brown trout strains, by river, across all years of study. Confidence intervals have been omitted for clarity. GC = Gilchrist Creek, SF = Seeforellen, WR = Wild Rose.

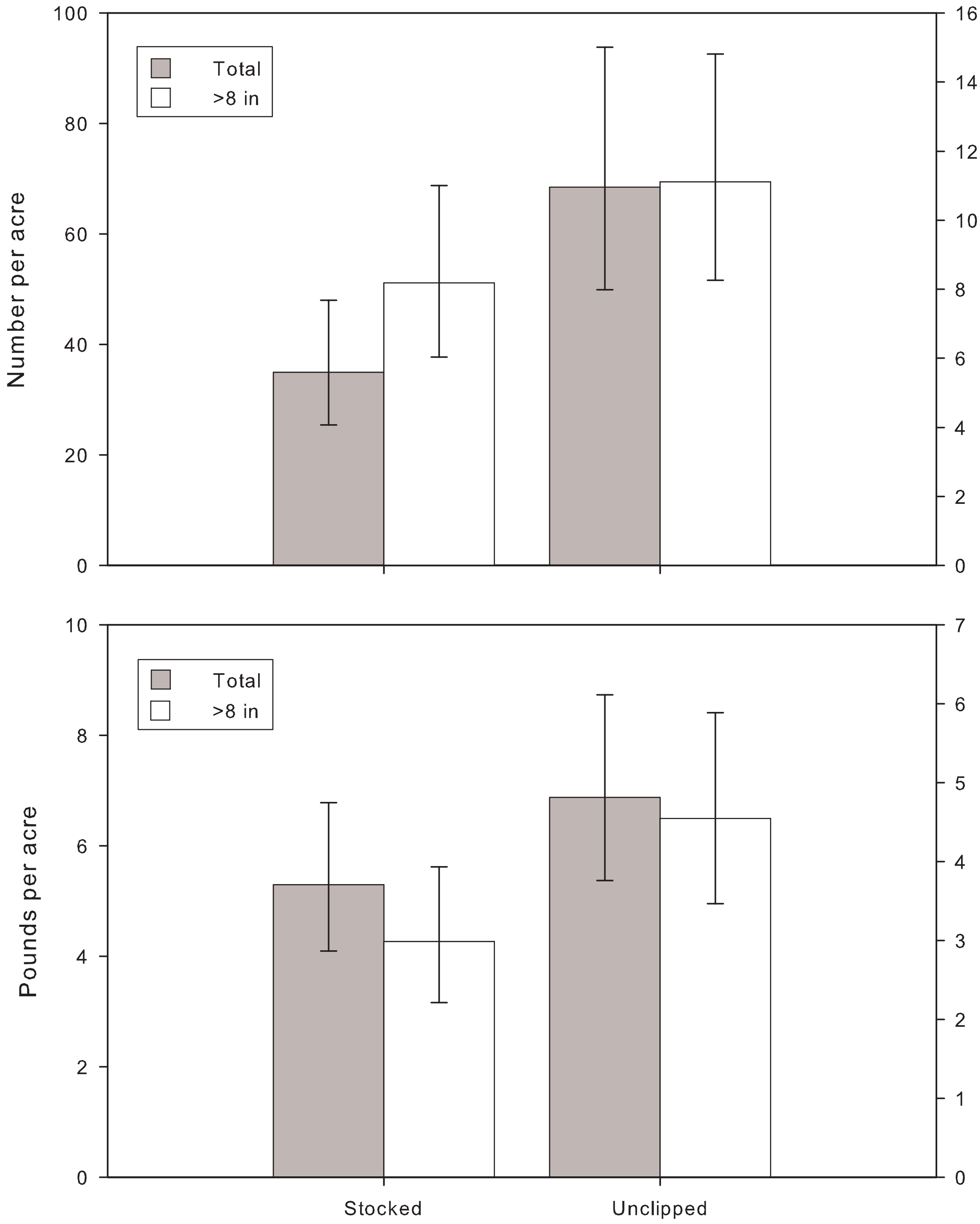

Figure 8.–Mean back-transformed density (top) and biomass (bottom) of stocked and unclipped brown trout across all years and six rivers of study. Total density and biomass corresponds to the left-hand axis, density and biomass of fish >8 in corresponds to the right-hand axis. The thin vertical lines represent the 95 % confidence intervals.

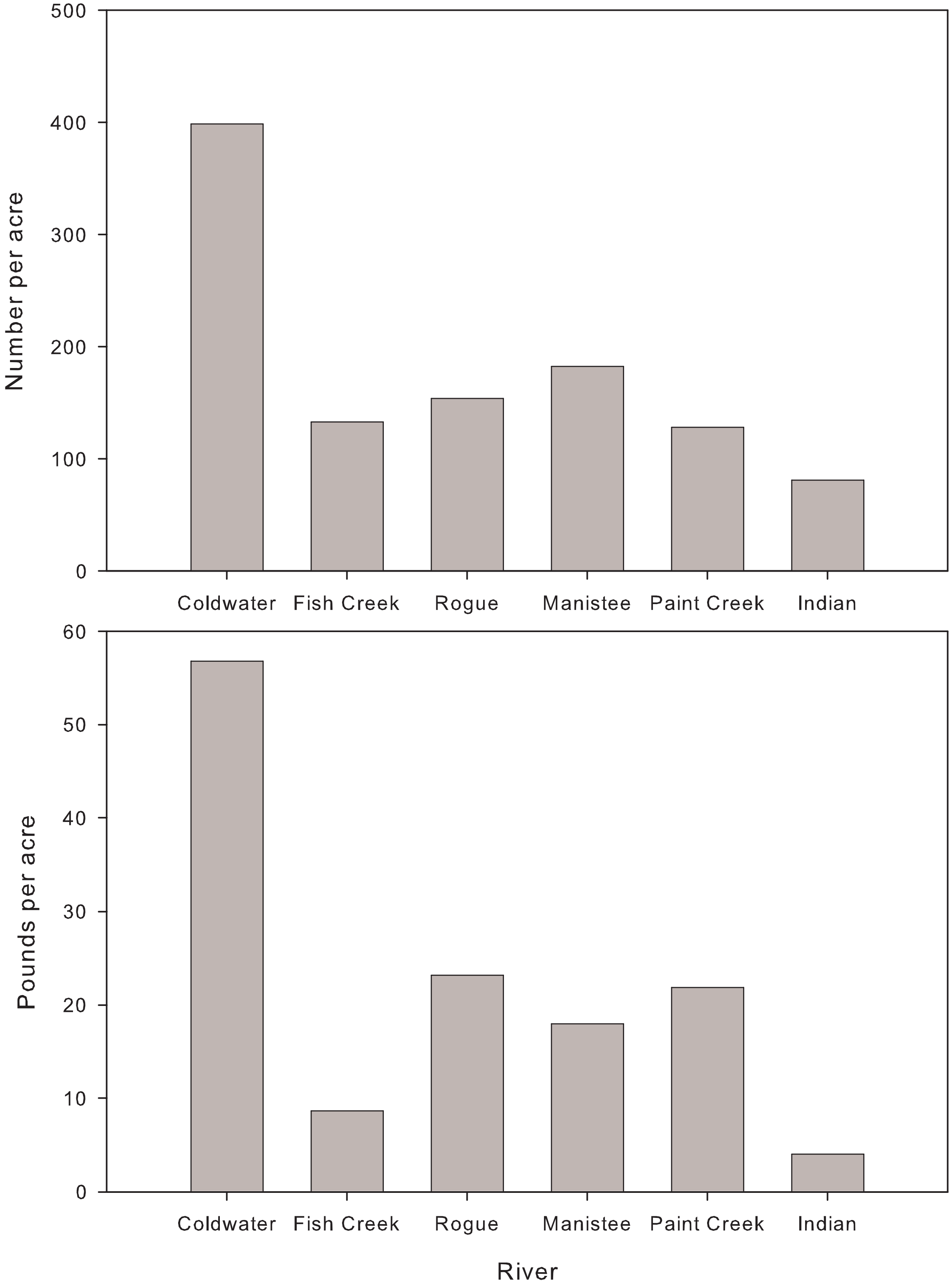

Figure 9.–Mean density (top) and biomass (bottom) of all brown trout (stocked and unclipped) by river. Confidence intervals have been omitted for clarity.

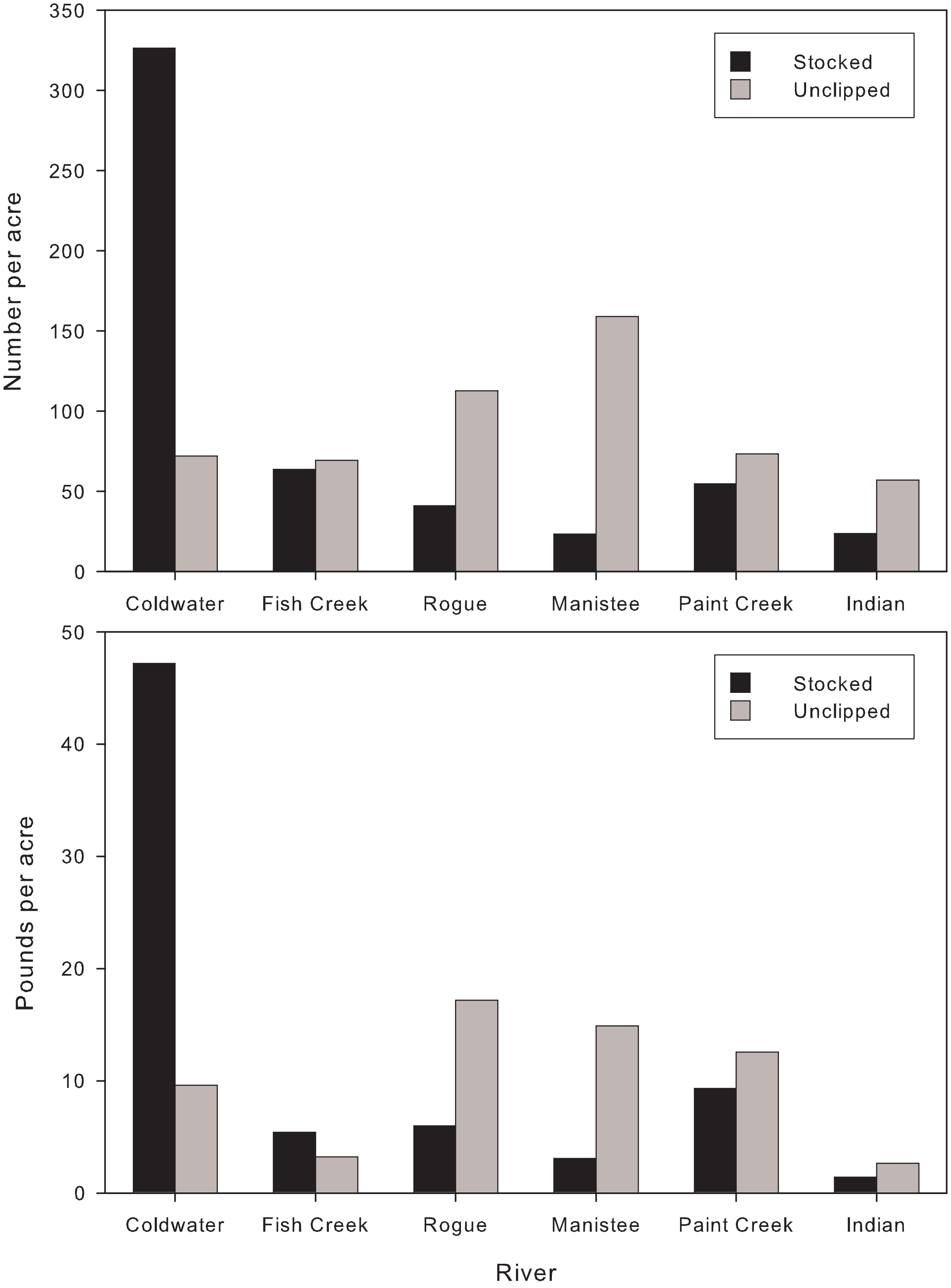

Figure 10.–Mean density (top) and biomass (bottom) of stocked and unclipped brown trout by origin and river. Confidence intervals have been omitted for clarity.

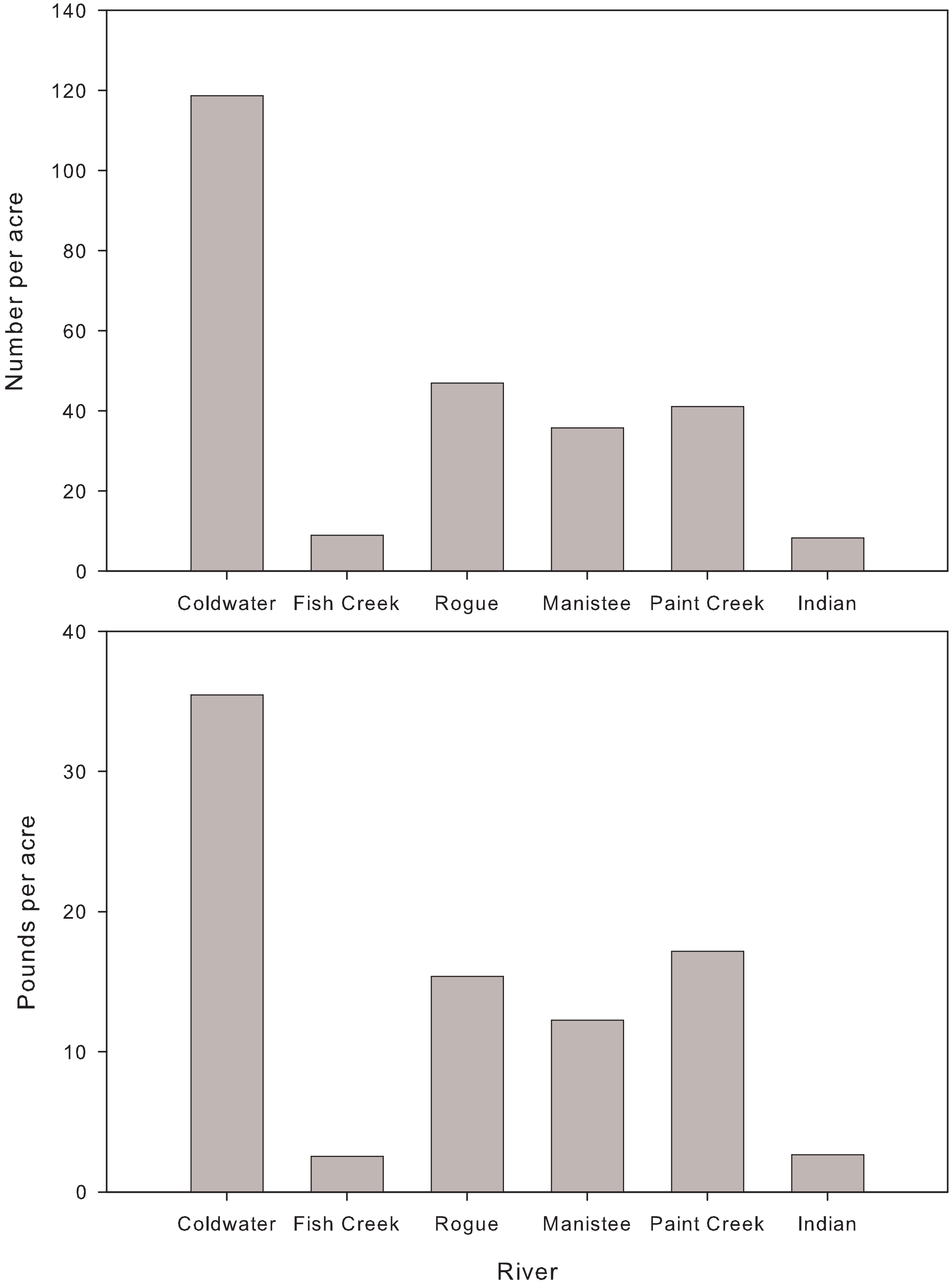

Figure 11.–Mean density (top) and biomass (bottom) of all brown trout >8 in (stocked and unclipped) by river. Confidence intervals have been omitted for clarity.

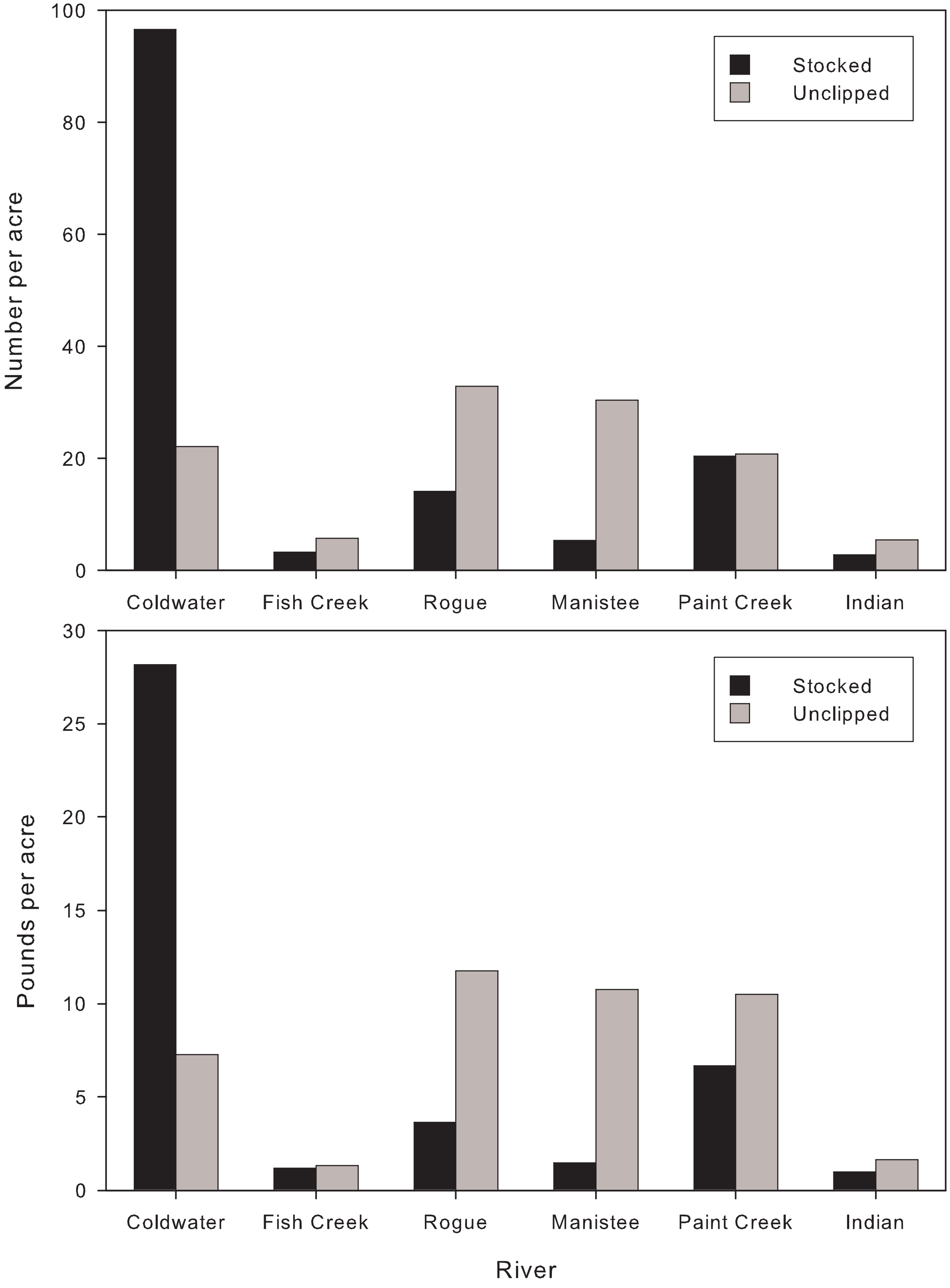

Figure 12.–Mean density (top) and biomass (bottom) of stocked and unclipped brown trout >8 in by origin and river. Confidence intervals have been omitted for clarity.

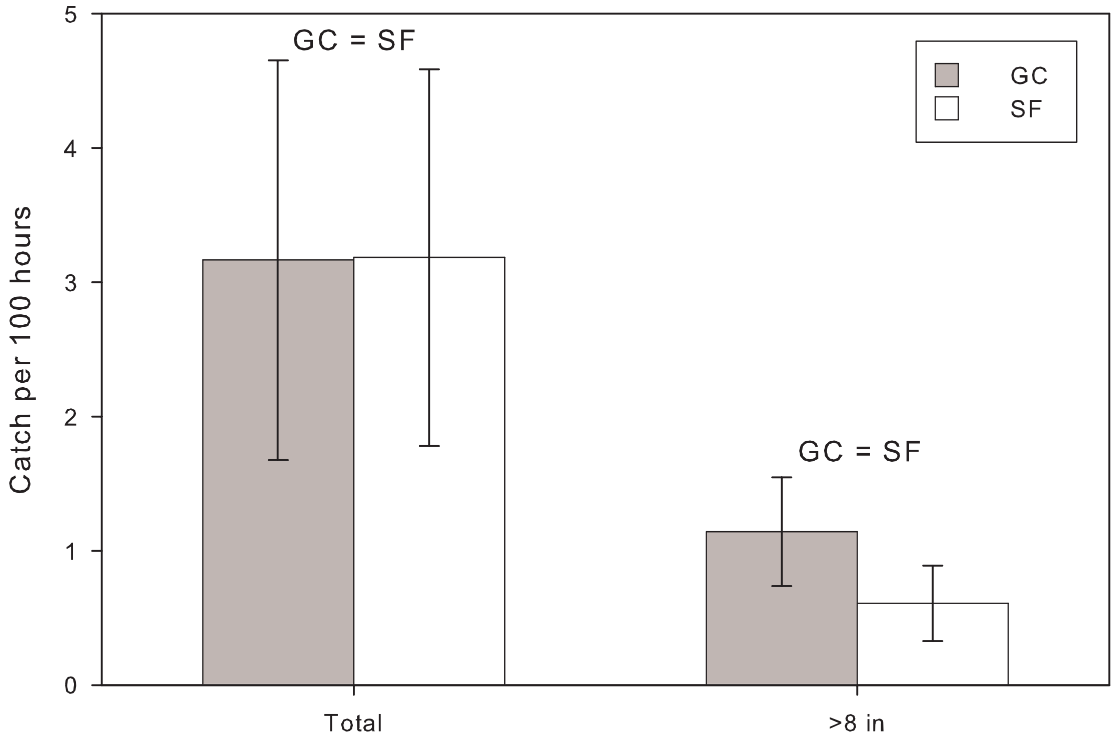

Figure 13.–Mean catch-per-effort (CPE), by strain, of stocked brown trout reported by volunteer anglers on the Manistee River, 1997-2001. The thin vertical lines represent 1 SE. GC = Gilchrist, SF = Seeforellen.

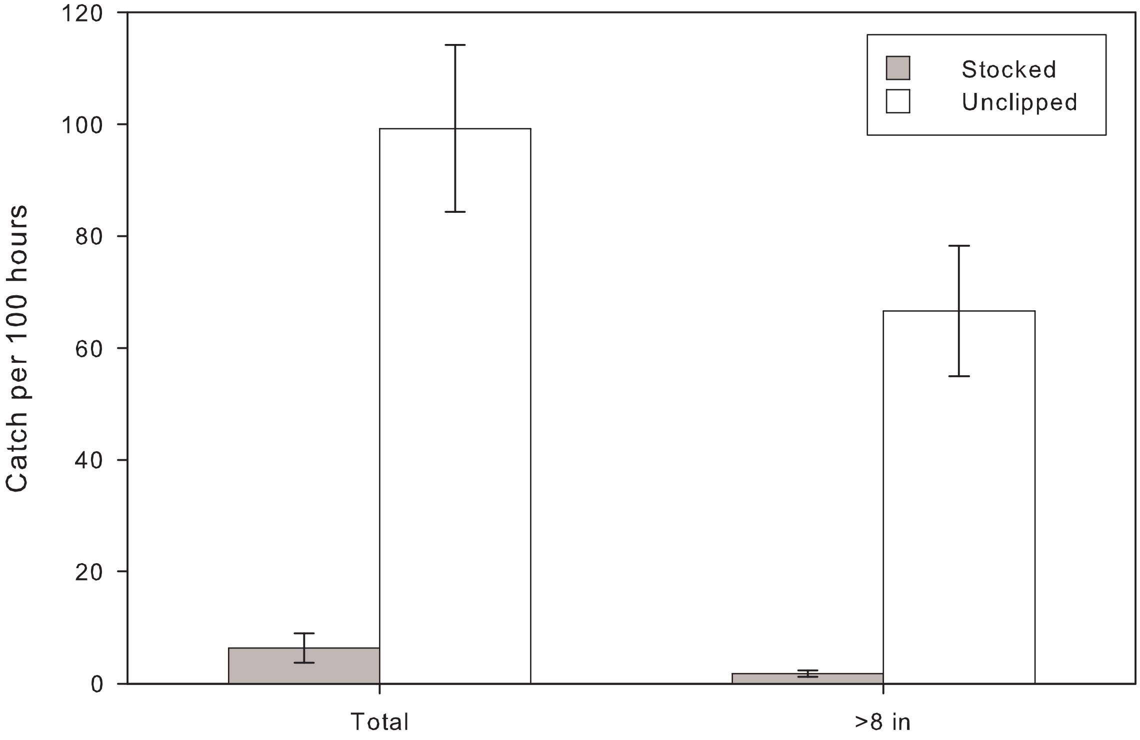

Figure 14.–Mean CPE of stocked and unclipped brown trout reported by volunteer anglers on the Manistee River, 1997–2001. The thin vertical lines represent 1 SE.

Table 1.—Brown trout strain evaluation sampling locations and selected thermal and hydrologic characteristics based on data from Michigan Department of Natural Resources fisheries management and research personnel and the United States Forest Service.

River	County	Mean daily July temperature (°F)	July mean temperature range (mean daily max -mean daily min) (°F)	90% exceedence flow (cfs) [a]	90% exceedence flow yield (cfs/mi^2) [a]
Coldwater River	Barry	65.3	5.5	13	0.17
Fish Creek	Montcalm	63.4	6.6	18	0.12
Indian River	Schoolcraft	68.4	7.8	110	0.36
Manistee River	Crawford	63.5	8.5	161	1.21
Muskegon River	Newaygo	71.2	9.5	1102	0.47
Paint Creek	Oakland	65.1	4.9	16	0.22
Rogue River	Kent	67.6	3.6	86	0.38

[a] Exceedence flows and yields for the Coldwater and Muskegon rivers are predicted values.

Table 2.—Selected rivers, stocking dates, and characteristics of trout stocked for brown trout strain performance evaluation.

River	Years stocked	Strain	Number stocked (fish/yr)	Prescribed stocking density (fish/acre)	Mean length (inches)	Mean length range (inches)
Coldwater River	1997–2000	Gilchrist Creek	2,635	155	4.3	3.7–4.8
	1997–2000	Seeforellen	2,635	155	5.9	5.6–6.4
Fish Creek	1997–2000	Gilchrist Creek	3,900	100	4.5	4.0–4.6
	1998–2000	Seeforellen	3,900	100	5.9	5.8–6.0
	1997	Wild Rose	3,900	100	7.2	–
Indian River	1997–2000	Gilchrist Creek	1,750	38	4.6	3.8–5.1
	1997–2000	Wild Rose	1,750	38	7.1	6.6–8.0
Manistee River	1997–2000	Gilchrist Creek	10,500	30	4.5	4.0–4.8
	1997–2000	Seeforellen	10,500	30	6.1	5.9–6.4
Muskegon River	1999–2000	Gilchrist Creek	17,500	125	4.3	4.0–4.7
	1999–2000	Wild Rose	17,500	125	6.7	6.7
Paint Creek	1997–2000	Gilchrist Creek	2,800	78	4.4	3.8–4.9
	1997–2000	Wild Rose	2,800	78	6.7	6.3–7.1
Rogue River	1997–2000	Gilchrist Creek	5,700	150	4.5	4.0–4.8
	1997–2000	Wild Rose	5,700	150	6.7	6.4–6.9

Table 3.—Selected site characteristics for brown trout strain evaluation sampling stations. N/A = data not available.

River	Survey station	Years surveyed	Minimum size limit (inches)[a]	Area (acres)	Average width (ft)	Average depth (ft)
Coldwater River	Broadway Road	1997–2000	8 (1997–1999), 12 (2000)	0.43	32.0	2.0
	Feightner Road	1997–2000	8 (1997–1999), 12 (2000)	0.59	32.0	1.5
Fish Creek	Sloan Road	1997–1999	8 (1997–1999), 10 (2000)	0.57	25.0	2.0
	Vickeryville Road	1997	8 (1997–1999), 10 (2000)	0.80	25.0	2.0
Indian River	Station 4	1997–2000	7 (1997–1999), 12 (2000)	1.02	44.5	2.1
	Station 14	1997–2000	7 (1997–1999), 12 (2000)	0.99	43.1	2.2
	Station 16	1997, 1999	7 (1997–1999), 12 (2000)	1.46	50.0	2.0
	Station 17	1998–1999	7 (1997–1999), 12 (2000)	0.50	43.9	2.0
Manistee River	M-72 Bridge	1997–2000	8 (1997–1999), 12/15 (2000)[b]	1.81	66.0	N/A
Muskegon River	Croton Dam to Pine Street	1999–2001	8 (1999), 10 (2000–2001)	1.31 miles	N/A	N/A
Paint Creek	Clarkston Road	1997–2000	8 (1997–2000)	0.32	13.0	1.0
	Silverbell Road	1997–2000	8 (1997–2000)	0.51	20.0	2.0
	Tienken Road	1997–2000	8 (1997–2000)	0.56	20.0	1.5
Rogue River	Edgerton Avenue	1997–2000	16 (1997–1999), 10 (2000)	3.67	80.0	N/A
	Summit Avenue	1997–2000	8 (1997–1999), 10 (2000)	5.33	116.0	N/A

[a] Changes in minimum size limits are due to new coldwater fisheries regulations that went into effect in 2000.

[b] Minimum size limit above M-72 bridge (12 inches) differs from minimum size limit below M-72 bridge (15 inches)

Table 4.—Designated volunteer angling river segments on the Manistee River.

Station	County
Mancelona Road to Co. Road 612	Otsego and Crawford
Co. Road 612 to highway M-72	Crawford
Highway M-72 to Yellowtrees Landing	Crawford and Kalkaska
Yellowtrees Landing to CCC Bridge	Kalkaska
CCC Bridge to Sharon	Kalkaska

Table 5.—P-values from mixed-effect analysis of variance modeling the effects of strain (excluding unclipped resident fish), river, and year on brown trout density, survival, and growth. N refers to the total number of population estimates, or point estimates of survival and growth, used in the analysis. NS = not significant.

Metric	Source of variation	F	df	P
Total density	Strain	41.07	2, 63.19	<0.001
N = 96	River	6.24	5, 8.22	0.011
	Year	–	–	NS
	River*Year	2.66	17, 64.01	0.002
Density >8 inches	Strain	4.68	2, 72.73	0.012
N = 96	River	10.84	5, 9.322	0.001
	Year	–	–	NS
	Strain*Year	2.05	9, 72.96	0.045
Survival to age 2	Strain	8.68	2, 57.16	0.001
N = 66	River	–	–	NS
	Year	–	–	NS
Survival to age 3	Strain	–	–	NS
N = 42	River	–	–	NS
	Year	–	–	NS
Post-stocking growth increment[a]	Strain	15.39	2, 45.52	<0.001
N = 81	River	–	–	NS
	Year	9.22	3, 47.29	<0.001
	River*Strain	5.24	5, 45.87	0.001
	River*Year	3.47	13, 47.40	0.001
Growth increment from age 1– 2	Strain	–	–	NS
N = 28	River	–	–	NS
	Year	–	–	NS

[a] Growth increment from time of stocking to first late summer or early fall sample after stocking.

Table 6.—Bonferroni-adjusted P-values from multiple comparison tests evaluating mean differences in density, survival, and growth between three stocked brown trout strains.

Metric	Comparison	t	df	P
Total density	Gilchrist Creek vs. Wild Rose	6.58	63.19	<0.001
	Gilchrist Creek vs. Seeforellen	6.24	63.19	<0.001
	Seeforellen vs. Wild Rose	1.71	63.19	NS
Density >8 inches	Gilchrist Creek vs. Wild Rose	1.17	72.47	NS
	Gilchrist Creek vs. Seeforellen	2.86	72.98	0.016
	Seeforellen vs. Wild Rose	1.79	73.36	NS
Survival to age 2	Gilchrist Creek vs. Wild Rose	3.09	57.96	0.010
	Gilchrist Creek vs. Seeforellen	3.27	62.83	0.005
	Seeforellen vs. Wild Rose	0.97	60.85	NS
Post-stocking growth increment[a]	Gilchrist Creek vs. Wild Rose	4.20	47.50	<0.001
	Gilchrist Creek vs. Seeforellen	3.90	49.55	0.001
	Seeforellen vs. Wild Rose	0.46	32.74	NS

[a] Growth increment from time of stocking to first late summer or early fall sample after stocking.

Table 7.—Mean length and range, in inches, of the three stocked brown trout strains across all rivers and years in which population estimates were made.

	Age 1		Age 2		Age 3		Age 4	
Strain	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Gilchrist Creek	6.8	4.7–8.5	10.0	8.3–12.2	12.8	11.2–16.5	14.7	13.5–15.5
Wild Rose	8.5	6.5–10.5	10.2	8.5–11.0	13.5	–	–	–
Seeforellen	7.5	5.8–9.5	9.6	8.5–11.5	10.3	–	–	–

Table 8.—P-values from mixed-effect analysis of variance modeling the effects of origin (stocked and unclipped resident fish), river, and year on brown trout density and biomass. N refers to the total number of point estimates of density or biomass used in the analysis. NS = not significant.

Metric	Source of variation	F	df	P
Total density	Origin	8.95	1, 84	0.004
N = 144	River	5.12	5, 84	<0.001
	Year	–	–	NS
	River*Origin	7.19	5, 84	<0.001
Total biomass	Origin	–	–	NS
N = 144	River	19.441	5, 84	<0.001
	Year	–	–	NS
	River*Origin	9.23	5, 84	<0.001
Density >8 in	Origin	–	–	NS
N = 144	River	19.12	5, 84	<0.001
	Year	–	–	NS
	River*Origin	5.64	5, 84	<0.001
Biomass >8 inches	Origin	4.729	1, 81	0.033
N = 144	River	16.513	5, 81	<0.001
	Year	3.029	3, 81	0.034
	River*Origin	7.908	5, 81	<0.001

Table 9.—Summary of brown trout catch, by strain and origin, reported by volunteer anglers on the Manistee River, 1997–2001.

	Hours	Catch per 100 hours (Total catch)				
Year	fished	All brown trout	Gilchrist Creek	Seeforellen	Stocked	Unclipped resident
1997	1041	83.0 (864)	8.7 (91)	5.8 (60)	14.5 (151)	68.5 (713)
1998	669	125.6 (840)	3.1 (21)	3.0 (20)	6.1 (41)	119.4 (799)
1999	679	127.5 (866)	2.7 (18)	6.9 (47)	9.6 (65)	118.0 (801)
2000	824	59.5 (490)	1.0 (8)	0.2 (2)	1.2 (10)	58.3 (480)
2001	627	132.1 (828)	0.3 (2)	0.0 (0)	0.3 (2)	131.7 (826)
Total	3840	101.3 (3888)	3.6 (140)	3.4 (129)	7.0 (269)	94.2 (3619)

Table 10.—Number of stocked brown trout, by age, recorded by volunteer anglers on the Manistee River, 1997–2001. GC = Gilchrist Creek.

	Age 1		Age 2		Age 3		Age 4	
Year	GC	Seeforellen	GC	Seeforellen	GC	Seeforellen	GC	Seeforellen
1997	91	60	–	–	–	–	–	–
1998	4	20	17	0	–	–	–	–
1999	16	47	2	0	0	0	–	–
2000	0	0	8	2	0	0	0	0
2001	–	–	–	–	2[a]	0	0	0

[a] Exact age unknown due to incomplete angler report. Assumed age 3.

Table 11.—Summary of brown trout catch recorded by creel clerks on the Muskegon River, 1999–2001. GC = Gilchrist Creek, WR = Wild Rose, UR = Unclipped resident.

	All brown	Total number of fish recorded				Percent of total catch			
Year	trout	GC	WR	Stocked	UR	GC	WR	Stocked	UR
1999	85	1	59	60	25	1.0	69.0	71.0	29.0
2000	14	1	9	10	4	7.0	64.0	71.0	29.0
2001	31	9	10	19	12	29.0	32.0	61.0	39.0
Total	130	11	78	89	41	8.5	60.0	68.5	31.5

Table 12.—Number of stocked brown trout, by age, recorded by creel clerks on the Muskegon River, 1999–2003. GC = Gilchrist Creek, WR = Wild Rose.

	Age 1		Age 2		Age 3		Age 4	
Year	GC	WR	GC	WR	GC	WR	GC	WR
1999	1	27	0	32[a]	–	–	–	–
2000	0	4	1	5	–	–	–	–
2001	0	0	8	10	1	0	–	–
2002	–	–	0	0	1	0	1	0
2003	–	–	–	–	0	0	3	0

[a] Carry-over from clipped, unpaired plant in 1998.

Table 13.—Length range (inches) of stocked brown trout, by age, recorded by creel clerks on the Muskegon River, 1999–2003. GC = Gilchrist Creek, WR = Wild Rose.

	Age 1		Age 2		Age 3		Age 4	
Year	GC	WR	GC	WR	GC	WR	GC	WR
1999	8.3	8.1–14.7	–	11.0–13.9	–	–	–	–
2000	–	8.8–10.8	11.2	12.6–15.0	–	–	–	–
2001	–	–	9.7–13.2	12.3–15.5	10.0	–	–	–
2002	–	–	–	–	20.2	–	19.1	–
2003	–	–	–	–	–	–	14.8–16.3	–

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James C. Schneider, Editor
Jay K. Wesley, Reviewer
Alan D. Sutton, Graphics
Deborah L. MacConnell, Desktop Publisher

Approved by Paul W. Seelbach

Appendix A.—Density and biomass data from the six study rivers with population estimate data available.

River	Site	Strain	Year	Total density (fish/acre)	Density >8 inch (fish/acre)	Total biomass (lbs/acre)	Biomass >8 inch (lbs/acre)
Coldwater River	Feightner Road	Unclipped	1997	16.1	10.0	4.0	3.8
			1998	87.3	15.2	8.1	3.7
			1999	142.2	25.8	10.8	7.0
			2000	236.8	76.3	32.4	26.7
		Gilchrist Creek	1997	310.4	72.5	39.9	13.6
			1998	415.9	207.1	90.5	71.9
			1999	598.8	45.1	53.1	21.4
			2000	273.5	142.0	55.7	40.8
		Seeforellen	1997	48.2	29.0	7.2	5.5
			1998	46.0	3.8	3.9	0.7
			1999	137.0	35.4	19.3	8.8
			2000	59.2	22.9	8.7	5.6
	Broadway Road	Unclipped	1997	14.4	8.1	3.2	3.1
			1998	4.8	3.3	1.8	0.8
			1999	27.4	4.0	1.7	1.1
			2000	46.3	34.3	14.6	12.0
		Gilchrist Creek	1997	256.7	58.5	32.2	11.0
			1998	113.7	45.6	19.9	15.8
			1999	79.3	7.0	8.3	3.4
			2000	195.9	63.8	25.0	18.3
		Seeforellen	1997	31.2	23.4	5.9	4.4
			1998	2.4	0.8	0.9	0.2
			1999	30.5	5.5	3.0	1.4
			2000	13.6	10.3	3.9	2.5
Fish Creek	Sloan Road	Unclipped	1997	46.9	0.0	1.7	0.0
			1998	98.1	0.0	2.2	0.0
			1999	100.3	20.4	7.7	4.8
		Gilchrist Creek	1997	22.1	0.0	1.8	0.0
			1998	139.6	5.7	9.0	1.6
			1999	16.7	3.7	1.5	0.7
		Wild Rose	1997	8.3	5.5	1.2	1.0
		Seeforellen	1998	62.3	1.9	6.2	1.2
			1999	9.3	1.9	1.2	0.3
	Vickeryville Road	Unclipped	1997	1.3	0.0	0.7	0.0
		Wild Rose	1997	15.0	2.4	0.5	0.4
		Gilchrist Creek	1997	17.5	0.0	0.8	0.0

Appendix A.—Continued.

River	Site	Strain	Year	Total density (fish/acre)	Density >8 inch (fish/acre)	Total biomass (lbs/acre)	Biomass >8 inch (lbs/acre)
Indian River	Station 14	Unclipped	1997	28.7	1.5	1.2	0.6
			1998	78.0	9.3	3.7	2.1
			1999	83.6	6.3	3.4	2.0
			2000	79.8	9.4	4.7	3.5
		Gilchrist Creek	1997	41.5	2.9	2.2	0.5
			1998	9.9	5.7	2.7	2.6
			1999	4.0	0.6	0.6	0.2
			2000	0.0	0.0	0.0	0.0
		Wild Rose	1997	8.6	5.2	1.7	1.6
			1998	0.0	0.0	0.0	0.0
			1999	1.3	0.6	0.2	0.2
			2000	0.0	0.0	0.0	0.0
Indian River	Station 4	Unclipped	1997	46.5	1.0	0.8	0.4
			1998	91.0	10.0	3.9	2.2
			1999	107.1	8.1	4.4	2.6
			2000	84.3	10.0	4.9	3.7
		Gilchrist Creek	1997	6.3	2.1	1.6	0.4
			1998	3.1	6.1	2.9	2.8
			1999	7.6	0.7	0.8	0.3
			2000	0.0	0.0	0.0	0.0
		Wild Rose	1997	2.1	3.6	1.2	1.1
			1998	0.0	0.0	0.0	0.0
			1999	0.0	0.7	0.3	0.3
			2000	0.0	0.0	0.0	0.0
	Station 17	Unclipped	1998	22.0	4.2	1.7	0.9
			1999	36.4	3.5	1.9	1.1
		Gilchrist Creek	1998	10.0	2.6	1.2	1.2
			1999	11.4	0.3	0.3	0.1
		Wild Rose	1998	8.0	0.0	0.0	0.0
			1999	2.3	0.3	0.1	0.1
	Station 16	Unclipped	1997	12.1	0.3	0.2	0.1
			1999	16.7	1.4	0.8	0.5
		Gilchrist Creek	1997	3.0	0.6	0.4	0.1
			1999	3.2	0.1	0.1	0.0
		Wild Rose	1997	0.0	1.0	0.3	0.3
			1999	0.0	0.1	0.0	0.0

Appendix A.—Continued.

River	Site	Strain	Year	Total density (fish/acre)	Density >8 inch (fish/acre)	Total biomass (lbs/acre)	Biomass >8 inch (lbs/acre)
Manistee River	M-72 bridge	Unclipped	1997	77.5	8.1	6.0	3.5
			1998	130.8	21.7	15.0	8.9
			1999	158.8	37.4	13.4	9.9
			2000	269.7	54.5	25.1	20.7
		Gilchrist Creek	1997	12.1	1.6	1.3	0.3
			1998	8.4	0.7	0.6	0.1
			1999	12.9	5.0	2.2	1.6
			2000	38.1	4.5	3.9	0.9
		Seeforellen	1997	0.0	0.0	0.0	0.0
			1998	4.9	0.7	0.5	0.1
			1999	8.6	6.5	2.6	2.4
			2000	8.2	2.2	1.1	0.4
Paint Creek	Clarkston Road	Unclipped	1997	21.8	10.9	7.4	7.3
			1998	51.0	3.6	4.8	2.8
			1999	59.1	3.7	1.9	0.7
			2000	66.2	27.9	10.7	8.0
		Gilchrist Creek	1997	58.0	7.3	7.1	1.3
			1998	25.5	21.9	8.4	8.0
			1999	7.4	0.0	0.3	0.0
			2000	13.9	3.5	2.3	1.2
		Wild Rose	1997	3.6	3.6	0.7	0.7
			1998	10.9	10.9	2.0	2.0
			1999	3.7	3.7	0.7	0.7
			2000	3.5	3.5	1.2	1.2
Paint Creek	Silverbell Road	Unclipped	1997	40.2	30.7	16.1	15.0
			1998	53.8	28.1	17.0	16.2
			1999	48.5	16.2	6.9	6.3
			2000	36.7	13.0	6.9	5.7
		Gilchrist Creek	1997	2.4	2.4	0.4	0.4
			1998	7.0	7.0	3.3	3.3
			1999	2.7	0.0	0.2	0.0
			2000	4.3	2.2	1.9	1.7
		Wild Rose	1997	2.4	0.0	0.3	0.0
			1998	0.0	0.0	0.0	0.0
			1999	8.1	8.1	1.7	1.7
			2000	6.5	4.3	1.2	0.9

Appendix A.—Continued.

River	Site	Strain	Year	Total density (fish/acre)	Density >8 inch (fish/acre)	Total biomass (lbs/acre)	Biomass >8 inch (lbs/acre)
Paint Creek	Tienken Road	Unclipped	1997	48.2	27.0	22.4	21.0
			1998	115.5	28.9	21.7	17.0
			1999	126.0	32.0	13.8	10.2
			2000	213.5	27.1	20.6	15.7
		Gilchrist Creek	1997	55.9	1.9	4.3	0.3
			1998	90.7	30.9	13.2	8.5
			1999	126.0	40.6	18.0	13.9
			2000	171.4	60.1	31.2	22.9
		Wild Rose	1997	9.6	0.0	1.0	0.0
			1998	6.2	0.0	0.7	0.0
			1999	32.0	29.9	10.1	9.8
			2000	6.0	3.0	1.6	1.4
Rogue River	Summit Avenue	Unclipped	1997	145.2	19.9	15.9	6.2
			1998	171.7	53.2	24.4	15.7
			1999	101.1	27.0	14.7	9.7
			2000	117.9	13.7	9.7	4.7
		Gilchrist Creek	1997	40.6	5.5	4.8	1.0
			1998	34.7	3.2	3.7	1.2
			1999	30.6	1.8	2.5	0.8
			2000	32.1	3.8	3.4	1.0
		Wild Rose	1997	18.4	17.3	3.7	3.6
			1998	7.2	3.7	1.1	0.7
			1999	14.6	9.1	2.5	1.9
			2000	7.6	6.5	1.6	1.5
	Edgerton Avenue	Unclipped	1997	113.8	32.2	17.6	12.4
			1998	146.1	68.8	32.0	26.4
			1999	44.1	21.4	8.2	6.7
			2000	60.7	26.4	14.9	12.3
		Gilchrist Creek	1997	25.4	0.0	2.0	0.0
			1998	29.1	17.8	5.7	4.9
			1999	10.1	6.6	3.1	2.9
			2000	27.8	6.1	4.8	2.9
		Wild Rose	1997	21.0	14.8	3.6	2.9
			1998	21.4	8.9	3.4	2.0
			1999	2.4	1.8	0.5	0.4
			2000	6.1	5.6	1.5	1.5

Appendix B.—Annual percent survival data from the six study rivers with population estimate data available.

River	Site	Strain	Cohort	Survival to age 2	Survival to age 3	Survival to age 4
Coldwater River	Feightner Road	Gilchrist Creek	1997	53.3	5.3	23.2
			1998	14.7	0.0	–
			1999	30.3	–	–
			2000	–	–	–
		Seeforellen	1997	0.0	0.0	0.0
			1998	3.8	N/A	–
			1999	21.3	–	–
			2000	–	–	–
	Broadway Road	Gilchrist Creek	1997	21.7	11.0	0.0
			1998	15.8	0.0	–
			1999	46.8	–	–
			2000	–	–	–
		Seeforellen	1997	0.0	0.0	0.0
			1998	0.0	0.0	–
			1999	0.0	–	–
			2000	–	–	–
Fish Creek	Sloan Road	Gilchrist Creek	1997	25.7	0.0	–
			1998	2.8	–	–
			1999	–	–	–
		Wild Rose	1997	45.6	–	–
		Seeforellen	1998	0.0	–	–
			1999	–	–	–
	Vickeryville Road	Wild Rose	1997	–	–	–
		Gilchrist Creek	1997	–	–	–
Indian River	Station 14	Gilchrist Creek	1997	23.8	0.0	0.0
			1998	0.0	0.0	–
			1999	0.0	–	–
			2000	–	–	–
		Wild Rose	1997	0.0	0.0	0.0
			1998	0.0	0.0	–
			1999	0.0	–	–
			2000	–	–	–
	Station 4	Gilchrist Creek	1997	49.5	0.0	0.0
			1998	0.0	0.0	–
			1999	0.0	–	–
			2000	–	–	–
		Wild Rose	1997	0.0	0.0	0.0
			1998	0.0	0.0	–
			1999	0.0	–	–
			2000	–	–	–
	Station 17	Gilchrist Creek	1998	0.0	–	–
			1999	–	–	–
		Wild Rose	1998	0.0	–	–
			1999	–	–	–

Appendix B.—Continued.

River	Site	Strain	Cohort	Survival to age 2	 to age 3	 to age 4
Indian River	Station 16	Gilchrist Creek	1997	–	–	–
			1999	–	–	–
		Wild Rose	1997	–	–	–
			1999	–	–	–
Manistee River	M-72 bridge	Gilchrist Creek	1997	0.0	0.0	0.0
			1998	59.9	0.0	–
			1999	9.5	–	–
			2000	–	–	–
		Seeforellen	1997	0.0	0.0	0.0
			1998	0.0	0.0	–
			1999	0.0	–	–
			2000	–	–	–
Paint Creek	Clarkston Road	Gilchrist Creek	1997	37.7	0.0	0.0
			1998	0.0	0.0	–
			1999	47.2	–	–
			2000	–	–	–
		Wild Rose	1997	0.0	0.0	0.0
			1998	0.0	0.0	–
			1999	0.0	–	–
			2000	–	–	–
	Silverbell Road	Gilchrist Creek	1997	100.0	0.0	0.0
			1998	0.0	N/A	–
			1999	0.0	–	–
			2000	–	–	–
		Wild Rose	1997	0.0	0.0	0.0
			1998	0.0	0.0	–
			1999	0.0	–	–
			2000	–	–	–
	Tienken Road	Gilchrist Creek	1997	59.0	45.3	40.2
			1998	44.4	70.4	–
			1999	66.9	–	–
			2000	–	–	–
		Wild Rose	1997	0.0	0.0	0.0
			1998	100.0	0.0	–
			1999	56.3	–	–
			2000	–	–	–
Rogue River	Summit Avenue	Gilchrist Creek	1997	7.2	31.4	0.0
			1998	2.9	0.0	–
			1999	18.5	–	–
			2000	–	–	–
		Wild Rose	1997	0.0	0.0	0.0
			1998	0.0	0.0	–
			1999	0.0	–	–
			2000	–	–	–

Appendix B.—Continued.

River	Site	Strain	Cohort	Survival to age 2	Survival to age 3	Survival to age 4
Rogue River	Edgerton Avenue	Gilchrist Creek	1997	67.9	24.2	22.6
			1998	20.1	59.3	–
			1999	79.0	–	–
			2000	–	–	–
		Wild Rose	1997	5.6	0.0	0.0
			1998	2.9	79.0	–
			1999	26.3	–	–
			2000	–	–	–

Appendix C.—Growth data from the six study rivers with population estimate data available.

				Mean length (inches)					Growth increment (inches)			
River	Site	Strain	Cohort	Stocking	Age 1	Age 2	Age 3	Age 4	Year 1	Year 2	Year 3	Year 4
Coldwater River	Feightner Road	Gilchrist Creek	1997	4.8	7.5	10.3	12.5	13.5	2.7	2.8	2.2	1.0
			1998	4.6	6.8	9.5	–	–	2.2	2.6	–	–
			1999	4.0	5.8	9.4	–	–	1.9	3.6	–	–
			2000	4.6	6.7	–	–	–	2.1	–	–	–
		Seeforellen	1997	6.4	8.1	–	10.3	–	1.7	–	N/A	–
			1998	5.7	7.0	11.5	–	–	1.2	4.6	–	–
			1999	5.9	7.2	8.7	–	–	1.3	1.5	–	–
			2000	6.0	7.7	–	–	–	1.7	–	–	–
	Broadway Road	Gilchrist Creek	1997	4.8	7.6	11.0	16.5	–	2.8	3.4	5.5	–
			1998	4.6	6.6	12.2	–	–	2.0	5.5	–	–
			1999	4.0	6.5	11.0	–	–	2.5	4.5	–	–
			2000	4.6	6.7	–	–	–	2.1	–	–	–
		Seeforellen	1997	6.4	8.3	–	–	–	2.0	–	–	–
			1998	5.7	6.5	–	–	–	0.8	–	–	–
			1999	5.9	7.9	–	–	–	2.0	–	–	–
			2000	6.0	7.9	–	–	–	1.9	–	–	–
Fish Creek	Sloan Road	Gilchrist Creek	1997	4.6	7.8	10.0	–	–	3.2	2.2	–	–
			1998	4.6	6.6	–	–	–	2.0	–	–	–
			1999	4.0	7.7	–	–	–	3.7	–	–	–
		Wild Rose	1997	7.2	6.5	9.8	–	–	–0.7	3.3	–	–
		Seeforellen	1998	5.8	5.8	8.5	–	–	0.0	2.7	–	–
			1999	5.9	6.2	–	–	–	0.3	–	–	–
	Vickeryville Road	Wild Rose	1997	7.2	7.6	–	–	–	0.4	–	–	–
		Gilchrist Creek	1997	4.6	6.3	–	–	–	1.6	–	–	–
Indian River	Station 14	Gilchrist Creek	1997	4.6	6.4	10.9	–	–	1.8	4.6	–	–
			1998	4.6	–	–	–	–	–	–	–	–
			1999	3.8	8.2	–	–	–	4.4	–	–	–
			2000	4.7	–	–	–	–	–	–	–	–
		Wild Rose	1997	7.2	9.3	–	–	–	2.2	–	–	–
			1998	8.0	–	–	–	–	–	–	–	–
			1999	6.6	10.5	–	–	–	3.9	–	–	–
			2000	6.8	–	–	–	–	–	–	–	–

Appendix C.—Continued.

				Mean length (inches)					Growth increment (inches)			
River	Site	Strain	Cohort	Stocking	Age 1	Age 2	Age 3	Age 4	Year 1	Year 2	Year 3	Year 4
Indian River	Station 4	Gilchrist Creek	1997	4.6	7.8	10.2	–	–	3.2	2.3	–	–
			1998	4.6	–	–	–	–	–	–	–	–
			1999	3.8	7.8	–	–	–	4.0	–	–	–
			2000	4.7	–	–	–	–	–	–	–	–
		Wild Rose	1997	7.2	10.5	–	–	–	3.3	–	–	–
			1998	8.0	–	–	–	–	–	–	–	–
			1999	6.6	–	–	–	–	–	–	–	–
			2000	6.8	–	–	–	–	–	–	–	–
	Station 17	Gilchrist Creek	1998	4.6	4.7	–	–	–	0.1	–	–	–
			1999	3.8	7.7	–	–	–	3.9	–	–	–
		Wild Rose	1998	8.0	8.5	–	–	–	0.5	–	–	–
			1999	6.6	9.5	–	–	–	2.9	–	–	–
	Station 16	Gilchrist Creek	1997	4.6	7.0	–	–	–	2.4	–	–	–
			1999	3.8	7.3	–	–	–	3.5	–	–	–
		Wild Rose	1997	7.2	–	–	–	–	–	–	–	–
			1999	6.6	–	–	–	–	–	–	–	–
Manistee River	M-72 bridge	Gilchrist Creek	1997	4.7	7.2	–	–	–	2.4	–	–	–
			1998	4.8	6.3	10.1	–	–	1.4	3.8	–	–
			1999	4.0	6.3	9.5	–	–	2.4	3.2	–	–
			2000	4.6	6.9	–	–	–	2.3	–	–	–
		Seeforellen	1997	6.4	–	–	–	–	–	–	–	–
			1998	6.2	7.1	–	–	–	0.9	–	–	–
			1999	6.2	9.5	–	–	–	3.3	–	–	–
			2000	6.0	7.8	–	–	–	1.7	–	–	–
Paint Creek	Clarkston Road	Gilchrist Creek	1997	4.9	7.5	10.5	–	–	2.6	3.0	–	–
			1998	4.4	7.5	–	–	–	3.1	–	–	–
			1999	3.9	5.5	10.5	–	–	1.6	5.0	–	–
			2000	4.6	7.2	–	–	–	2.6	–	–	–
		Wild Rose	1997	7.1	8.5	–	–	–	1.4	–	–	–
			1998	6.3	8.5	–	–	–	2.2	–	–	–
			1999	6.6	8.5	–	–	–	1.9	–	–	–
			2000	6.8	10.5	–	–	–	3.7	–	–	–

Appendix C.—Continued.

				Mean length (inches)					Growth increment (inches)			
River	Site	Strain	Cohort	Stocking	Age 1	Age 2	Age 3	Age 4	Year 1	Year 2	Year 3	Year 4
Paint Creek	Silverbell Road	Gilchrist Creek	1997	4.9	8.5	11.2	–	–	3.6	2.7	–	–
			1998	4.4		–	13.5	–	–	–	N/A	–
			1999	3.9	6.5	–	–	–	2.6	–	–	–
			2000	4.6	7.5	–	–	–	2.9	–	–	–
		Wild Rose	1997	7.1	7.5	–	–	–	0.4	–	–	–
			1998	6.3		–	–	–	–	–	–	–
			1999	6.6	8.8	–	–	–	2.2	–	–	–
			2000	6.8	8.5	–	–	–	1.7	–	–	–
	Tienken Road	Gilchrist Creek	1997	4.9	6.4	9.5	11.5	15.5	1.5	3.1	2.0	4.0
			1998	4.4	6.5	9.3	11.2	–	2.1	2.8	1.9	–
			1999	3.9	5.6	8.3	–	–	1.7	2.8	–	–
			2000	4.6	6.1	–	–	–	1.5	–	–	–
		Wild Rose	1997	7.1	7.1	–	–	–	0.0	–	–	–
			1998	6.3	7.5	10.5	–	–	1.2	3.0	–	–
			1999	6.6	9.1	8.5	–	–	2.5	–0.6	–	–
			2000	6.8		–	–	–	–	–	–	–
Rogue River	Summit Avenue	Gilchrist Creek	1997	4.8	7.4	10.7	12.5	–	2.6	3.3	1.8	–
			1998	4.6	6.5	9.0	–	–	1.9	2.5	–	–
			1999	4.0	5.9	8.7	–	–	2.0	2.8	–	–
			2000	4.5	6.6	–	–	–	2.1	–	–	–
		Wild Rose	1997	6.9	8.8	–	–	–	1.8	–	–	–
			1998	6.4	7.9	–	–	–	1.5	–	–	–
			1999	6.7	8.2	–	–	–	1.5	–	–	–
			2000	6.7	8.8	–	–	–	2.1	–	–	–
	Edgerton Avenue	Gilchrist Creek	1997	4.8	6.5	9.7	12.1	15.0	1.7	3.2	2.4	2.9
			1998	4.6	6.6	9.5	12.8	–	1.9	3.0	3.3	–
			1999	4.0	6.0	9.5	–	–	2.0	3.5	–	–
			2000	4.5	6.8	–	–	–	2.2	–	–	–
		Wild Rose	1997	6.9	8.3	11.0	–	–	1.3	2.7	–	–
			1998	6.4	7.8	10.5	13.5	–	1.4	2.7	3.0	–
			1999	6.7	8.2	10.5	–	–	1.4	2.3	–	–
			2000	6.7	8.7	–	–	–	2.0	–	–	–