Research Article

Wildland Fire: An Opportunistic Event for Reintroducing a Native Salmonid

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ABSTRACT

The Missionary Ridge Fire (summer 2002) burned approximately 28 520 ha in the San Juan Basin, Colorado. Prior to the fire, no native Colorado River cutthroat trout (*Oncorhynchus clarki pleuriticus*) had been observed in the San Juan Basin for over 100 yr due to over-fishing, introduction of non-native fishes, and habitat alteration. Mud and ash flows into the Florida River in fall 2002 and spring 2003 resulted in a complete fish kill of non-native rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*).

Between 2003 and 2007, the Colorado Division of Wildlife released 138 728 Colorado River cutthroat trout ranging from 5 cm to 35 cm in length within a 22.5 km reach of the Florida River. Two barriers, a reservoir dam and an irrigation diversion dam, prevented non-native fish from entering this reach. Each fall from 2003 through 2007, we surveyed two locations on the Florida River and estimated population size. Heavy silt deposits and extremely high river flows (3.8 m^3 s^{-1}) precluded us from making population estimates during 2003 to 2005. The catch of Colorado River cutthroat trout decreased from 76 % in 2006 to only 44 % in 2007. Interspecific competition and predation by rainbow and brown trout, whirling disease (*Myxobolus cerebralis*), and extreme fluctuations in regulated river flows in 2007 may have contributed to the observed decline in cutthroat trout. It is still too early to conclude whether reintroduction efforts of Colorado River cutthroat trout have been successful, but early indications suggest non-native trout are beginning to re-colonize this section of the Florida River at the expense of the cutthroat trout.

Keywords: aquatic ecosystem, Colorado River cutthroat trout, Missionary Ridge Fire, *Oncorhynchus clarki pleuriticus,* reintroduction, wildland fire

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INTRODUCTION

Wildland fire has diverse effects on aquatic ecosystems depending on fire intensity, frequency, and severity. Post-fire floods can rejuvenate stream habitats by exporting fine sediments and importing large amounts of spawning gravel, cobble, woody debris, and nutrients, which can result in higher fish productivity than before fire (Burton 2005). However, post-fire floods may also result in complete mortality and displacement of benthic macroinvertebrates, amphibians, and fishes over the short-term, with recovery often occurring 7 yr to 10 yr following fire, although permanent local extinction can occur in some isolated populations (Gresswell 1999, Minshall 2003, Dunham *et al*. 2007). Numerous native fish species in the United States are listed or petitioned for listing under the federal Endangered Species Act (ESA) or are species of special concern at the state and federal level due to habitat degradation, fragmentation, introduction of non-native fishes, and over-fishing (Minckley and Deacon 1991). Over the past century, local and regional extirpations of native fish species have occurred and numerous extant populations are now small, isolated remnants of their previous larger, more continuous historical distribution (Young *et al.* 1996, Rieman *et al.* 2003). Negative effects of wildland fire can pose a natural threat to these now isolated native fish populations. However, in environments of extirpated native fish, wildland fire can exterminate non-native fish populations and, thereby, provide an opportunity to reintroduce native fish to their former habitat.

During the summer of 2002, the Missionary Ridge Fire burned approximately 28 522 ha in the San Juan Basin near Durango, Colorado (Figure 1). The fire occurred in an area of record low fuel moisture levels, a consequence of a drought resulting from low winter snowpack and only 3.3 cm of precipitation in the previous six months. The fire resulted in various severities in nine different vegetation types. The Forest Service Remote Sensing Application Center classified a satellite image using different spectral wavelength bands to delineate areas of low, moderate, and high burn severity at 30 m resolution using a Landsat7 image (USDA 2002). San Juan National Forest staff verified burn severity by field visits, direct soil observations, and helicopter reconnaissance to produce the final burn severity map.

Almost half of the 28 522 ha of the Missionary Ridge Fire burned at moderate or high burn severity (USDA 2002). Approximately half of the moderate or high burn severity occurred in aspen (*Populus tremuloides*), cool-moist mixed conifer, or subalpine vegetation communities. Aspen and cool-moist mixed conifer stands historically had a fire return interval of approximately 50 yr to 100 yr and a mixed-severity fire regime with surface and crown fire behavior occurring during the same fire event (Kaufmann *et al.* 2000, Fulé *et al.* 2003, Grissino-Mayer *et al.* 2004, Margolis *et al.* 2007). Cool-moist mixed conifer is dominated by white fir (*Abies concolor*) and Douglas-fir (*Pseudotsuga menziesii*) with occasional ponderosa pine (*Pinus ponderosa*) in small patches on warm sites, exposed ridges, and on meadow edges. Subalpine forests are dominated by Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*). Subalpine forests have a fire return interval of ≥200 years and are characterized by infrequent, high severity, stand-replacing fire (Schoennagel *et al.* 2004, 2007; Bigler *et al.* 2005). The remaining half of the burned area with a moderate or high burn severity was in pure ponderosa pine and warm-dry mixed conifer vegetation communities (TWS 2003). Warm-dry mixed conifer is composed of ponderosa pine as the dominant tree species followed by white fir and Douglas-fir. Warm-dry mixed conifer

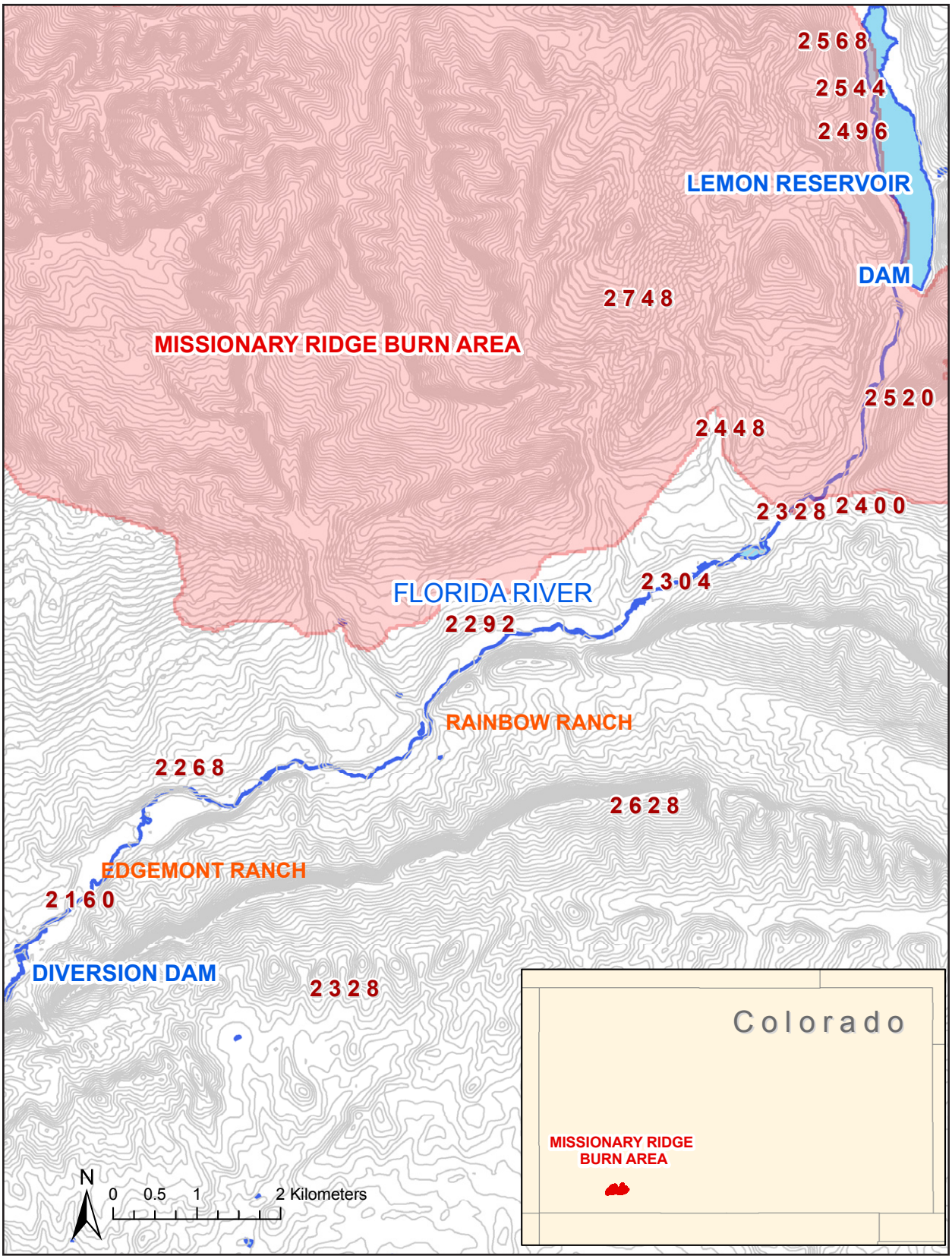

Figure 1. The Missionary Ridge Fire burn area near the two sampling sites, Rainbow Ranch and Edgemont Ranch, near Durango, Colorado, USA.

forests share many characteristics with ponderosa pine forests including a frequent, low severity fire regime and a fire return interval of 10 yr to 30 yr with moderate and high burn severities considered uncharacteristic (Fulé *et al.* 1997, Romme *et al.* 2003). When a vegetation community burns outside its historical fire regime, it can result in uncommon post-fire vegetation structural changes (e.g., complete consumption of overstory trees, lack of understory regeneration, etc.) because the vegetation did not evolve under these fire severities (Covington and Moore 1994).

Fire consumes organic material (e.g., litter, duff, and tree canopy), dries out the soil, and creates hydrophobic soils that decrease water infiltration and can result in overland water and debris flows (Scott and van Wyk 1990, Hatten *et al.* 2005). Intense summer convective thunderstorms associated with the monsoon season following the Missionary Ridge Fire in 2002 resulted in the transport and deposition of abnormally high volumes of sediment and ash into the San Juan Basin (Cannon *et al.* 2003). Mud and ash flows into tributaries of the Florida River in 2002 and 2003 resulted in a complete fish kill of primarily non-native rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) due to altered fish habitat from changed water chemistry including total dissolved solids, dissolved oxygen, and pH (P. Somers, Colorado Division of Wildlife, unpublished report; Barb Horn, Colorado Division of Wildlife, personal communication).

Electrofishing surveys conducted by the Colorado Division of Wildlife (DOW) prior to the Missionary Ridge Fire showed trout biomass in the Florida River averaged approximately 4.6 kg ha^{-1} (Barb Horn, Colorado Division of Wildlife, unpublished data). The combination of unusually high fire severity and high post-fire debris flow rapidly eliminated non-native fish populations and provided a unique situation to study native fish reintroduction. Consequently, the DOW, with the cooperation of property owners within a 22.5 km reach of the Florida River, took advantage of this situation to reintroduce a native salmonid species to its historical range. Colorado River cutthroat trout (*Oncorhynchus clarki pleuriticus*) currently occupies approximately 8% of its historical range

Figure 2. Colorado River cutthroat trout captured during 2008 electrofishing survey, Florida River, southwest Colorado, USA. Photo credit: Julie E. Korb.

(Hirsch *et al.* 2005) (Figure 2). In the state of Colorado, this cutthroat trout is classified as a sensitive species by Region 2 of the U.S. Forest Service and by the Bureau of Land Management (BLM). In 1994, the DOW and U.S. Forest Service established a conservation strategy agreement for Colorado River cutthroat trout in southwest Colorado (Langlois *et al.* 1994). The goal of the 2005 agreement among Colorado River Basin states and federal and tribal fish and wildlife agencies is to assure long-term viability of cutthroat trout throughout its historical range. To maintain and increase current populations, the agreement suggested introducing new populations where ecologically and economically feasible while preserving genetic diversity of the species (Colorado River Cutthroat Trout Coordination Team 2006). The Missionary Ridge Fire provided the opportunity to reintroduce cutthroat trout to unoccupied habitat within its historical range.

Prior to the fire in 2002, Behnke (1992) established that no cutthroat trout had been present in the lower Florida River Basin for over 100 yr due to over-fishing, introduction of non-native fishes, and habitat alteration. From 2003 to 2007, the DOW stocked 138 728 Colorado River cutthroat trout, ranging from 5 cm to 35 cm and comprising four genetic strains within a 22.5 km reach of the Florida River from Lemon Dam to Edgemont Ranch (Table 1). Two barriers, a reservoir dam at the beginning of the reach and an irrigation diversion dam at the end of the reach, prevented non-native fish from entering this stretch of the Florida River (Figure 1). The Colorado Division of Wildlife used hatchery-propagated fish from established wild brood stocks in the reintroduction (Mike Japhet, Colorado Division of Wildlife, unpublished report). The goal was to create a recreational fishing opportunity based on a native trout fishery that includes annual stocking of 5.1 cm Colorado River cutthroat trout. A viable, self-sustaining population of cutthroat trout is unlikely without annual stocking because the Florida River is infected with whirling disease (*Myxobolus cerebralis*). Whirling disease, a non-native parasite with which Colorado River cutthroat did not evolve, is a limiting factor to recruitment of adult cutthroat trout (Nehring 2006). Low and middle (<3000 m) elevational aquatic environments are the most altered systems in mountain environments because of urban development and agriculture, making these environments priorities for restoration (Rieman *et al.* 2003). The Colorado Division of Wildlife has conducted electrofishing surveys for the past 5 yr (2003 to 2007) to determine the success of the reintroduction efforts. A limited number of studies monitor the responses of fish populations to fire and fire-related effects (Dunham *et al.* 2003). Our main objective of this study was to characterize

Table 1. Colorado cutthroat trout stocking history of the Florida River from Lemon Dam to Edgemont Ranch. CR1 = A strain of Colorado cutthroat trout; NAN = Nanita Lake strain of Colorado cutthroat trout; WEM = Weminuche strain of Colorado cutthroat trout; NAV = Navajo River strain of Colorado cutthroat trout.

Date	Strain	Length (cm)	# stocked
6/8/2003	CR1	30.5	133
6/22/2003	CR1	30.5	133
7/8/2003	CR1	30.5	134
6/1/2004	CR1	12.7	5 000
6/22/2004	CR1	30.5	1 000
8/1/2004	CR1	2.5	26 000
4/1/2005	NAN	30.5	1 449
6/1/2005	CR1	12.7	5 000
9/1/2005	CR1	5.1	20 000
6/1/2006	WEM	35.6	890
6/1/2006	CR1	12.7	5 000
9/1/2006	NAV	5.1	35 000
10/15/07	CR1	2.5	38 989
Total			138 728

the distribution and abundance of Colorado River cutthroat trout at two sites within a reach of the Florida River that had burned with varying severity.

METHODS

Study Area

The headwaters of the Florida River are on the southern slopes of the Needle Mountains, 16 km southwest of the Continental Divide in southwestern Colorado, USA. The Florida River is a tributary to the San Juan River, part of the upper Colorado River basin. The Florida River has a 109 km^2 drainage area above Lemon Dam and ranges in elevation from 2423 m at the dam to over 3962 m at the headwaters (Robert Autobee, Bureau of Reclamation, unpublished report). In 1963, Lemon Dam and Reservoir were constructed to provide irrigation, flood control, and recreation. The reservoir's total capacity is 4952×10^4 m^3 with an average annual discharge of 8120×10^4 m^3 (Robert Autobee, Bureau of Reclamation, unpublished report). Spring and early summer snowmelt provides the majority of run-off into the reservoir followed by high-intensity summer and fall rainstorms.

Depending on river flows, we conducted electrofishing surveys at Rainbow Ranch and Edgemont Ranch sites near Durango, Colorado, within a 22.5 km reach of the Florida River between September and October from 2003 to 2007. These surveys followed the 2002 Missionary Ridge Fire and subsequent stocking of Colorado River cutthroat trout. Rainbow Ranch is located 11.2 km and Edgemont Ranch is 16.6 km below Lemon Dam at elevations 2225 m and 2184 m, respectively, on gentle, 2° to 4° slopes (Figure 1). Average flows in the Florida River below the dam are relatively stable throughout the year and vary from winter flows of 0.4 m^3 s^{-1} to 0.6 m^3 s^{-1} to downstream water deliveries during the summer months around 7.1 m^3 s^{-1} to 8.5 m^3 s^{-1}.

Field Methods

We used a pulsed, direct-current electrofishing bank unit or two backpacking units to conduct the surveys each year. At each location, we surveyed a 152.4 m length of stream with two passes following the Seber-LeCren two-pass removal method of population estimation (Seber and LeCren 1967). We netted each individual trout; however, we considered speckled dace (*Rhinichthys osculus*) and mottled sculpin (*Cottus bairdii*) as incidental to the capture of trout and made no effort to conduct a population estimate on these species. Although incidental to the capture of trout, the netting effort for mottled sculpin, speckled dace, and other non-salmonids was similar each year. We identified fish to species, weighed each individual to the nearest gram, measured for total length to the nearest millimeter, and returned all native fishes to the water.

Statistical Analysis

We entered field data into a Visual dBase database and estimated the population size at each site for species with fish ≥150 mm total length using the Seber LeCren two-pass formula (Seber and LeCren 1967, Bagenal 1978)

$$P = 1 - \left[P_2 \div \left(P_1 + 1\right)\right] \quad (1)$$

$$\hat{N} = \left(P_1^2 - P_2\right) \div \left(P_1 - P_2\right) \quad (2)$$

$$CI = 1.96 \times \sqrt{P_1^2 \times P_2^2 \left(P_1 + P_2\right) \div \left(P_1 - P_2\right)^4} \quad (3)$$

where P = capture probability, P_1 = number captured on the first pass (≥150 mm total length), P_2 = number captured on the second pass (≥150 mm total length), $\hat{N}$ = population estimate in site or reach, and CI = 95 % confidence interval around $\hat{N}$.

We combined fish data from both sites for each individual sample year to capture an overall population and biomass estimate for

the Florida River. We multiplied our Colorado River cutthroat trout population estimates by a correction factor based on the length and width of each sampling site and expanded it over the entire reach to determine the number of cutthroat km^{-1}. We calculated biomass estimates by multiplying the mean weight of all cutthroat trout collected at each site by the number of cutthroat at each site (cutthroat kg ha^{-1}). We calculated 95 % confidence intervals (CI) for all cutthroat km^{-1} and cutthroat kg ha^{-1}.

RESULTS

Mottled sculpin was the only species we captured after the fire in 2003 and 2004 (Table 2). By 2005, we captured Colorado River cutthroat trout at both sites, as well as mottled sculpin, speckled dace, and non-native brown trout (Table 2). In 2005, our density and biomass estimates of cutthroat trout are questionable because high river flows, which reached 3.8 m^3 s^{-1}, reduced netting efficiency and resulted in broad confidence intervals. In 2005, the cutthroat trout population and biomass estimates in combined sites were 164 cutthroat km^{-1} (CI ± 101) and 22 kg ha^{-1} of cutthroat (CI ± 7.8). We captured three different size classes of cutthroats ranging from 7.6 cm to 40.6 cm during the 2005 survey (Figure 3).

Table 2. Total number of fishes captured in the Florida River at the Edgemont and Rainbow Ranch sites during the 2003-2007 survey period.

	2003	2004	2005	2006	2007
Colorado River cutthroat trout	0	0	22	112	23
Rainbow trout	0	0	0	21	3
Brown trout	0	0	2	13	21
Rainbow x cutthroat trout	0	0	0	0	1
Mottled sculpin	6	6	28	73	13
Speckled dace	0	0	1	14	0
Smallmouth bass	0	0	0	0	1

In 2006, we caught 752 Colorado River cutthroat km^{-1} (CI ± 145) and 40 kg ha^{-1} (CI ± 7.8) of cutthroat in the two sites combined. Our netting efficiency increased in 2006 because of low flows, 0.62 m^3 s^{-1}, and resulted in narrower confidence intervals. Colorado River cutthroats comprised 76 % of the adult trout (≥150 mm total length) captured in 2006. However, we also captured both non-native trout species, brown trout (5 %) and rainbow trout (19 %). According to our capture data, mottled sculpin were relatively abundant (31 % of all fish captured; Table 2). We observed four age classes of cutthroat, including young of the year at both sites.

In 2007, we estimated the population density and biomass for both sites combined to be 198 Colorado River cutthroat km^{-1} (CI ± 116) and 22 kg ha^{-1} (CI ± 7.8), respectively. Cutthroat trout represented only 44 % of the adult catch. Biomass estimates of cutthroat trout at the Edgemont Ranch site went from a high of 53 kg ha^{-1} in 2006 to only 17 kg ha^{-1} in 2007. Cutthroat trout comprised 71 % of the adult fishes captured at the Edgemont site in 2007, but were lower in abundance compared to 2006 (272 cutthroat km^{-1} versus 1140 cutthroat km^{-1}). We observed the same pattern at the Rainbow Ranch site where cutthroat trout declined in abundance from 454 cutthroat km^{-1} in 2006 to 159 cutthroat km^{-1} in 2007, and biomass estimates of cutthroat trout went from 31 kg ha^{-1} in 2006 down to 22 kg ha^{-1} in 2007.

For both sites combined, non-native trout (brown and rainbow trout) abundance increased from 275 trout km^{-1} (CI ± 100) in 2006 to 385 trout km^{-1} (CI ± 172) during 2007. Non-native rainbow trout in the 20 cm to 26 cm length range were relatively abundant (629 fish km^{-1}) at the Edgemont Ranch site in 2006, but virtually absent in 2007 (51 fish km^{-1}). In 2007, brown trout represented 100 % of the non-native fish captured at the Rainbow Ranch site. Brown trout at the Rainbow Ranch site increased from 18 trout km^{-1} (CI ± 0) in 2006 to 68 trout km^{-1} (CI ± 50) in 2007.

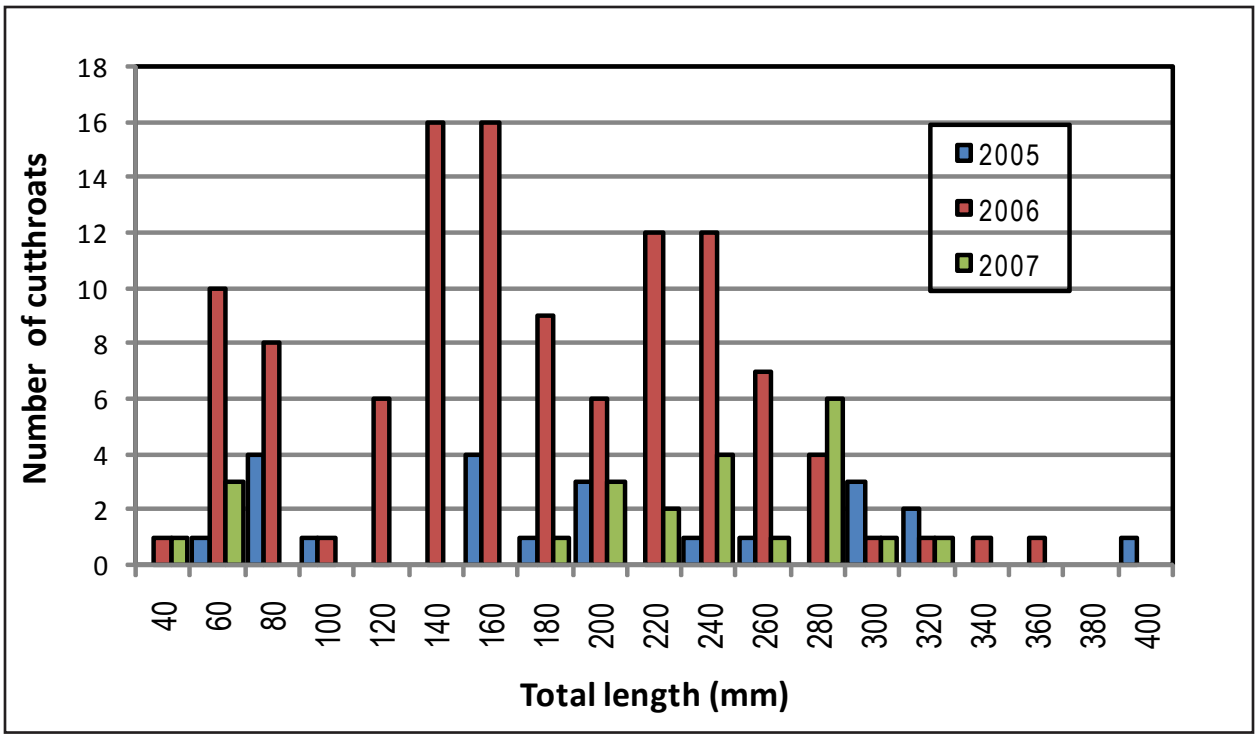

Figure 3. Length frequency histogram of Colorado River cutthroat trout captured from 2005 to 2007, Florida River, southwest Colorado, USA.

We observed four age classes of Colorado River cutthroat trout, including young of the year at both sites. The abundance of juvenile cutthroat and brown trout (<140 mm total length) declined sharply from 2006 (Figure 3). In 2006, we captured 27 young Colorado River cutthroat trout at the Rainbow Ranch site and only captured three young cutthroat trout in 2007.

DISCUSSION

Native Colorado River cutthroat trout did not evolve with any other trout species, and therefore are extremely susceptible to interspecific competition and predation by non-native salmonids, particularly at a young age (Benke 1992). We observed both rainbow trout and brown trout at each location we surveyed in 2006 and 2007. Rainbow trout could have escaped from adjacent stocked ponds that were unaffected by the fire or intentionally stocked by private landowners along the Florida River during our survey period (2003 to 2007) (Jim White, Colorado Division of Wildlife, personal communication). Brown trout may have initially escaped out of ponds or tributaries unaffected by the fire.

The widespread natural distribution of Colorado cutthroat trout historically limited the risk of extirpation by wildfire. Today, Colorado cutthroat trout are more susceptible to the effects of high severity fires within a particular watershed due to a reduced geographic distribution. As non-native trout invaded their habitat, most Colorado cutthroat trout populations dispersed into isolated reaches of streams, thereby reducing their ability to emigrate from these isolated areas after extreme fire events.

In addition to immediate die-off after fires, the effects of fire on Colorado cutthroat trout populations may extend to post-fire floods. Chronic changes in channel morphology and vegetation loss may affect recruitment and population stability for years to come (J.N. Rinne, U.S. Forest Service, unpublished data). Shearer Creek is a small first order tributary to

the Florida River. Post-fire floods extirpated non-native brook trout, and DOW stocked Colorado cutthroat trout from 2005 to 2007 after constructing a fish migration barrier near the confluence. The DOW observed multiple-year classes of cutthroats when they stocked the stream in 2007. However, a high intensity rainstorm during the summer of 2008 filled many of the pools with sediment and they collected only one adult year class during electrofishing surveys in 2008 (White, Colorado Division of Wildlife, personal communication). The instability of Shearer Creek following wildfire and its apparent effects on the cutthroat trout population six years after the Missionary Ridge Fire serves to illustrate the long term effects of fire on cutthroat trout.

In 2006, we captured eight brown trout young of the year at the Rainbow Ranch site, and one brown trout, >51 cm and 1.8 kg, in spawning condition at the Edgemont site. The presence of young brown trout in the Florida River suggests successful reproduction in waters heavily infected with whirling disease. Because Colorado River cutthroat trout did not evolve with whirling disease, they are extremely vulnerable to its effects and typically exhibit malformations of the cranium and spine resulting in a whirling swimming motion and poor survival (Nehring 2006). Excess fine sediment from ash accumulation and unstable watersheds may increase the amount of habitat for tubifex worms (*Tubifex tubifex*), the intermediate host of *Myxobolus cerebralis*. Brown trout, which evolved with the disease, can reproduce in a whirling disease environment, and their young, although infected with the parasite, may show no clinical symptoms of the disease (Nehring 2006). The majority of cutthroat trout the DOW stocked were ≥5.1 cm, beyond the fry stage where high mortality rates are typically observed in cutthroat trout infected with whirling disease (Nehring 2006). The negative interactions with an ever-increasing brown trout population in the Florida River may remove young cutthroat trout from the population faster than they can be annually stocked by the DOW (J. White, Colorado division of wildlife, unpublished report).

Another factor affecting the abundance of both native Colorado River cutthroat trout and non-native trout are fluctuating in-stream flows from Lemon Reservoir. In-stream flows in the Florida River below Lemon Reservoir are relatively stable throughout the year, varying from 0.4 m^3 s^{-1} to 0.6 m^3 s^{-1} in the winter, to 7.1 m^3 s^{-1} to 8.5 m^3 s^{-1} in the summer. In spring 2007, there was a spike in the river that reached 20.8 m^3 s^{-1} on 25 April (Figure 4). Water discharge records showed a highly variable release with flows jumping from 2.7 m^3 s^{-1} to 8.5 m^3 s^{-1} in just 30 minutes and declining from 20.8 m^3 s^{-1} to 8.0 m^3 s^{-1} in only three hours (J. White, unpublished report). The DOW established ramping rates, incremental increases or decreases in managed flows, for adjacent rivers to protect trout fisheries below the reservoirs and dams. For McPhee Reservoir on the Dolores River in southwest Colorado, the DOW recommended increasing ramping rates 1.4 m^3 s^{-1} every three hours to a maximum of 11.3 m^3 s^{-1} per day and a reduction of flows by 1.2 m^3 s^{-1} every three hours to base flows, approximately 1.2 m^3 s^{-1} to 2.0 m^3 s^{-1}, over the course of six days. Drastic changes in water discharge can contribute to the decline of young fish and older trout by stranding or desiccating fish in well vegetated, shallow backwaters and side channels. Anticipating post-fire flood events and managing stream flows through ramping rates, when possible, can help mitigate extreme post-fire effects on sensitive species such as the Colorado River cutthroat trout.

It is still too early to conclude whether reintroduction efforts of Colorado River cutthroat trout within the 22.5 km of the Florida River below Lemon Reservoir were successful. However, early indications suggest non-native trout are beginning to re-colonize

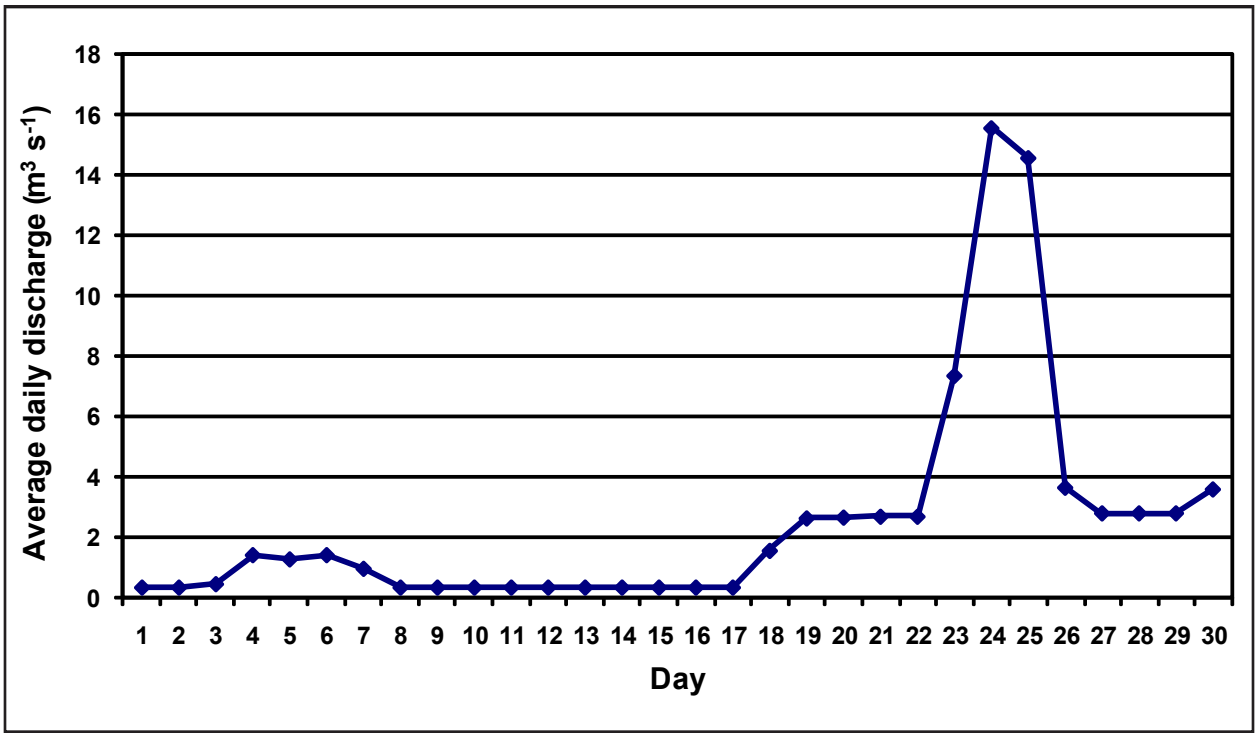

Figure 4. Average daily discharge below Lemon Reservoir in the Florida River in southwestern Colorado, USA, during April, 2007.

this section of the Florida River at the expense of cutthroat trout. The Colorado Division of Wildlife will continue to monitor cutthroat trout and other fishes to determine the long-term trajectory of the reintroduction. Mottled sculpin were abundant at both sites in 2006 and 2007, suggesting that the submerged river cobbles they rely on for shelter, food, and reproduction are free of excessive fine sediment. This finding is encouraging and suggests that the Florida River is rebounding from the effects of the fire-related fish kill in August of 2002. However, not all rivers rebound from fire. In some watersheds in Arizona, where complete fish mortality occurred following fire, recovery has not occurred due to the combined effect of isolation and watersheds being too small to support long-term persistence of fishes (Rinne 2004). Overall, fire impacts on fishes are usually short-term and research has shown that even in the most severely impacted streams, habitat conditions and trout populations improved significantly within 5 yr to 10 yr following wildfire, especially in larger, interconnected systems (Rieman and Clayton 1997, Dunham *et al.* 2003, Burton 2005, Dunham *et al.* 2007).

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