Fire Effects on Aquatic Habitats and Biota In Madrean-type Ecosystems: Southwestern United States

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Abstract.—Intense wildfires effectively remove vegetation, degrade watershed condition, and result in altered stream hydrographs and increased sediment input to streams. Case histories from five headwater streams in Arizona and New Mexico show effects of wildfire on aquatic habitats, fishes, and their food supply may be marked and long-lasting. Recent (1989-90) wildfires effectively extirpated two populations of brook trout (*Salvelinus fontinalis*), one of rainbow trout (*Oncorhynchus mykiss*) and the type locality population of the endangered Gila trout, (*O. gilae*). Aquatic macroinvertebrates densities declined to zero within 1 month after the fire, and diversities dropped 25 to 70% a year later. Trout populations re-introduced 1 year after the fire declined 85 to 97% in a two-year period. Highly variable streamflow and fluctuations in Gila trout populations in one stream in southwestern New Mexico suggest the effects of wildfire on stream habitats and biota may be long lasting. Forest Service management and research must continue to cooperate in examining the effects of not only wildfire but prescribed fire on aquatic habitats and biota within southwestern riparian areas.

INTRODUCTION

In the Madrean Floristic Province of the southwestern USA and northern Mexico, there is a direct correlation between surface elevation and precipitation (Dunbier 1968) and ultimately the occurrence of perennial streams. The mountain ranges of the Basin and Range Geomorphic Province are more mesic than are the desert floors (or basins) because of orographically produced precipitation. These montane "sky island" landscapes thus contain the major proportion of the perennial streams in the area (Rinne 1995). However, the vagaries of the local climate (Green and Sellers 1964) result in periodic low and intermittent flows, even in these upper elevation streams.

In the streams of the more mesic montane areas, salmonids occur naturally (Rinne 1985, 1988) or have been widely introduced for sport fishing. The Apache trout (*Oncorhynchus apache*) and the Gila trout (*O. gilae*) evolved in montane streams in Arizona (Miller 1972) and New Mexico (Miller 1950), respectively. However, introductions of nonnative salmonids, principally rainbow (*O. mykiss*), brown (*Salmo trutta*), and brook (*Salvelinus fontinalis*) trout for sport fishing have significantly reduced both the historic range and numbers of both Apache and Gila trout (Rinne 1985, Rinne and Minckley 1985).

In addition to fish introductions, man-induced land management activities (Debano and Schmidt 1989), instream enhancement efforts (Rinne 1981b; 1982), water harvesting (Rinne and Minckley 1985), and natural disturbance events such as drought, wildfire, and flooding (Rinne 1981a, Rinne and Lafayette 1991) have collectively impacted these native trouts through habitat alteration and loss. Because of variability of streamflow and land management activities, both native and introduced trouts now live in marginal habitats.

Historically, wildfire has been a natural disturbance event on the watersheds of Madrean montane

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regions. These fires occurred every 4-5 years (Swetman 1990), and were ground level and understory in nature (Dieterich and Hibbert 1988, Wright 1990). Accordingly, forest vegetation, largely ponderosa pine (*Pinus ponderosa*), occurred in more open stands, and understory was reduced (Covington and Moore 1992).

Since the beginning of the 20th Century, suppression and control of wildfire have altered the natural process of periodic burning, and have resulted in increased fuel loads, understory and brush, and stand density (Wright 1990, Covington and Moore 1992). In combination, these factors can produce intense, rapidly spreading wildfires that consume vegetation and ground litter over vast portions of forest watersheds.

In the Southwestern USA and northern Mexico, the fire season of May-June is immediately followed by the summer monsoon season in July-August. Accordingly, the denuding of watersheds by wildfire is potentially followed by localized, heavy precipitation and runoff into streams (Rinne and Medina 1995). To date, there is no information on the effects of wildfires on the quality and quantity of these runoff events on southwestern riparian-stream ecosystems. Understanding these effects on aquatic resources is basic to effective and responsible management of National Forest lands.

The recent wildfires in Yellowstone National Park brought into focus the issue that we cannot control all fires, and some will destroy resources in spite of all efforts to control them. The Yellowstone fires have a very long fire return interval (200-300 years; Romme and Despain 1989) compared with semi-arid forest ecosystems of the Madrean Archipelago, where historically (pre-suppression era) fires in ponderosa pine burn at 3-5 year intervals (Dieterich and Hibbert 1988, Swetnam 1990). The former have a greater potential for destruction because of fuel accumulations over centuries. In the Southwest, fuel accumulations in ponderosa pine between 40-50 years would be roughly equivalent to those of the Yellowstone region. Nevertheless, the effects and use of fire in the two ecosystems are very different.

Anderson et al. 1976, Tiedemann et al. 1979, and Lyon et al. 1978 found few specific studies of the effects of fire on fishes via either post-fire changes in water quality or quantity. Gottfried and Debano (1990) reported that, although nutrient levels changed significantly in a stream following a prescribed fire in ponderosa pine in east-central Arizona, changes were too small to adversely affect water quality. Most water quality studies have not addressed the potential effects of short-term nutrient enrichment of the riparian zone and water on the complex aquatic faunal assemblages. The timing of nutrient and sediment discharge, for example, could adversely affect reproduction of aquatic fauna. On the other hand, nutrient enrichment of the aquatic environment could be highly beneficial to algaes and aquatic macrophytes that flourish under such conditions.

Prescribed fire has been widely used as a tool to manage fuel and vegetation on southwestern watersheds (Dieterich 1980, Harrington and Sackett 1988, Krammes 1990). Since the 1970s, prescribed fire has been used in an attempt to reveal and at the same time mimic what has occurred naturally in fire ecology for centuries (Covington and Moore 1992). Every year, thousands of hectares are burned by prescription in the U.S. Forest Service's Southwest Region. There is an urgent need to address both natural wildfires and those prescribed by man, and their comparative impact on management of all natural resources on forest lands.

This paper reviews primarily the effects of wildfires on riparian-aquatic habitats, and discusses three case histories of wildfires in Arizona and New Mexico. Specifically, we:

1. Review and discuss information on altered stream hydrographs and sediment production from watersheds affected by wildfires;
2. Present data on fish and macroinvertebrate populations following a 12,000 ha wildfire that occurred in summer 1990 in Arizona;
3. Review the aftermath of a 4,000 ha wildfire that occurred in summer of 1989 in New Mexico and its effects on an endangered trout; and
4. Suggest the possible influences of a wildfire 40 years ago on another stream containing an endangered trout.

Our objectives are to:

1. Increase the level of awareness of the potential effects of wildfire management on stream habitats, fishes, and fisheries; and
2. Make a plea for the need to monitor and conduct additional research on the potential effects of fire in the Madrean Province on fish habitats and populations.

This is not an exhaustive but rather and introductory document on the effects of both prescribed and wildfire on fish and their habitats.

WILDFIRE EFFECTS

Water Yield

Water yield increases from prescribed fires and wildfires in Madrean-type ecosystems are discussed in more detail in DeBano and Neary (this volume). Apart from immediate increases in surface runoff which can transport ash and sediment into streams, a major concern is that if more precipitation continues to leave a watershed as surface runoff, baseflows will eventually decrease. In extreme conditions, perennial streams could become ephemeral, with devastating effects on aquatic ecosystems.

Peakflows

The effects of fire on storm peakflows are highly variable and complex (DeBano and Neary). The high velocities and flow volumes of peakflows are responsible for most sediment transport, and alteration of channel geomorphic characteristics that adversely impact fishes. Watersheds in the Madrean Province are much more prone to enormous peakflow responses due to geomorphology (high elevation ranges), climate (monsoon weather conditions and a close source of moist, tropical air), and soils (shallow, clay-rich, and potentially hydrophobic). Peakflow increases of 3 - 971 times have been measured after wildfires in the northern reaches of the Madrean Province (DeBano and Neary).

Sediment

Sediment Yields From Fires

In North America, the regions where wildfire accounts for the highest portion of total sediment yield include the Madrean Archipelago and the chaparral steeplands of southern California (Swanson 1981). Natural sediment yields can range from 0.001 to 5.530 Mg/ha. Sediment yields usually are the highest the first year following the fire and decline in subsequent years as vegetation recovers. However, this process is slower in the Madrean Province so recovery times can be much longer than in more humid regions. All fires increase sediment yield, but wildfires produce the largest amounts (28 - 369 Mg/ha).

Debris Flows

Debris flows are the largest, most dramatic form of mass wasting to deliver sediment to streams. They can range from slow moving ash slurries and earth flows to rapid avalanches of soil, rock, and woody debris. DeBano and Neary discuss this topic in more detail. Debris flows can account for 50% of the total post-fire sediment yield delivered to stream channels in some ecosystems.

The impacts of debris flows on riparian ecosystems are multiple, and largely negative. A stable stream channel reflects a dynamic equilibrium between incoming and outgoing sediment and streamflow. Large, sudden inputs of sediments into streams cause rapid aggradation of channels. Although increased peakflows after fires can also produce channel downcutting (degradation), the process of aggradation from debris flows dominates in the short-term. Narrow, distinct channels turn into broad, braided systems. The results are damaged fish habitat, reduced macroinvertebrate populations and diversity, and extirpation of fish populations.

Water Chemistry

Undisturbed ecosystems usually have tight cycles for major cations and anions, resulting in low concentrations in streams. Disturbances such as fires that interrupt normal nutrient cycling processes can result in the increased concentrations of inorganic ions in soil solution and leaching to streams via subsurface flow. Inputs of nutrients to streams also can increase during post-fire washoff of ash or during aerial drops of fire retardant.

Excess nutrients carried to streams can increase aquatic plant productivity, reduce the potability of water supplies, and produce toxic effects in aquatic organisms. Anions such as phosphate and cations such as calcium and potassium can be exported from watersheds at 10 times their normal rate immediately after severe disturbances, but don't necessarily alter water quality as far as fish are concerned. During stormflows after the Dude Fire (discussed in the next Section on Case Histories), there was some initial concern that the anion-cation content of the ash slurry may have had a toxic effect on salmonids.

However, aside from the limited observational data on trout mortality following the Dude Fire (see below) there are no quantitative data to unequivocally support this hypothesis, and the elevated suspended sediment concentrations were certainly enough to produce a purely physical effect.

Studies of water chemistry after wildfires show increases in NO_3-N concentrations with maximums in Madrean ecosystems ranging from 0.6 to 12.0 mg/L. Increases in NO_3-N would be higher if volatilization into the atmosphere were not a major pathway of nitrogen loss. Except for the municipal water quality implications of elevated NO_3-N concentrations, post-fire water changes in Madrean Province ecosystems have generally not been demonstrated to be a problem for fishes. However, ammonium ions (NH_4^+) released by retardants dropped during wildfire suppression can be a toxicity problem for fish and macroinvertebrates. Retardant loads dropped parallel to and over streams can kill fish for distances in excess of 1000 m.

Temperature

Large fires can raise the temperature of especially small headwater streams during the conflagration. However, more serious and long-term problems arise due to direct heating of the water surface by the sun because vegetational shading to the stream has been destroyed. Increases up to 17 degrees Celsius have been measured . Rising water temperatures reduce dissolved oxygen (O_2) concentrations; O_2 concentrations <10 mg/L create problems for salmonid survival. Increases of 1-5 degrees C that are not a problem at sea level could become problematic at high altitudes of the Madrean Province. However, effects of fire on stream temperatures relative to fish have not been studied in the Madrean system.

CASE HISTORIES IN SOUTHWEST

The Dude Fire, Arizona

In late June 1990, a lightning strike set off a wildfire that consumed over 12,000 ha of forested land below the Mogollon Rim on the Tonto National Forest of central Arizona (Fig. 1). It destroyed over 50 homes, cost several million dollars for suppression, and resulted in the loss of 6 lives. The Dude Fire is now known as both the largest and the worst wildfire in Arizona history in terms of hectares of forest burned and loss of human life and property.

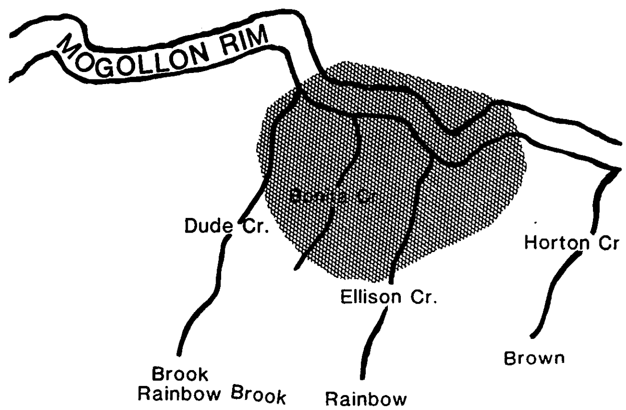

Figure 1. The relative size and positioning of the Dude Fire across the watersheds of Dude, Bonita, and Ellison Creeks, below the Mogollon Rim.

The Dude Fire burned across the watersheds of Dude, Bonita, and Ellison Creeks (Fig. 1). These streams had been under study since 1985. Although a tragedy in many ways, this natural disturbance event provided an excellent opportunity to examine the effects of wildfire on wild salmonid populations. In 1985, we began collecting baseline information on water quality, fish and macroinvertebrate populations on a group of contiguous first-order, headwater streams below the Mogollon Rim. These data (Rinne and Medina 1988, Rinne 1990), designed to serve as a "frame of reference" for information to be collected following proposed changes in grazing strategy on several allotments (Rinne and Lafayette 1991), fortuitously provided a basis for evaluating the effects of post-fire events.

Postfire hydrology

The first runoff events resulting from the developing summer monsoon season occurred between July 6th and 10th. Because of the small nature (volume) of these flow events and the availability of an extensive (5-10 cm) ash layer in both the riparian corridor and immediate hillslopes, these flows were described as "slurry flows." Concentrations of up to 700,000 mg/L suspended solids were recorded from grab samples in headwater reaches of these streams, where base flows approximate 10.6 m^3/min). With continued summer thunderstorms, larger flood events began on July 10-11 and persisted intermittently for 2 weeks.

Effects on resident fishes

Prior to the fire, trout densities in the three streams ranged between 360 and 440 fish/km (Rinne and Medina 1988; Table 1). Sampling immediately postfire (7-2-90) and prior to runoff events indicated that trout populations were slightly, although not significantly ($P > 0.05$), reduced. Although fish were not sampled immediately after the "slurry" runoff events, we observed fish swimming in all three creeks. A few dead trout were observed in pools or on streambanks.

On July 25th after subsidence of flooding no trout were captured in the reach of stream in which original stock was introduced (Table 1). Sampling after the summer monsoon season in the same reaches in October, 1990 again yield no trout. In February 1991, the entire reaches of Dude, Bonita, and Ellison creeks affected by the fire were sampled, and a single large (300 mm) brook trout was taken about 100 m from the head spring of Dude Creek. Thus, the flooding following the Dude Fire had effectively extirpated salmonids in these headwater streams below the Mogollon Rim.

Table 1. Comparison of the effects of fire on trout densities (estimated mean number per km) in three streams below the Mogollon Rim, central Arizona.

Stream	Pre-fire	7-2-90	7-25-90	10-90	2-91
Dude Creek	360	260	0	0	1
Bonita Creek	440	360	0	0	0
Ellison Creek	400	160	0	0	0

Fish restoration activities

In May 1991, 11 months after the fire, rainbow trout were restocked in Ellison Creek and brook trout in Bonita Creek (Table 2). The objectives of this effort were to determine:

1. If fish would survive atypical post-fire flood events without extensive, presumably toxic ash flows;
2. How surviving populations might respond in numbers and displacement;
3. If reproduction would occur; and
4. How the two species of fish would respond through time to changes in stream habitats and a potentially altered aquatic macroinvertebrate food base (Table 3).

Table 2. Response of stocked rainbow and brook trout to post-fire hydrology, May 1991 to July 1993. Numbers are total individuals either stocked (May 1991) or recaptured for the two streams.

Stream	May 1991	October 1991	June 1993	July 1993
Bonita	85	22	23*	34
Ellison	58	23	5	2**

35 young-of-year taken

*** 50+ young-of-year taken*

Sampling in October 1991 after a significant monsoon season revealed introduced fish stocks were reduced by over 60% in both creeks. Of trout recovered, none was over 0.5 km downstream from introduction sites, and no individuals were collected upstream of stocking sites. Fish were in excellent condition in Bonita Creek and individual growth from May to October was very good (mean Total Length (TL) 162 mm vs mean TL of 200 mm, respectively). No young-of-year rainbow trout were taken in Ellison Creek, indicating either the lack of successful spawning following introduction, or loss of young-of-year through summer flow events.

Because brook trout spawn in autumn, Bonita Creek was sampled in June 1992 following winter flow events. This species not only maintained numbers equal to October 1991 (Table 2), but, mean size had increased from 200 to 240 mm TL, spawning had been successful and fry were of a larger mean size compared to pre-fire (mean 80-90 mm TL vs mean 50-

Table 3. Aquatic macroinvertebrates per square ft surber sampler, in streams prior to and following the Dudefire.

Stream	Pre-fire 1985-86	Immed. post-fire July 3	Post-sludge flow July 13	Post-flood July 26	Post-winter May 91
Bonita	500-800	350	No data	8	553
Dude	500	460	No data	12	259
Ellison	700-900	1,000	100	0	608

Stream	Oct 1991	June 1992	November 1992
Bonita	4,400	3,800	1,100
Dude	2,800	800	3,200
Ellison	6,500	2,900	1,300

60 mm TL, respectively). Accordingly, the brook trout in Bonita Creek were reproducing successfully and both fry and adults were in excellent condition and exhibiting excellent growth a year and a half after introduction. We attribute condition and growth to reduced number of fish relative to food supply (e.g. macroinvertebrates; Table 3).

Only four rainbow trout were captured in Ellison Creek in June 1992. Three of the four were in the release area and one was about 2 km downstream. No young-of-year rainbow trout were collected. On July 7, 1993, after a winter of significantly above average precipitation and runoff, Bonita and Ellison creeks were sampled again. Thirteen brook trout averaging 254 mm TL were captured and released in Bonita Creek. All had been displaced downstream to a reach of stream where only 1 trout was taken in October 1991. Sampling in Ellison Creek resulted in only 2 adult rainbow (TL 300 mm+). Young-of-year were collected in both streams, however.

Aquatic macroinvertebrates

Prior to the fire, estimated mean aquatic macroinvertebrate densities ranged from 5000-9000/m^2 in the three streams within the burn area (Rinne 1996). Samples immediately after the fire and prior to either slurry or flood flow events indicated no significant effect on populations. Sampling in the three creeks following a slurry flow event (July 10), however, revealed a 7-fold to 10-fold reduction in macroinvertebrate density. Further sampling in late July following several significant flood events revealed populations were effectively reduced to zero. Sampling after winter flow events (May 1991) indicated populations had partially recovered. Analyses of additional samples collected in autumn 1991 and 1992 indicated population densities had not stabilized and were fluctuating below pre-fire densities. Macroinvertebrate diversity (number of taxa) was reduced from 25% (Bonita) to over 70% (Dude and Ellison) from pre-fire levels.

The Divide and McKnight Fires, New Mexico

In the 1980s, Main Diamond Creek, Gila National Forest, contained the largest population (*ca.* 5,000 individuals) of the endangered Gila trout (Mello and Turner 1980). The stream had many log structures added (Rinne 1981b) to increase pool habitat and sustain this native wild trout population in a marginal, headwater stream (Regan 1966). Based on size structure, the population in Main Diamond Creek appeared to be stunted, presumably caused by artificial creation of an over abundance of pool habitat (Regan 1966, Rinne 1982). By comparison, McKnight Creek (Gila National Forest) supported a population of Gila trout introduced from Main Diamond Creek that ranked second in total numbers of fish only to Main Diamond (Mello and Turner 1980).

A major objective of the Gila Trout Recovery Plan was to duplicate all five natural populations of this endangered trout (U.S. Fish and Wildlife Service 1984). Such a strategy was designed to reduce the probability that natural disturbance events such as drought, flooding, or wildfire would destroy any of these populations. The Recovery Plan stated, "While there is little danger that a single catastrophic event (e.g., forest fire) would ever exterminate all populations of Gila trout simultaneously, such an occurrence could seriously reduce numbers of the species and threaten efforts to secure its future. On the other hand, a catastrophe could exterminate one or more of the native populations, ..."

In July 1989 a lightning strike ignited a wildfire on the ridge between Main and South Diamond Creeks. Before it was extinguished, the Divide Fire consumed over 4,000 ha of forest vegetation on the watersheds and in the riparian areas (Propst et al. 1992). Because of the concern for elevated runoff and possible toxic flows of ash, an immediate, combined effort by the Forest Service and New Mexico Game and Fish removed 566 Gila trout and placed them in the U. S. Fish and Wildlife Service's Mescalero National Fish Hatchery for subsequent restocking. Initial slurry flows were similar to those described following the Dude Fire. However, large amounts of ash were transported into the stream (Propst et al. 1992). Two weeks later several kilometers of Main Diamond were sampled. A single,live Gila trout was found. Sampling about 1.5 km in October 1989 after extensive flooding as a result of denudation of the watershed, revealed no individuals of this endangered species. Electrofishing of the entire 6 km of previously inhabited portions of Main Diamond Creek in May 1990 again revealed no fish. Similar to Main Diamond, sampling of South Diamond Creek and its headwaters yielded only one Gila trout.

During the 1980s, a series of 50-100 year flood events occurred in McKnight Creek. These events drastically changed channel morphology. Based on original introductions and periodic sampling by personnel at New Mexico State University indicated these floods greatly impacted the Gila trout population (Medina and Martin 1988 and Fig. 2). Such changes could be attributed to a wet cycle, increased runoff from the watershed, or the combination of both. Although not specifically studied, we suggest that the McKnight Creek stream channel may yet be adjusting to the large 20,000+ ha wildfire on the headwaters of McKnight Creek roughly four decades earlier (Medina and Martin 1988).

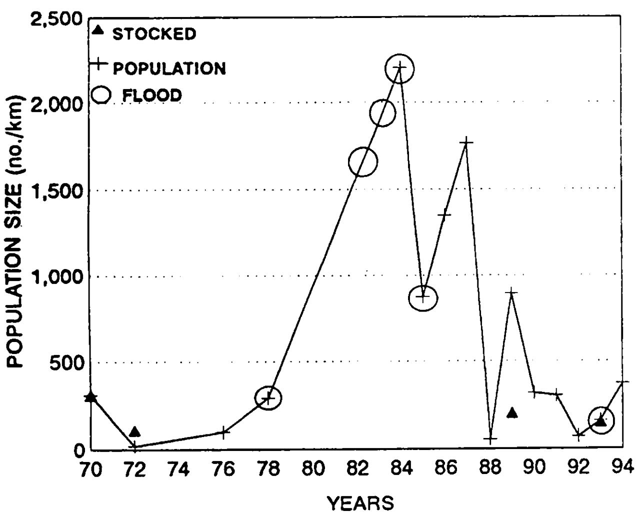

Figure 2. Fluctuations in Gila trout populations in McKnight Creek two to four decades after wildfire.

DISCUSSION

There is very little published information on the effects of either natural wildfire or prescribed fire on stream habitat and associated fisheries in the Southwest (Severson and Rinne 1990). Because of the marked effects of the aftermath of wildfires discussed above, and the amount of area burned annually by prescribed fire in the southwestern region, it is essential, for several reasons, that this lack of information be addressed. First, the demand for recreational fishing in the Southwest is high compared to national averages (Everest and Summers 1982). Equally important is the fact that the majority of the native fishes in the Southwest are threatened, endangered, sensitive, or of special concern and thereby are protected by law (Rinne and Medina 1995, Rinne and Minckley 1991). Federal agencies are mandated by the Endangered Species Act of 1973 to insure that Federal land management activities do not negatively impact or "take" federally listed species. Further, because Forest Service sensitive species are both numerous and are candidates for federal listing, they must also be wisely conserved. In combination, the economic demand for a recreational fishing resource and the legal mandate to protect a valuable, declining native fish fauna render it timely and essential to begin to address not only wildfire but prescribed fire effects on fishes as well.

Trout occupying marginal, headwater habitats such as those in Dude, Ellison, Bonita, Main Diamond and McKnight Creeks are particularly vulnerable to wildfire effects. Case histories suggest the probability is very high that total fish populations will be lost following a large wildfire. Although more subtle, cumulative, and unstudied the impacts following prescribed burns potentially affect both the short- and long-term habitats and food supply of fishes. Our data suggest that toxic slurry or ash flows are immediately fatal to a portion of the population. Survivors of these events become physiologically stressed. Flood flows following slurry flows then effectively extirpate surviving individuals. The extent of fish loss will depend both on burn intensity and size, frequency, and duration of flows during the summer monsoon. Springs or upwellings may serve as refugia, as apparently occurred for the one surviving brook trout recorded at the head of Dude Creek.

The marked effect of the aftermath of fire on salmonid species in these three case histories presents a paradox. "Why do any wild populations of native trout, or any other native species of fishes, occur throughout headwater streams within forested landscapes in the Southwest?" Fires have been occurring for centuries in these landscapes (Dieterich 1980, Krammes 1990). This paradox needs closer examination.

The population of Gila trout in Main Diamond Creek was the largest of all natural populations of this endangered species albeit possibly attributable to extensive stream habitat improvement structures. Nevertheless, this and four other natural populations (Mello and Turner 1980) have persisted through historic time. Based on the aftermaths of the Dude and Divide fires, one should not expect any native salmonids to be present in headwater streams in the Southwest. The native Apache trout was formerly (late 1800s) so abundant in the White Mountains of Arizona that it was not unusual to catch 100 in an afternoon (Rinne 1985). Other native non-salmonid native fish species also persist in montane streams on National Forests in the Southwest (Rinne and Medina 1995). Considering historic (pre 1890) fire cycles (4-5 years) in the Madrean Province of the Southwest and northern Mexico (Dieterich 1980, Swetnam 1990) one would not expect any of these species to be present today in highly vulnerable, headwater habitats. It becomes apparent that "not all things equal" on our forested watersheds between a century or more ago and the present. The question needs to be asked "Why, in spite of historical fire patterns and studies that suggest total extirpation of populations following large wildfires, do any native fishes persist in southwestern riparian-stream ecosystems?"

Because forest landscapes historically consisted of more open stands of pine, fires were typically more frequent, less intense, and smaller. High intensity crown fires were a rare occurrence (Covington and Moore 1992). Wildfires were modified first by heavy grazing and then by fire suppression efforts. Increased fire suppression resulting in fuel loading on forest watersheds has resulted in the opposite effect—greater frequency of larger fires that are more intense, localized, and consume a greater percentage of watershed vegetation, and denude a greater percentage of landscape surfaces. Generally, fires burn in mosaics and consume only a portion of the total watershed vegetation. The Dude Fire was estimated to have burned an average of 65% of pre-fire vegetation; in certain areas on the Bonita and Ellison Creek watersheds it totally removed all vegetation.

Historically, the lower intensity, naturally caused wildfires were followed by the summer monsoon season, just as occurred on the Divide and Dude fires. However, with less fuel buildup and lower intensity, non-crowning fires, extensive toxic ash flows and massive flood event were less likely. The combination of less post-fire ash entering streams, and reduced likelihood of subsequent massive floods has permitted trouts and other native fishes to survive in montane, headwater habitats through time.

In a cumulative perspective, the current extensive use of prescribed fire as a forest management tool in the southwestern USA could be an important factor in influencing sustainability of fish populations and distributions. A prescribed burn (The Shannon Burn) near the Dude Fire (Medina and Baker 1996) and observed accumulations of sediment after a single flood event upstream of a newly-constructed weir on Dude Creek in summer 1991, suggest the potential cumulative effects of sediment on fishes and their food supply and habitats following even prescribed fire are potentially as great a threat as from wildfires.

Although not immediately fatal to salmonids in marginal headwater habitats, the amounts of sediment (< 2 mm) mobilized from watersheds following even small, low-intensity "control" burn such as the Shannon Burn could temporarily alter habitat for both fishes and their food supply. Cumulatively in time and space, this impact could become significant. Fine sediment effectively fills the interstices of substrate and ultimately reduces macroinvertebrate density (Bjornn, et al. 1977; Rinne and Medina 1988; Everest et al. 1987). This negative impact on food supply, combined with aggradation in pool habitats essential for fish survival during both drought and winter periods, may indeed be as great as after natural wildfire.

The fire on the McKnight Creek watershed occurred almost 4 decades ago. Further, Gila trout were not introduced into Mcknight until 1972, almost 20 years post-fire. The response of the Gila trout in Mcknight and those trout introduced following the Dude fire suggests that re-establishing salmonid populations in such marginal, headwater habitats will be a time consuming perhaps impossible management exercise. Any time frame will be a function of burn intensity, watershed size, flow intensity, and species of fish. Stream improvement structures were heavily impacted by flooding in the 1980s in McKnight Creek. The Gila trout population, although reduced and subject to marked fluctuations, continues to survive. Nevertheless, several decades may be required for watersheds subjected to severe wildfire to completely stabilize to the point of dampening extreme flow events and fluctuations in riparian-stream habitats and fish populations.

CONCLUSIONS

Fire has been a natural disturbance factor in Madrean forested landscapes for centuries. Prior to European settlement of the area, frequent, low intensity fires were common. These fires affected the watersheds that fed the streams containing both native salmonids, Apache and Gila trout, and other native fishes. Occasionally these natural disturbance events severely impacted fish habitats and populations, but, not to the extent we are witnessing today.

With ever-increasing urbanization of forested montane areas in the Southwest (Medina 1990), a "prescribed natural fire" management philosophy to reduce fuel loads would probably lead to some hot, crowning wildfires that not only are potentially destructive to forests, private property, and human life, but to stream habitats and fishes.

Current fire management philosophy was severely tested during the 1988 Yellowstone Fires (Romme and Despain 1989; Philpot 1990; Varley 1990). Continuing to suppress wildfires in order to prevent destruction of private property or threat to human life needs re-examination relative to the natural, historical, wildfire frequency occurrences and vegetational succession. Permitting fuel build up through fire suppression only increases the probability of devastating wildfire. Romme and Despain (1989) present an excellent ecological/fire management scenario for the Yellowstone ecosystem. Except for tree species and successional cycles, the same scenario would be applicable to fire management in Madrean ecosystems.

Containment/confinement strategy of addressing wildfires is a basic component of fire management philosophy. On one hand, fuel buildups occur as fires are suppressed. On the other, prescribed fire is a management tool widely employed to reduce fuel loading and reduce the threat of holocausts such as the Dude, Divide, and Mcknight fires. These two fire management philosophies must be corroborated relative to each other and with management of two high priority management activities in the Southwest: riparian-stream habitats and fishes.

Select "ecological assessment" panels following the Yellowstone fires concluded that some kind of "natural-fire program" is appropriate and necessary for maintaining the wilderness value of parks and refuges. Although National Forests are typically managed for multiple uses rather than wilderness values, fire management of forested landscapes in the Southwest that is synchronized with natural processes (e.g. vegetational succession and fire ecology) has a greater probability of minimizing impacts on all renewable natural resources, including fishes.

Forest Service management and research must continue to cooperate in examining the potential effects of both suppression and prescription fire management strategies on riparian habitats and associated native and recreational fishery resources in the southwestern region. Such a partnership must be approached in the context of "naturalness" (Philpot 1990), "ecology-based resource management" of the U. S. Forest Service, and sustainability of ecosystems (Lubchenco, et al. 1991).

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