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[Article]

Comparative Abundance, Survival, and Growth of One Wild and Two Domestic Brown Trout Strains Stocked in Michigan Rivers

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Abstract.—Stocking is commonly practiced to create, sustain, or enhance fisheries, but comprehensive evaluations of stocking success are rare. I assessed the relative abundance, survival, and growth of three strains of brown trout *Salmo trutta* that were stocked as sympatric populations into six rivers to evaluate relative stocking performance from 1997 to 2000. Stocked brown trout from wild broodstock were initially smaller but were more abundant and had higher survival and growth rates than fish from two domestic strains. However, on average, the densities and biomass of all stocked brown trout were lower than the densities and biomass of unclipped resident brown trout. Fisheries managers must consider the performance of individual stocked brown trout strains, as well as the performance of stocked brown trout in general, when implementing or reviewing brown trout stocking programs.

The stocking of trout into rivers where low natural reproduction or some other habitat feature limits the quality of trout fisheries is a common fisheries management practice. 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 performance (i.e., low abundance, survival, growth, and return to anglers) frequently exhibited by domesticated trout strains is the direct result of years of inbreeding and forced selection (Vincent 1960; Avery et al. 2001). As a result, the domesticated strains are unable to handle severe environmental variation, adapt to ecological conditions, or avoid predation (Fraser 1981; Avery et al. 2001). Accordingly, the introduction of wild salmonid strains into hatchery systems is often carried out by fisheries managers hoping to improve the performance of stocked salmonids.

Evidence in the literature suggests that wild salmonid strains outperform their domestic equivalents. For example, Greene (1952), Vincent (1960), Flick and Webster (1964, 1976), Fraser (1981), Webster and Flick (1981), and Lachance and Magnan (1990) all documented that wild strains of brook trout *Salvelinus fontinalis* exhibited greater survival than domestic strains in natural and seminatural environments. Vincent (1960) also noted that wild brook trout grew at rates that were comparable to or higher than those of 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 brook trout in four small lakes. Other studies comparing wild and domestic trout strains have focused on the brown trout *Salmo trutta*, a game fish that is popular among both anglers and managers (Scott and Crossman 1973). However, neither these studies nor those focusing on other salmonids have evaluated measures of performance such as abundance, survival, and growth among sympatric populations that have been stocked into multiple systems over several years.

Most stocking evaluations have focused on single metrics of performance; for example, research conducted in Michigan has shown that domestic brown trout stocked into rivers exhibit substantially lower survival than naturalized brown trout reared in the same systems (Alexander and Peterson 1983). Similarly, other studies in Michigan lakes (Alexander 1987) and natural systems elsewhere (Berg and Jørgensen 1991; Skaala et al. 1996; Weiss and Schmutz 1999) have documented higher survival rates in wild brown trout strains than in domestic strains. Alexander (1987) and Avery et al. (2001) also found higher growth of wild brown trout strains than domesticated strains. Accordingly, the wild Gilchrist Creek (GC) strain of brown trout was transferred into the Michigan Department of Natural Resources' (MDNR) hatchery system in the mid-1990s in the hopes that the progeny of these fish would survive better and produce better recreational fisheries in stocked rivers than the two available domesticated brown trout strains, Wild Rose (WR) and Seeforellen (SF). Both the WR and SF strains have been in Michigan's hatchery system for nearly two decades and are used in other hatchery programs across the United States.

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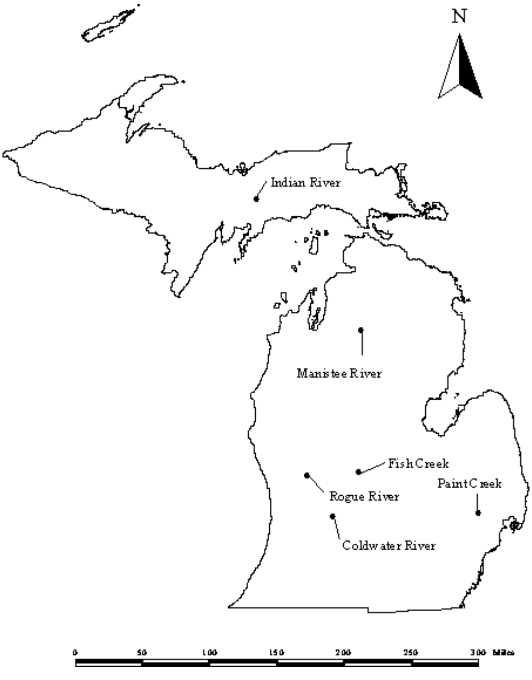

FIGURE 1.—Locations of six Michigan rivers selected for an evaluation of wild and domesticated brown trout strain poststocking performance.

Poor performance of stocked fish limits the management options available to fisheries managers and increases associated costs (Flick and Webster 1976). Given the substantial monetary and human resources invested into rearing these fish, a comprehensive brown trout strain evaluation that measures multiple metrics of performance across systems and through time in sympatric populations would provide critical information on the success of stocking efforts to fisheries managers. Therefore, the objectives of this study were to (1) assess the abundance, survival, and growth of wild GC and domestic WR and SF strains of brown trout, (2) assess differences in the abundance, survival, and growth of each stocked strain across rivers and years, and (3) assess the contribution of hatchery-reared brown trout to brown trout populations in stocked rivers.

Methods

Fisheries managers identified rivers with suitable physical and thermal habitat, high fishing pressure, and low recruitment as candidates for brown trout stocking. Systems with historically poor performance of stocked brown trout were chosen as potential systems for strain evaluations. Priority for inclusion in this study was given to systems that provided easy access to fish planting units and that were amenable to sampling by field personnel. Geographic location was also considered to ensure that all study sites were not distributed within the same region of the state. Six rivers that fit these criteria were subjectively chosen for brown trout strain comparisons upon consultation with fisheries researchers (Figure 1). All have the thermal characteristics necessary to support trout; mean July temperatures in these systems range from 63.4°F to 68.4°F (Wills 2005).

Michigan 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. Although there is no record of brown trout stocking into GC, these nonnative fish undoubtedly were derived from either unrecorded fish plantings or historic fish plantings elsewhere in the watershed. Eggs used for SF broodstock brown trout were originally obtained by the MDNR from the New York State Department of Environmental Conservation's Caledonia State Fish Hatchery in the late 1980s and early 1990s. Eggs used for the original WR broodstock were obtained from the Wisconsin Department of Natural Resources' WR State Fish Hatchery in the late 1980s.

Hatchery personnel spawned the GC, SF, and WR broodstock brown trout annually between October and December, depending upon strain. The fertilized eggs were then transferred to egg trays and were incubated at 45°F for 85–90 d. After 90 d, 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, SF, and WR brown trout were given a unique fin clip in each year prior to stocking to distinguish strain and year-class. Hatchery personnel estimated mean length prior to stocking for each strain based on a random subsample of yearling fish (Table 1).

In the spring of 1997, paired plantings of yearling brown trout (equal numbers of the GC strain and the SF or WR strain; Table 1) were initiated at survey stations in the six study rivers. The number of survey stations in each river ranged from one to four; the majority of systems had two to three stations. Survey stations ranged in size from 0.32 to 5.33 acres and were physically (i.e., presence of a dam) or geographically (i.e., as great a distance as possible) separated from other stocking locations in the same system to minimize the probability of fish immigration from other stocking sites. Paired plantings continued in each river through 2000 to provide for replicated observations of the performance of the three brown trout strains.

TABLE 1.—Selected rivers, stocking dates, and characteristics of brown trout stocked in six Michigan rivers for strain performance evaluation (strains are Gilchrist Creek [GC], Seeforellen [SF], and Wild Rose [WR]).

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

Field personnel estimated brown trout populations by electrofishing in the late summer or early fall of each planting year (1997–2000) at most survey stations. Population estimates were made by either depletion or mark–recapture methods. Field personnel electrofished each survey station with a 240-V DC stream electrofishing unit equipped with two or three anode probes. Sampling began at the downstream end of the station and moved upstream, covering the entire width of the channel. Depletion surveys consisted of two to three passes and were completed on the day that the survey was initiated, while mark and recapture survey passes were separated by a minimum of 24 h. Block nets were not used because of logistical constraints. Brown trout that were 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). Field personnel archived brown trout population data from the six study rivers during the 4 years of paired plantings. 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.

I used the MicroFish 3.0 software package (Van Deventer and Platts 1989) to estimate the densities of GC brown trout, SF or WR brown trout, and unclipped resident brown trout at survey stations where depletion methods were used. For each year and survey station, I combined data for 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 size-groups (age-groups) (estimated from a length-frequency histogram) that were likely to have similar catchability and added these population estimates together to derive the total estimate. Since larger individuals are more susceptible to capture than are smaller individuals (Libosvarsky 1962), stratification by size-group helps to avoid size-related heterogeneity in capture probability (Riley and Fausch 1992). I calculated the total population estimate, converted this estimate to density (number/acre), and apportioned density into strains and inch-groups based upon the proportion of new (once-caught) fish captured on all combined depletion passes. The number of fish equal to or exceeding 8.0 in total length (TL) was summed to approximate the number of legal-sized fish per acre, as most of the study rivers had an 8.0-in minimum size limit for the duration of the study. I converted the number of fish per acre to pounds per acre and used the length–weight relationships presented in Schneider (2000) to calculate the total biomass of all inch-groups and of fish 8.0 in or larger.

I used the Chapman modification of the Petersen mark–recapture formula (Ricker 1975) to estimate the densities of GC brown trout, SF or WR brown trout, and unclipped resident brown trout at survey stations where field personnel collected data for mark–recapture population estimates. For each year and survey station, I combined data for all captured brown trout (regardless of strain) to determine a total brown trout population estimate. As was similarly done for the depletion estimates, I calculated separate population estimates for size-groups (age-groups) (estimated from a length-frequency histogram) that were likely to have similar catchability and added them together to derive the total population estimate. I then converted this estimate to density (number/acre) and apportioned density into strains and inch-groups based upon the proportion of unmarked (i.e., no temporary caudal clip) fish captured on the combined marking and recapture runs (Avery et al. 2001). The density and biomass of

8.0-in and larger fish and the biomass of all inch-groups were calculated as described above for depletion estimates.

Individual ages of stocked fish were known, since all hatchery cohorts were given a strain-specific fin clip prior to stocking. I calculated the weighted mean length at age for each strain from all new fish captured on all combined depletion passes or on the combined marking and recapture runs. 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 (DeVries and Frie 1996). 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 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 because I assumed that differences in weight were possible between strains, I did not use standard brown trout length–weight regressions to estimate among-strain differences in weight gain or total biomass.

I used mixed-effect analysis of variance to determine whether the performance of stocked brown trout varied as a function of strain, river, and year in 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 8.0-in and larger brown trout, 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 contributions of stocked fish and unclipped fish to the total population. Since many of the unclipped resident fish were presumably young of the year (<4.0 in TL), I used total density and total biomass as metrics of performance. For all mixed-effect models, I treated river, year, and strain (or origin for comparisons of density and biomass between stocked and unclipped resident brown trout) as fixed effects and survey station (nested within river) as a random effect. Interactions and main effects were examined individually and were removed from the model when not significant. When appropriate, I transformed the data to meet the necessary distributional assumptions. I used Bonferroni-adjusted P-values for multiple comparisons of density, survival, and growth among strains, and I set the rejection criterion α at 0.05 for all analyses. All data were analyzed with SPSS version 11.5 (SPSS, Inc. 2002).

Results

Based on 96 separate population estimates (generated from a combination of rivers, survey stations, and years), the total density of stocked brown trout varied significantly by strain (Table 2). Mean total density was significantly higher for GC brown trout than for either SF or WR brown trout (Table 3; Figure 2). No significant difference was detected between SF and WR strains. Mean total density of stocked brown trout also varied by year and river regardless of strain, as indicated by a significant river × year interaction (Table 2).

A significant strain × year interaction indicated variability in the density of 8.0-in and larger brown trout across strains and years (Table 2). Point estimates of GC brown trout density were less than those of WR brown trout density during the first and third years of the study, while in the second and fourth years GC brown trout density was higher than WR brown trout density (Figure 3). The density of 8.0-in and larger SF brown trout remained relatively stable throughout all years of study and was lower than density estimates of 8.0-in and larger GC or WR brown trout. Population estimates of 8.0-in and larger stocked trout also varied significantly by river; the highest densities occurred in the Coldwater River, followed by Fish Creek, the Indian River, the Manistee River, the Rogue River, and Paint Creek.

Since the estimated 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 I 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 than did the SF and WR brown trout strains (Table 3). No significant difference in survival to age 2 was detected between SF and WR brown trout (Table 3; Figure 4). Mean survival to age 3 or 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 2). Some age-3 (8 fish) and age-4 (3 fish) GC brown trout were captured during sampling, whereas few age-3 SF or WR brown

TABLE 2.—Summary of a mixed-effect analysis of variance that modeled the effects of stocked brown trout strain (excluding unclipped resident fish), river, and year on density, survival, and growth in six Michigan rivers. The value of *N* indicated the total number of population estimates or point estimates of survival and growth used in the analysis.

Metric	*N*	Variation	*F*	df	*P*
Total density (number/acre)	96	Strain	41.07	2, 63.19	<0.001
		River	6.24	5, 8.22	0.011
		Year			
		River × year	2.66	17, 64.01	0.002
Density of fish ≥8 in (number/acre)	96	Strain	4.68	2, 72.73	0.012
		River	10.84	5, 9.32	0.001
		Year			
		Strain × year	2.05	9, 72.96	0.045
Survival to age 2 (%)	66	Strain	8.68	2, 57.16	0.001
		River			
		Year			
Survival to age 3 (%)	42	Strain	2.129	2, 33.07	0.135
		River			
		Year			
Poststocking growth increment (in)[a]	81	Strain	15.39	2, 45.52	<0.001
		River			
		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
Age 1–2 growth increment (in)	28	Strain	2.271	2, 28.04	0.122
		River			
		Year			

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

trout (one fish each) and no age-4 SF or WR brown trout were caught during this study.

Although smaller at the time of stocking, the GC fish grew faster in the first summer after stocking and in general were similar in length to the SF or WR fish after 1 year (Table 4). However, the presence of a significant river × strain interaction indicated variability in age-1 growth across rivers and strains (Table 2). Point estimates of the initial growth after stocking of GC brown trout were higher than those of SF or WR brown trout across all rivers, whereas the initial growth of SF and WR brown trout varied considerably among rivers (Figure 5). The initial growth after stocking for age-1 fish also fluctuated among rivers and years, as indicated by a significant river × year interaction (Table 2). Although the point estimate of the mean growth increment from age 1 to 2 was slightly higher for GC brown trout than for SF and WR brown trout, growth from age 1 to 2 did not vary significantly by strain (Table 2). Because SF and WR brown trout survival to ages 3 and 4 was very low, I did not have sufficient data to statistically compare growth increments of either strain to those of the GC strain. The mean length of the GC strain was similar to the mean lengths of the SF and WR strains at age 3 (Table 4).

On average, the total density of stocked fish was nearly half that of unclipped resident fish. However, significant variability in the densities of stocked and

TABLE 3.—Bonferroni-adjusted *P*-values from multiple comparison tests evaluating mean differences in density and survival between three brown trout strains stocked in six Michigan rivers during 1997–2000 (strains are Gilchrist Creek [GC], Seeforellen [SF], and Wild Rose [WR]).

Metric	Strain comparison	*t*	df	*P*
Total density (number/acre)	GC versus WR	6.58	63.19	<0.001
	GC versus SF	6.24	63.19	<0.001
	SF versus WR	1.71	63.19	0.274
Survival to age 2 (%)	GC versus WR	3.09	57.96	0.010
	GC versus SF	3.27	62.83	0.005
	SF versus WR	0.97	60.85	0.999

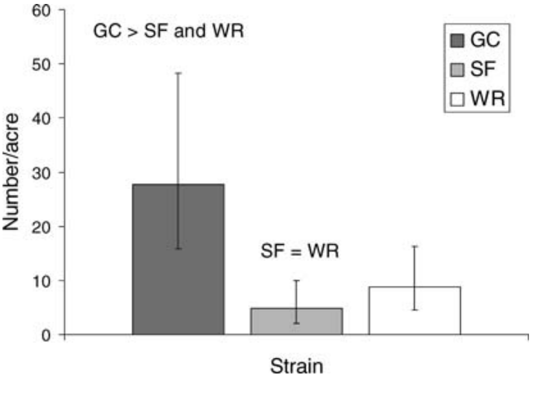

FIGURE 2.—Mean back-transformed total density of three brown trout strains (GC = Gilchrist Creek, SF = Seeforellen, and WR = Wild Rose) stocked in six Michigan rivers during 1997–2000. The thin vertical lines represent 95% confidence intervals.

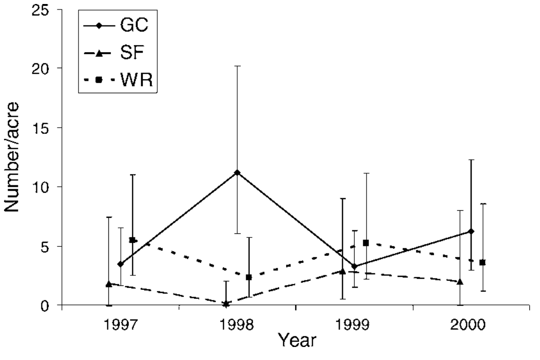

FIGURE 3.—Mean back-transformed density of 8.0-in and larger brown trout of three strains (GC = Gilchrist Creek, SF = Seeforellen, and WR = Wild Rose) stocked in six Michigan rivers during 1997–2000. The thin vertical lines represent 95% confidence intervals.

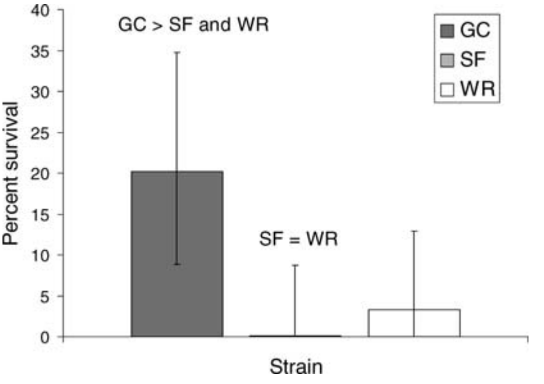

FIGURE 4.—Mean back-transformed survival to age 2 for three brown trout strains (GC = Gilchrist Creek, SF = Seeforellen, and WR = Wild Rose) stocked in six Michigan rivers during 1997–2000. The thin vertical lines represent 95% confidence intervals.

unclipped resident brown trout occurred across rivers, as indicated by a river × origin interaction (Table 5). Point estimates of density were highest for unclipped resident fish in all rivers except the Coldwater River, in which the total density of stocked fish was 4.5 times higher than that of unclipped resident fish (Figure 6). Similar to the results for total density, significant variability in the biomass of stocked and unclipped resident brown trout also occurred across rivers, as indicated by a river × origin interaction (Table 5). Point estimates of total biomass were higher for unclipped resident fish than for stocked 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, respectively, that of unclipped resident fish (Figure 6). The presence of significant river × origin interactions for the density and biomass of 8.0-in and larger brown trout indicated variability of these metrics across rivers and origin (Table 5). Point estimates of the density and biomass of 8.0-in and larger brown trout were highest for unclipped resident fish in all rivers except the Coldwater River. Again, differences in density and biomass estimates were most notable in the Coldwater River, where the density and biomass of 8.0-in and larger stocked brown trout were 4.4 and 3.9 times higher, respectively, than those of 8.0-in and larger unclipped resident brown trout (Figure 7).

Discussion

I found that the wild GC brown trout exhibited higher survival than the domestic SF and WR strains. On average, survival of GC brown trout during the first year after stocking was more than 100 times higher than that of SF brown trout and more than six times higher than that of WR brown trout. In addition, several 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 and in some cases legal-sized GC fish were higher than the densities of the SF and WR strains throughout the study. Weiss and Schmutz (1999) also observed that the survival of hatchery brown trout was substantially lower than that of wild fish after 1 year in an Austrian stream, while Berg and Jørgensen (1991) noted that poststocking mortality of wild brown trout was lower than that of hatchery-origin brown trout in a Denmark river. In Wisconsin, Avery et al. (2001) documented that survival was much higher in a stocked wild brown trout strain than in domesticated brown

TABLE 4.—Mean length and length range (in) of three brown trout strains stocked in six Michigan rivers across all years in which population estimates were made.

	Age 1		Age 2		Age 3		Age 4	
Strain	Mean length	Mean length range	Mean length	Mean length range	Mean length	Mean length range	Mean length	Mean length 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			

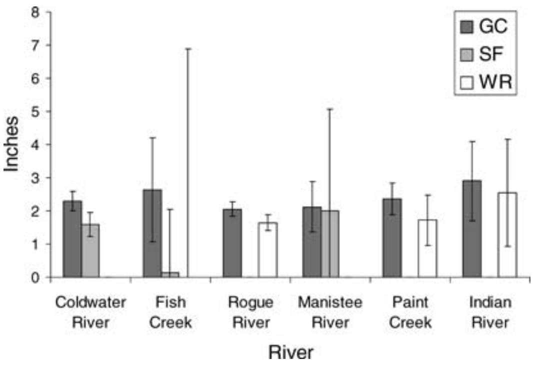

FIGURE 5.—Mean growth increment from stocking to time of first sampling for three brown trout strains (GC = Gilchrist Creek, SF = Seeforellen, and WR = Wild Rose) stocked in six Michigan rivers during 1997–2000. The thin vertical lines represent 95% confidence intervals.

trout in two rivers during 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, and Alexander and Peterson (1983) documented that the survival rate of age 1–3 hatchery-reared brown trout was significantly lower than that of wild brown trout in a Michigan stream. Clearly, these results indicate the potential for greater poststocking survival in wild trout strains than domesticated strains.

TABLE 5.—Summary of a mixed-effect analysis of variance that modeled the effects of origin (stocked or unclipped resident fish), river, and year on brown trout density and biomass in six Michigan rivers. The *N*-value indicates the total number of density or biomass point estimates used in the analysis.

Metric	*N*	Source of variation	*F*	df	*P*
Total density (number/acre)	144	Origin	8.95	1, 84	0.004
		River	5.12	5, 84	<0.001
		Year			
		River × origin	7.19	5, 84	<0.001
Total biomass (lb/acre)	144	Origin			
		River	19.441	5, 84	<0.001
		Year			
		River × origin	9.23	5, 84	<0.001
Density of fish ≥8 in (number/acre)	144	Origin			
		River	19.12	5, 84	<0.001
		Year			
		River × origin	5.64	5, 84	<0.001
Biomass of fish ≥8 in (lb/acre)	144	Origin	4.729	1, 81	0.033
		River	16.513	5, 81	<0.001
		Year	3.029	3, 81	0.034
		River × origin	7.908	5, 81	<0.001

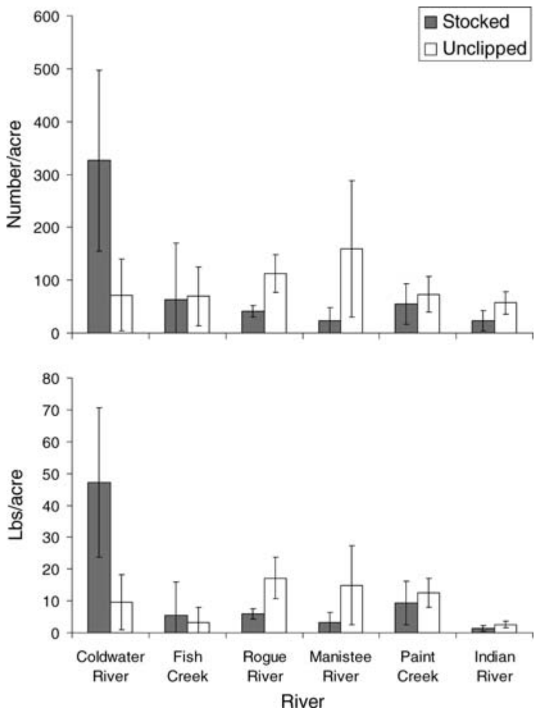

FIGURE 6.—Mean density (top panel) and biomass (bottom panel) of three stocked brown trout strains and unclipped resident brown trout in six Michigan rivers. The thin vertical lines represent 95% confidence intervals.

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 brown trout strain displayed growth that was superior to the growth of other wild strains and a domestic strain in four Michigan lakes. The initial growth of GC brown trout during the first summer after stocking in my study was nearly two times that of SF brown trout and 1.5 times that of WR brown trout when adjusted for initial length. 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.

In my study systems (with the exception of the Coldwater River), the densities of stocked brown trout

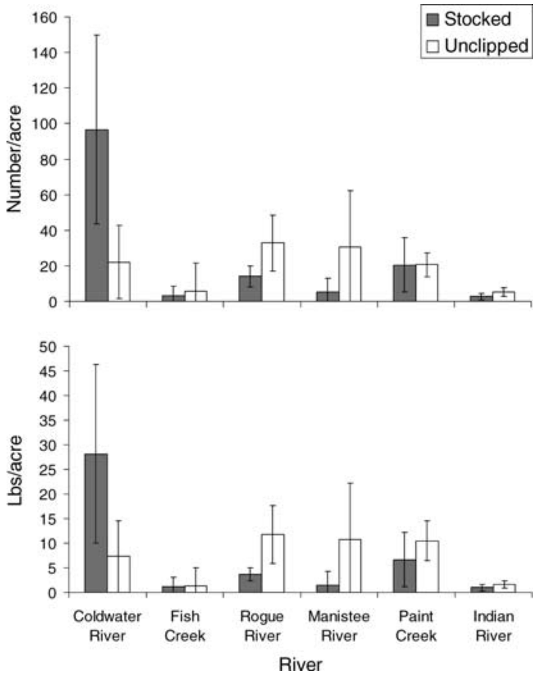

FIGURE 7.—Mean density (top panel) and biomass (bottom panel) of 8.0-in and larger stocked brown trout of three strains and unclipped resident brown trout in six Michigan rivers. The thin vertical lines represent 95% confidence intervals.

on average were much lower than the densities of unclipped resident fish. Although some unclipped resident fish may have been carry-overs of stocked fish from previous years, the low survival of the domestic strains in this study suggests that the possibility of this was minimal. Also, the presence of unclipped resident fish smaller than 4.0 in TL indicates that natural reproduction is occurring. Fisheries managers should judge whether such natural reproduction is enough to sustain the fishery; if it is, managers should consider making more efficient use of resources by reducing or discontinuing stocking.

Variability due to river and year and their interactions with origin (stocked versus unclipped resident fish) was present in my six study systems. Significant river effects may account for the different characteristics of the study systems, such as stocking densities, available habitat, and thermal regimes. For example, stocking densities in the Coldwater River were much higher than those of other rivers included in this study. Although the level of stocking may explain why the density of stocked brown trout was higher than that of unclipped resident brown trout in this river, habitat may also play a role. The Coldwater River is a channelized system; during the time period when data were collected for this study, this river contained a finite amount of substrate suitable for spawning and little or no woody material to provide cover (J. Wesley, MDNR, personal communication). Therefore, the potential of brown trout to reproduce is limited relative to that of other rivers with higher-quality physical habitat. Significant year effects indicated yearly environmental variability or differences in hatchery production lots. The presence of significant interactions, especially in density and biomass comparisons between stocked and unclipped resident fish, complicated data interpretation. Such interactions indicate that the variety of environmental conditions present in the rivers of study had variable effects on stocked fish as well as on the natural reproduction of unclipped resident fish.

Since the primary goal of stocking is to maintain or improve fisheries, the return of stocked fish to the angler should 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 12.0-in minimum size limit; however, those authors noted that the significantly higher survival of wild brown trout provided the opportunity for similar or increased angler returns in the following years. Creel data available for the time period in which this study was conducted offers contrasting results (Wills 2005). In the Manistee River, volunteer angler creel information suggested that catch rates were very similar between the wild GC brown trout and the domestic SF strain. In contrast, the proportion of domestic WR brown trout in the creel of interviewed anglers on the Muskegon River, where paired plantings were made from 1999 to 2001, was much higher than that of the wild GC strain.

Fisheries managers should obtain and weigh information on angler catch rates and returns relative to management objectives when considering which strain to stock. Lack of angler data makes it difficult to determine whether the low survival that I observed for the SF and WR strains was partly due to the fact that these fish were slightly larger at the time of stocking than the GC strain (and hence were susceptible to harvest sooner) or entirely due to poor fitness as the result of domestication. Although the higher mean length at age observed for age-1 SF and WR brown trout suggests that these strains may be more vulnerable to angler harvest than GC fish during their first summer after stocking, the among-strain differences in density of 8.0-in and larger brown trout, particularly between GC and SF fish, imply that in some years more legal-sized GC brown trout were available for harvest. Although some WR and SF brown trout are undoubtedly susceptible to angler harvest before many of the GC fish, the higher survival of GC brown trout to older age-classes indicates their excellent performance and potential to provide sustained recreational angling opportunities.

Besides a lack of rigorous angler data, my study has other limitations. Although two-pass depletion sampling is frequently used to conduct population estimates (Heimbuch et al. 1997), the technique is often biased and prone to failure if the number of fish collected during the second pass is greater than or equal to the number of fish captured during the first pass (Pollock 1991). Accordingly, Riley and Fausch (1992) advocated that a minimum of three passes should be conducted when the depletion method is used, while Peterson and Cederholm (1984) recommended use of mark–recapture population estimates. Although none of the population estimates that I calculated from the two-pass depletion technique failed, three-pass depletion or mark–recapture estimates would have been more desirable and might have provided a more accurate estimate of abundance. In addition, the ability of field personnel to distinguish stocked brown trout strains from each other and from 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 are unrecognizable, bias in the population, survival, and growth estimates could occur. Since quality control data from the hatchery were not available, I assumed that (1) the fin clips given to the stocked brown trout were of good quality, (2) the trained field personnel responsible for sampling recognized the clips, and (3) any unrecognizable clips were present in equal proportions among all strains. I also assumed that the stocked brown trout distributed themselves consistently throughout the study sites across all years of study and were equally vulnerable to capture. Inconsistent distribution of stocked brown trout throughout the study sites would again subject the population, survival, growth, and angler harvest estimates to bias.

Fisheries managers should consider the results of this and other studies that have demonstrated the greater performance of wild salmonid strains relative to domestic salmonid strains when determining stocking strategies. I found that the wild GC strain of brown trout survived and grew better than the domestic WR and SF strains. Seeforellen brown trout exhibited the lowest survival and lowest immediate poststocking growth of the three strains and should be stocked with caution in lotic systems. I also found that in general, the density and biomass of stocked brown trout were lower than those of unclipped resident fish.

The finding that wild GC brown trout displayed higher survival and growth than the domestic WR and SF strains is extremely relevant to stocking strategies and fisheries management. In 2000, the minimum size limits in the majority of my study rivers changed from 8.0 in to 10.0 or 12.0 in. 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 age-4 GC brown trout allows the chance for natural reproduction to occur, as such fish will probably be sexually mature.

By determining the necessity of stocking 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 for stocking into streams where higher size limits require good poststocking survival for a year or more so that fish can achieve the minimum size limit.

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