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Does Wildfire Threaten Extinction for Salmonids? Responses of Redband Trout and Bull Trout Following Recent Large Fires on the Boise National Forest

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Introduction

The potential for wildfire to impact aquatic ecosystems and their associated threatened, endangered, or sensitive species is of increasing concern. Recent (since 1988) large-scale fires followed by dramatic hydrologic disturbances spark much of this interest. Broad swaths of western forest lands, where fire suppression and past silvicultural activities have radically altered vegetation structure and fuel loads, are ripe for high-intensity fires. The potential seems greatest in warm/dry habitat types that historically were dominated by frequent, but low intensity burns. Interconnected, fuel-laden stands may now link areas that historically burned less frequently or uniformly into large, homogeneous areas that are vulnerable to high-intensity, stand replacing events (Agee 1988; Henjum et al. 1994). Recent fires in the Pacific Northwest seem to confirm these expectations.

Wildfires influence aquatic ecosystems both directly and indirectly. Direct effects include heating or abrupt changes in water chemistry (Minshall et al. 1989; McMahon and de Calesta 1990). Indirect effects include changes in hydrologic regime, erosion, debris flows, woody debris loading and riparian cover (Swanson and Lienkaemper 1978; Brown 1989; Megahan 1991; Bozek and Young 1994). Intense fires and related events have killed fish (Bozek and Young 1994) and even caused local extinctions (Propst et al. 1992; Rinne 1996). Conceivably, large and intense fires could threaten populations of sensitive salmonids such as bull trout, chinook salmon, steelhead, and others that are depressed from other causes. Historical fires, however, were a natural and potentially important part of the disturbance regime for terrestrial and aquatic systems (Reeves et al. 1995). Large fires supplied woody debris and triggered hydrologic events and debris flows that transported coarse substrates to stream channels. These processes may well have provided the materials that maintained productive habitats for fish and other organisms (Swanson et al. 1990; Reeves et al. 1995).

The magnitude and intensity of recent fires heighten concerns regarding forest/ecosystem health, the potential loss of valuable wood fiber and private property, and the apparent threat to sensitive species. Such concerns have galvanized new efforts to reduce fuel loads and stand densities through mechanical treatment and the use of prescribed fire. These efforts create a quandary for biologists and managers working with aquatic systems. The long-term negative effects of timber harvest activities on aquatic ecosystems are well documented (see papers in Meehan 1991 and Salo and Cundy 1987; Henjum et al. 1994). The effects of fire on fish are more equivocal. Do large fires really threaten extinction for many existing salmonid populations? What influences the risk?

Large fires in the Boise River basin on the Boise National Forest in 1992 and 1994 provided an opportunity to examine these questions relative to populations of two sensitive salmonids. Bull trout (*Salvelinus confluentus*) is a category-one species under the Endangered Species Act (ESA), and redband or interior rainbow trout (*Oncorhynchus mykiss*) is recognized as a species of special concern by the Idaho Department of Fish and Game. Some isolated redband populations have been petitioned for formal listing under ESA. Both species inhabit streams caught within fires described as among the most destructive ever observed on the Forest. We initiated work on the responses of these fishes to wildfire and related effects in 1992. The work was planned as long term and much is incomplete. Our preliminary results and the body of literature regarding the disturbance and recovery of aquatic communities provide a base, however, to initiate the discussion.

Study Area and Species Background

The Boise River Basin is contained almost wholly within the southern batholith section of the northern Rocky Mountain physiographic province. The geology is dominated by granitic rock of the Idaho Batholith. Stream flows are dominated by snowmelt, but summer thunderstorms also occur. Mean annual air temperature at 1,600 m is about 5° C. Forest habitat types (Steele et al. 1981) are predominantly Douglas-fir (*Pseudotsuga menziesii*), and

Ponderosa pine (*Pinus ponderosa*) at low and mid elevations and subapline fir (*Abies asiocarpa*) at higher elevations.

In five days of August, 1992, lightning-ignited fires on the Forest and adjacent lands burned 105,000 hectares within a contiguous area along the South and Middle Forks of the Boise River (Figure 1). High fuel loading and extended drought contributed to high fire intensity. Nearly complete loss of vegetative cover occurred throughout much of the area (Maloney et al. 1995).

We selected two watersheds as primary study sites within the 1992 burn area, Sheep Creek and Rattlesnake Creek. Burn intensities were particularly high in some segments of the riparian corridors. Preliminary surveys in intensely burned reaches found little surviving emergent vegetation, numerous dead fish, no live fish or other vertebrates, and no or very few macro invertebrates. Population estimates were not available prior to the fire, but previous surveys conducted by the Boise National Forest and Idaho Department of Fish and Game showed that bull trout and redband trout were common in both systems. In addition, extensive fish population surveys throughout the Boise River basin provided a general comparison of fish densities and species compositions expected in similar waters. The two watersheds are similar in landscape characteristics (Table 1). Both drain into the Boise River basin above Arrowrock reservoir, and both are open to movement of fish to and from the larger basin. Both support the same vertebrate communities, which include bull trout, redband trout, sculpin (*Cottus* spp), tailed frogs (*Ascaphus truei*), and transient populations of mountain whitefish (*Prosopium williamsoni*) and several cyprinids.

We also began studies on a redband trout population in a third watershed, Cottonwood Creek, in 1992. The Cottonwood Creek watershed was unaffected by the 1992 fires, but burned extensively under very similar conditions in 1994. Although Cottonwood Creek is smaller than Sheep Creek or Rattlesnake Creek, it is in a similar setting (Table 1). The stream is isolated from the Boise River in most years by an impassable culvert and does not support bull trout. Redband trout were abundant and found throughout the stream in 1992 and 1993.

Redband trout are native to the Boise River basin and may represent remnant populations of the anadromous

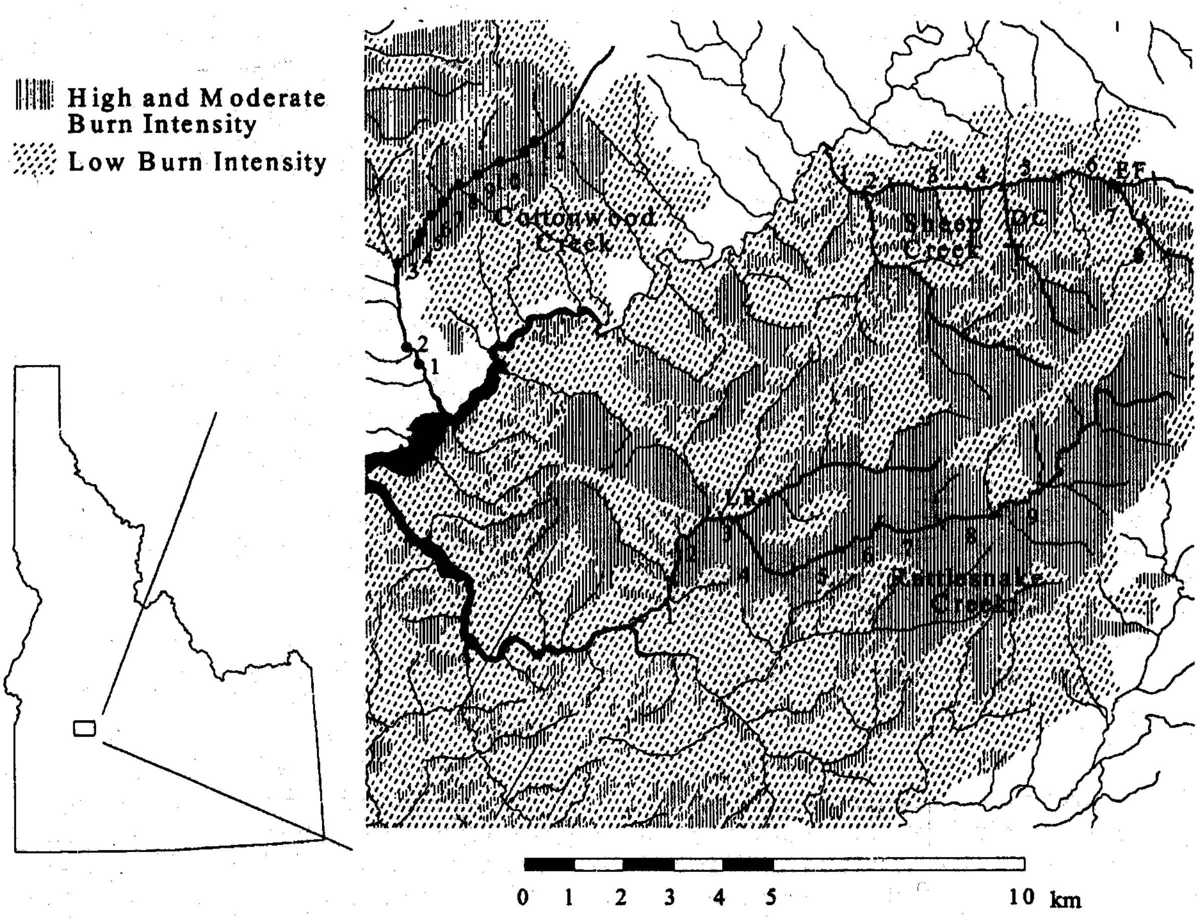

Figure 1. Map of study streams and burn intensity for the 1992 and 1994 fires in the Boise River basin, Idaho. Stream reaches and sites designated for sampling are shown by number or letter (EF = East Fork Sheep Creek, DC = Devils Creek, LR = Little Rattlesnake Creek).

Table 1. Characteristics of watersheds for study streams influenced by the 1992 and 1994 fires on the Boise National Forest.

Watershed	Watershed Area (Ha)	Mean Stream Gradient (%)	Max Basin Elevation (m)	Min Basin Elevation (m)
Sheep Creek	11,315	6.5	2771	1048
Rattlesnake Creek	11,539	4.4	2482	988
Cottonwood Creek	5,824	7.3	2216	975

rainbow trout or steelhead that inhabited the basin prior to isolation by downstream dams. Redband trout are common throughout the basin, inhabiting streams of all sizes (Rieman and McIntyre 1995). Redband trout in the interior sub-basins of the Columbia River basin typically exhibit both resident and migratory life-history patterns. The resident form resides in natal tributaries or watersheds (like Sheep Creek and Rattlesnake Creek) throughout life, while the migratory form may spawn and rear for some period in a tributary system before moving to a larger river or lake to mature. Both forms are thought to exist throughout the Boise River basin but detailed life-history studies have not been done. Watersheds that are isolated from the main river by natural or human made barriers (culverts, dams) support only the resident form.

Bull trout are also found throughout the Boise River basin, and also exhibit migratory and resident life-history patterns (Rieman and McIntyre 1995). Bull trout are less abundant than redband trout, with fish found in less than half of the waters inventoried throughout the basin (Rieman and McIntyre 1995). Individual adult and subadult bull trout may range widely, but spawning and juvenile rearing appear to be restricted to the colder headwaters of larger watersheds (Rieman and McIntyre 1995). In the Sheep Creek and Rattlesnake Creek watersheds, for example, juvenile bull trout would be expected in roughly the upper third of the available stream reaches. Resident bull trout may remain within their natal tributaries throughout life. Migratory forms may rear for two or three years in the headwater streams before moving into the larger rivers, lakes, or reservoirs to mature (Rieman and McIntyre 1993). Once mature, the adults may make repeated, annual, spawning migrations. The resident and migratory forms can be distinguished by virtue of size; migratory adults typically are much larger than the resident adults. Both forms can occur in the same populations (Rieman and McIntyre 1993).

Methods

Fire and Watershed Effects

The Boise National Forest mapped burn intensity throughout the fire perimeters in the fall immediately following each event. Burn intensity was based on condition of above ground vegetation. High intensity was defined as areas where the canopy was completely consumed leaving only black needles or needleless trees and leafless hardwoods and brush. Moderate intensity was defined as areas with 50 to 100% scorched canopy. Scorched canopy was recognized as fire killed needles and leaves that remained on the trees and brush.

We surveyed the study streams by foot in the September following the fires. We qualitatively mapped fire intensity within the riparian zone along the main stream reaches described below. Although virtually the entire lengths of streams within each watershed were influenced by the fires, some areas were more strongly altered than others. We classified each reach as either high or low intensity effect based on the predominant condition of emergent vegetation. We considered high intensity burn reaches as those where most leaves and needles along the length of the reach were consumed in the fire. In many cases whole trees, shrubs, and downed wood were also consumed by the fire. In most cases fire intensity mapped for the adjacent forest was also high.

Distribution and Abundance of Fish Sheep

Creek and Rattlesnake Creek. We initiated sampling to describe the distribution and abundance of fishes in mid September following the 1992 fire. Snorkeling and electrofishing were used in Sheep Creek in 1992, but sampling was limited to electrofishing in Rattlesnake Creek that year. Snorkeling was the primary method used to describe distribution and abundance in subsequent years in both systems. All snorkeling was conducted from the last week of August through the middle of September in each year. All electrofishing was conducted from the middle of September through the first week of October in each year.

Each stream was stratified into reaches representing distinct channel segments of similar gradient, confinement and discharge. Reaches were contiguous and varied in length from 1 to 3.3 km, covering most of the perennial streams in each watershed (Figure 2). The last reach in Sheep Creek was below a bedrock cascade that was a barrier to fish passage. We found no fish in the stream above the cascade and assume that all of the potential fish habitat was below that point. Some suitable habitat existed in the stream above the last reach in Rattlesnake Creek, but the channel was small and we believe that more than 90 % of the habitat available to fish was within our sampled area.

Snorkeling or electrofishing was completed in seven reaches in 1992, but included eight or nine reaches in subsequent years. Our snorkel methods followed those outlined by Thurow (1994). Fish were recorded in three length groups (< 75 mm, 75 to 150 mm and > 150 mm). In the first year one to three sites about 50 m in length were sampled in each reach. In the following years 15 to

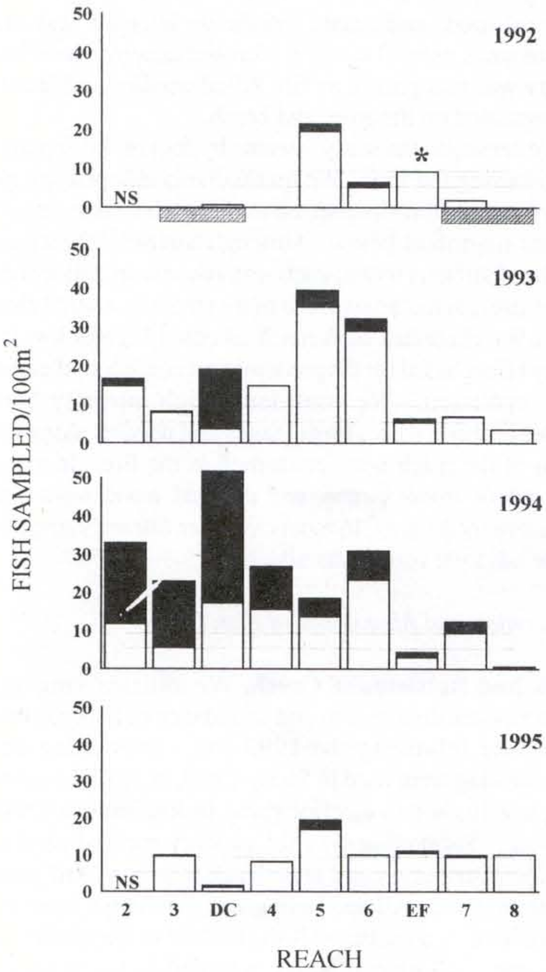

Figure 2. Distribution and number of redband trout sampled in Sheep Creek from 1992 to 1995. The shaded bar under the figure for 1992 designates the reaches with high intensity burns in the riparian area. Dark portions of the histograms represent fish less than 75mm which are predominantly young-of-the-year; open portions represent larger fish. The * designates electrofishing data summarized when snorkel data were not available. NS designates no sample available. The dashed horizontal lines represent the 50% and 75% cumulative frequency (i.e. 75% of sites less than) for sampled numbers in similar stream reaches throughout the Boise River Basin.

20 sites ranging from about 3 to 15 m in length were snorkeled in each reach. The sampling after 1992 was designed to provide complete population estimates for each reach. For the purposes of this paper, however, we report only the sampled densities for two size groups to demonstrate trends in the distribution and the abundance of juvenile and older fish.

Single pass electrofishing was conducted with a backpack shocker in both stream systems in all years. Electrofishing was used initially to survey for presence of fish after the fire in Rattlesnake Creek when high turbidity, low water temperatures, and limited time preempted further snorkel sampling. Electrofishing was continued to provide more detailed size and growth information and as a measure of relative abundance when snorkeling was not possible. A single site of 80 to 150 m was fished in each sampled reach. Electrofishing data were summarized in the same format as the snorkel data and are reported here only when snorkel data were unavailable.

We did not have pre-fire data for Sheep and Rattlesnake creeks for comparison with post-fire fish response. We summarized similar density information for streams sampled throughout the Boise River basin in 1993 and 1994 as outlined by Rieman and McIntyre (1995). We used the cumulative frequency distribution for all of the sampled densities as a base for interpretation of the numbers observed in the burned reaches.

Cottonwood Creek. Sampling in Cottonwood Creek was initiated in September 1992, two years before the fire, as part of an independent project. All sampling in this system was conducted by electrofishing in five to 10 sites, each approximately 100 m long, distributed through the length of the stream (Figure 2). Sampling was designed to provide complete population estimates using block nets and multiple pass removal methods. We present only the density estimates from the catch per-area-sampled to describe the trends in distribution and abundance of the redband trout found in this stream.

Results

General Observations of Fire and Watershed Effects

The 1992 and 1994 fires burned with moderate or high intensity throughout much of the three study watersheds (Figure 1). Along the stream channels we classified high intensity effects in four of the nine study reaches in Sheep Creek, six of 10 reaches in Rattlesnake Creek, and six of the 10 sites in Cottonwood Creek (Figures 2, 3, and 6 below). Data on channel and habitat responses following the fires have not been summarized, but important effects in the flow, sediment, and temperature regimes of each stream were evident in the first year following each event. Increased surface erosion and large pulses of fine sediments occurred throughout each system. In many cases pools were virtually filled with new material, although pools in higher gradient channels often remained relatively free of sediment. Debris flows producing pulses of both fine and coarse sediments and woody debris occurred in at least one small tributary channel in each watershed. In reaches with high intensity burn effects shading from riparian cover was virtually eliminated. Woody debris in stream channels was often burned as well.

In subsequent years the effects of altered hydrology and delivery of sediments and coarse debris were clearly evident. Channels were highly dynamic. Some habitats for fish were lost or altered by the loss of old wood and filling of pools with sediments, while others were created by the formation of new pools, channels and undercut banks in response to the recruitment of new wood from fire killed trees. Debris flows scoured some small high gradient channels dramatically simplifying habitats within them or in the larger stream immediately below the confluence with those channels. Debris flows also delivered a substantial volume of coarse materials that did or are likely to contribute to complexity of channels downstream.

Riparian vegetation was not killed along the intensely burned reaches. Although cover from emergent vegetation was lost immediately after the fires, resprouting from roots has been pronounced and the canopy from vegetation immediately adjacent to the channel increased substantially in following years in all intensely burned reaches.

Distribution and Abundance of Fish

Six stream reaches were sampled in Sheep Creek and six reaches in Rattlesnake Creek immediately following the 1992 fires. Eight or nine reaches were sampled in each stream in subsequent years. In 1992 densities of redband trout and bull trout were very low or nonexistent in reaches that were intensely burned (Figures 2, 3, 4, and 5). Dead fish were observed in all four of the intensely burned reaches in Sheep Creek and no live fish could be found in reach eight of Sheep Creek or in reaches six through eight in Rattlesnake Creek. We could not sample reach nine of Rattlesnake Creek in 1992 or 1993. However, because burn intensity appeared to be especially high in this reach, and because similar or less intensely burned reaches downstream were apparently defaunated, we believe it unlikely that many if any fish persisted in that reach immediately after the fire. Redband trout persisted in relatively high numbers in reaches immediately adjacent to the intensely burned reaches in both the Sheep and Rattlesnake watersheds (Figures 2 and 3). Bull trout persisted in modest numbers in the adjacent reaches of Sheep Creek (Figure 4). In Rattlesnake Creek, however, only a few individuals were found in a single downstream reach (Figure 5). Spawning and initial rearing of bull trout is restricted to the higher, colder, reaches of streams throughout the Boise River Basin (Rieman and McIntyre 1995) and was likely limited to the area above reach seven in Rattlesnake Creek. We found juvenile bull trout only in the upper reaches of both streams. For that reason we believe that virtually the entire juvenile and resident adult population of bull trout was eliminated by the fire in this watershed.

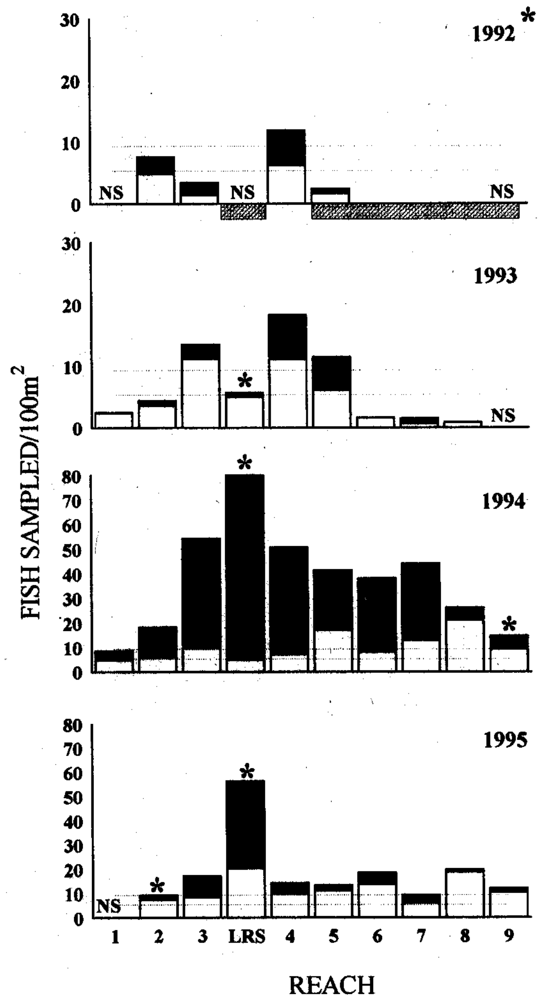

Figure 3. Distribution and number of redband trout sampled in Rattlesnake Creek from 1992 to 1995. The shaded bar under the figure for 1992 designates the reaches with high intensity burns in the riparian area. Dark portions of the histograms represent fish less than 75mm which are predominantly young-of-the-year; open portions represent larger fish. The * designates electrofishing data summarized when snorkel data were not available. NS designates no sample available. The dashed horizontal lines represent the 50% and 75% cumulative frequency (i.e. 75% of sites less than) for sampled numbers in similar stream reaches throughout the Boise River Basin.

Both bull trout and redband trout were found in the intensely burned reaches of Sheep Creek and Rattlesnake Creek in 1993 and subsequent years. Densities of redband trout fluctuated among years throughout both streams and were strongly influenced by variation in the number of juvenile fish (Figures 2 and 3). Although variation was pronounced, by 1995 the densities in most stream reaches including those strongly influenced by the fires were high in comparison to other streams throughout the Boise River Basin (Figures 2 and 3). Very high numbers of juvenile redband trout in Devil's Creek in 1993 and 1994 and in

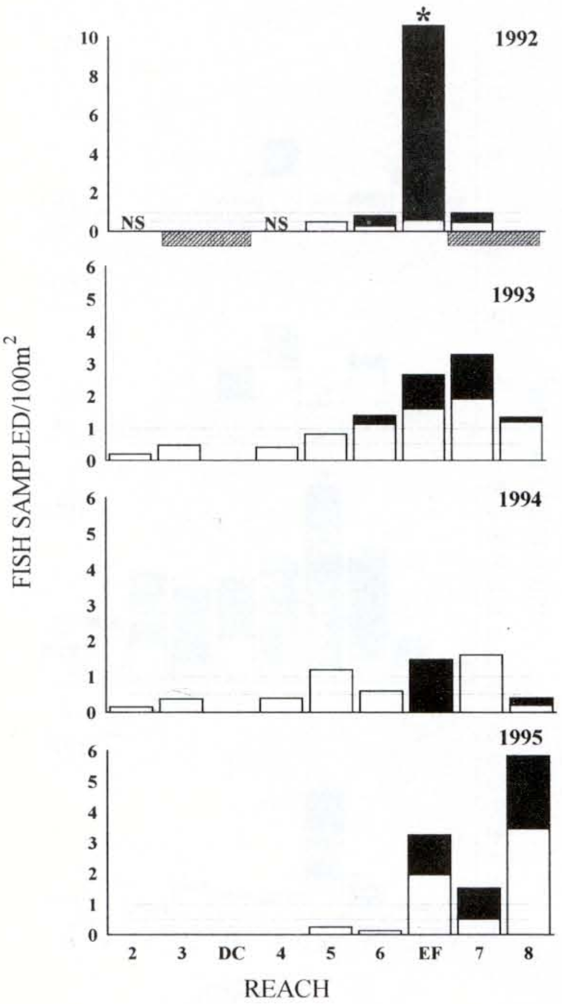

Figure 4. Distribution and number of bull trout trout sampled in Sheep Creek from 1992 to 1995. The shaded bar under the figure for 1992 designates the reaches with high intensity burns in the riparian area. Dark portions of the histograms represent fish less than 150mm which are considered juveniles (Rieman and McIntyre 1995); open portions represent larger fish. The * designates electrofishing data summarized when snorkel data were not available. NS designates no sample available. The dashed horizontal lines represent the 50% and 75% cumulative frequency (i.e. 75% of sites less than) for sampled numbers in similar stream reaches throughout the Boise River Basin.

many of the lower or mid reaches of both streams in 1994 was particularly striking. The increase in numbers for the higher reaches (7, 8 in Sheep Creek; 7, 8, 9 in Rattlesnake Creek) was driven primarily by movement of older individuals with little recruitment of young fish.

The relatively large numbers of young bull trout observed in reach nine of Rattlesnake Creek (Figure 5) was initially puzzling in light of the believed defaunation of the upper part of this stream. In late August of 1994, however, we observed five large (>400 mm) adult bull trout holding in reach four. The timing and presence of the large fish indicated that a migratory life-history had persisted in the Rattlesnake Creek population. The extended movement pattern for this life history implies that both sub-adult and adult fish were outside the Rattlesnake Creek watershed during the fire, but had returned to reproduce in the fall.

Five sites were sampled in Cottonwood Creek in 1992 and 12 sites in later years. The numbers of redband trout were relatively high throughout the stream in 1992 and 1993. Immediately following the fire in 1994 densities in the five intensely burned sites were much lower than

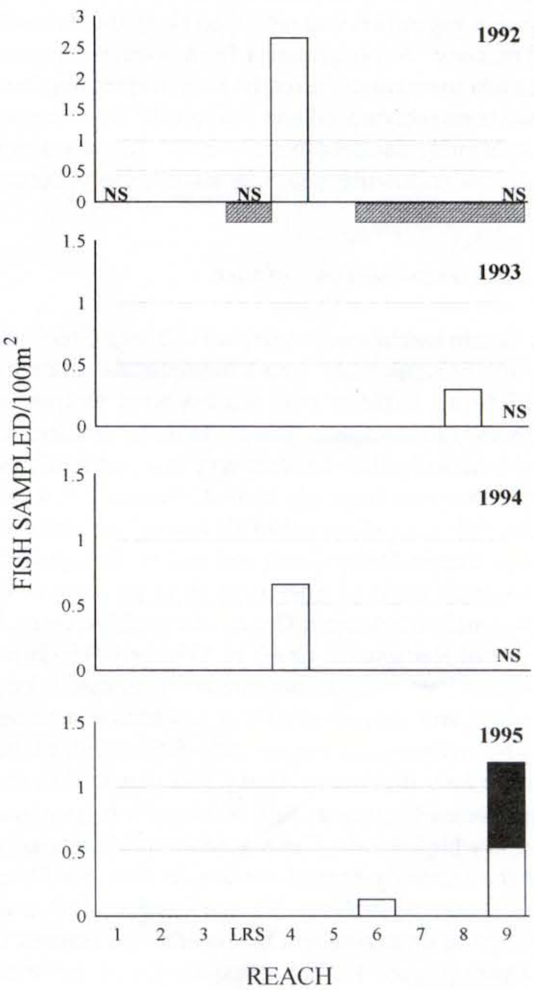

Figure 5. Distribution and number of bull trout trout sampled in Rattlesnake Creek from 1992 to 1995. The shaded bar under the figure for 1992 designates the reaches with high intensity burns in the riparian area. Dark portions of the histograms represent fish less than 150mm considered juveniles (Rieman and McIntyre 1995); open portions represent larger fish. The * designates electrofishing data summarized when snorkel data were not available. NS designates no sample available. The dashed horizontal lines represent the 50% and 75% cumulative frequency (i.e. 75% of sites less than) for sampled numbers in similar stream reaches throughout the Boise River Basin.

in preceding years or the adjacent sites (Figure 6). In 1995 fish were again relatively abundant in all reaches, and in most cases at densities comparable to those prior to the fire. Juvenile fish were less important in 1995 than earlier years, however.

Discussion

Fires that burned in the Boise River basin in 1992 and 1994 exemplify large and intense events that would have been rare historically, but seem more likely to occur in the future. Both fires profoundly altered fish populations and habitat. We found evidence of extensive direct mortality, as well as increased erosion, debris torrents, and other indications of likely effects on the productivity and stability of available habitat and these populations. Habitat and populations appeared to be very dynamic following the fires, and the effects are likely to persist for years or decades (see Minshall et al. 1989).

Despite the catastrophic appearance of the effects, the short term recovery of bull trout and redband trout populations has been dramatic. Fish were present in the defaunated reaches within 1 year, and numbers approached those in unaffected stream reaches in 1 to 3 years. In some reaches, juvenile densities were very high suggesting that recruitment might even have benefited from the effects of fire. At least in the short term, populations of redband trout and bull trout within the Boise River basin appear to have the ability to adapt to, and recover from, changes in their environments associated with intense wildfire.

Two mechanisms were important in the short-term recovery that we observed: 1) refounding of defaunated reaches through dispersal from local or internal refuges; and 2) refounding through complex life history and overlapping generations.

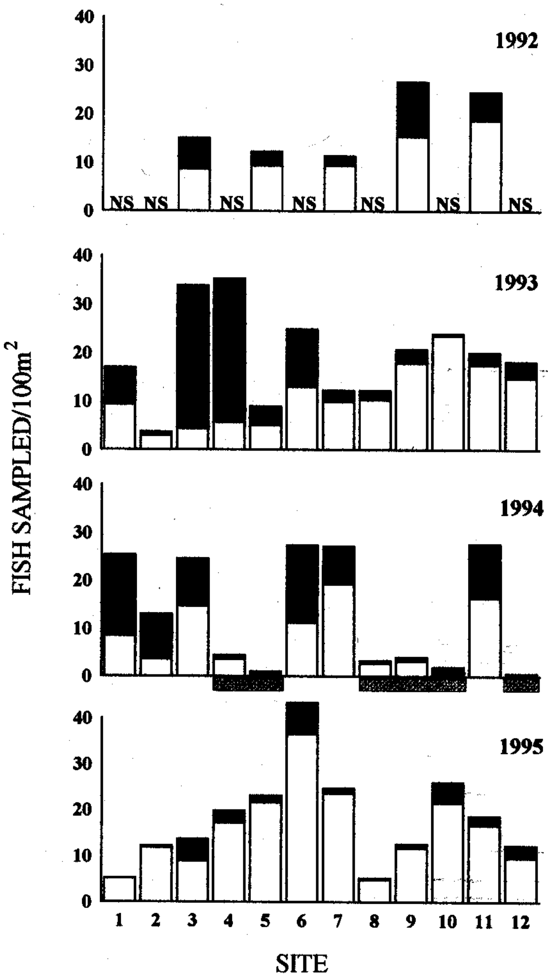

Figure 6. Distribution and number of redband trout sampled in Cottonwood Creek from 1992 to 1995. The shaded bar under the figure for 1994 designates the sites with high intensity burns in the riparian area. Dark portions of the histograms represent fish less than 75mm which are predominantly young-of-the-year; open portions represent larger fish. All sites were sampled by electrofishing. NS designates no sample available.

Local Refuges. Despite the broad scale and intensity, the fires in these watersheds left a definite mosaic of intensely burned, lightly burned, and unburned areas. Some tributary streams retained intact riparian vegetation, while some mainstem sections displayed a patchwork of burn intensity in the riparian zone. In Cottonwood Creek, for example, we found depauparate reaches interspersed with areas supporting very high densities of fish. In Sheep and Rattlesnake creeks, we found high densities immediately below long reaches that were devoid of fish. Fish were wholly eliminated from reaches in smaller streams such as Devil's Creek, and from the upper portions of Sheep and Rattlesnake creeks. Although fish were strongly affected, the fires of 1992 and 1994 did not produce a uniform or complete elimination of fish or disruption of habitat.

Recolonization of the affected reaches was influenced by the proximity, and direction of refuges. In Cottonwood Creek, where redband trout persisted in patches throughout the stream, numbers and age structures approached preburn conditions in the first year. Fish were reestablished in depauparate reaches by dispersal from both upstream and downstream sources over relatively short distances. In Sheep and Rattlesnake creeks, where redband trout were apparently eliminated in the upper reaches, recolonization must have occurred through dispersal from downstream sources over longer distances and a longer time frame. Although fish were present in substantial numbers in the severely affected reaches within the first year, numbers and age structures continued to vary over the period of study. Our observations are consistent with other studies of recolonization in fish populations following major disturbance and defaunation. In general, where internal refuges (i.e. sites of persistence within the spatial extent of the population) exist, recolonization occurs rapidly. Recovery often is evident in a few years (Meffe and Sheldon 1990; Niemi et al.1990; Yount and Niemi 1990; Lamberti et al. 1991; Detenbeck et al. 1992; Bayley and Osborne 1993) or even weeks (Sheldon and Meffe 1995).

The mechanism and rate of recolonization is strongly influenced by the local environment (Sheldon and Meffe 1995). Mechanisms that stimulate recovery or compensate for habitat losses might be triggered or enhanced by the disturbance event (Bisson et al. 1996; Minshall et al. 1989). For example, we observed high densities for young-of-the-year redband trout in several reaches influenced by the fires or related hydrologic effects. This is not consistent with a concept of fire as a catastrophic event, causing only negative changes in habitat conditions (i.e. loss of riparian cover, increased water temperatures and fine sediments). In small, cold streams, increased solar exposure may translate to warmer water, increased primary production (Minshall et al. 1989), and ultimately faster growth or higher carrying capacities for juvenile fish (Murphy and Meehan 1991). Similar positive responses in growth and production have been observed for other salmonids following large natural disturbances (Bisson et al. 1988) Although the fires killed fish and may depress production in some life stages for some time, they also may have created the potential for important compensation within these populations.

In summary, broadly distributed habitats suitable for these fishes during and after the fire provided for recolonization. The benefits of spatially redundant and complex habitats to the persistence and resilience of populations at multiple scales is well established in theory (den Boer 1968; Poff and Ward 1990; Sedell et al. 1990) and building empirical evidence (e.g. Pearsons et al. 1992).

Life History. We found evidence with both bull trout and redband trout that large-scale movements, other than those associated with the simple diffusion of fish from refuges within the stream, influenced recovery. In Rattlesnake Creek we believe that bull trout were nearly if not completely eliminated from the upper stream. Had the population been limited to a resident life history, the entire population could have been lost. We cannot eliminate the possibility that some fish survived in local refuges that we did not locate, but the observation of large adults moving into the system in September, strongly suggests that an adult or subadult component of the population persisted outside the watershed. A similar, though smaller scale effect, may have occurred with redband trout in Little Rattlesnake and Devil's creeks, where large numbers of juvenile fish were found in streams that had been vacant the year before.

It appears that a complex of life-history patterns also provided a temporal and a spatial hedge against extinction. Similar results have been reported for salmonid populations influenced by wildfire (Novak and White 1989) and other disturbances (Titus and Mosegaard 1992; Armstrong et al. 1994). Strong support is also found in life-history theory for salmonids (Gross 1991; Thorpe 1994 b) and other species (Poff and Ward 1990).

Theory proposes the persistence of multiple life-history strategies as a mechanism stabilizing populations in variable environments (Gross 1991; Thorpe 1994 b) but also as a mechanism that leads to full exploitation of, and may be dependent on, a complex of available habitats (Healey 1994; Lichatowich and Mobrand 1995). We expect that diverse life-histories are maintained because of an evolutionary history in variable environments (Poff and Ward 1990). Spawning and rearing habitats for bull trout are distributed primarily in higher elevation, colder watersheds. Because high elevation areas throughout the region were more likely to experience mixed or high intensity fires (Arno 1980) many populations have experienced this pattern of disturbance. We should expect that, in an evolutionary sense, bull trout are well acquainted with large, intense fires. The existence of complex life histories such as the mixed migratory behaviors and overlapping generations found in the Boise River basin could be the expression of strategies that have emerged because of the disturbance of fire and associated hydrologic events. We also expect the expression of complex life-histories to be tied to the template of the available habitats (Healey 1994; Thorpe 1994 a; and also see Turner et al. 1995 for discussion of larger scales). If the spatial and temporal complexity of habitats is lost the expression of complex life histories can be lost as well.

The two pathways we have suggested for the short term recovery of salmonids influenced by the Boise fires imply that the nature of the habitats available to the populations strongly influenced the result. The complexity of the landscapes undoubtedly led to the mosaic in burn effects but also a mosaic of pre-fire stream habitat conditions that provided important refuges within the burn perimeter. That same complexity of stream habitats, the size of the basins and the connection of the watersheds to a larger river basin are likely important in the full expression of diverse life histories. In the short term, these bull trout and redband trout populations, seem to have the potential for dramatic recovery from very large intense wildfires. Similar potential in other populations likely depends on the quality and extent of available habitats.

We do not know the long term effects of these fires. Fires often trigger increased surface erosion (Megahan 1991) and, if followed by intense storms, debris torrents and channel scour also may be common (Brown et al. 1989; Swanson et al. 1990). In many cases the short term rate of erosion and sediment delivery following a fire can outweigh the effects of roads and timber harvest activities (Megahan 1991). Changes in vegetation and watersheds influencing hydrologic and temperature regimes and erosion that influence fish habitat may persist for years and perhaps decades (Minshall et al. 1989; Brown 1989). The long term legacy in many cases, however, can be positive (Swanson and Lienkaemper 1978; Brown 1989; Swanson et al. 1990; Reeves et al. 1995). Increased inputs of large wood and coarse sediments from dispersed sources or storm triggered debris flows are also likely to follow large fires (Brown 1989; Megahan 1991; Reeves et al. 1995) and have been common in our study watersheds. The larger materials often store fine sediments, and provide the hydraulic complexity necessary for sorting of larger materials that represent critical elements of fish habitat. The intensive debris and scour events that generate the materials are often localized (Megahan 1991) and confined to the smaller, high gradient channels (Swanson et al. 1990). The movement of fine sediments may occur in pulses or waves that are not uniform in time or space (Reeves et al. 1995). Although the volumes of fine sediments can be large they may be relatively short lived and patchy in relation to the effects of other more chronic disturbances such as roading and timber harvest activities (Reeves et al. 1995). Others have found that the erosional and hydrologic effects of large fires decline substantially within 10 years (Brown 1989; Beaty 1994). Historically this episodic contribution of coarse debris may have been key to the creation and maintenance of complex, instream habitats (Brown 1989; Swanson and Lienkaemper 1978; Reeves et al. 1995). Emerging theory strongly suggests that natural disturbance regimes may have been critical to the maintenance of such habitats and the productivity of the associated populations (Reeves et al. 1995) as well as the genetic and phenotypic diversity that supports resilience of populations in the short term and adaptation in the long term (Poff and Ward 1990). The suppression of fire in recent history could well have contributed to the overall decline in productivity of fish habitats throughout the region. Arguably the recent fires might be viewed as a badly needed "house cleaning" for overstocked forests as well as an infusion of materials critical for the maintenance of productive habitats.

So are these fires good or bad for existing populations of native salmonids? As generally seems to be the case in ecology the answer depends. Larger and more intensive fires may result in local extinctions of very small and isolated populations. Many species and populations, however, may still have the ecological diversity necessary for dealing with this disturbance. Although fire may create important changes in watershed processes (e.g. surface erosion and mass failure) that are often considered negative for fish, the spatial and temporal nature of the disturbances is important (Reeves et al. 1995). Fire and the associated hydrologic effects can be characterized as pulsed disturbances as opposed to the more chronic "press" effects linked to permanent roads or extended timber harvest activities (see Yount and Niemi 1990). The effects of fire are more likely to be episodic, dispersed through time and space. Species such as bull trout and redband trout appear to have been well adapted to such pulsed disturbance. The population characteristics that provide for resilience in the face of such events, however, likely depend on large, well connected and spatially complex habitats that can be lost through chronic or press effects of other management. A critical element to resilience and persistence of many populations for these and similar species will be the restoration or maintenance of highly complex, well connected habitats, across a mosaic of streams and watersheds.

Throughout the Pacific Northwest the effects of chronic watershed disturbance, the introduction of exotic species, and barriers such as dams, diversions, and road culverts, have resulted in the fragmentation and isolation of salmonid populations and the elimination or serious depression of historic life-history patterns (Rieman and McIntyre 1993; Frissell et al. 1993; Henjum et al. 1994; Lichatowhich and Mobrand 1995). By expanding our efforts in timber harvest to minimize the risks of large fire, we risk expanding what are well established negative effects on streams and native salmonids. In general, previous attempts to minimize such effects in any single watershed have led to the dispersal of activities across broad areas (Reeves et al. 1995). The chronic and widespread nature of timber harvest and other human related disturbance has led to a loss of spatial complexity of stream environments, that ultimately can be reflected in the loss of complexity and diversity and distribution of populations and life histories (Frissell et al. 1993; Reeves et al. 1995). We do not expect conventional timber harvest activities to produce watershed effects equivalent even to very large wildfires. It also is not clear that attempts to manipulate the structure and processes of whole ecosystems (i.e beneficially manipulate the fire regime) can ever be successful (Baker 1994; Stanley 1995). The perpetuation or expansion of existing road networks, and other activities might well erode the ability of populations to respond to the effects of large scale storms and other disturbances that we clearly cannot change.

There is growing interest for intensive forest management to reestablish more natural landscape patterns and disturbance regimes, but the risks and benefits of that management vary across the landscape. In our haste, forest health treatment projects have been justified from all perspectives including the risk of extinction for sensitive species such as bull trout and redband trout. There is undoubtedly a point where the risk of fire outweighs the risk of our management, but that point needs to be discovered through careful evaluation and scientific study not through the opposing powers of emotional or political rhetoric. Our experience with the effects of the recent fires is incomplete. The picture that emerges both from our experience and the available literature, however, suggests that the consequences of large fires are not as catastrophic as some have anticipated. Managers must weigh that knowledge against other needs.

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