PERSISTENCE OF APACHE TROUT FOLLOWING WILDFIRES IN THE WHITE MOUNTAINS OF ARIZONA

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Wildfires are a natural disturbance that can rejuvenate and rebuild trout habitat by stimulating flood scour and deposition (Gresswell 1999; Bisson et al. 2003). However, several case studies from Arizona and New Mexico have shown severe reductions in fish populations shortly after wildfires (Neary et al. 2005). The consequences of wildfire are a particular concern in the mountainous watersheds that harbor Apache trout (*Oncorhynchus gilae* ssp. *apache*) and Gila trout (*Oncorhynchus gilae* ssp. *gilae*). Populations of these federally protected species are scattered among small stream reaches that are isolated by the presence of non-native trouts, intermittent flows, thermal regimes, natural barriers, and barriers to exclude non-native trout (Brown et al. 2001; Rieman et al. 2003; USFWS 2006). Wildfires have extirpated seven populations of Gila trout since 1989, impeding recovery efforts (Propst et al. 1992; USFWS 2006). Emergency evacuation of populations threatened by fire has become an important element of Gila trout recovery (Anderson 1992; USFWS 2006), and has been recommended as a "fundamental management approach" for conserving isolated populations of rare native fishes (Rinne 2004). However, because evacuation is costly and stressful to fish, managers need to know when it is necessary to prevent population losses.

The extent of the threat to Apache trout from wildfire has not been clear, since large wildfires have not struck its ancestral home on Mount Baldy in the White Mountains of Arizona in several decades (Dieterich 1983; Gomez and Tiller 1990). Place names such as Aspen Butte, Aspen Ridge, and Burnt Mountain suggest that this landscape has experienced stand-replacing wildfires, because extensive stands of aspen (*Populus tremuloides*) often reflect past wildfires in mixed-conifer forests (Swetnam et al. 2001; Margolis 2003). However, a recent study of stand-replacing high-elevation fires (Margolis 2003) did not include the White Mountains, in part because other areas offered clearer historical evidence of such fires (Ellis Margolis, personal communication).

Recent climatic conditions and historical management practices have increased the likelihood of large and severe wildfires in the White Mountains. Widespread insect infestations, abetted by warm winters and dry summers, have killed huge swaths of spruce in bands around Mount Baldy (Lynch 2004). The combination of increased forest fuels and warming temperatures over the past century has increased the likelihood of wildfires across vegetation zones in Arizona mountains (Cocke et al. 2005). Researchers have asserted that past timber harvest and road construction activities have rendered habitats more vulnerable to post-fire impacts; this combination of threats has motivated many land managers and community members to express concern that large wildfires in the White Mountains could jeopardize valued resources such as Apache trout (Abrams 2005). Debates over how to manage forests in the face of such risks need to be guided by analyses of wildfire effects within local landscape contexts (Rieman et al. 2003).

Two streams (Grant Creek and KP Creek) whose high-elevation watersheds have recently experienced wildfires (the Steeple fire of July 2003 and KP fire of May 2004) are especially important because they represent ancestral habitat for native trout (Figure 1). Native trout had been collected from KP Creek in 1904, although the taxonomic identity is uncertain because the original specimens have been lost (Miller 1950). KP Creek was later stocked with a strain of Apache trout from an unconnected stream as part of recovery efforts (Dowling and Childs 1992). Researchers have concluded that the present-day trout populations in both KP Creek and Grant Creek are hybridized with rainbow trout (Figure 2; Rinne 1985; Dowling and Childs 1992; USFWS 2003). The current recovery plan is to stock these streams with the Spruce Creek lineage of Gila trout, which appears to be an intermediate form between Gila and Apache trout (Riddle et al. 1998; USFWS 2003). The impact of wildfire on the two creeks was thus not a major concern from a conservation standpoint, but their response to wildfires could yield insights into how wildfires might affect other streams that have been designated for recovery of Apache trout.

The severity of a burn within a stream's watershed is a primary factor in predicting the impact of fires on aquatic systems. Burton (2001) found that 60–88 percent of the watersheds of streams that experienced high levels of post-fire debris flooding had burned at high severity; only 14–37 percent of the watersheds of streams that did not experience post-fire debris flooding were burned at high severity. Cannon (2001) has reported that the percent of watershed area burned at moderate to high severity is an important predictor of debris flows, and Schaffner and Reed (2005) successfully predicted increases in peak flows by calculating area burned at moderate to high severity. Managers can easily evaluate burn severity in the aftermath of a wildfire, making it an important and accessible tool for predicting fish persistence in different settings.

A variety of factors besides burn characteristics affect the responses of stream ecosystems to wildfires, including human influences and natural landscape attributes (Schaffner and Reed 2005). Cannon et al. (2003) found that slopes greater than 30 percent and soils with increased permeability and organic matter content were associated with increased probability of fire-induced debris flows. Debris flows are also strongly related to the occurrence of post-fire storm events (Cannon 2001), but it is difficult to predict such events. The availability of lightly burned refugia and absence of barriers are two factors that help fish avoid impacts from fires (Burton 2001; Bisson et al. 2003).

Previous research in the White Mountains indicates that landscape attributes such as topography, geology, and vegetation type need to be considered when evaluating fish habitat (Long and Medina 2005). Within a region, mean basin elevation and slope help to explain variation in post-fire flooding (Schaffner and Reid 2005). Therefore, comparing landscape attributes of the study streams to those designated for Apache trout recovery would help in evaluating whether their post-fire responses would be representative. Extrapolating the responses of two streams to a much larger and more diverse region is speculative, but it could help managers who must act on limited information concerning the risk of wildfires to Apache trout.

METHODS

This study examined the upper reaches of KP and Grant Creeks, perennial tributaries of the Blue River (Figure 1). A five-person team from the Rocky Mountain Research Station (RMRS) sampled fish populations and habitat conditions at seven 50 m long sampling sites in KP and Grant Creeks in June of 2004 (Figure 3), after the KP fire was contained. Fish populations were resampled at six of the sites one year later. The team attempted to relocate sites that had been sampled for fish in September of 1995 by the Arizona Game and Fish Department (AGFD) as part of their General Aquatic Wildlife Surveys (GAWS) program. The team successfully located three of those monitoring sites (labeled 22, 20, and 19 from upstream to downstream) in the upper

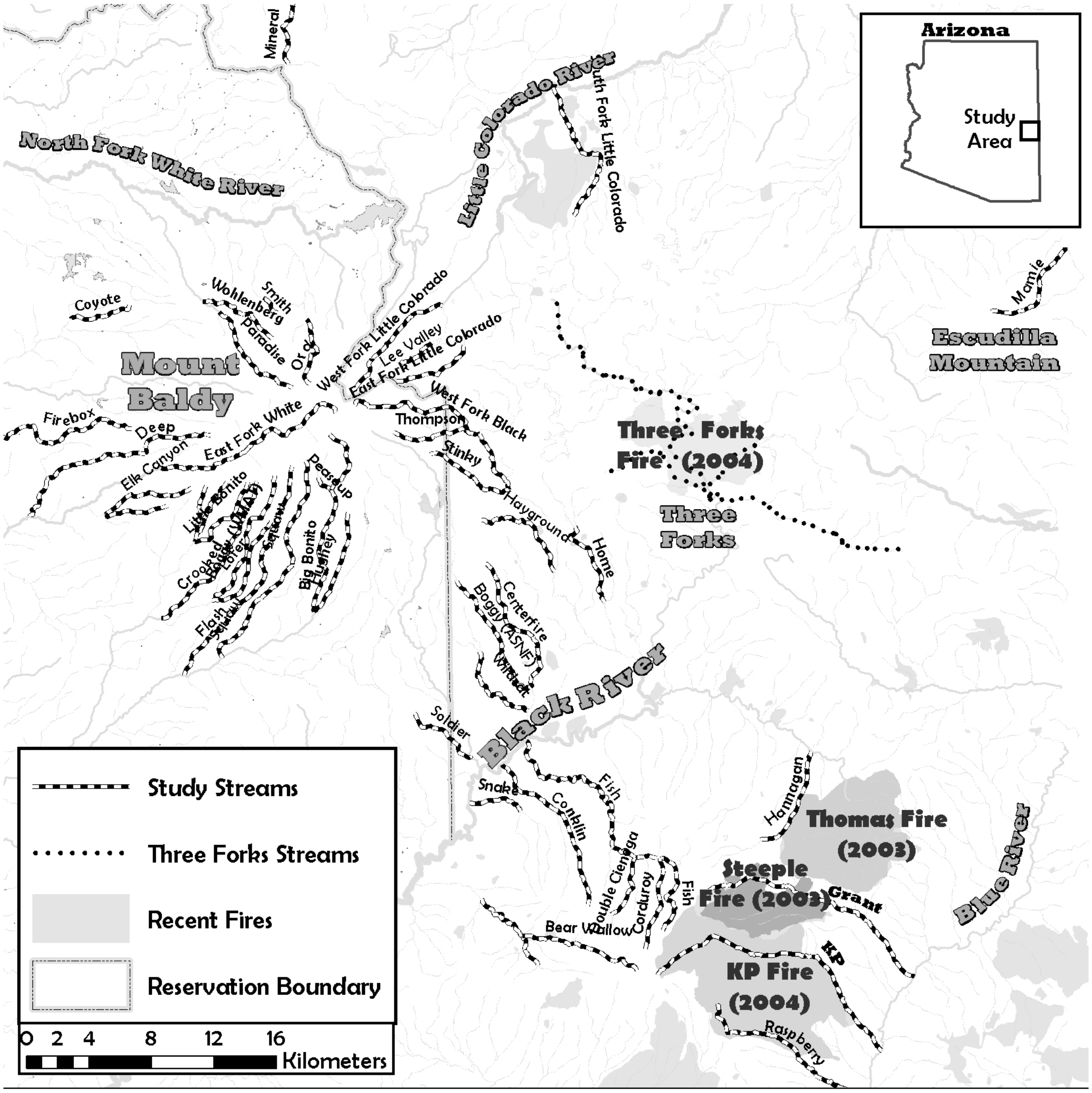

Figure 1. Locations of Apache trout streams and the study streams in the White Mountains of east-central Arizona.

reaches of Grant Creek, although AGFD had sampled fish only at the middle site. In KP Creek, the original site markers could not be located, so the team approximated the three uppermost sites (24, 23, and 22 from upstream to downstream) based on the descriptions of channel gradient and intra-station distances recorded on the 1995 survey forms. Fish populations were sampled using backpack-mounted electroshocking gear. Each reach was blocked off with nets to prevent fish from escaping during sampling and each was sampled three times using the depletion method (Zippin 1958). Lengths of all fishes were recorded and used to calculate mean lengths with 95 percent confidence intervals. The maximum likelihood population estimate and 95 percent confidence interval were calculated at each sampling site using the Microfish 3.0 computer program (Van Deventer and Platts 1989).

Figure 2. Hybridized Apache trout collected in KP Creek, June 2004.

Landscape Attributes of Study Sites

Watersheds of the study sites were delineated using the hydrologic modeling tools in ArcMap version 9 (ESRI, Redlands, CA). Burn severity information (based on differenced normalized burn ratio data calculated from satellite images) provided by the Apache-Sitgreaves National Forest was incorporated into the geographic database, and the data were used to calculate the percent of each watershed burned at moderate to high severity.

Mapping landscape attributes of KP and Grant Creek served to compare them to the 36 streams that the Apache Trout Recovery Team has identified as priorities for conservation of pure strains of Apache trout within its ancestral range (Ruiz and Novy 2000). A coarse-scale map of Arizona (Reynolds 1988) available in digital format from the Arizona Land Resource Information System served to characterize site geology (Figure 4). The two major geologic types are felsic volcanic formations along the upper slopes of Mount Baldy and mafic volcanic formations along the lower slopes and adjacent plateaus. Slopes were calculated using ArcMap to process 10 m digital elevation models of the region (Figure 5). Data for the vegetation layer were provided by the U.S. Geological Survey's GAP analysis program. In the three major mixed-conifer forest types that predominate within the range of Apache trout (Figure 6), the dominant tree species are Engelmann spruce (*Picea engelmannii*), Douglas fir (*Pseudotsuga menziesii*), and ponderosa pine (*Pinus ponderosa*).

Maps and elevations in the draft recovery plan and Arizona Game and Fish Department's GAWS reports indicated the upper and lower limits of habitat in each stream,

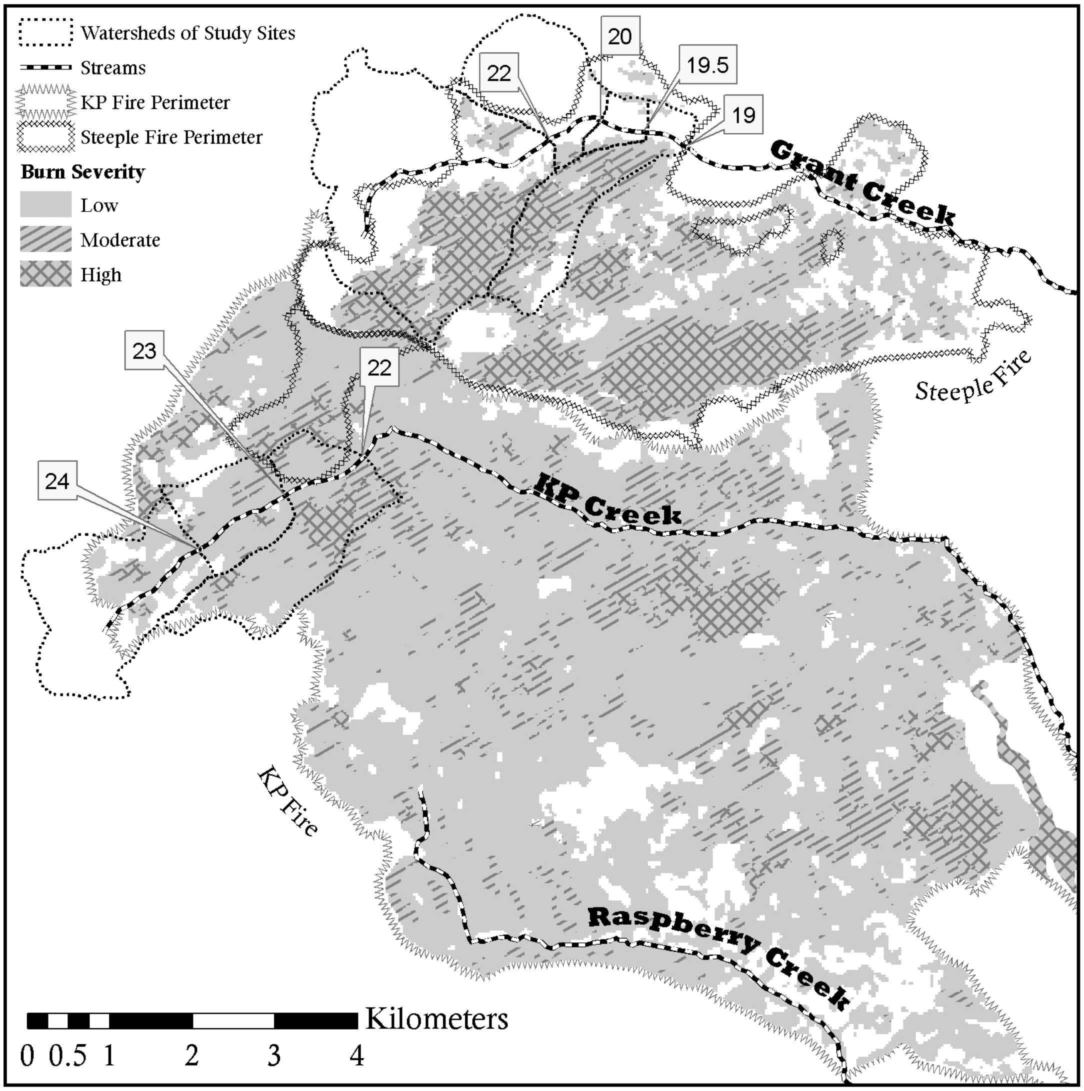

Figure 3. Map of fire impact study sites with overlay of burn severity for the KP and Steeple fires.

and in the absence of upstream limits, the beginning of a solid blue line on topographic maps approximated the start of habitat. The blue-line method provides only a rough approximation of suitable habitat (Svec et al. 2005), but it facilitates comparison of the general landscape characteristics of Apache trout streams. Figure 7 classifies the streams into three landscape types based on the characteristics at the upper end of habitat within a stream. The highest-elevation habitat could serve as a refuge from wildfire impacts if only the lower part of the watershed were burned.

RESULTS

KP Creek

The estimates of trout population at the three reaches sampled in KP Creek in 2005 were higher than or equal to the population counts at their approximate locations when surveyed 10 years earlier (Table 1). The numeric data from 2004 were misplaced and not recovered, but the memories of the

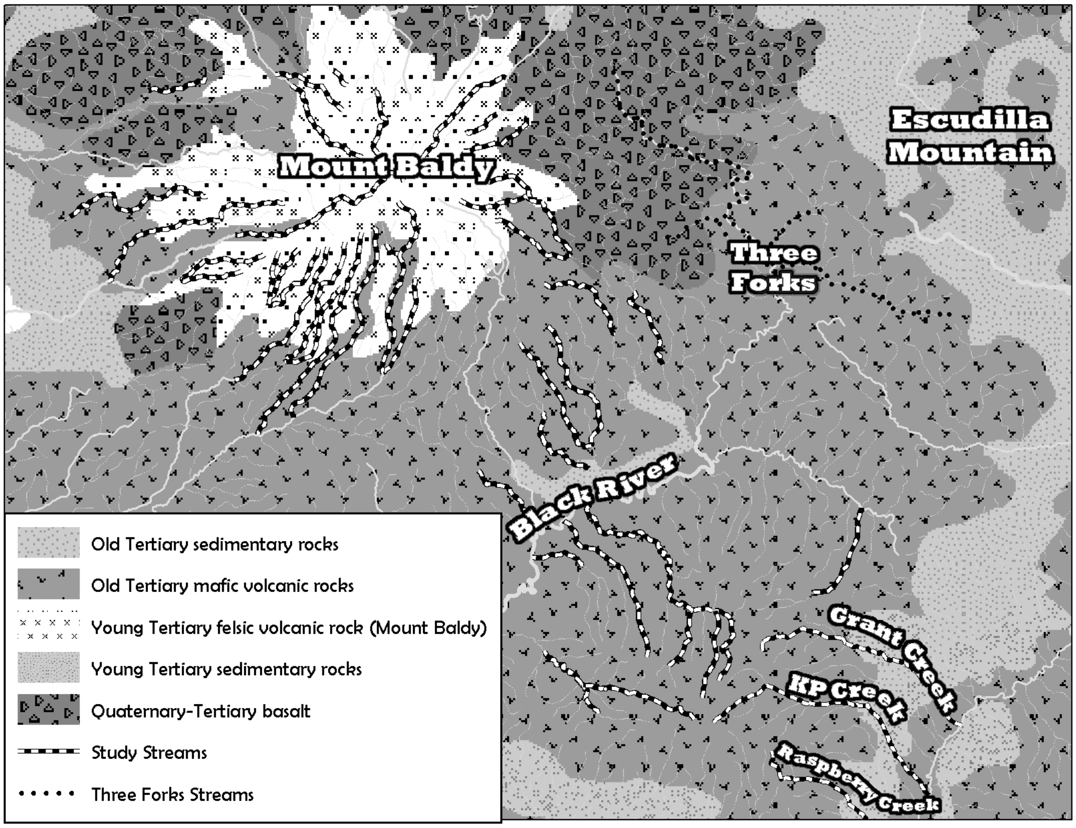

Figure 4. Geology of the White Mountains, revealing that Apache trout streams originate from the felsic slopes of Mount Baldy (light area) or on adjacent mafic plateaus (dark gray and medium gray areas with triangular stippling).

surveyors were that the numbers and sizes of fish were similar to those collected in 2005. Photographs taken during sampling in 2004 indicated that fishes were present in sizes ranging from at least 95 to 195 mm.

The percent of severely and moderately burned watershed above each site increased from 4.7 percent at the upstream site to 8.4 percent at the middle site and to 19.1 percent at the downstream site. The team observed no evidence of recent debris flows or channel incision at the sites in 2004 or 2005, but a very large debris fan was observed in the channel < 100 m downstream from the lowermost site in 2004 (Figure 8). It emanated from a drainage that burned at high severity in the previous year's Steeple fire, which had burned into the KP watershed.

Grant Creek

In Grant Creek, temporal comparisons were limited by the fact that fish had been sampled only at one site (20) prior to the fire. That sample was collected in September of 1995. Resampling was conducted in early June in both 2004 and 2005. The population estimate within reach 20 in 1995 was twice the levels estimated in 2004 and 2005 (Table 1). However, the fish in the 1995 sample were only half the length of those in 2004 and 2005. The apparent abundance of small fish could reflect seasonal variation, since the late summer sampling could have collected young-of-year fish. Sampling at a downstream site (19) yielded higher population estimates and smaller sizes compared

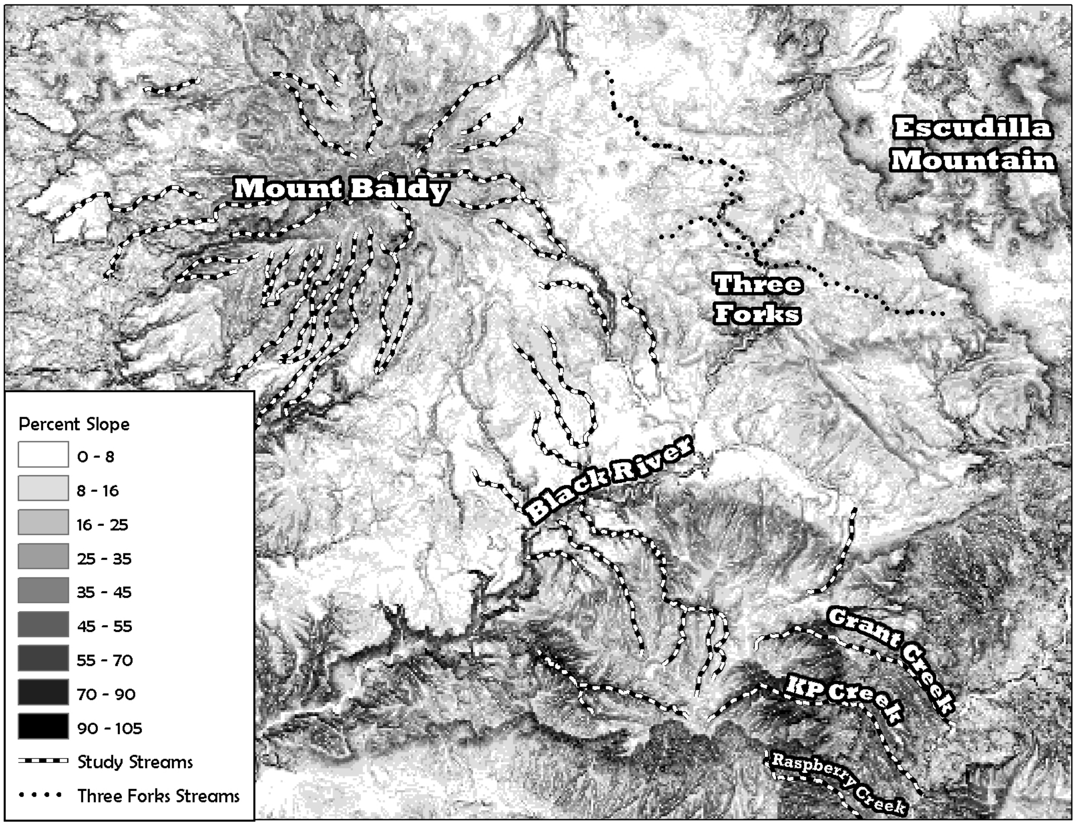

Figure 5. Topography of the White Mountains with darker shading indicating steeper slopes.

to site 20 in both 2004 and 2005 (Table 1). A reach between sites 19 and 20 (19.5) that was sampled only in 2004 had sizes and numbers of trout similar to site 20 (Table 1). Sampling at the uppermost site (22) indicated that no fish were present even though that reach had flowing water in 2004 and 2005.

The percent of watershed burned at moderate to high severity at the sampling sites was higher than at sites in KP Creek (Table 1). The channel along Grant Creek was impacted by debris flows emanating from side canyons in several locations. These flows formed alluvial fans that confined the channel and induced upstream aggradation. Water flowed underneath piles of woody debris in the reach above site 20 (Figure 9). Although the reach itself was not heavily impacted, the pile had the potential to block fish movements upstream. A debris fan below site 19 also appeared to have formed another potential barrier. Site 22 had the highest burn severity and was the only sampled reach where the channel was incised.

Landscape Comparison

KP and Grant Creeks are similar to most Apache trout streams in that they flow through mixed-conifer forests in mafic canyons. However, their upper watersheds (where the study sites were located) are relatively steeper than most Apache trout watersheds (Figure 5). Habitat in 11 Apache trout streams extends into the high-elevation (over 3000 m) spruce zone on Mount Baldy, and seven others harbor Apache trout only within the lower elevation (below 2500 m) ponderosa pine zone (Figure 7).

Table 1. Trout population estimates, lengths, and burn severity at sites on Grant Creek and KP Creek, White Mountains, Arizona (x = no data, NA = not applicable).

Site	Population Estimate (Total Catch to Upper 95% CI)			Mean Length ± 95% CI (in mm)			% Watershed Burned at Moderate to High Severity
	9/95 (pre-fire)	6/04 (before runoff from fire)	6/05 (1 year after fire)	9/95 (pre-fire)	6/04 (before runoff from fire)	6/05 (1 year after fire)	
Grant 22	x	0	0	NA	NA	NA	29.8%
Grant 20	28 (28-29)	14 (14-15)	15 (15-15)	84 ± 11	174 ± 11	174 ± 28	23.2%
Grant 19.5	x	13 (13-14)	x	x	179 ± 7	x	22.4%
Grant 19	x	20 (18-27)	23 (19-35)	x	158 ± 11	154 ± 21	28.3%
KP 24	4*	x	11 (11-13)	x	x	115 ± 32	4.7%
KP 23	12*	x	12 (12-13)	x	x	129 ± 17	8.4%
KP 22	25*	x	33 (33-35)	x	x	140 ± 12	19.1%

*1995 data for KP creek were reported only as total fish caught, not a maximum likelihood estimate based upon three-pass depletion.

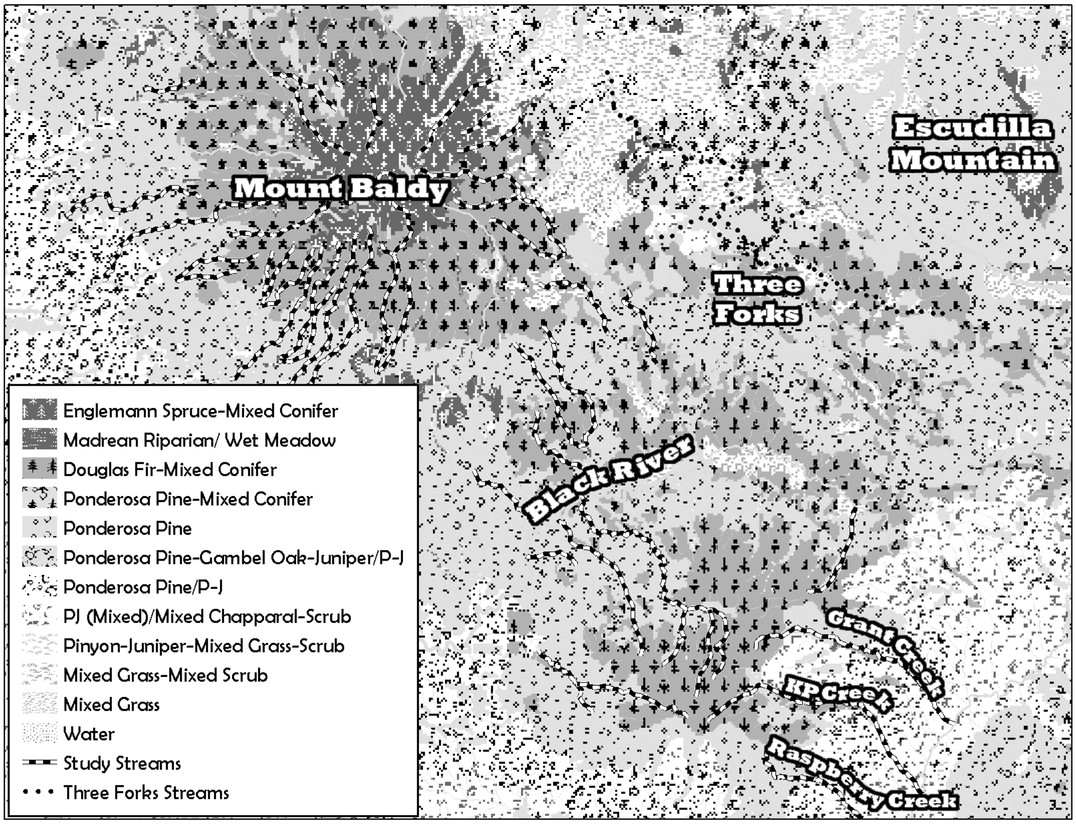

Figure 6. Vegetation types in the White Mountains, with darker shades representing high-elevation communities with naturally less frequent fire regimes.

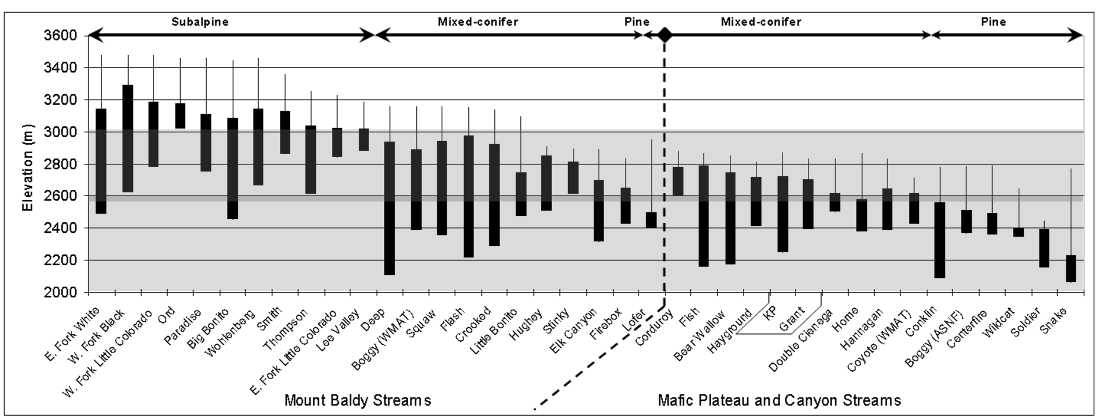

Figure 7. Bar chart representing the approximate elevation ranges of trout habitats in study streams arranged by geologic types and shaded by approximate vegetation zone. The whiskers above each bar denote the elevation at the summit of each watershed.

Figure 8. Large debris flow in KP Creek below site 22, emanating from a small area that was severely burned by the Steeple fire the year previously.

DISCUSSION

The differences in fish populations and lengths in Grant Creek before and after the fires could reflect seasonal variation (i.e., fewer young fish in the June samples) or post-fire impacts that might have inhibited recruitment of young fish. The data from both creeks are insufficient to evaluate whether the fire caused changes in abundance. They do demonstrate that fish persisted in both KP and Grant Creeks for at least the first year of post-fire runoff, which Neary et al. (2005) have suggested is a critical timeframe for extirpations to occur. The Steeple fire appeared to have induced debris flows along both KP and Grant Creeks, resulting in debris piles that could have created barriers to fish movement. Such flows were not observed in the year after the less severe KP fire. These results are consistent with the hypothesis that the extent of moderate to high burn severity is an important predictor of physical impacts such as debris flows. Since trout did survive in both streams, the results indicate that wildfires that are severe enough to induce debris flows do not necessarily extirpate trout populations.

Table 2 compiles previous research by the Rocky Mountain Research Station and other published reports of wildfire impacts on fish populations within watersheds in eastern Arizona. The percent of each watershed burned at moderate or high severity was calculated using the methods described previously. The KP fire also burned the headwaters of Raspberry Creek, which flows

Table 2. Impacts of fires on fish habitat in east-central Arizona based on various case studies between 1990 and 2004.

Fire	Location (in Arizona)	Streams Examined	Dominant Upland Vegetation	Watershed Area Burned at Moderate–High Severity	Hydro-Geomorphic Impacts	Effects on Fish Populations	References
Dude (1990)	Mogollon Rim	Bonita Creek	Pine	> 75%*	Debris flows and channel incision	Extirpation	Rinne 1996
		Ellison Creek	Pine	> 75%*	Debris flows and channel incision	Extirpation	
		Dude Creek	Pine	> 50%*	Debris flows and channel incision	Extirpation (1 trout found 1 year later)	
White Springs (1996)	Mogollon Rim	White Spring	Pine	~ 75%	Debris flows and channel incision	Extirpation	Long & Endfield 2000
Steeple (2003)	White Mtns	Grant Creek (site 19)	Douglas fir/ pine	28.3%	Debris flows and channel incision	Trout persisted	This study
		Raspberry Creek	Pine	7.0%	—	Trout persisted	
Rodeo-Chediski (2002)	Mogollon Rim	Limestone Canyon	Pine	72%	Debris flows and channel incision	Extirpation	Long & Burnette 2004
Steeple (2003)	White Mtns	Grant Creek (site 19)	Douglas fir/ pine	30%	Debris flows and channel incision	Trout persisted	This study
		Raspberry Creek	Pine	7.0%	—	Trout persisted	USFWS 2006
KP (2004)	White Mtns	KP Creek (site 22)	Douglas fir/ pine	19.1%	Not observed 1 year post-fire	Trout persisted	This study
Three Forks (2004)	White Mtns	N. Fork E. Fork Black River	Douglas fir/pine, mixed grass/shrub	3.5%	Short-term turbidity increase due to ash	Trout persisted	Unpub. data, J. Rinne, C. Carter & J. Long
		Boneyard Creek		4.8%			(RMRS)
		W. Fork E. Fork of Black River		6.4%			

*Estimated based on fire perimeter maps and observations by J. Leonard, an RMRS technician who has studied the Dude fire.

Figure 9. Debris flow in Grant Creek above site 20.

down a steep, south-facing slope through ponderosa pine forest (Figures 6 and 7). In response, federal and state agencies evacuated a portion of the Gila trout population that had been introduced to the stream, and the U.S. Forest Service set a backfire to inhibit the spread of the fire. A maximum of only 7 percent of the watershed burned at moderate to high severity; the U.S. Fish and Wildlife Service reported that trout survived in the creek (USFWS 2006).

The Three Forks fire burned 3200 hectares in the relatively flat headwaters of the East Fork of the Black River (Figures 2 and 6). Only 4–6 percent of each tributary drainage burned at moderate to high severity (Table 2). Historical data from AGFD's GAWS surveys indicate that brown trout and various warmwater species such as desert sucker and speckled dace were present in samples from all periods, although Apache trout were not. The samples were highly variable between sampling periods both before the fire and afterwards. The post-fire samples in 2004 and 2005 showed that fish persisted and no changes in channel morphology were observed (unpublished data of J. Rinne, C. Carter, and J. Long on file at the RMRS in Flagstaff).

The Steeple, KP, and Three Forks fires had more moderate impacts compared to earlier wildfires on ponderosa pine forests along the Mogollon Rim west of the White Mountains. Several of the earlier fires, including the Dude fire of 1990 (Rinne 1996), the White Springs fire of 1996 (Long and Endfield 2000), and the Rodeo-Chediski fire of 2002 (Long and Burnette 2004; Long et al. 2005), induced fish extirpations and major impacts to stream channels including channel avulsion and rapid incision. In each case, localized extirpations of fish populations occurred within the first couple of years at sites where more than 50 percent of the watershed area burned at moderate to high severity (Table 2).

The Aspen fire of 2003 burned most of the upper Sabino Creek watershed and thus triggered an evacuation of rare Gila chubs from Sabino Creek (Tobin 2004). Post-fire debris flows in the canyon substantially modified aquatic habitats and initially appeared to eliminate all aquatic vertebrates in the canyon (USDA 2004). However, researchers subsequently discovered several adult and numerous young Gila chubs in a large pool (Tobin 2004). Forty-seven percent of the watershed above that reach burned at moderate to high severity.

These case studies of fire impacts are consistent with a hypothesis that the proportion of moderate to high severity burn is a useful predictor of impacts to fishes and their habitats. Specifically, extirpations have been reported for streams where more than half of the watershed burned at moderate to high severity. By consistently collecting pre- and post-fire data, future studies could test such a threshold of burn severity.

Despite its potential utility, an index of burn severity is a simple metric that ignores many factors that are likely to influence post-fire stream impacts. However, landscape classifications can help to control for important factors such as watershed steepness, soil erodibility, and availability of refugia. Managers need to tailor their management strategies to the historic fire regime within particular forest types (Schoennagel et al. 2004). Accordingly, the typology used in Figure 7 may be helpful in planning management of Apache trout habitats.

Spruce Zone

Stand-replacing wildfires in the subalpine zone dominated by spruce are normally infrequent due to high moisture (Veblen et al. 1991; Swetnam and Baisan 1996), but stand-replacing fires have been reported in spruce-fir communities in northern New Mexico during severe droughts in the mid eighteenth century (Margolis 2003). The risk of stand-replacing wildfires in this zone may be increasing due to the combination of drought, warming, and insect outbreaks, which has increased fuel loads in the form of needles and dead trees. A combination of drought, historical fire suppression, and heavy insect damage fueled the 11,800 ha Nuttall Complex fire in spruce-fir and mixed-conifer forest on Mount Graham in 2004 (Koprowski et al. 2005). The fire, which burned 59 percent of the watershed of Marijilda Creek at moderate to high severity, induced extreme flooding and debris flows (Schaffner and Reed 2005), demonstrating that high-elevation streams in east-central Arizona are vulnerable to high-severity wildfire given the current climate and stand conditions. However, management options may be limited because fuel reduction treatments are unlikely to mitigate fire hazards in this naturally dense forest type (Schoennagel et al. 2004).

The spruce zone on Mount Baldy, which harbors many of the larger populations of Apache trout, was the source of three of the remaining pure lineages of this fish (Ord, East Fork White River, and Smith). Watersheds in this zone have slopes in excess of 30 percent, relatively coarse-textured geologic formations, and soils with high organic-matter content (Long et al. 2003). If the relationships reported by Cannon et al. (2003) apply to this region, then post-wildfire debris flows could be more likely to occur in streams on Mount Baldy than in streams on the adjacent basaltic plateaus. On the other hand, several of the high-elevation streams, including Ord Creek, East Fork of the White River, and Big Bonito Creek, have multiple perennial tributaries that could provide refuge for trout.

Mixed Conifer Zone (Douglas fir Dominated)

The KP and Steeple fires resulted in relatively large, mixed-severity burns within the Douglas fir zone following several years of drought conditions; mixed-severity fire regimes are typical in this zone (Rollins et al. 2000; Margolis 2003). Dieterich (1983) found that the mean fire return interval in this forest type in the White Mountains is 22 years, and stand-replacing fires appear to be uncommon. However, severe droughts combined with heavy fuel loading and insect outbreaks could trigger more severe fires in this forest type. Two such fires occurred in 1951—the Escudilla fire east of Mount Baldy (Savage and Mast 2005) and the McKnight fire in New Mexico (Rollins et al. 2000). The McKnight fire left a legacy of incised and unstable channels prone to scouring (Medina and Martin 1988), and harsh floods have repeatedly diminished the populations of Gila trout that were introduced into McKnight Creek after the fire (USFWS 2003). That outcome suggests that wildfires in this zone could have more severe consequences than were observed during this study.

Ponderosa Pine Zone

Fire-scar studies have suggested that wildfires in relatively dry ponderosa pine forests along the Mogollon Rim of Arizona and the Gila Mountains of New Mexico have historically been primarily low ground fires with return intervals of less than 10 years (Swetnam and Baisan 1996). More than two-thirds of Apache trout streams extend into the ponderosa pine zone. Meanwhile human alteration of fire regimes in those forest types may have increased the occurrence of high-severity crown wildfires (Brown et al. 2001; Savage and Mast 2005), which caused the fish extirpations reported from the Mogollon Rim. Not all wildfires in ponderosa pine forests in Arizona and New Mexico have caused such severe impacts, though; for example, Earl and Blinn (2004) reported that recent wildfires in ponderosa pine forest in New Mexico generated relatively short-lived impacts to streams. The risks of high-severity wildfire are lower when such stands are kept less dense (Rollins et al. 2000). Nevertheless, as is the case in other forest types, severe fires may also have occurred naturally during warmer, drier periods (Pierce et al. 2004). In the relatively moist ponderosa pine forests found at higher elevations, mixed-severity fire regimes naturally predominate and treatments to reduce the risk of high-severity wildfire are less likely to be effective (Schoennagel et al. 2004).

CONCLUSIONS

KP and Grant Creeks are similar in geology, topography, and vegetation to the majority of streams planned for recovery of Apache trout. These streams extend into mixed conifer forests where mixed-severity wildfires such as the KP and Steeple fires are typical. Fish extirpations have been reported from streams in drier, lower-elevation forest types where wildfires have been more severe, but long-term fire history studies suggest that high-severity wildfires do occur in high-elevation forest types during extended dry periods. Trout populations persisted following the mixed-severity wildfires in KP and Grant Creeks, indicating that evacuation of populations may be unnecessary when a watershed is not severely burned. While many factors can influence the likelihood of fish persistence, burn severity can be determined rapidly using satellite imagery. Consequently, until more confirmatory studies are conducted, that metric may help managers evaluate whether to evacuate Apache trout populations that are threatened by wildfires.

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