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DISCLAIMER

ABSTRACT

A wildfire in southwestern New Mexico in 1989 led to the loss of habitat for half the total known endangered Gila trout population. Immediately after the fire, it was estimated that the watershed would not support reestablishment of Gila trout for at least 15 to 20 years. It was also decided that livestock grazing would never again be possible. Monitoring of the stream profile, temperature, and pH; riparian vegetation; and stream suspended sediment content indicated sufficient recovery to allow for reintroduction of Gila trout five years following the wildfire. Prior to 1989, the watershed had not burned in over 100 years. Subsequent small re-burns in 1993 and 1997, and grazing and trampling by trespass cattle at the end of the dry season in May 1996 did not affect water quality above tolerance levels of the Gila trout. Managed livestock grazing each year after 1996 during June, July, and August (the monsoon season) had no detrimental effects on Gila trout habitat.

Key words: Gila trout, stream profile, runoff, suspended sediment, water temperature, water pH.

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INTRODUCTION

The Divide Fire of early July 1989 burned a large portion of the headwaters (mainly southwestern portions) of Main Diamond Canyon, a tributary of the Gila River. The watershed had been protected from fire for decades, and significant amounts of needles, leaves, branches, and logs provided unnatural amounts of surface fuel plus aerial fuel loading. The fire occurred following a year of drought, which left the forest in an extremely dry condition. Gila trout were found in several tributary streams of the Gila River, but about half the population lived in the small perennial creek in Main Diamond Canyon. Part of the Gila trout population in Main Diamond Creek was captured and removed immediately following the fire. Subsequent rains to the partially barren watershed brought heavy runoff, which was loaded with ash, suspended sediment, and bedload in late summer 1990. Geomorphic features of the canyon bottom changed significantly and no fish were found in the creek by late fall 1990.

Rinne and Carter (2008) claimed that prior to the 1990s, there was little information on the effects of wildfire on aquatic ecosystems. Since about half of Yellowstone National Park burned in 1988, information on fire effects on aquatic ecosystems has increased significantly. Most of the information is on forested ecosystems in the northern Rockies (Gresswell 1999). The most comprehensive effort addressing wildfire issues and aquatic ecosystems was published in the spring 2003 issue of *Forest Ecology and Management* from a workshop held in Boise, Idaho in 2002 (Rieman et al. 2003). Rinne, a leading fisheries biologist in the southwestern United States, claims that there was little information available on the effects of wildfire on fishes of the Southwest, especially Gila trout.

Gila trout were not identified until 1950 (Miller 1950). Early conservation efforts for Gila trout in Main Diamond Creek included creation of pool habitats by using log structures installed by the Civilian Conservation Corps during the 1930s (Brown et al. 2001). These were still present in Main Diamond Creek in 2010. Gila trout are found in about eight segments of the Gila River in New Mexico (Figure 1). Propst and others (1992) first discussed the impacts of fire on Gila trout in headwater streams in southwestern New Mexico as affected by the Divide Fire of 1989. They described the effects as catastrophic with fish killed that were not captured prior to flooding. Historically, wildfires in this region were primarily lightning-caused understory fires occurring in the dry spring and early summer months. Swetnam and Dieterich (1985) reported that the cool-burning understory fires returned on 3-7 year intervals in ponderosa pine forests and 75-100 year intervals in the highest elevation spruce-fir forests. Cooper (1960) concluded that crown fires were extremely rare or non-existent in the region prior to the 1950s. These naturally occurring fires started being suppressed about 1900 by the newly created U.S. Forest Service and the utilization of fine fuels by livestock and increased native deer populations as the result of predator controls. Predators included coyotes, wolves, bears, and mountain lions. Because the frequency of fires decreased, large downed woody materials, saplings, and brush began to increase. These changes increased the potential for catastrophic crown fires (Rieman and Clayton 1997). Although livestock and deer numbers have greatly decreased since 1950, predator and elk numbers have increased significantly.

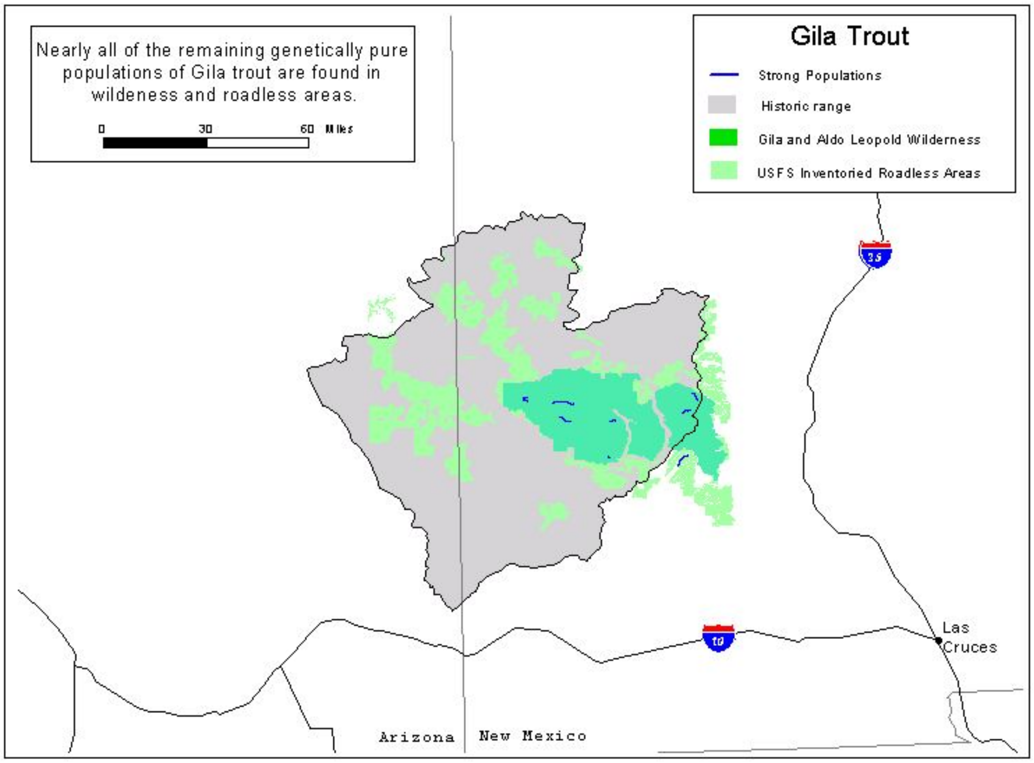

Figure 1. Distribution of Gila trout in New Mexico; http://www.westerntrout.org/trout/maps/gila.jpg.

Following the Divide Fire and subsequent floods, recovery of the watershed to a suitable condition for restocking of Gila trout was estimated from at least 15 to 20 years. Return of livestock was deemed untenable. The objective of this research was to monitor water quality and geomorphic changes in the Main Diamond Creek watershed to determine when conditions would be suitable for re-introduction of Gila trout. Data collection began in the summer of 1991 immediately below the burned area near the James Brothers Spring on Main Diamond Creek.

WATERSHED DESCRIPTION

The Main Diamond watershed is located adjacent and west of the Continental Divide between Lookout Mountain and Diamond Peak in the Black Range of the Gila mountains in southwestern New Mexico. Flow is from southeast to northwest. The burned area was 100 meters above and upstream of the James Brothers Spring. James Brothers Spring was located in the bottom of Main Diamond Canyon near the southeast corner of section 26 of Township 11 South and Range 10 West (Latitude: N 33° 17.838', Longitude: W 107° 51.352'). The elevation of the spring is 2,362 meters (7,750 feet) above sea level. The highest point in the Main Diamond Canyon watershed was 3,002 meters (9,850 feet) above sea level. The watershed was estimated at 2,368 hectares (5,850 acres) above the James Brothers Spring. The perennial flowing portion of the stream is 3.62 kilometers (2.25 miles) with a 3.60% slope. The higher ephemeral flowing portion of the stream is 2.82 kilometers (1.75 miles) with a mean slope of 11.09%. The entire watershed is 8.45 kilometers (5.25 miles) with a mean slope of 7.58%. Canyon sides are steep and range from 30 to 60% slope.

The watershed above the James Brothers Spring is dominated by mixed conifers predominantly on the northeastern exposures and includes ponderosa pine (*Pinus ponderosa* Laws), Douglas fir (*Pseudotsuga menziesii* Franco), white fir (*Abies concolor* (Gord. & Lend.) Lindl), southwestern whitepine (*Pinus strobiformis* Engelm.), Engelmann spruce (*Picea engelmannii* Parry), and quaking aspen (*Populus tremuloides* Michx.). These species grow down into the riparian areas, which includes willows (*Salix* spp. L.) and thinleaf elders (*Alnus tenuifolia* Nutt.). The southwestern exposures are dominated by hairy mahogany (*Cercocarpus breviflorus* Gray), gray oak (*Quercus grisea* Liebm.), and Gambel oak (*Quercus gambelii* Nutt.) with scattered conifers.

The Divide Fire of 1989 burned 1,740 hectares (4,300 acres) or about one half of the watershed above the James Brothers Spring on the southwestern portion, which faces the northeast. All livestock were immediately removed from this grazing pasture for an unspecified and possibly indefinite period of time. In addition to the original fire in 1989, about 50 hectares (120 acres) reburned as a result of lightning in 1993 about 1.6 kilometers (1 mile) above the James Brothers Spring and adjacent to the creek. During the drought of early 1996, about 30 mature bovines trespassed into the watershed from the middle to the end of May. Their hoof prints were ocularly estimated to be a mean of one in every square meter (10.76 square feet) of the riparian area. In early July 1997, a prescribed fire was conducted in the Black Range that included 243 hectares (600 acres) that were burned in 1989 plus 202 hectares (500 acres) on the northeastern portion of the watershed. Disturbances from 1989 through 1998 included:

1. The burn of 1989
2. Re-burn of 50 hectares or 120 acres in 1993
3. Livestock trespass in 1996
4. Prescribed re-burn of 243 ha (600 acres) and burn of 202 new hectares (500 acres) in 1997

METHODS

Precipitation

Precipitation was measured with a continuous recording weighing rain gage from May through September from 1991-1998 (Hamon et al. 1979). The gage was located about 100 meters above James Brothers Spring. Measurements were not taken at other times of the year because of inaccessibility to this remote part of the wilderness area and because most precipitation resulting in high flows occurred during the monsoonal summer months.

Stream Profile

Geomorphic changes were quantified with 20 cross sections located at 50 meter intervals beginning at 100 meters above James Brothers Spring in Main Diamond Creek. Additional stream profiles were measured at the mouth of each tributary (Dendy et al. 1979). Every May between 1992 and 1998, elevations along transects were read at 10 cm intervals with a surveyor's transit.

Runoff

In mid-May of each year, a recording stage recorder was installed 100 meters above the James Brothers Spring to measure stream depth (Gwinn et al. 1979; Carter and Davidian 1969; Buchanan and Somers 1974). This stream segment was uncontrolled but stable for the entire monitoring period.

Suspended Sediment

Suspended sediment was collected with two Manning automatic sediment samplers at staggered six-hour intervals, so that a 0.5 liter sample was drawn every 3 hours (Dendy et al. 1979; Renard et al. 1986; Ward 1984). Each week, 56 suspended sediment samples were taken to the watershed laboratory at New Mexico State University, oven-dried, and weighed to determine sediment concentration (mg l^{-1}).

Stream Temperature

It was suggested in early summer 1993 that water clarity was suitable for Gila trout, but water temperatures were too high as a result of shade loss due to the fire (Sanchez 1993).

Prior to the fire, the water temperatures were cooler than the normal range for Gila trout to the point of being almost detrimental for optimum growth (Turner 1993). A continuous recording thermometer was installed during the second week of June 1993 to measure summer water temperatures.

Stream pH

Suspended sediment samples were measured for pH. This is one of the primary indicators used for the evaluation of surface waters for their suitability for various beneficial uses. Most natural waters are buffered by a carbon dioxide-bicarbonate system (Cole 1975).

RESULTS AND DISCUSSION

Precipitation

Mean precipitation for the five-month sample period in each year between 1991 to 1998 was 223.7 mm (8.78 inches) (Tables 1a and 1b). Total precipitation for the five-month sampling period was greater than the mean for three years, not significantly different for one year, and less than the eight-year mean for three years (Table 1a). The years 1994 and 1998 were considered to be drought years based on total five-month precipitation departure from the mean (-33.2% and -38.0%, respectively). Although not recorded, the spring of 1996 was dry also. The wettest year was 1997, which was 45.6% above the mean.

Table 1a. Monthly precipitation (mm) from 1991 through 1998 for the five-month sampling period each year.

	Year								
Month	1991	1992	1993	1994	1995	1996	1997	1998	Mean
May	19.1	21.6	3.8	11.4	5.1	0.0	34.5	0.0	11.9
June	85.1	74.9	27.4	53.3	6.4	20.8	13.0	1.0	35.2
July	79.2	57.2	107.2	49.5	91.2	56.1	185.9	88.6	89.4
August	111.1	27.9	56.1	35.2	128.3	60.2	28.0	47.7	61.8
September	0.0	0.0	2.5	0.0	61.0	72.9	64.4	1.5	25.3
Total	294.6	181.6	197.0	149.4	292.0	210.0	325.8	138.8	223.7
Departure Mean (%)	+31.6	-18.8	-11.9	-33.2	+30.5	-6.1	+45.6	-38.0	

Table 1b. Monthly precipitation (inches) from 1991 through 1998 for the five-month sampling period each year.

	Year								
Month	1991	1992	1993	1994	1995	1996	1997	1998	Mean
May	0.75	0.85	0.15	0.45	0.20	0.00	1.36	0.00	0.47
June	3.35	2.95	1.08	2.10	0.25	0.82	0.51	0.04	1.39
July	3.12	2.25	4.22	1.95	3.59	2.21	7.32	3.49	3.52
August	4.37	1.10	2.21	1.39	5.05	2.37	1.10	1.88	2.43
September	0.00	0.00	0.10	0.00	2.40	2.87	2.54	0.06	0.97
Total	11.59	7.15	7.76	5.89	11.50	8.27	12.83	5.46	8.78
Departure Mean (%)	+31.6	-18.8	-11.9	-33.2	+30.5	-6.1	+45.6	-38.0	

Vegetation

From ocular estimates and examination of aerial photographs, most of the burned parts of the watershed were bare in 1990. During spring 1991, resprouts of woody species, especially Gambel oak and quaking aspen appeared on the bare portions. By fall 1991, plant cover was increasing on the majority of the burn. However, plant establishment was slow on several areas, especially in the higher elevations. By fall 1992, plant cover continued to increase due to wet periods early in the growing season. This increased growth continued through the summer of 1993 and survived the drought of 1994 and early 1995. Vegetation continued to increase following subsequent fires through 1998.

Runoff

Maximum stream depth was dynamic through 1995 with the greatest depths and weekly fluctuations being in 1995 (Figure 2).

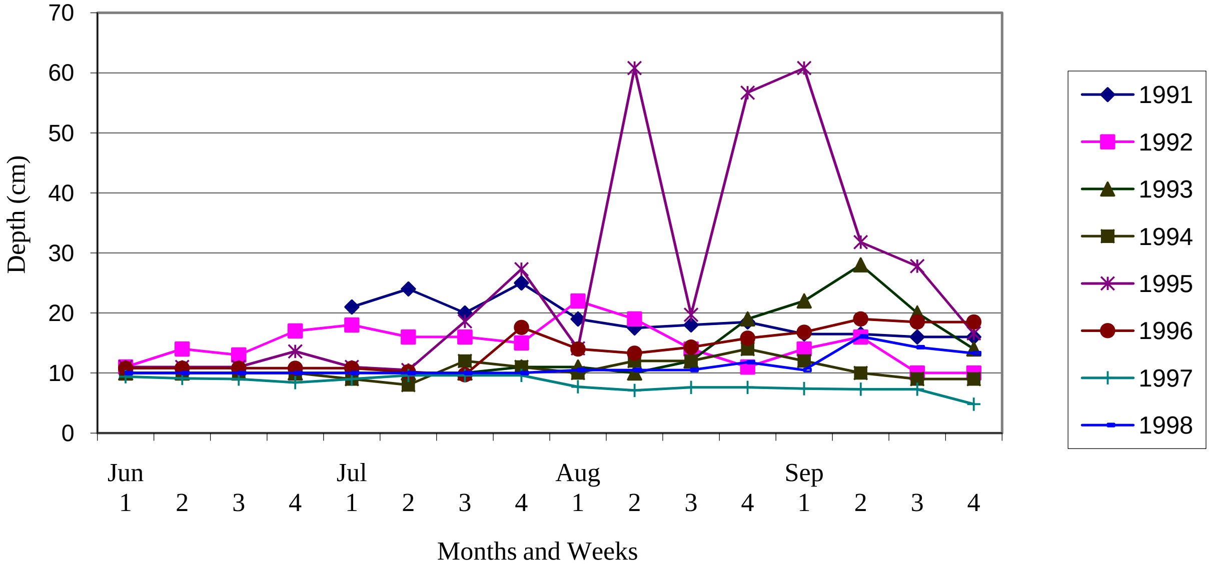

Figure 2. Stream depth at the end of each week from 1991 through 1998 for the four-month sampling period of each year.

This is attributed to residual effects of the 1989 fire and large precipitation events in August and September 1995 (Table 1a and 1b). Precipitation in August 1991 was similar to August 1995 but the high flows of August 1991 were not as deep as in August 1995. This is attributed to the precipitation in August 1991 being scattered across the month with low intensities. Depths during this study never reached 1 m as compared to debris indicating deeper streamflows during 1989 and 1990, which measured greater than 1 m during those two years. By 1996, stream depths had decreased from previous years and continued to decrease through 1997 and 1998, even though 1997 had high amounts of precipitation, especially in July. Although parts of the watershed were burned in 1995 and 1997, they were small enough portions of the watershed to be considered as small contributors of total runoff. It is not evident that the bovine presence in 1996 had any measurable effects on stream water depth. Continuously low runoff amounts the last three years of the study were attributed to stable watershed conditions.

Suspended Sediment

Mean and maximum weekly sediment concentrations were low during most weeks after 1991 (Tables 2 and 3). During 1991, maximum sediment concentrations taken at three-hour intervals were highest during the first week of July (10,140 mg l^{-1}).

Table 2. Mean weekly sediment concentration (mg l^{-1}) from 1991 through 1998 for the four-month sampling period each year.

	Year								
Month	Week	1991	1992	1993	1994	1995	1996	1997	1998
June	1	10	*	47	16	15	14	17	16
	2	12	11	21	15	12	21	22	11
	3	15	16	35	14	16	36	38	16
	4	16	36	21	24	18	25	304	11
July	1	18	*	30	12	39	34	52	21
	2	799	30	36	*	*	46	38	15
	3	3,269	15	28	8	12	184	24	15
	4	564	37	28	*	10	30	35	53
August	1	460	22	38	10	75	18	38	17
	2	491	28	21	8	10	7	26	26
	3	665	118	42	8	23	12	4	56
	4	*	22	18	8	21	238	24	27
September	1	*	43	*	8	31	50	14	29
	2	18	56	27	*	35	22	10	11
	3	10	12	25	*	15	62	8	24
	4	20	15	20	*	22	43	68	15

* Missing data

Table 3. Maximum sediment concentration (mg l^{-1}) at any three-hour period within weeks from 1991 through 1998 for the four-month sampling period each year.

	Year								
Month	Week	1991	1992	1993	1994	1995	1996	1997	1998
June	1	51	*	246	26	27	36	25	38
	2	28	29	73	*	27	38	32	20
	3	23	43	53	24	82	52	49	24
	4	318	214	39	25	41	72	2,484	163
July	1	10,140	*	38	80	67	58	900	196
	2	4,117	138	219	67	*	192	41	34
	3	2,280	198	53	*	35	1,712	52	29
	4	2,404	172	63	50	20	50	50	224
August	1	4,000	48	40	*	975	86	323	29
	2	7,620	110	126	59	16	32	60	89
	3	5,817	332	43	14	66	70	35	253
	4	*	58	33	27	26	320	154	58
September	1	*	111	*	45	42	103	18	69
	2	47	497	60	19	38	32	27	32
	3	41	29	55	*	36	148	14	123
	4	29	56	38	*	61	62	821	54
* Missing data									

After 1991, mean sediment concentration levels were usually less than 100 mg l^{-1}. A question arises as to how much sediment is desirable or tolerable. Some typical values of total suspended solids are given in Table 4.

Table 4. Typical values for total suspended solids (mg l^{-1}) in runoff for selected rivers in the U.S. and several foreign countries (Stednick 1991, Milliman and Meade 1983).

Site	Total Suspended Solid (mg l^{-1})
Skagit River at Marblemount, Washington	12
Ogeechee River near Eden, Georgia	14
Cache la Poudre River near Ft. Collins, Colorado	16
Colorado River at Imperial, California	18
Rogue River near Agness, Oregon	23
Tualatin River at West Linn, Oregon	23
Cumberland River near Grand River, Kentucky	28
North Fork Whitewater River near Elba, Minnesota	29
Yellowstone River near Livingstone, Montana	47
Amazon River in Brazil	143
La Plata River in Argentina	196
Colorado River at Stateline, Colorado	240
Yukon River in United States	308
Danube River in Romania	325
Mekong River in Vietnam	340
Mississippi River in United States	362
Arkansas River near Coolidge, Kansas	484
Ganges River near Brahmaputra, India	1,719
Nile River in Egypt	3,667
Yellow River in China	22,040

The relationship between sediment concentrations and desirable or tolerable levels for fish habitat is complicated and not fully understood, especially for rare species such as the Gila trout. However, other studies indicate migrating salmonids avoid waters with high sediment loads, or cease migration when such loads are unavoidable (Cordone and Kelley 1961, Bjornn and Reiser 1991). Bell (1991) cited a study in which salmonids did not move in streams where the suspended sediment concentration exceeded 4,000 mg l^{-1} (as a result of a landslide). Thus, high turbidity in rivers may delay migration.

Bjornn and Reiser (1991) reported that in most streams, there are periods when the water is relatively turbid and contains variable amounts of suspended sediments. Larger juvenile and adult salmon and trout appear to be little affected by ephemerally high concentrations of suspended sediments that occur during most storms and episodes of snowmelt (Cordone and Kelley 1961, Sorenson et al. 1977). Bisson and Bilby (1982) reported that juvenile coho salmon avoided water with turbidities that exceeded about 400 mg l^{-1}, which may occur in certain types of watersheds and with severe erosion. Berg and Northcote (1985) reported that feeding and territorial behavior of juvenile coho salmon were disrupted by short-term exposures (2.5-4.5 days) to turbid water (up to 300 mg l^{-1}). Newly emerged fry appear to be susceptible to even moderate turbidities compared to older fish. Turbidities in the 125-275 mg l^{-1} range reduced growth and caused more young coho salmon and steelhead to emigrate from laboratory streams than did clear water (Sigler et al. 1984).

Other authors reported that elevated levels of suspended sediment may have both acute and sublethal effects on salmonids. Noggle (1978) reported that suspended sediment concentrations of 1,200 mg l^{-1} caused direct mortality of underyearling salmonids. Reduced growth and feeding activity have been reported at concentrations as low as 300 mg l^{-1} (Noggle 1978, Sigler et al. 1984). McLeay and others (1984) tested the responses of wild Arctic grayling in the laboratory to sediment obtained from a Yukon gold dredging operation. They reported that underyearling fish could withstand long-term exposure (six months) to suspended sediment concentrations up to 1,000 mg l^{-1}, but that a variety of sublethal effects (for example, impaired feeding activity, decreased scope for activity, reduced growth, downstream displacement, and decreased resistance to other environmental stressors) occurred at concentrations as low as 100 mg l^{-1}. McLeay and others (1984) showed that Arctic grayling could tolerate short-term (four day) exposures to suspended sediment concentrations as high as 250,000 mg l^{-1} at 15° C, but that tolerance was reduced at 5° C. Sigler and others (1984) reported downstream displacement of salmonids in response to concentrations of suspended sediment greater than 100,000 mg l^{-1} from severely disturbed lands. Conte (1992) suggested 80 mg l^{-1} of total suspended and settleable solids for aquaculture hatcheries or production facilities.

Gila trout were re-introduced in 1994. Sediment concentration reached 975 mg l^{-1} in 1995 with no detectable mortality (Table 3). Sediment concentrations reached 1,712 mg l^{-1} in 1996 and 2,484 in 1997 with no detectable mortality. Gila trout seem to tolerate high levels of suspended sediment relative to other salmonid species. This is not surprising considering that fires were probably a naturally occurring phenomena for many millennia resulting in occasional spikes in turbidity.

Stream Temperature

Minimum temperatures ranged from 7.0 to 16.0 °C (44.6 to 60.8 °F). Maximum temperatures ranged from 12.0 to 20.5 °C (53.6 to 68.9 °F). The greatest differences between minimum and maximum temperatures occurred the last two weeks of September when temperatures fluctuated 6.0 °C (10.8 °F). Conte (1992) references Piper and others (1982) and Bell (1991) for temperature ranges for survival, optimum growth, and spawning of common freshwater fish species (Table 5).

Table 5. List of common freshwater fish species grown in the western United States along with temperature ranges for survival, optimal growth, and spawning (Piper et al. 1982; Bell 1991).

	Temperature in °C			Temperature in °F		
Species	Survival Range	Optimum Range	Spawning Range	Survival Range	Optimum Range	Spawning Range
Brook Trout	0-23	7-13	7-13	32-72	45-55	45-55
Atlantic Salmon	0-24	10-17	6-10	32-75	50-62	42-50
Chinook Salmon	0-25	10-14	7-13	32-77	50-57	45-55
Coho Salmon	0-25	9-14	7-13	32-77	48-58	45-55
Brown Trout	0-26	9-16	7-13	32-78	48-60	48-55
Rainbow Trout	0-26	10-16	10-13	32-78	50-60	50-55
White Sturgeon	0-26	18-21	14-17	32-78	65-69	57-63
Golden Shiner	0-32	10-17	18-27	32-90	50-80	65-80
Striped Bass	0-32	13-24	13-22	35-90	55-75	55-71
Fathead Minnow	0-35	7-27	13-27	32-95	45-80	55-80
Goldfish	0-35	7-27	13-27	32-95	45-80	55-80
Common Carp	0-35	13-27	13-27	32-95	55-80	55-80
Black Bass	0-35	13-27	16-18	32-95	55-80	60-65
Bluegill	0-35	13-27	18-27	32-95	55-80	65-80
Flathead Catfish	0-35	18-27	21-27	32-95	65-80	70-80
Channel Catfish	0-35	21-29	23-28	32-95	70-85	72-82

Stream temperatures in Main Diamond Creek were well below the maximum for survival and well above the minimum for survival for Gila trout. Actual temperatures were slightly above or below the maximum for optimum growth and well above the minimum for optimum growth for Gila trout.

Stream pH

The pH of Main Diamond Creek varied from 6.4 to 8.2, with most weekly values between 7.0 and 8.0. These levels are within safe limits for Gila trout.

Stream Profile

Although the streambed experienced extreme shifts back-and-forth across the canyon bottom in 1990, it was observed at photo points that the stream bed experienced little movement in 1991. From

May 1992 until May 1993, 10 transects showed a slight gain in profile height and 10 transects showed a slight decrease in profile height (Table 6).

Table 6. Stream profile changes (cm) after 1991 and through 1998 as measured at the end of May each year.

	Years					
Transect	1992-1993	1993-1994	1994-1995	1995-1996	1996-1997	1997-1998
1	-2.76	0.80	-2.36	-10.40	-1.66	6.6
2	-1.35	1.27	-2.00	4.34	1.28	-2.40
3	-4.04	-1.44	-1.35	-3.61	2.89	2.53
4	-2.51	1.02	1.63	5.91	-3.69	-0.09
5	-1.66	-0.74	-3.79	1.63	0.11	-1.46
6	0.97	-3.45	-0.58	0.35	1.31	1.66
7	0.47	2.11	-4.30	-1.92	7.46	-6.24
8	0.94	-1.03	-1.98	-0.68	4.34	0.10
9	-3.71	2.64	-6.43	-6.47	-3.44	-0.57
10	0.28	-1.43	5.43	-3.73	1.45	2.05
11	-1.37	0.63	-2.23	-2.39	-0.29	5.5
12	1.41	-0.95	-2.93	-6.87	7.72	5.94
13	1.97	-1.15	1.98	-3.22	3.95	-2.38
14	-4.11	5.46	-8.88	-0.30	0.39	-7.39
15	1.28	0.37	-1.69	7.22	2.45	-1.91
16	6.37	-3.41	-4.22	0.92	1.88	1.01
17	-2.69	-1.92	5.8	-2.98	0.72	0.29
18	-2.05	-0.54	1.12	3.83	2.60	-3.64
19	0.56	-2.26	1.61	1.13	-1.24	-2.11
20	2.69	-5.79	3.58	8.24	-8.43	-4.81
Mean	-0.47	-0.49	-1.08	-0.45	0.89	-0.37
Standard Deviation	2.57	2.39	3.65	4.70	3.45	3.69

Overall, from May 1992 until May 1993 the 20 profiles showed a decrease of 0.47 cm (-0.02 feet or -0.18 inch). From May 1993 until May 1994, eight transects showed a slight gain in profile height and 12 transects showed a slight decrease in profile height. Overall, from May 1993 until May 1994 the 20 profiles showed a decrease of 0.49 cm (-0.02 feet or -0.19 inch). Most of the change probably occurred during the forest-wide flooding of November 1994.

From May 1994 until May 1995, seven transects showed a slight gain in profile height and 13 transects showed a slight decrease in profile height (Table 4). Overall, from May 1994 until May 1995, the 20 profiles showed a decrease of 1.08 cm (-0.04 feet or -0.42 inch). From May 1995 until May 1996, nine transects showed a slight gain in profile height and 11 transects showed a slight decrease in profile height (Table 4). Overall, from May 1995 until May 1996, the 20 profiles showed a decrease of 0.45 cm (-0.01 feet or -0.18 inch).

From May 1996 until May 1997, 14 transects showed a slight gain in profile height and six transects showed a slight decrease in profile height (Table 4). Overall, from May 1996 until May 1997, the 20 profiles showed an increase of 0.89 cm (0.03 feet or 0.35 inch). From May 1997 until May 1998, nine transects showed a slight gain in profile height and 11 transects showed a slight decrease in profile height (Table 4). Overall, from May 1997 until May 1998, the 20 profiles showed a decrease of 0.37 cm (-0.01 feet or -0.15 inch).

Therefore, from 1993 through 1998, changes in height were measured in centimeters or millimeters. The large shifts in heights by decimeters and even more than a meter that were experience prior to 1993 were no longer evident. This reflects stabilization of the riparian area and probably the watershed as the riparian area’s health is related to watershed health.

CONCLUSIONS

Because of high sediment concentration levels, reintroduction of Gila trout into the Main Diamond Creek was not recommended in 1991. Vegetation, geomorphologic stability, stable streamflows, low sediment concentrations, and favorable water temperatures reflect overall watershed stability and were suitable for reintroduction of Gila trout by 1994. Prior to the burn, water temperatures were quite cold for trout, but may be more suitable following the burn.

One hundred and forty-four Gila trout were captured in McKnight Creek on September 14 and planted into Main Diamond Creek on September 15, 1994. Additionally, about that many were planted in Main Diamond Creek in September 1995 and 1996. Fifty permitted bovines grazed in the watershed in 1996 during June, July, and August. Eighty permitted bovines grazed in the watershed for the same three months after 1996 and each year throughout the remainder of the study. Water quality and quantity suitable for Gila trout were not adversely affected by additional burns and the introduction of bovines (managed and trespass).

Can Gila trout survive present management practices in west-central New Mexico? Much of the area occupied by Gila trout is under prescribed natural fire management that allows naturally occurring fires to burn in certain areas and under certain constraints. Brown and others (2001) state that these fires may not be adequate to reduce fuel loads to a level sufficient to prevent catastrophic crown fires of the type observed in the recent past. A more active prescribed burning program may be needed to contribute to a more sustainable forest and riparian structure that is less susceptible to catastrophic crown fires.

The most remarkable finding in this monitoring study was how rapidly the watershed recovered following the fire in 1989 compared to what was estimated by forest managers. The runoff, sediment load, and geomorphic shifts were significant. Although relatively minor disturbances continued after 1989, by the fifth year following the initial disturbance, the watershed had recovered enough to reintroduce Gila trout and livestock.

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