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MANAGEMENT BRIEFS

Short-Term Effects of Wildfire on Fishes and Aquatic Macroinvertebrates in the Southwestern United States

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Abstract.—A brief (3-year) study on three headwater streams in the Tonto National Forest, Arizona, documented the immediate effects of wildfire on fishes and their food supply. Hydrologic events following a 1990 wildfire in Arizona effectively extirpated two populations of brook trout *Salvelinus fontinalis* and one population of rainbow trout *Oncorhynchus mykiss*. Aquatic macroinvertebrate densities in affected streams (1) declined to near zero within a month after the fire, (2) recovered to only 25–30% of prefire diversity in two of the streams 1 year later, and (3) continued to fluctuate postfire. Salmonid stocks reintroduced into two of the affected streams a year after the fire declined 75% within a year. The quality and quantity of hydrologic events interact after fires in southwestern landscapes and climatic regimes to markedly affect populations of fish and macroinvertebrates. Managers and researchers in the Southwest must be on the alert for field situations that provide an opportunity to cooperatively examine the long-term effects of both wild and prescribed fires on fishes and on their food supply and habitat.

Historically, wildfires have been natural disturbances in southwestern montane watersheds. Characteristically, these fires occurred every 4–5 years (Swetman 1990) and were ground level and understory in nature (Dieterich and Hibbert 1988; Wright 1990). Because of these periodic burns (Covington and Moore 1994), forest vegetation, largely ponderosa pine *Pinus ponderosa*, occurred in open stands, and the understory was regularly reduced. Suppression and control of wildfires have altered the natural, historic process of periodic burning and has resulted in fuel load buildups, increases in understory and brush, and increases in stand density (Wright 1990; Covington and Moore 1994). In combination, these factors, under the proper burning conditions, can result in intense, rapidly spreading wildfires that are difficult to control and that consume vegetation and ground litter over vast portions of forested watersheds.

In the Southwest, the May–June fire season is immediately followed by the summer monsoon season in July and August. Accordingly, the denuding of watersheds by wildfire is usually followed by heavy precipitation and runoff into streams that contain many threatened and endangered native fishes (Rinne and Medina 1995). To date, there is no information on the effects of wildfires on either the quantity or quality of postfire runoff events or their effect on fishes and their primary food supply, aquatic macroinvertebrates. The relevance and importance of understanding these effects is basic to effective and responsible management of National Forests and public lands in general.

This paper discusses the aftermath of a wildfire in Arizona and its short-term effects on fishes and aquatic macroinvertebrates; it is not intended as an exhaustive documentation of the effects of wildfire on fish and macroinvertebrates. Rather, the objectives are to increase the level of awareness of the potential effects of fire on fishes and fisheries and to make a plea for the need to monitor and conduct research over the long-term on the potential effects of fire, both natural and man-induced (prescribed), on fish habitats and populations.

Methods

Between 1985 and 1989, baseline information on water quality and fish and macroinvertebrate populations was collected on a group of contiguous first-order headwater streams below the Mogollon Rim, Tonto National Forest, Arizona (see Rinne and Medina 1988). Data were to be used to establish a baseline for these parameters in these streams. Subsequent monitoring and evaluation of the effects of grazing on several U.S. Forest Service allotments could then be based on this "frame of reference" (Rinne and Lafayette 1991). Although management changes were never instituted, these data provided critical baseline or pretreatment information for determining the effects of a naturally occurring wildfire (the Dude Fire) on fishes and aquatic macroinvertebrates.

Methods of data collection are detailed in Rinne and Medina (1988) and Rinne (1990). In brief, fishes within 50-m stream reaches were collected *with backpack electrofishing gear. Sections were* enclosed with block nets and sampled three times, starting downstream and moving upstream. Fishes were weighed to the nearest gram, measured to nearest millimeter (total length, TL), and returned alive to the stream. Macroinvertebrates were sampled with a Surber sampler. Three samples were taken in cobble–pebble substrate at three standard sampling sites in the lower reaches of each stream. Specimens were preserved in a formalin–alcohol–glycerin solution in the field. Samples were later sorted, identified, and counted in the laboratory, and densities were calculated. Selected prefire information on fishes, aquatic macroinvertebrates, and water quality data previously collected on all streams have been published elsewhere (Rinne and Medina 1988; Rinne 1990).

Study Area

In late June 1990, a lightning strike set off a wildfire that ultimately consumed over 12,000 ha of forested land below the Mogollon Rim (Rinne and Neary, in press), destroyed over 50 homes, cost several million dollars to control, and resulted in the loss of six lives. The Dude Fire is now *known as both the largest and the worst wildfire* in Arizona history in terms of the area of forest burned and loss of human life and property. Despite the tragedy, the existence of prefire baseline data provided an excellent opportunity to examine the fire's effects on resident wild salmonid populations and aquatic macroinvertebrates.

The Dude Fire burned across the watersheds of three streams, Dude, Bonita, and Ellison creeks, that were under study between 1985 and 1989. All three streams lie within the Tonto National Forest below the Mogollon Rim in central Arizona. They are first-order, low-gradient (<5%) headwater streams that issue from beneath this major fault block. Mean widths of the three streams are similar (~2 m), and base flows are less than 1 m^3/min (Rinne and Medina 1988). Their watersheds have been subjected to the standard multiple use management practices of timber harvest, grazing, and recreational use.

TABLE 1.—Estimated mean number of salmonids per kilometer in three streams below Mogollon Rim, central Arizona, before and after the Dude wildfire in late June 1990. Numbers of samples are in parentheses, ranges of estimates are in brackets.

Stream	Prefire, 1985–1986	1990 Jul 2	1990 Jul 25	1990 Oct 15	Feb 15, 1991
Dude Creek	226 (21) [40–560]	345 (4) [100–680]	0	0	1
Bonita Creek	440 (22) [60–380]	380 (4) [340–420]	0	0	0
Ellison Creek	513 (21) [80–1,420]	265 (4) [200–300]	0	0	0

Results

Postfire Hydrology

The first observed runoff into the three streams in the burn area occurred between July 6 and 10. *The small volume of resulting streamflow events* combined with the availability of an extensive (5–10 cm) ash layer on both the riparian corridor and immediate hillslopes resulted in what is best described as "slurry flows." Concentrations of suspended solids of up to 700,000 mg/L were recorded from grab samples in headwater reaches of these streams where flows average 5.6 m^3/min. Automated sampling equipment recorded concentrations ranging from 214 to 71,000 mg/L in lower reaches where base flows averaged 56.5 m^3/min. During slurry events, suspended sediment concentrations were elevated (>71,000 mg/L) until runoff increased flows and diluted the concentration of suspended sediment. With the continued presence *and increasing intensity of the summer thunder-*storms, larger flood events (>200 m^3/min) began on July 11 and persisted intermittently and variably for 2 weeks.

Population Dynamics of Wild Fish

Before the fire, salmonid densities in the three streams ranged from 40 to 1,420 fish/km (Table 1). Sampling immediately after the fire (July 2, 1990) and prior to postfire runoff events indicated that salmonid populations were slightly reduced in Bonita Creek and reduced somewhat more in Ellison Creek, although the difference was not significant ($P > 0.05$). By comparison, salmonid population density in Dude Creek had increased. Fish sampling was not conducted immediately after the slurry runoff events; however, visual observations indicated live fish in all three creeks, although a few dead individuals were observed in pools or on streambanks following these hydrologic events.

A subsidence of flooding occurred by July 24. Sampling of two 50-m study sections in each of the three streams on July 25 revealed no salmonids (Table 1). In October 1990, the same results were obtained upon sampling the entire lower reaches *of all three streams that encompassed previous* (1985–1989) 50-m study reaches. In February 1991, the entire lengths of Dude, Bonita, and Ellison creeks were sampled. A single large (300

TABLE 2.—Aquatic macroinvertebrate densities (individuals/m^2, in thousands) and diversity (number of taxa, in parentheses) in streams before and after the Dude wildfire, in late June 1990. Slurry flows occurred before the July 13, 1990, sampling date.

Stream	Prefire, 1985–1986	1990			1991		1992	
		Jul 3	Jul 13	Jul 26	May 20	Oct 16	Jun 8	Nov 10
Bonita	5.4–8.6 (22)	3.8	5.9 (10)	0.09	6.0 (16)	4.4	3.8	1.1
Dude	5.4 (21)	5.0	0.7 (25)	0.13	2.8 (7)	0.8	2.5	3.2
Ellison	7.6–9.7 (27)	10.8	1.8 (27)	0	6.5 (7)	2.9	2.9	1.3

mm) brook trout *Salvelinus fontinalis* was captured about 100 m from the head spring of Dude Creek. The drastic change in the hydrograph during the first few months after the Dude Fire had effectively extirpated salmonids in these headwater streams below the Mogollon Rim.

Population Dynamics of Aquatic Macroinvertebrates

Prior to the fire, estimated mean aquatic macroinvertebrate densities ranged from 5,000 to 10,000 individuals/m^2 in the three streams (Table 2). Samples taken immediately after the fire and before either slurry or flood flow events indicated no significant effect of the fire on aquatic macroinvertebrate populations. However, sampling after slurry flow events in Dude and Ellison creeks (July 13) revealed an 86–90% reduction in macroinvertebrate density. Sampling in all three creeks on July 26, following several significant flood events, revealed that populations had fallen to near zero. Subsequent sampling after winter flow events (May 1991) indicated populations had apparently partially recovered in Bonita and Ellison creeks. Analyses of additional samples collected in autumn 1991 and 1992 indicated macroinvertebrate populations had not stabilized and were fluctuating below prefire densities. A year later, macroinvertebrate diversity (number of taxa) was reduced by 25% (Bonita) to over 70% (Dude and Ellison) from prefire levels.

TABLE 3.—Number of brook trout (Bonita Creek) and rainbow trout (Ellison Creek) stocked or recaptured after the Dude wildfire in late June 1990. Value for May 1991 are numbers of fish stocked. Values for the other sampling dates are numbers of fish recaptured; values in parentheses are numbers of young-of-year fish observed or captured.

Stream	1991		1992	1993
	May	Oct	Jun	Jul
Bonita	85	22	23 (35)	78[a]
Ellison	58	23	5	2 (100+)

[a] Includes fish captured in early September 1993 in different stream reaches.

Population Dynamics of Introduced Fish

The objectives of this postfire effort were to determine (1) whether fish would survive flood events in the summer of 1991 in the absence of the extensive, presumably toxic, ash flows that occurred immediately postfire (summer 1990), (2) how, in the event of survival, fish populations would respond in numbers and displacement, (3) whether reproduction would occur, and (4) the response of the fish over time (3 years) to changes in stream habitats and a potentially altered food base of aquatic macroinvertebrates (Table 2).

In May 1991, rainbow trout *Oncorhynchus mykiss* were stocked in Ellison Creek and brook trout were stocked in Bonita Creek (Table 3). To remove any bias associated with hatchery stock, the rainbow trout were taken from a wild population in nearby Webber Creek; the brook trout were captured and transported from a wild population in Willow Creek, above the Mogollon Rim. Fish from Webber Creek ranged from 90 to 200 mm TL in size, and those from Willow Creek from 150 to 180 mm TL. Because of the single brook trout found in Dude Creek in February, the species was not stocked at that time.

Sampling in October 1991 after summer flows revealed that not more than 40% of the introduced fish survived in either creek (Table 3). Of the brook trout captured in Bonita Creek, none were more than 0.5 km downstream from introduction sites, and no individuals were collected upstream of stocking sites. In Ellison Creek, three rainbow trout were displaced within 100 m downstream of the lowermost introduction site. Fish were in excellent condition in Bonita Creek compared with observed condition at time of stocking. Individuals grew from a mean size of 162 mm in May to a mean of 200 mm in October. No young-of-year rainbow trout were taken in Ellison Creek, indicating either lack of spawning due to stress or postspawning condition or loss of young-of-year, along with many (30+; Table 3) adults, through summer flow events.

Because brook trout would potentially spawn in autumn, the 1991 sampling was conducted in June 1992, after winter flows. The stocked brook trout in Bonita Creek maintained numbers equal to October 1991 estimates in the same stream reach (Table 3); however, mean size of fish had increased from 200 mm to 240 mm TL. In addition, not only had successful spawning taken place, but fry were of a larger size (range, 80–90 mm TL) than prefire fry (1985–1989; mean 50–60 mm; Rinne and Medina 1988). In summary, almost a year and a half after introduction, the population of brook trout in Bonita Creek was reproducing successfully, and both fry and adults were in excellent condition and growing rapidly.

In contrast, only five of the original stock of rainbow trout in Ellison Creek were captured by electrofishing in June 1992. Four of the five fish were in the release area and one was about 2 km downstream. No young-of-year rainbow trout were collected during the June 1992 sampling in Ellison Creek.

On July 7, 1993, after a winter of greatly above average precipitation and runoff, both creeks were sampled again. Thirty-four brook trout averaging 254 mm TL (range, 210–280 mm) were captured and released in Bonita Creek. All had been displaced downstream by increased flows to a reach of stream where only one brook trout was captured in October 1991. Forty-four additional brook trout (180–245 mm) were collected in early September upstream of the reaches sampled in early July. Sampling in Ellison Creek resulted in the capture of only two adult rainbow trout (320 and 315 mm); however, over 100 young of year (80–100 mm) were observed and counted during sampling (Table 3).

Discussion

Based on the response of fish populations immediately after the fire and the survival of restocked trout in Ellison and Bonita creeks, toxic slurry or ash flows are apparently immediately fatal to a high percentage of salmonids. Survivors of these events become physiologically stressed, and subsequent flood flows may then effectively extirpate surviving individuals through downstream displacement or mortality. The extent of fish loss will be dependent on (1) burn intensity, (2) the size, frequency, and duration of flows during the summer monsoon, and (3) the permanency of downstream reaches to which fish may be displaced. Springs or upwellings may serve as refugia, as apparently occurred for the one surviving brook trout recorded at the head of Dude Creek.

The loss of fish following the Dude Fire is not unique. In July 1989, the Divide Fire in southwestern New Mexico consumed over 4,000 ha of forest vegetation on the watersheds and riparian areas of Main Diamond and South Diamond creeks (Rinne 1991; Propst et al. 1992). Similar to the Dude Fire, initial low-volume flow events also resulted in slurry flows that transported large amounts of ash into Main Diamond Creek, which contained the largest single population of Gila trout *Oncorhynchus gilae gilae* (5,000+ individuals; Rinne and Medina 1988; Rinne 1991; Propst et al. 1992). Two weeks later, several kilometers of the creek were sampled and only one Gila trout was found alive. Sampling about 1.5 km of the stream in October 1989, after extensive flooding that resulted from denudation of the watershed, revealed no individuals of this federally endangered species. Electrofishing in May 1990 of the entire 6 km of the previously-inhabited portions of Main Diamond Creek again revealed no fish. These and similar effects following the Dude Fire suggest that changes in quality and quantity of water dictated by precipitation and flow events negatively and markedly impact fish populations in streams in the Southwest.

Populations of aquatic macroinvertebrates, the primary food supply of salmonids, are also drastically reduced by postfire water quality and quantity. Deposition of ash in stream substrates following low, postfire flow events may be more toxic to this group of organisms than to fish. Potential reduction in substrate oxygen levels may result in mass mortality of these substrate-dwelling organisms. Marked differences in estimated densities of macroinvertebrates in Bonita Creek compared with Dude and Ellison creeks where slurry flows had occurred (Table 2) illustrate that slurry flows, even in absence of flood events, are highly detrimental to these aquatic organisms. Flooding has an additional, cumulative, negative effect on macroinvertebrates as shown by the further reduction in densities in all creeks (Table 2). Altered stream hydrography resulting from watershed denudation and flooding continue to influence macroinvertebrates, based on both reduction and marked fluctuations of macroinvertebrate densities and diversity. Similar to the streams affected by the Dude Fire, macroinvertebrate populations in Main Diamond Creek have displayed parallel patterns of fluctuation in both density and diversity following the Divide Fire (Gerald Jacoby, New Mexico Highlands University, personal communication).

Results of this study concern the effects of wildfires on streams habitats and organisms. Prescribed or control burns are used extensively to manage forests in the Southwest (Wright 1990). Although not immediately fatal to salmonids in headwater marginal habitats, the amounts of sediment mobilized from watersheds following these normally small, low-intensity burns (Rinne and Neary, in press) could temporarily alter salmonid spawning substrates and the rearing areas for aquatic macroinvertebrates. Cumulatively, this impact could be severe. 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 the saturation of spawning substrates and the aggradation of pool habitats essential for fish survival during drought and winter periods, could be substantial. Indeed, the chronic impact of fine sediment accumulation in substrates may have as great an influence on salmonid populations as does the immediate, short-term response to ash flows and changes in hydrography following a natural wildfire.

Management Implications

There is no published information on the effects of either natural wildfires or prescribed fires on stream habitats and associated fisheries in the Southwest (Krammes 1990; Severson and Rinne 1990). The demand for recreational fishing in the Southwest (U.S. Forest Service Region 3, Arizona and New Mexico) is very high compared with national averages (Everest and Summers 1982). In addition, the majority of the native fishes in the Southwest (Johnson and Rinne 1982; Rinne and Minckley 1991) and in forest streams (Rinne and Medina 1995) are federally designated as "threatened," or "endangered" and are thereby protected by law. Federal agencies are mandated by the Endangered Species Act of 1973 to insure that their activities do not negatively impact or "take" federally listed species. Further, because the numerous species designated as "sensitive" by the U.S. Forest Service are candidates for federal listing, they must also be wisely conserved (U.S. Forest Service 1993; Rinne and Medina 1995). In combination, the economic demand for a recreational fishing resource and the legal mandate to protect a valuable, declining native fish fauna make addressing the effects on salmonids of wild and prescribed fires both timely and essential.

Fire has played a major role in the evolution of southwestern forested ecosystems (Dieterich and Hibbert 1988; Covington and Moore 1994). Management and research efforts by the U.S. Forest Service must jointly examine the potential effects of suppression and prescription fire management strategies on the long-term management of native and recreational fish resources in the Southwest (Rinne and Neary, in press). Such a partnership must be approached within the context of "naturalness" (Philpot 1990), "ecology-based resource management" (U.S. Forest Service 1992), and the sustainability of ecosystems (Lubchenco et al. 1991).

References

Bjornn, T. C., and six coauthors. 1977. Transport of granitic sediment in streams and its effects on insects and fish. Idaho Forest Wildlife and Range Experiment Station Bulletin 17:1–43.

Covington, W. W., and M. M. Moore. 1994. Southwestern ponderosa forest structure—changes since Euro-American settlement. Journal of Forestry 92: 39–47.

Dieterich, J. H., and A. R. Hibbert. 1988. Fire history in a small ponderosa pine stand surrounded by chaparral. U.S. Forest Service General Technical Report RM-191:168–173.

Everest, F. H., and five coeditors. 1987. Fine sediment and salmonid production: a paradox. University of Washington Institute of Forest Resources Contribution 57:98–142.

Everest, F. H., and P. B. Summers. 1982. The sport fishing resource of the national forests—its extent, recreational use, and value. U.S. Forest Service, Washington, D.C.

Johnson, J. E., and J. N. Rinne. 1982. The Endangered Species Act and Southwest fishes. Fisheries 7(2): 1–8.

Krammes, J. S., editor. 1990. Effects of fire management on southwestern natural resources. U.S. Forest Service General Technical Report RM-191.

Lubchenco, J., and 15 coauthors. 1991. The sustainable biosphere initiative: an ecological research agenda. Ecology 72:371–412.

Philpot, C. W. 1990. The wildfires in the northern Rocky Mountains and greater Yellowstone area—1988. Transactions of the North American Wildlife and Natural Resources Conference 55:185–187.

Propst, D. L., J. A. Stefferud, and P. R. Turner. 1992. Conservation and status of Gila trout, *Oncorhynchus gilae*. Southwestern Naturalist 37:117–125.

Rinne, J. N. 1990. The utility of stream habitat and biota for identifying potential conflicting forest land uses: montane riparian areas. Forest Ecology and Management 33/34:363–383.

Rinne, J. N. 1991. Gila trout, *Oncorhynchus gilae*. Pages 274–279 *in* J. Stoltz and J. Schnell, editors. The wildlife series—trout. Stackpole Books, Harrisburg, Pennsylvania.

Rinne, J. N., and R. A. Lafayette. 1991. Southwestern riparian–streams ecosystems: research design, complexity, and opportunity. U.S. Forest Service Research Paper RM-299:1-8.

Rinne, J. N., and A. L. Medina. 1988. Factors influencing salmonid populations in six headwater streams, central Arizona, USA. Polish Archives of Hydrobiology 34:515–532.

Rinne, J. N., and A. L. Medina. 1995. Implications of multiple-use management strategies on native southwestern (USA) fishes. Pages 110–123 *in* R. M. Meyer, editor. Fisheries resource utilization and policy. Proceedings of the World Fisheries Congress, theme 2. Oxford & IBH Publishing, New Delhi.

Rinne, J. N., and W. L. Minckley. 1991. Native fishes in arid lands: a dwindling resource of the desert Southwest. U.S. Forest Service General Technical Report RM-206:1-45.

Rinne, J. N., and D. G. Neary. In press. The effects of fire and its management on southwestern (USA) riparian–aquatic habitats and fishes. U.S. Forest Service General Technical Report RM.

Severson, K. E., and J. N. Rinne. 1990. Increasing habitat diversity in southwestern forests and woodlands via prescribed fire. U.S. Forest Service General Technical Report RM-191:94–104.

Swetman, T. W. 1990. Fire history and climate in the southwestern United States. U.S. Forest Service General Technical Report RM-191:6–17.

U.S. Forest Service. 1992. Ecology-based resource management. Albuquerque, New Mexico.

U.S. Forest Service. 1993. Every species counts action plan, Region 3, U.S. Forest Service. Albuquerque, New Mexico.

Wright, H. A. 1990. Role of fire in management of southwestern ecosystems. U.S. Forest Service General Technical Report RM-191:1–5.