A Native Westslope Cutthroat Trout Population Responds Positively After Brook Trout Removal And Habitat Restoration

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Abstract

The distribution and abundance of westslope cutthroat trout (*Oncorhynchus clarki lewisi*; WCT) have dramatically declined across much of their historical range, but particularly within the upper Missouri River basin of Montana. A genetically pure remnant WCT population inhabits White's Creek in the Missouri River basin, Montana; however, this population was extremely low during the early 1990s (~ 80 fish ≥75 mm long) due primarily to interaction with sympatric, nonnative brook trout (*Salvelinus fontinalis*) and habitat alterations caused by past dredge and placer mining. From 1993 to 2000 brook trout were removed by repeated electrofishing. In 1995 the mining-impacted portion of the stream was restored and a fish migration barrier was constructed. Brook trout were successfully removed from White's Creek above the constructed barrier after eight years of intensive electrofishing effort. The population of WCT increased dramatically, at least seven-fold, following removal of brook trout, with the most pronounced response seen for age-0 WCT. The portion of White's Creek where stream habitat was restored supported similar abundances of WCT (catches of ~30 WCT ≥75 mm long/100 m of stream) as found in natural stream reaches above and below this restored portion. Following brook trout removal, standing crops of WCT in allopatry were similar to combined standing crops of brook trout and WCT in sympatry prior to initiation of brook trout removal. Electrofishing appeared to be an effective tool for removal of brook trout in this small stream with relatively uncomplex habitat; however, we caution that it may not be effective in larger systems.

Keywords: brook trout, competition, electrofishing, fish barrier, habitat restoration, native trout conservation; nonnative fish removal, *Oncorhynchus clarki lewisi*, westslope cutthroat trout, *Salvelinus fontinalis*

Introduction

The distribution and abundance of westslope cutthroat trout (*Oncorhynchus clarki lewisi*; WCT) have dramatically declined across much of their historical range, but particularly within the upper Missouri River basin of Montana (Liknes and Graham 1988, Behnke 1992, McIntyre and Rieman 1995, Van Eimeren 1996, Shepard et al. 1997). Factors associated with this decline include introductions of nonnative fishes, habitat changes, and over-exploitation (Hanzel 1959, Liknes and Graham 1988, Behnke 1992, McIntyre and Rieman 1995). Genetic introgression with introduced rainbow (*O. mykiss*) and Yellowstone cutthroat (*O. c. bouveri*) trout also represents a serious threat to WCT throughout their range (Allendorf and Leary 1988). Leary et al. (1987) suggested that the subspecies WCT should be accorded the same attention given to taxonomically recognized species due to their high amount of genetic divergence. Due to a relatively high amount of genetic variability observed among populations of WCT, Allendorf and Leary (1988) recommended conservation of many populations throughout its historical range as necessary to conserve genetic diversity presently contained within this subspecies.

Shepard et al. (1997) estimated that genetically pure populations of WCT within Montana's upper Missouri basin currently occupy <5 percent of their historical range and indicated that many remaining extant populations in the Missouri basin had relatively low probabilities of persisting for the next century unless conservation measures were implemented. Montana has a long history of WCT conservation and formalized a collaborative statewide conservation agreement with federal land management agencies and several private organizations (Montana Fish, Wildlife and Parks 1999). A primary objective in this conservation agreement is the protection and expansion of existing populations.

Many habitats historically occupied by WCT now contain populations of nonnative trout and in many cases these nonnative trout have totally replaced WCT (MacPhee 1966, Griffith 1972, Behnke 1979 and 1992, Liknes and Graham 1988, McIntyre and Rieman 1995). This type of replacement has also been suggested for other cutthroat trout subspecies (Behnke 1979 and several papers in Gresswell 1988). Griffith (1988) reviewed the literature on competition between cutthroat trout and other salmonids and concluded that interactions between native rainbow trout and WCT probably resulted in either spatial or niche segregation between the two species.

In the upper Missouri basin a large proportion of historical WCT habitats are now occupied by nonative brook trout (*Salvelinus fontinalis*) introduced into the basin during the early 1900s (Shepard et al. 1998). Griffith (1970, 1972, 1974) documented dietary overlap between brook trout and WCT and suggested that brook trout could replace WCT, but this replacement likely occurs only after degradation of habitat has reduced or eliminated WCT. Thomas (1996) observed that young brook trout inhibited foraging efficiency of juvenile Colorado River cutthroat trout (*O. c. pleuriticus*) in a controlled laboratory setting. She suggested that this inhibition might be the mechanism responsible for decreased growth rates she documented for cutthroat trout in the wild. Underwater microhabitat observations on positions occupied by brook trout and greenback cutthroat trout (*O. c. stomias*) by Cummings (1987) indicated that juvenile brook trout excluded juvenile cutthroat trout from more favorable stream positions.

A population of WCT inhabits White's Creek, a tributary to the upper Missouri River entering Canyon Ferry Reservoir south of Helena, Montana (Fig. 1). By 1993 WCT in White's Creek had been reduced to about 80 individuals that occupied two different areas of the stream separated by an intermittent segment of channel that only flowed during high flow events. Factors believed primarily responsible for this low WCT abundance included the invasion and establishment of a relatively strong brook trout population and impacts of past placer and dredge mining activities on aquatic habitats over a 1 km portion of the stream channel below the intermittent channel. Moore et al. (1983), Moore et al. (1986), Larson et al. (1986), and Kulp and Moore (2000) found that repeated, intensive electrofishing removals conducted over time reduced or exterminated nonnative rainbow trout populations allowing native brook trout populations to rebound in streams of the Great Smokey Mountains National Park. Thompson and Rahel (1996) evaluated depletion electrofishing for removal of brook trout in three streams of Wyoming to conserve Colorado River cutthroat trout and found that densities of brook trout could be dramatically reduced, but not eradicated, by three-pass depletion electrofishing. They also reported that an additional single electrofishing pass conducted the year after the three-pass effort helped to further reduce brook trout numbers, especially age-1 fish that were missed as age-0 the previous year.

We wished to evaluate if 1) repeated electrofishing efforts could successfully

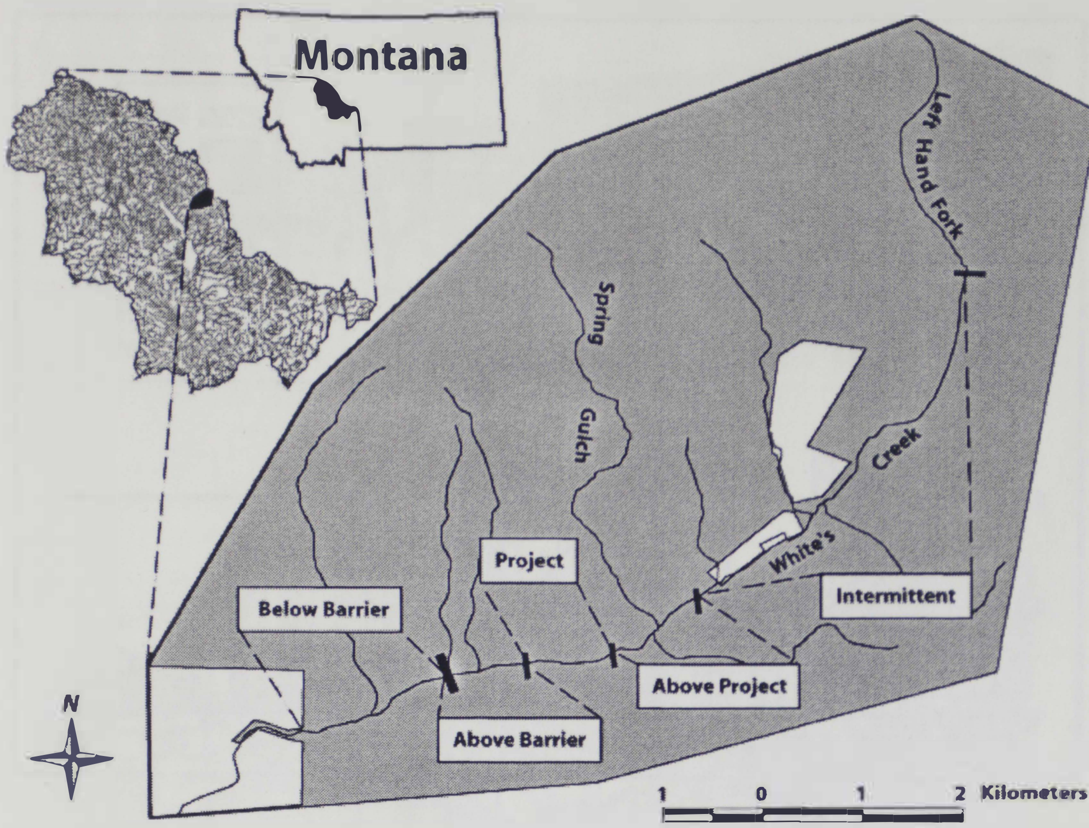

Figure 1. Map of White's Creek study area showning Forest Service (shaded) and private (unshaded) ownership, location of constructed fish barrier (dark bar), and reaches that were sampled (boxes designate named reaches).

remove brook trout from White's Creek, and 2) reductions or elimination of brook trout would result in positive population responses by WCT and, if so, what demographic parameters of the WCT population would be affected. In addition, we discuss whether combined habitat reclamation and brook trout removal would result in a different response by WCT than brook trout removal alone; and if interactive mechanisms between brook trout and WCT could be inferred from the population response exhibited by WCT following removal of brook trout.

Study Area Description

White's Creek lies within the White's Gulch drainage on the east side of Canyon Ferry Reservoir, a large reservoir on the Missouri River above Helena, Montana (Fig. 1). All White's Creek's flow from the Forest Service boundary (stream km 8.8) downstream was diverted for flood and sprinkler irrigation, except during extreme high spring runoff events. This de-watering of the channel below the Forest Service boundary has isolated the upper portion of the drainage from Canyon Ferry Reservoir. Flows were also intermittent in the upper basin, from stream km 13.6 up to the Left Hand Fork of White's Creek (km 18.4; Fig. 1). Base summer flows in White's Creek below Spring Gulch Creek usually ranged from 0.05 to 0.15 m^3/sec and there was high inter-annual variation in summer monthly flows during this study (Fig. 2). Wetted widths averaged about 2 m, average depth was about 10 cm, pools comprised 10-20 percent of all habitat types, and while small (<150 mm diameter) woody debris was fairly common (75-175 pieces/km), large (>150 mm) debris was relatively scarce (4-19 pieces/km) based on habitat surveys in three separate sections of approximately 100 m. About 400 m of channel in the Left Hand Fork of White's Creek maintained an

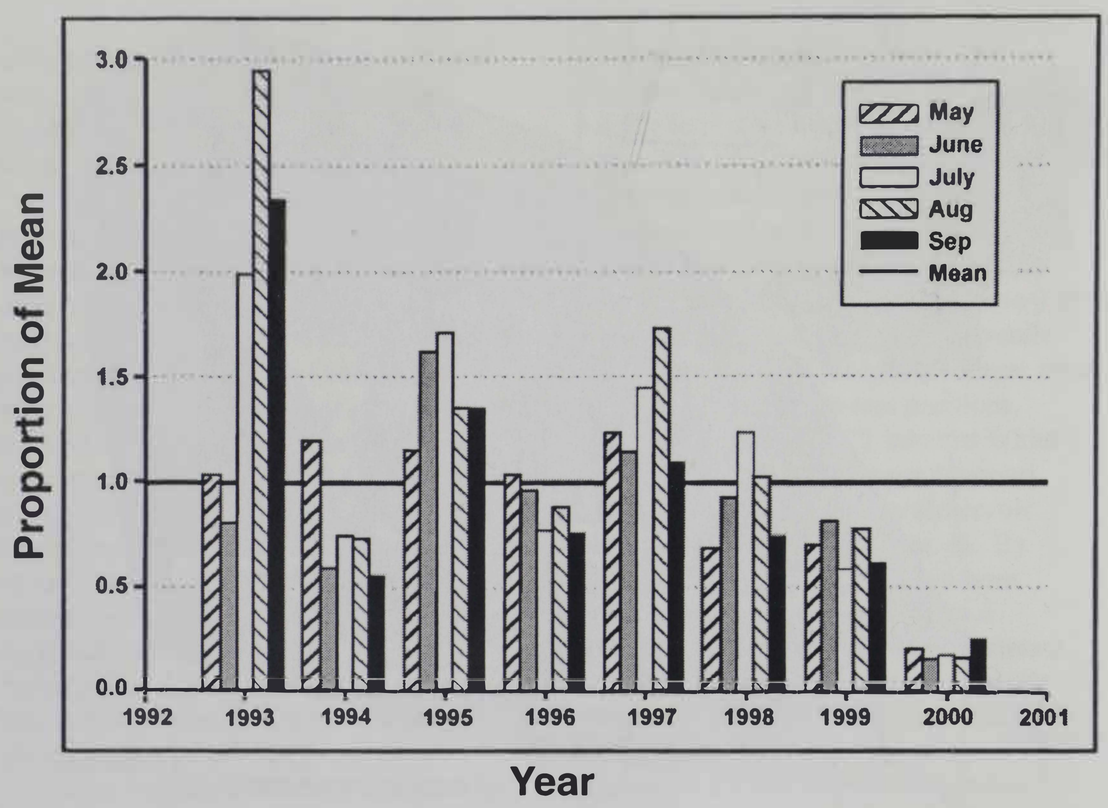

Figure 2. Proportion of mean monthly flows from May through September from 1993 through 2000 in Prickley Pear Creek, a USGS gauged tributary near White's Creek, based on 59 years of record showing the exteme high flows of summer 1993, higher than average flows in 1995 and 1997, and drought conditions of 1999 and 2000.

estimated yearlong flow (~0.03 m^3/sec) originating from springs, but its flow subsided into the streambed near its mouth with White's Creek. Onset Optic Stowaway® thermographs deployed during the summers of 1997 and 1999 at two locations below Spring Gulch Creek measured average daily summer water temperatures that ranged from 8 to 10 °C.

Past placer and dredge mining activities heavily impacted the portion of White's Creek from stream km 11.4 to 12.4. These impacts included the diversion of most of White's Creek's flow into a diversion canal located along the north valley wall, several large dredge ponds located within the valley floor, and intermittent flows between some of these dredge ponds (Fig. 3, top). An extremely high flood event occurred after an intense local thunderstorm during the summer of 1993 (Fig. 2). This flood event resulted in breaching of the diversion canal and several of the dredge ponds creating several large headcuts within the channel.

The only fish species found in White's Creek above the Forest Service boundary were WCT and brook trout. No rainbow trout have been captured in White's Creek above the Forest Service boundary although rainbow trout from Canyon Ferry Reservoir have been sampled spawning in the lowermost reaches of White's Creek immediately above the reservoir.

METHODS

During the fall and winter of 1995 reclamation of the mining impacted reach (1.0 km; Project reach) of White's Creek was undertaken. This reclamation included total reconstruction of the stream channel and valley bottom; installation of 11 grade control structures across the channel, eight of which crossed the entire valley width; placement of woody debris in the channel

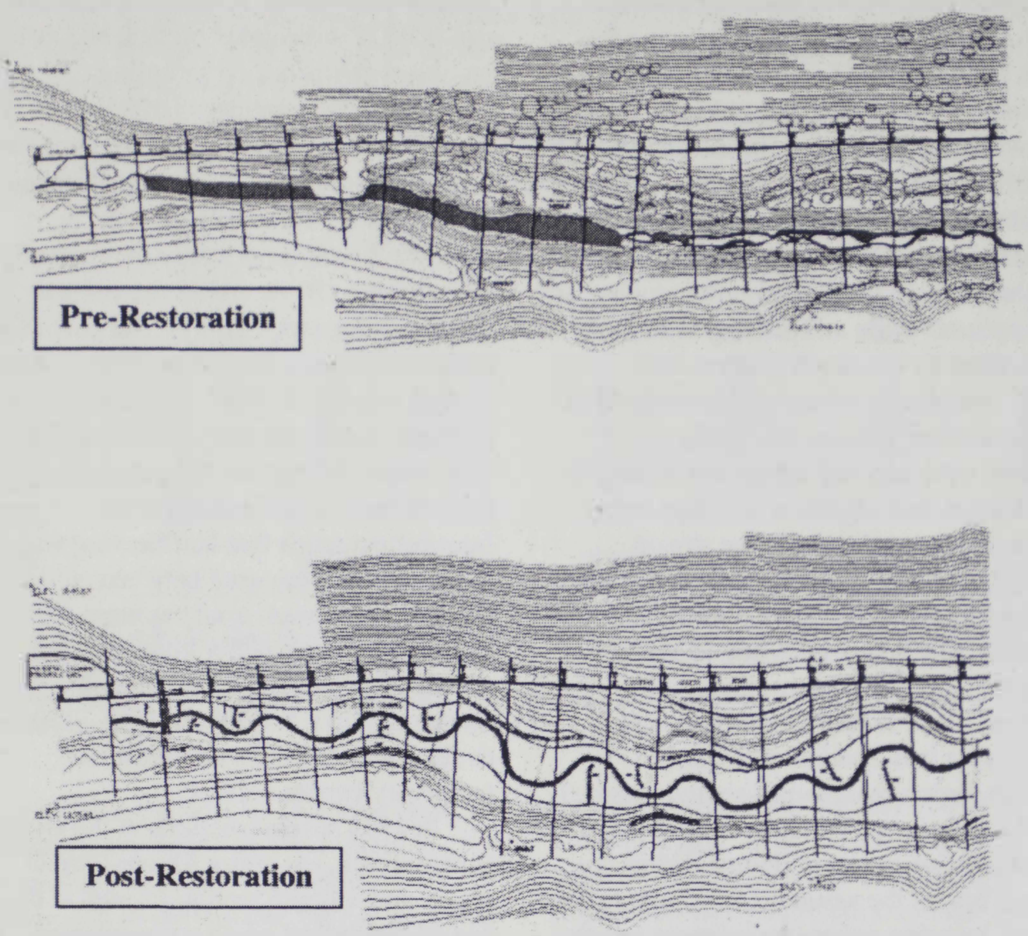

Figure 3. Plano-metric maps of the Project reach of White's Creek pre- and post-restoration showing contours, channel location, and cross-sections (maps provided by Inter-fluve, Bozeman, Montana).

and on the floodplain; and planting of vegetation throughout the floodplain (Fig. 3). A barrier to upstream fish movement also was constructed at stream km 10.6 in the fall of 1995. This barrier was constructed using treated wood and consisted of a 1.5-m drop onto a treated wood apron that is designed to prevent the formation of a scour pool at the base of the barrier that could be used as a jump pool. In addition, the channel was widened immediately below the barrier to prevent water from backing up against the barrier at peak streamflows.

Four designated reaches were surveyed during the study. The first reach (Below Barrier) went from the Forest Service boundary upstream to the constructed barrier. This reach was about 1800 m long, but most sampling occurred immediately below the constructured barrier. The second reach (Above Barrier) extended from the wooden crib barrier up to the bottom end of the reclaimed portion of the stream and was approximately 750 m long. The third reach (Project Area) consisted of the entire 1000-m long reclaimed portion of the channel. The fourth reach (Above Project) was from the top boundary of the Project upstream 1200 m to where the flow in the channel normally becomes intermittent. The Left Hand Fork (Fig. 1) may have contributed a few downstream WCT migrants to the study reaches during high water flows; however, the population in the Left Fork was very low and stable during the study (~30 WCT ≥75 mm long).

Electrofishing was used to remove brook trout and estimate populations of brook trout and WCT using depletion estimators (Van Deventer and Platts 1989). Fish were captured using Smith-Root BP-15 and BP-12 backpack electrofishers operated at voltages in the range of 100-600 V, frequencies under 50 Hz, and pulse widths less than 2 msec to maximize the number of fish captured while minimizing injury to fish caused by the shock (Dwyer et al. 2001). An electrofishing crew consisted of a crewmember wearing the backpack shocker, a primary dip netter that followed the shocker, and usually a backstop netter who kept a large dip net in the stream channel below the two other crewmembers. The backstop net was large enough that it generally spanned at least half of the channel in most sample sections. In addition, block fences or nets (6.5-mm mesh) were installed between sample sections during most sampling and removal events. All electrofishing passes in each sample section were conducted within four hours. We met the assumption of population closure by using either block fences or nets at the upper and lower ends of all sample sections (or, in a few cases, locating sections so they had shallow riffles or velocity barriers at their upper and lower boundaries), the use of a back-stop netter during sampling to prevent fish from moving downstream, and the relatively short time it took to complete all sample passes (White et al. 1982).

Total lengths (mm), species, and pass number were recorded for all captured fish. Weights (g) were not measured for all captured fish, but a relatively large sub-sample of fish, evenly distributed among all the fish sampled, were weighed during initial brook trout removal efforts and during at least two of the post-removal sampling efforts. For a few sample events neither lengths nor weights were measured for brook trout <100 mm (age-0), instead they were counted and their total numbers were recorded by pass and species. Age-0 (<60 mm) WCT were usually not netted during sampling to reduce handling mortality; however, relative abundances of age-0 WCT were noted on data sheets based on observations during sampling.

During the summer of 1993, prior to the major flood event, depletion population estimates were made in several sample sections in the Above-Project reach; however, brook trout were not removed during these efforts. After the summer 1993 flood event, a temporary barrier culvert was installed between the Above-Project and Project reaches at about stream km 12.4. Multiple electrofishing passes (usually two) were made throughout the entire Above-Project reach and a portion of the Intermittent reach that had flowing water. Block fences were used between all sample sections. All brook trout captured during these efforts were either killed and buried on-site (fish <150 mm), killed and transported to a Food Bank (fish ≥150 mm), or relocated downstream below the temporary barrier culvert.

In 1994 several sections in the Below Barrier reach, the entire Above-Project reach, and a single section located at the top end of the Project reach were sampled. All brook trout captured in the Above Project reach were killed and buried on-site. In 1995 the dredge ponds were sampled by a raft-mounted electrofishing unit while being drained in preparation for reclamation construction. Due to high numbers of brook trout captured in the dredge ponds by electrofishing and netted during the draining of these ponds, neither an exact count nor any measurements of brook trout removed from these ponds was recorded. Instead, the total number of brook trout removed was estimated by counting the approximate number of brook trout in a hand held net full of fish and counting the number of nets full of fish removed from these ponds. The entire Above-Barrier reach was sampled twice in 1995, following construction of the barrier and removing brush in this portion of the stream channel. Brush removal consisted of cutting and removing vegetation and woody debris that overhung the channel and a few accumulations of debris within the channel

Table 1. Length sampled and total numbers of brook trout removed from three reaches of White's Creek above a constructed fish barrier from 1993 through 2001. The number of brook trout removed from the Project reach during 1995 was estimated based on footnote.

Year	Above-Barrier		Project		Above-Project		Total EBT removed
	Length (m)	EBT removed	Length (m)	EBT removed	Length (m)	EBT removed	
1993	0	-	130	-	1200[1]	111	111
1994	0	-	230	-	830	33	33
1995	750	1499	1000	2750[2]	1200	22	4271
1996	750	138	800	4	350	2	144
1997	750	119	1000	12	350	4	135
1998	750	59	1000	9	1000	170	238
1999	750	60	800	4	1130	27	91
2000	750	4	400	0	620	0	4
2001	750	0	50	0	0	-	-
Total		**1879**		**2779**		**369**	**5027**

[1] A second sampling was done over 1,000 m of this reach later in the year and the recorded number of brook trout removed was for both sampling events.

[2] Number approximated based on approximate number of fish per dip net and total number of dip nets full of fish removed.

to permit easier access by shocking crews. In addition, the entire Above-Project reach was sampled in 1995. Following construction of the wooden barrier at stream km 10.4, the temporary barrier culvert between the Project and Above-Project reaches (km 12.4) was removed. All brook trout captured during 1995 were relocated below the wooden barrier. A few WCT captured within the Project area in 1995, immediately prior to reclamation, were relocated to locations either immediately above the wooden barrier or above the project area.

Electrofishing estimates and associated brook trout removal efforts continued annually from 1996 through 2000 in the Above-Barrier, Project, and Above-Project reaches; however, in 1996 and 1997 only three monitoring sections (each 100 to 150 m long) within the Above-Project reach were sampled (Table 1). Prior to shocking the Above-Barrier reach in 2000 brush was again cleared to permit shocking crews easier access.

Indices of relative abundance were derived by reporting catch of each species (fish ≥ 75 mm) on the first electrofishing pass, standardized as number/100 m of channel length for all sampling events. We used depletion estimators to calculate population estimates (Van Deventer and Platts 1989) for fish ≥75 mm long and converted to density of fish/ha for all multiple-pass sampling events. Depletion estimators consistently under-estimate true populations, especially when only two passes are made and capture probabilities are <0.90 (Riley and Fausch 1992). White et al. (1982) recommended that three or more passes are necessary unless the capture probability is ≥0.8. Riley and Fausch (1992) suggested that three passes reduced estimate bias. Of the 52 estimates of WCT we made, 41 were two-pass estimates and 11 were three-pass estimates. Estimated probabilities of capture were at least 0.7 for all two-pass population estimates for fish 75 mm and longer and were ≥0.8 for 80 percent of the population estimates.

We estimated total biomass by species for three sample sections in the Above-Project reach by averaging weights of all captured fish by species for length groups of 75-149 mm and ≥150 mm. Average weights and estimated numbers for each size group were used to estimate standing crop for each size group, as well as total standing crop, and reported as grams/m^2; however, we did not include age-0 WCT in total standing crop estimates. Condition factors for individual fish were computed as Fulton-type condition factors (Anderson and Gutreuter 1983) and averaged by reach for all fish ≥75 mm long captured during late summer to early fall (Aug-early Oct). We used a statistical *t*-test assuming unequal variances to test for significant differences ($P < 0.05$ indicated significance) in fish condition by species between fish captured before and during initial brook trout removal efforts (before removal) versus those captured following initial brook trout removal efforts (after removal).

Results

Brook Trout Removal

Slightly over 5000 brook trout were removed from the portion of White's Creek above the wooden barrier from 1993 to 2000 (Table 1). Most of these (~4200) were removed in 1995 when the dredge ponds were drained. Once removal efforts began in each reach, numbers of brook trout removed in subsequent years declined dramatically. However, we thought extensive removal efforts conducted in the Above-Project reach from 1993 to 1995 were successful, so we did not attempt extensive removal efforts in 1996 and 1997. Instead, we limited our efforts to monitoring three sample sections of 100-150 m each to document recovery of WCT. Apparently brook trout either successfully re-colonized this upper portion of the creek from lower reaches, or some mature brook trout evaded removal efforts and successfully reproduced, because in 1998 we captured numerous brook trout in this reach. Consequently, during 1998 we again removed brook trout from this entire reach. By year 2000 we captured only four brook trout while sampling all reaches despite extensive sampling efforts and found no brook trout in 2001 in an 800-m section above the wooden barrier (all of the Below-Project reach and about 50 m of the Project reach).

We more effectively removed larger brook trout (>100 mm) than smaller fish, particularly during early removal efforts (Fig. 4). For example, only brook trout ≥130 mm were captured in initial removal efforts in the Above-Project reach during 1993. During 1994 a few adult-sized and numerous age-0 brook trout were captured in this reach, and by 1997 and 1998, only age-0 and age-1 brook trout were captured. After these age-0 brook trout reached age-1 (>100 mm) in 1998 and 1999 they were more vulnerable to capture.

Average condition factors of brook trout were significantly ($P<0.001$) lower after we began to remove them (1.16 before, $n=237$, versus 1.04 after, $n=204$). Average condition factors still significantly differed ($P<0.001$) when assessed for fish ≥100 mm long (1.17 before removal, $n=177$, and 1.09 after, $n=97$), which suggested that though we more effectively removed larger brook trout during our initial removal efforts, this was not the only cause for differences in condition factors.

Response of Westslope Cutthroat Trout

Numbers of WCT increased following removals of brook trout; however, numbers of cutthroat trout increased only slightly during the first two years following the initial brook trout removal effort. By the fourth year following initial brook trout removals, populations and relative abundance of WCT had reached levels similar to, or higher than, combined populations of brook and cutthroat trout when removals began (Fig. 5 and 6). The estimated population of WCT 75 mm and longer increased almost seven-fold in the Above-Project reach from 1993 to 1999; from about 80 fish to over 340. The increase was even more dramatic in the Above-Barrier reach, where the estimated population increased from about 10 in 1995 to over 340 in 1999.

Estimates of standing crops (g/m^2) in three sample sections within the Above-Project reach showed that, following an

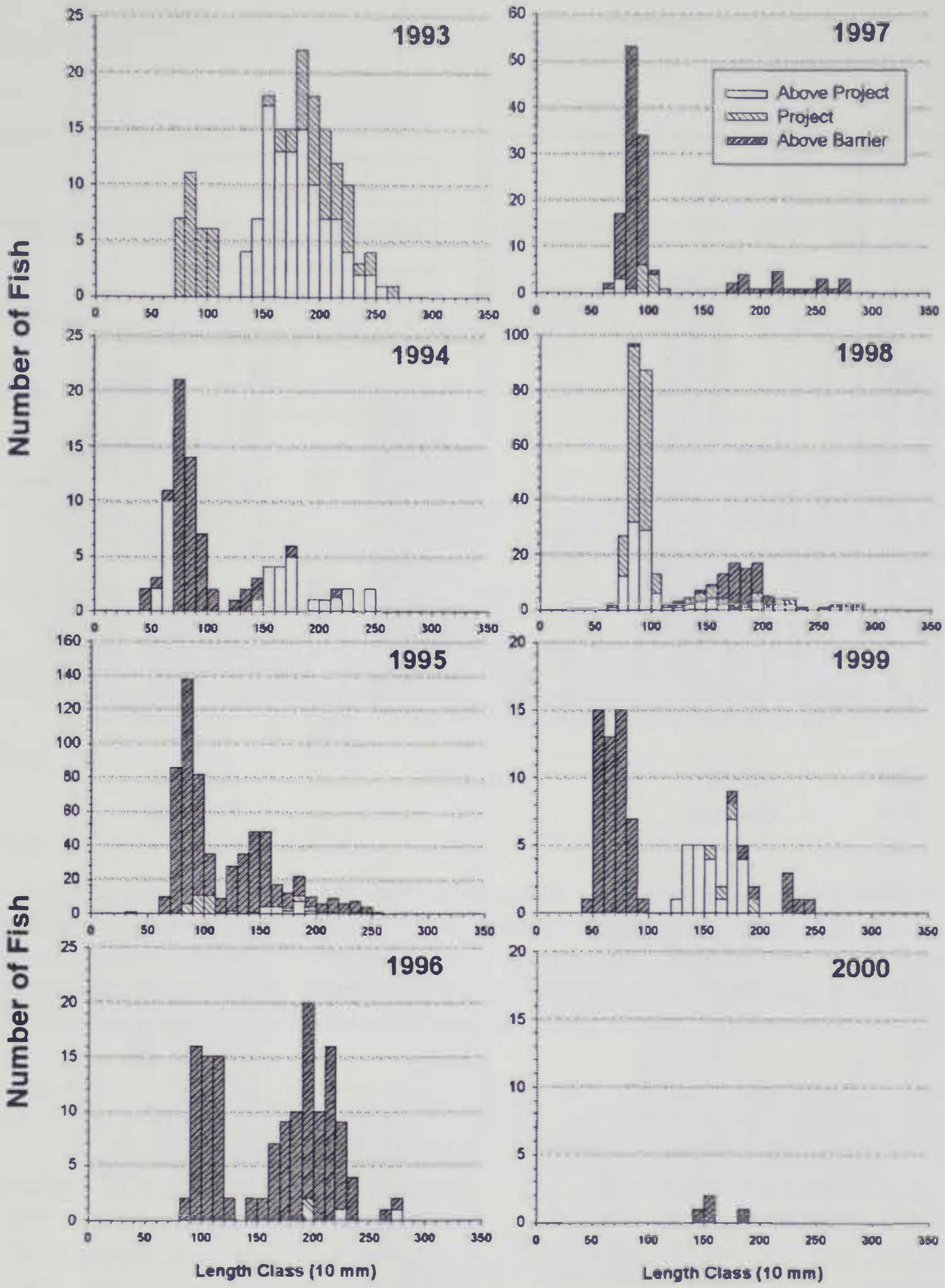

Figure 4. Length frequency histograms for brook trout captured and removed from three reaches of White's Creek from 1993 through 2000. Note that y-axis scales change and that the number of small (<100 mm) brook trout captured increased, while the number of larger brook trout decreased after initial removal efforts.

initial decline in standing crops immediately following the first two years of brook trout removals, WCT standing crops increased to levels at least as high as those observed when both species existed in sympatry (Fig. 7). Standing crop data showed less yearly fluctuations than population and relative abundance data and standing crop information is probably a better measure of population responses because it is a more consistent and stable measure of abundance. Average condition factors of WCT (≥75 mm) were slightly, but not significantly (P=0.14), lower following

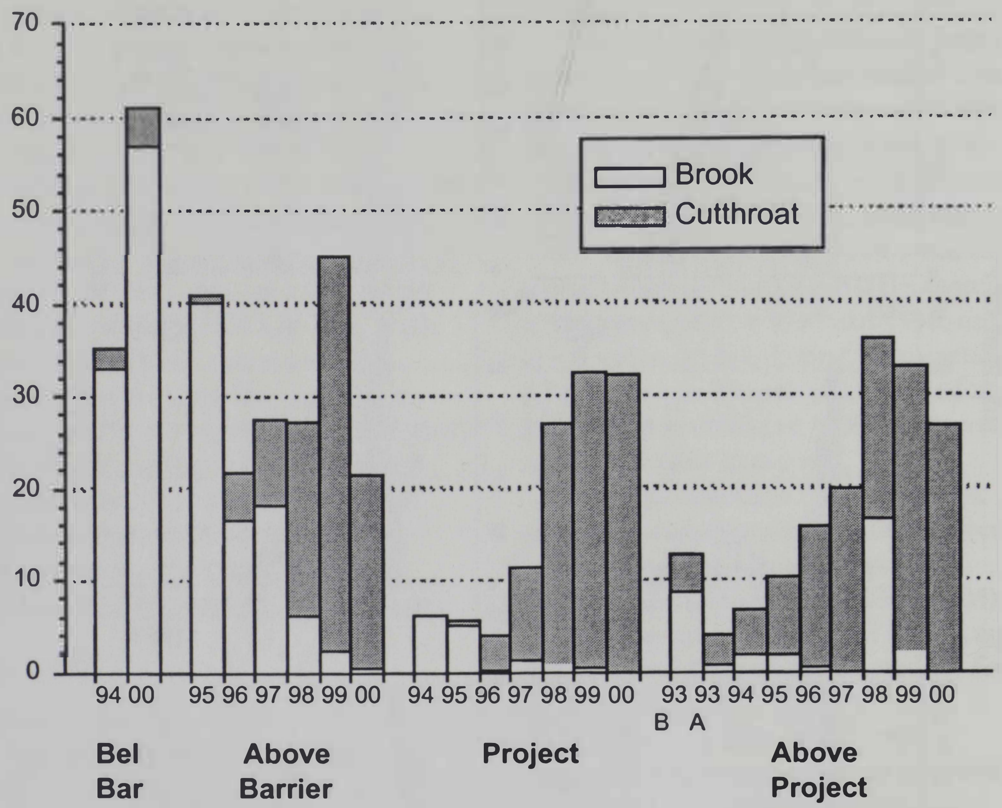

Figure 5. Relative abundance (catch per 100 m in the first electrofishing pass) of brook trout (open bars) and westslope cutthroat (shaded bars) 75 mm and longer in four reaches of White's Creek from 1993 to 2000. Brook trout were not removed from the reach below the wooden crib barrier (Bel Bar). Some of the Above Project reach was sampled once before brook trout were removed in 1993 (93 B) and immediately after brook trout were removed (93 A).

removal of brook trout (0.96 before removal, n=151, versus 0.94 after, n=1497), but were not different when assessed for WCT ≥100 mm long (average condition of 0.94 both before removal, n=133, and after, n=1008; P=0.94).

Length frequency histograms and observations of age-0 WCT that were seen, but not captured, indicated that age-0 WCT (<60 mm) comprised progressively larger proportions of the population after 1995 (Fig. 8). Numerous age-0 WCT were observed, but no attempts were made to capture these age-0 within the Project reach in 1996, one year following its reclamation. In 1997, when efforts were made to capture small WCT, age-0 WCT fish made up a significant proportion of captured fish in all three treated reaches and this strong 1997 year-class of WCT carried through as age-1 (~80-100 mm) fish in 1998 (Fig. 8). Approximately 30 percent of all captured fish ≥75 mm long were longer than 200 mm in the Above-Project reach during 1993 when brook trout removals began. The proportion of these ≥200 mm fish increased to 34-55 percent during 1997 through 1999; however, the proportion of larger fish declined in 2000.

Habitat Restoration

Our observations indicated that flows during peak flow events remained within the constructed Project reach channel from 1995 to 2001, despite higher than normal peak flows experienced during 1997 (Fig. 2). We observed some over-bank flows for a short time during 1996 and 1997, but erosion of valley surface materials outside

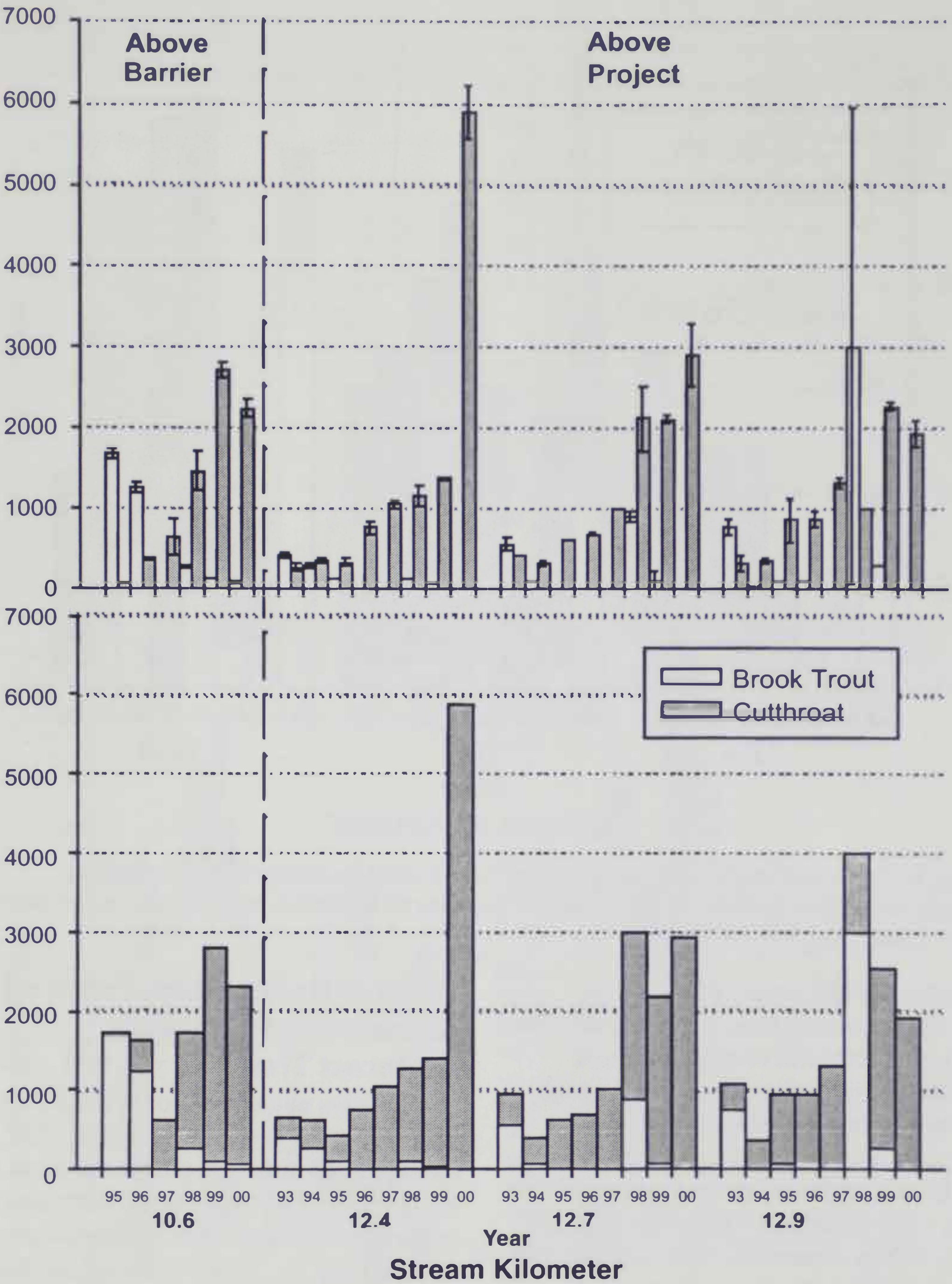

Figure 6. Estimated numbers of brook (open bars) and westslope cutthroat (shaded bars) 75 mm and longer per hectare of stream surface area and associated 95% confidence intervals (vertical lines-top graph) in four sections (designated by stream kilometer) of White's Creek from 1993 through 2000. Kilometer 10.6 was within the Above Barrier reach and km 12.4, 12.7, and 12.9 were within the Above Project reach.

the stream channel was minimal; no new channels were created during peak flow events. We believe that incorporation of underlying valley-wide grade control structures prevented high flows from eroding new stream channels. Valley bottom hay bales and silt fences also effectively prevented rill and channel erosion down the valley floor during the four years it took for valley-bottom vegetation to re-establish. Woody species have yet to become well established, despite two attempts to plant woody species sprigs.

Surface stream flows often become

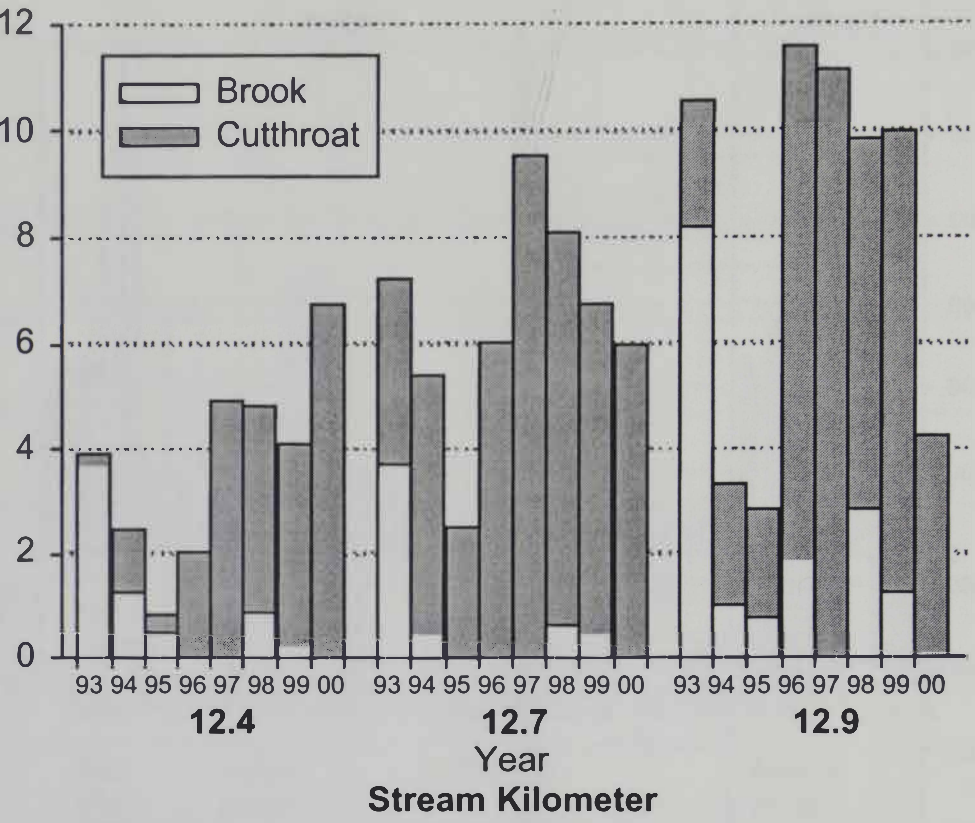

Figure 7. Estimated standing crops (g/m^2) of brook trout (open bars) and westslope cutthroat trout (shaded bars) in three sample sections of White's Creek located in the Above Project reach from 1993 to 2000.

intermittent in the lower portion of the Project reach during base flow periods. The length of intermittent channel declined annually as fine sediments carried by high flow events helped seal the streambed; however, drought conditions in 1999 and 2000 have contributed to the lower portion of this restored channel going dry (Fig. 2). Woody debris elements and excavated pools incorporated into the channel also maintained their integrity throughout this period.

Average daily water temperatures from July 15 to September 15 averaged 2.6 °C higher below the Project reach than above during the summer of 1997, immediately following construction. However, by 1999, after riparian vegetation had begun to establish, differences in average daily water temperatures above and below the Project Area were much less pronounced, averaging only 0.9 °C higher below the project area.

Effect of Habitat Restoration on Abundance of Westslope Cutthroat Trout

Relative abundances of WCT ≥75 mm long within the three reaches from 1998 through 2000 indicated that abundances of WCT within the Project reach were similar to the Above-Barrier and Above-Project reaches (Fig. 5). These data suggest that channel restoration completed in the Project reach provided habitat that was as suitable for WCT as habitats provided by the natural channel immediately above and below the Project reach in White's Creek. Re-colonization of this Project reach by WCT, primarily age-0, began immediately following restoration and removal of all fish from this reach, and progressed rapidly so that this Project reach supported densities of WCT similar to adjacent reaches within about three years.

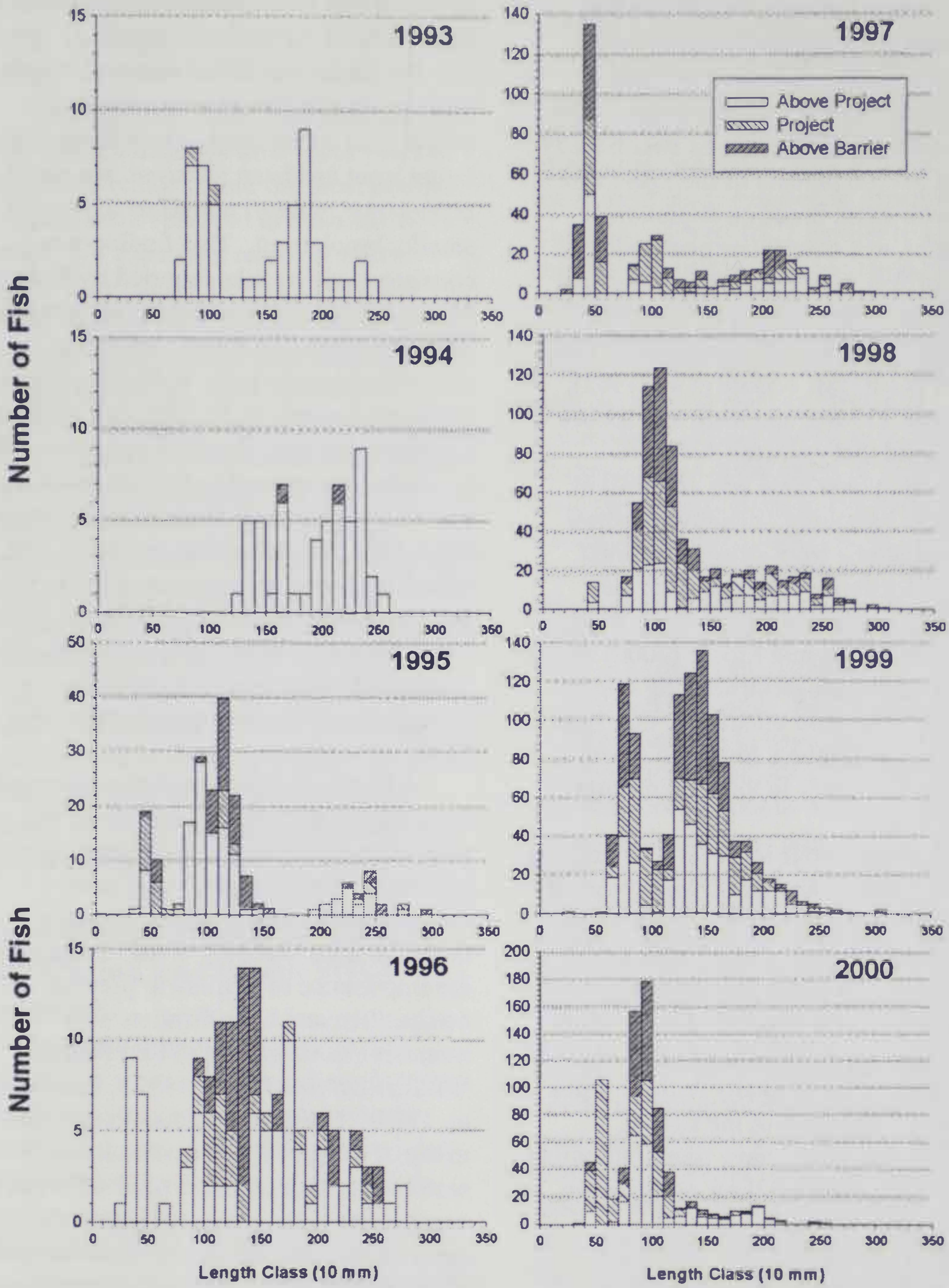

Figure 8. Length frequency histograms for westslope cutthroat trout captured in three reaches of White's Creek from 1993 through 2000. Note that y-axis scales change and that number of smaller age-0 (< 60 mm) and age-1 (60 to 120 mm) westslope cutthroat trout captured increased dramatically following initial brook trout removals (1993 through 1995).

Discussion

Effectiveness of Brook Trout Removals using Electrofishing

In this small, simple stream, we effectively removed brook trout using electrofishing; however, it took us eight years to accomplish an apparent total removal. Sampling found no brook trout in the Project and Above-Project reaches during 2000 and no brook trout in the Above-Barrier reach during 2001.

Thompson and Rahel (1996) found that single three-pass electrofishing removal efforts in headwater portions of three Wyoming tributaries that supported native Colorado River cutthroat trout successfully removed 59-100 percent of the age-1 and older brook trout, based on depletion efficiencies, and over 90 percent based on number of fish removed. They found that efficiencies for removal of age-0 brook trout were lower, based on number of fish removed (42-83%). Moore et al. (1983), Moore et al. (1986), and Kulp and Moore (2000) found that repeated intensive electrofishing over time was effective at reducing or removing nonnative rainbow trout populations from streams in Great Smokey Mountains National Park that historically supported native brook trout populations. Kulp and Moore (2000) found that four three-pass electrofishing efforts within the same year effectively eliminated recruitment of rainbow trout, but a fifth effort was necessary to totally eliminate rainbow trout.

We enhanced our removal efficiency by having vegetation and small woody debris that overhung the stream channel trimmed twice during the seven-year brook trout removal effort to allow our shocking crews easier access to the channel. De-watering and reclamation of the dredge pond areas of stream allowed us to totally remove brook trout from these areas of the stream, something that would have been impossible to do by electrofishing these ponds when they were full of water.

Repeated removal over the entire stream was necessary for at least four consecutive years, similar to results reported by Kulp and Moore (2000). We mistakenly believed we had effectively removed brook trout from the Above Project reach after three years of removals, so we only conducted limited removal efforts in association with annual monitoring of three sample sections during 1996 and 1997. Brook trout populations expanded in this reach during that time period and additional intensive removal efforts were required during 1998 and 1999 to effectively eliminate brook trout from this reach.

We found that initial removal efforts were more effective at removing larger (>100 mm) brook trout. Once most of these larger trout had been removed, we could concentrate more of our effort to remove smaller brook trout. This finding was consistent with results reported by Kulp and Moore (2000) for removal of rainbow trout and Thompson and Rahel (1996) for removal of brook trout. Following brook trout removal efforts in 1995 and 1996, it appeared that only the 1998 year-class of brook trout (spawned in the fall of 1997) was very successful. Consequently, once these 1998 year-class fish reached a size where they were more vulnerable to backpack electrofishing (>100 mm) during 1999, they were effectively removed. No successful brook trout reproduction appeared to occur above the barrier after 1998.

A barrier to upstream fish movement is necessary at the lower boundary of any removal project to ensure that nonnative species do not move upstream to re-colonize reclaimed habitats. Existing cutthroat trout recovery plans recognized the importance of barriers to prevent competition and hybridization with nonnative trout species (USDI Fish and Wildlife Service 1993a, 1993b, Langlois et al. 1994). Harig et al. (2000) found that many of the greenback cutthroat trout restoration attempts that failed were due to competition with nonnative salmonids. In most cases, removal efforts were not totally effective, but in some cases re-invasion over man-made barriers occurred following the restoration. Harig et al. (2000) cautioned that man-made barriers are not as effective as natural waterfalls. Thompson and Rahel (1998) evaluated fish passage at man-made barriers thought to be protecting native Colorado River cutthroat trout from invasion by brook trout. They found several brook trout moved upstream past a rock-gabion barrier and one brook trout was found above a culvert barrier, but they speculated that an angler moved this trout.

Response of Westslope Cutthroat Trout to Suppression of Brook Trout

Westslope cutthroat trout populations increased dramatically after three years of brook trout removal, and the most dramatic increases were observed in abundances of age-0 WCT soon after removal efforts began. Cummings (1987) and Thomas (1996) indicated that juvenile brook trout interfered with juvenile cutthroat trout's foraging efficiency and microhabitat selection. Numerous age-0 WCT utilized the recently re-constructed channel within the Project Area immediately after its construction, probably due to vacant habitats it provided. The standing crop of WCT in allopatry was similar to the combined standing crop of WCT and brook trout in sympatry; however, condition of WCT did not significantly change following brook trout removal. Research in Idaho indicated that removal of brook trout prior to stocking greatly enhanced stocking success for westslope cutthroat trout fry (Cowley 1987, Strach and Bjornn 1989).

Confounding Effects of Habitat Restoration and Brook Trout Removal

Our data did not show that WCT populations within the Project reach were any higher than in the other two reaches where brook trout were also removed, but no habitat enhancement was undertaken. Thus, we could not test if, or how much, habitat restoration contributed to the population level of WCT we observed in the Project reach. In addition, our data did not let us empirically test whether habitat restoration alone would have resulted in a community shift favoring WCT; however, we suggest that habitat restoration alone probably would not have resulted in much of a response by the WCT population without simultaneous removal of brook trout. We reached this conclusion because prior to their removal, brook trout dominated the fish community in the two reaches adjacent to the dredge pond reach, where stream habitats were in relatively good condition. In these adjacent reaches WCT were being replaced by brook trout, even in relatively high-quality stream habitats. The combination of habitat restoration and brook trout removal within the Project reach resulted in densities and standing crops of WCT similar to adjacent reaches where stream habitat was in good condition. Thus, all we can conclude is that habitat restoration successfully provided habitats of similar quality as present in adjacent natural reaches. Habitat restoration has been shown to increase abundance and distribution of cutthroat trout (House and Boehne 1985 and 1986, Young et al. 1999); however, in these studies cutthroat trout either existed in allopatry or in sympatry with other native fishes and thus, did not face competition from nonnative salmonids.

We acknowledge that these dredge pond habitats could have provided a source of brook trout to adjacent habitats while allowing brook trout to dominate fish communities in these adjacent reaches. However, research we have conducted in other streams, where no similar ponds existed (either beaver or dredge), suggests that brook trout will replace WCT, even in the absence of pond area sources (Shepard et al. 1998). Pond habitats also might have raised stream temperatures below these ponds, affecting interactions between brook trout and cutthroat trout to favor brook trout (DeSato and Rahel 1994); however, this mechanism is speculative because we have no water temperature information from below the ponds prior to their removal.

Fausch (1989) suggested that distributions of brook trout and WCT might be influenced by stream gradient, with brook trout occupying lower gradient stream reaches (with maximum abundance observed at gradients <3%), and WCT occupying higher gradient reaches (with maximum abundance in gradients ranging from 6 to 14%). The senior author and others previously developed a regression model that related the presence and abundance of brook trout and numerous habitat variables to explain observed variation in abundance of WCT (Shepard et al. 1998). Using principal components analyses, they derived components indicative of water temperature, pool frequency, stream size, stream gradient, and ranked levels of logging, road construction, livestock grazing, and mining activities that, along with brook trout presence and abundance covariates, led to regression equations that significantly (R^2 from 0.79 to 0.80; $P<0.01$) related to observed abundance of WCT. Based on these studies and our observations in White's Creek, we suggest that in streams with lower stream gradients and warmer water temperatures, such as White's Creek, brook trout populations will likely replace WCT populations. To conserve WCT in these types of streams, brook trout will have to be removed or periodically suppressed.

Native Fish Conservation Management Implications

White's Creek was initially chosen to test the feasibility of physically removing nonnative brook trout and assess the response of the native WCT population to that removal. While removal of the brook trout population was accomplished, it took seven years of intensive effort. The WCT population responded positively, increasing from an initial population of less than 75 fish (ages 1 and older) to over 1000 age-1 and older fish; however, the low initial population size of WCT raises concerns for potential genetic inbreeding depression and a severe population bottleneck (Meffe 1986, Allendorf and Leary 1986). We observed some WCT with malformed opercules, but are unsure if this was related to genetic problems or diet. We suggest that restoration efforts should be initiated before populations decline to levels below 50 effective breeding individuals (e.g., Allendorf et al. 1997), which probably translates to at least 100 adult-sized (>130 mm; Downs et al. 1997) fish.

Our results suggest that brook trout replace WCT and that the mechanism for this replacement may be behavioral interaction between age-0 brook and WCT. Following removal of brook trout abundances of age-0 WCT increased dramatically in all reaches, but especially within the Project reach where all fish had been removed. Since brook trout emerge several months earlier than WCT (early summer versus late summer) they have a competitive size advantage over WCT in the same cohort that is maintained through at least their first year of life. Griffith (1972) found that age-0 brook trout maintained a 20-mm size advantage over WCT of the same age group in Idaho streams and consistently dominated age-0 WCT during behavioral interactions; however, he believed interactions were minimized due to utilization of different microhabitats. Sabo and Pauley (1997) suggested that size is perhaps equally important as species in determining competitive dominance between sympatric populations of cutthroat trout and coho salmon (*O. kisutch*). We suggest that most streams have limited microhabitats consisting of slow, shallow-water habitats near cover for age-0 trout; consequently, intense behavioral interactions likely occur between age-0 brook trout and WCT with brook trout dominating due to their larger size.

We recognized that successful restoration of WCT requires sites containing high quality habitats (Griffith et al. 1989) in a mosaic that will change over time (Young 1995). Ideally these sites should include refugia (Sedell et al.1990, Pearsons et al. 1992) where some individuals could withstand extreme events and subsequently disperse to re-colonize vacant habitats. Hilderbrand and Kershner (2000) suggested that total habitat size should support 2500 individuals, based on earlier work by Allendorf et al. (1997), which they translated to stream lengths of about 10 to 50 km depending upon relative fish abundance. Harig et al. (2000) evaluated success of 37 greenback cutthroat trout (*O. c. stomias*) restoration efforts and found that 23 had failed due to reinvasion of nonnative species (48% of the failures) or because restoration was done in unsuitable habitats (43%).

A potential problem associated with long-term persistence of the WCT in White's Creek is the fact that this WCT population has a relatively short reach of available habitat, about 3 km, that puts this population at a high risk of extinction due to both stochastic and demographic pressures (Rieman and McIntyre 1993, 1995, Hilderbrand and Kershner 2000, Harig et al. 2000). Hilderbrand and Kershner (2000) recommended a population of at least 2500 individuals to avoid inbreeding depression and reduce extinction risk. Using our catch rates of about 30 fish/100 m (Fig. 5) along with an estimated capture efficiency of about 0.8 expanded over the 3 km of available habitat results in a ballpark total estimate of about 1125 WCT in the portion of White's Creek above the barrier. This suggests that the WCT population in White's Creek is at a relatively high risk of going extinct, a fact we readily acknowledge. Fortunately, White's Creek has several perennial springs that enter White's Creek within the restoration area, providing a more stable environment and local refugia that might reduce extinction risk from stochastic environmental events.

We acknowledge the relatively high extinction risk for WCT in White's Creek, even after the elimination of brook trout due to their limited numbers and restricted and isolated habitat. However, we suggest that genetic introgression and nonnative competition threats may outweigh stochastic risks over the short-term, making isolation of many remaining WCT populations a reasonable and necessary short-term conservation strategy. Montana's conservation agreement for WCT (Montana Fish, Wildlife and Parks 1999) calls for replication and re-founding of existing populations that will likely be lost due to stochastic or demographic pressures. Montana fish managers have recognized that human intervention will be necessary to act as the dispersal agent to re-found WCT populations lost from isolated headwater habitats due to stochastic processes.

While physical removal of brook trout was ultimately possible in White's Creek, we do not believe it is a viable alternative in most places currently occupied by sympatric populations of WCT and nonnative competitors. White's Creek is a small (2-m wetted width and average depth of ~10 cm), relatively uncomplex stream with little woody debris and relatively low levels of instream cover, making shocking efficiencies relatively high. In addition, the restoration within the Project reach allowed for total removal of brook trout from in-channel ponds. We believe that chemical removal of nonnative fish will be necessary in most systems (Stevens and Rosenlund 1986, Gresswell 1991, Buktenica et al. 2000, Brooks and Propst 2001).

Another consideration relates to the cost of physical removal. We estimate that it cost at least $30,000 for the eight years of removals, assuming an hourly salary and benefits rate of $10, daily per diem rates of $37, and associated travel costs (all costs are US 1999). It cost an additional $15,000 for the barrier installation. We did not include costs of the valley restoration, since this restoration was a mining reclamation effort; however, this restoration work contributed to the removal effort by draining ponds occupied primarily by brook trout. These costs must be viewed as low because this stream was easily accessible throughout its length and was located relatively close to a field office. This translates to about $10,000/km for removal treatments plus the cost of the barrier.

In conclusion, this study indicated that 1) brook trout could successfully be removed from a small, relatively simple stream using electrofishing, but it took eight years of effort to accomplish, 2) a severely depressed WCT population re-bounded to levels at least seven times higher than pre-removal estimates following brook trout removal, 3) biomass of WCT in allopatry was similar to the combined biomass of brook trout and WCT in sympatry, and 4) where habitat restoration occurred in conjunction with brook trout removal, densities and biomass of WCT were nearly as high as adjacent natural sections of stream channel.

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