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Fish and stream habitat risks from uncharacteristic wildfire: Observations from 17 years of fire-related disturbances on the Boise National Forest, Idaho☆

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Abstract

Several large, uncharacteristic wildfires occurred on the Boise National Forest in Southwest Idaho, from 1986 to 2003. From 1987 to 1994, severe wildfires burned almost 50% of the ponderosa pine forest types (about 200,000 ha). The intensity of the fires varied across the landscape, with a mix of low to moderate severity, and lesser amounts of high burn severity. After the fires, localized debris flows favored smaller order streams in watersheds less than 4000 ha in size, where there had been mostly high severity burning. Locally, areas experiencing high heat and post-fire debris flows had reduced fish numbers and altered fish habitats. Uncharacteristic wildfires on the managed portions of the Boise National Forest appeared to have more pronounced, short-term effects on fish habitats as compared with characteristic wildfires in the Central Idaho Wilderness. Even in the most severely impacted streams, habitat conditions and trout populations improved dramatically within 5–10 years. Post-fire floods apparently rejuvenated stream habitats by exporting fine sediments and by importing large amounts of gravel, cobble, woody debris, and nutrients, resulting in higher fish productivities than before the fire. These observations suggest that important elements of biodiversity and fish productivity may be influenced, or even created by fire-related disturbances. In some cases, habitats that were completely devoid of salmonid fishes just after the debris floods, were later re-colonized with migrants returning from downstream or nearby tributary rearing habitats. Re-population was likely enhanced by higher fecundity, homing instinct, and greater mobility of the larger migratory fish. Ecosystem restoration activities that reduce both short- and long-term threats of uncharacteristic wildfire on imperiled fishes could be emphasized in areas where local populations may be weak and/or isolated, but potentially recoverable. But forest ecosystem restoration alone may not reduce risks to fish if existing habitat conditions and isolation are limiting the population.

Keywords: Salmonids; Imperiled fishes; Wildfire; Floods; Debris flows

1. Introduction

Fishes of the USA's interior Northwest evolved with wildfire. Though varying in intensity and frequency, fire has been an integral component of aquatic ecosystems for thousands of years. In the Ponderosa Pine

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type, characteristic (historic) fire regime was marked by the high frequencies of non-lethal surface fires. As a result of fire preclusion and forest management practices of the last century, this fire regime has been altered. Decades of fire suppression, logging, and grazing removed fire-adapted species. Forests shifted to dense stands of Douglas-fir and other fire-sensitive species (Noss et al., 1995). These altered forests burn with uncharacteristically large size and severity. In just 8 years, severe wildfires burned almost 50% of the ponderosa pine forest types (about 200,000 ha) of the Boise National Forest in Southwest Idaho (Burton et al., 1999). Fig. 1 shows the large amount burned in recent years (in red), as compared with the previous 85 years (in blue).

The large fires of the past two decades, burned in a mosaic of high, moderate and low severity (Fig. 2). High severity fires burn extensively through the forest canopy, consume large woody surface fuels, and tend to render portions of the soil hydrophobic, or resistant to infiltration. By contrast, moderate and low severity fires burn mostly in the understory, leaving most of the overstory vegetation alive. It is in areas of "high severity" that dramatic effects to stream fishes were observed. Of 32 watersheds burned by the recent fires, 5 (15%) experienced post-fire debris floods that significantly altered fish habitats, and these were primarily associated with watersheds in which high severity burning occurred over most of the area. Thus, post-fire monitoring was conducted to answer the following questions:

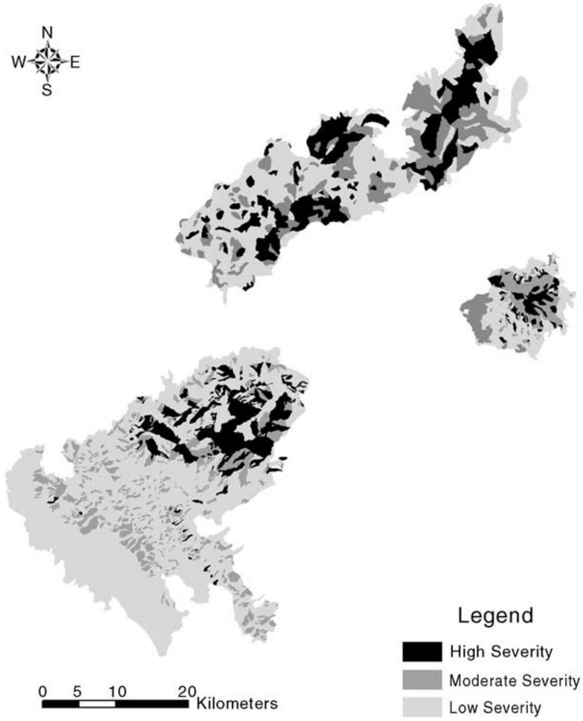

Fig. 2. Several recent large wildfires on the Boise National Forest, showing a mosaic of fire severities.

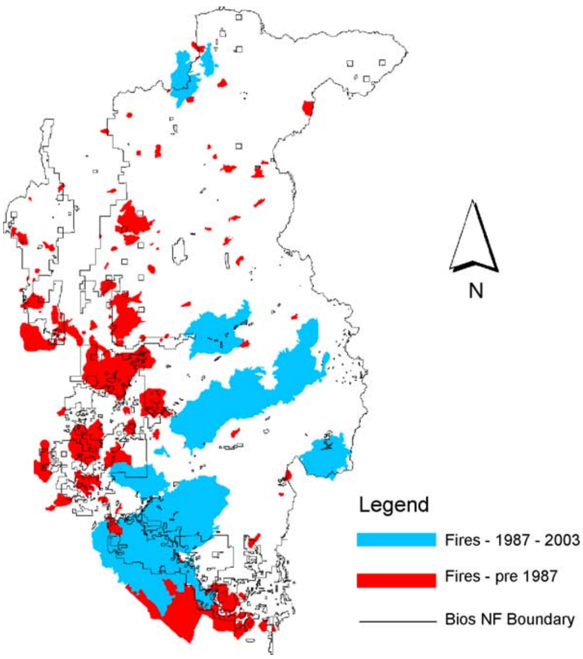

Fig. 1. Historic (characteristic) wildfires on the Boise National Forest, Idaho and recent (1987–2003) uncharacteristic wildfires fires, showing the expanded extent of burning in recent years.

(a) What habitat characteristics are altered, created or maintained by characteristic wildfire?
(b) Are these habitat characteristics at risk from uncharacteristic wildfire?
(c) If a species population size is depressed, does that increase its vulnerability to uncharacteristic wildfire?
(d) How might fish habitat restoration, making a population more resilient to disturbance, reduce short- and long-term risks of uncharacteristic wildfire?

This paper attempts to answer these questions based upon observations on the Boise National Forest during the past 17 years.

2. Methods

Standard fish habitat inventory methods, developed by the Intermountain Research Station's Enhancing Fish Habitats Research Work unit in 1990, were used to measure the habitat features in burned forests of the Boise National Forest. The same methods were used to characterize fish habitats within both burned and unburned watersheds in central Idaho wilderness streams (Overton et al., 1995, 1997). These methods characterize habitat types, dimensions, substrate sizes, streambank stability, large woody debris, and cover characteristics of stream reaches of reasonably constant size and channel type. Local fish abundance was estimated using standard 2-pass electrofishing techniques by electrofishing stream reaches approximately 100 m long. Reaches on the same stream were separated by 800–1600 m. Stream substrate composition was estimated using the Wolman method (Wolman, 1954).

2.1. Short-term responses of fish habitat after uncharacteristic wildfire

I compared fish habitat of streams in burned and unburned watersheds in the Central Idaho Wilderness, with streams in managed portions of the Boise National Forest. With respect to the Central Idaho Wilderness streams, Boise National Forest streams are comparable in size, gradient, substrate, vegetative cover, elevation, and topography. The managed portion of the Boise National Forest is located adjacent to the wilderness area, and both are dominated by landscapes of the Central Idaho Batholith, a broad igneous intrusion associated with mountainous terrain of pine and fir forests. It was assumed that fires and related post-fire disturbances in the wilderness, where fire suppression has been minimized, are more characteristic of historic fire regimes, and are limited in extent and severity. It has been suggested that fish habitat disruptions resulting from post-fire floods and landslides in the wilderness were neither extensive nor pervasive (Minshall and Brock, 1991; Ott and Maret, 2001; Overton et al., 1995). Among 80 wilderness watersheds evaluated by Overton et al. (1995), 8 (10%) had experienced wildfire within the previous 5 years. No data are available on the severity of these wildfires, but it is presumed that they burned with characteristic intensities. Most habitat characteristics were comparable between burned and unburned streams in the wilderness watersheds, although percent surface fine sediments were substantially higher in habitats of watersheds subjected to wildfire (Table 1).

By contrast, more than 50% of the Ponderosa Pine watersheds in the Boise National Forest experienced wildfires between 1986 and 1994, many of which burned with uncharacteristic intensity (Fig. 2). Short-term habitat alterations associated with streams in burned watersheds were more pronounced on the Boise National Forest than in the wilderness streams. As shown in Table 1, recently burned streams had lower percent fine sediments (28% versus 37%), less substrate gravel (24% versus 55%), and lower volumes of large woody debris (5.4 versus 16.4 pieces/100 m). These differences may reflect the higher degree of flood scour that occurred following uncharacteristic wildfires on the Boise National Forest.

2.2. Short- and long-term risks of uncharacteristics wildfires on fish

Fish mortality following wildfires may result from the heating effects of fire, or from adverse post-fire conditions of water quality and quantity. Large fires in 2002 and 2003, in forested watersheds of the Southwestern USA, accounted for a total loss of fish in one stream, a 90% reduction in four streams, and a 70% reduction in two streams. These reductions resulted from post-fire changes in water quality and quantity, and habitat alterations (Rinne, 2004). During an experimental burn bordering a small stream in Washington, "distress" among yearling rainbow trout (*Oncorhynchus mykiss*) and several species of native fishes and mortality of native chinook salmon (*Oncorhynchus tshawytscha*) were attributed to fire-induced changes in stream pH (Cushing and Olson, 1963). Also, in a watershed study in Oregon a prescribed fire caused immediate mortality via stream heating (Moring, 1975). Water temperature increases

Table 1
Stream habitat characteristics of burned and unburned forests of the Central Idaho Wilderness (characteristic wildfire), and burned and unburned forests of the Boise National Forest (uncharacteristic wildfire)

Habitat characteristic	Unburned			Recently burned		
	Samples (*n*)	Mean	95% Confidence interval	Samples (*n*)	Mean	95% Confidence interval
Central Idaho Wilderness						
Stream width (m)	16413	5.8	5.7–5.9	771	5.3	5.1–5.5
Stream depth (m)	16237	0.27	0.267–0.273	761	0.3	0.290–0.310
Maximum water depth (m)	10151	0.69	0.68–0.70	467	0.7	0.68–0.72
% Surface fines (<6 mm)	11679	26.7	26.2–27.1	603	42.0	39.6–44.3
% Surface gravel	4358	31.9	31.4–32.4	70	33.7	30.7–37.2
% Stable streambanks	12298	87.6	87.2–88.0	526	97	96.2–97.8
Large wood debris (100 m)	11921	5.04	4.95–5.13	442	5.12	4.70–5.54
Boise National Forest						
Stream width (m)	767	4.5	4.2–4.8	965	4.0	3.9–4.1
Stream depth (m)	996	0.20	0.18–0.22	1611	0.12	0.115–0.124
Maximum water depth (m)	362	0.56	0.52–0.60	782	0.49	0.47–0.51
% Surface fines (<6 mm)	649	36.6	34.6–38.6	898	28.1	27.1–29.1
% Surface gravel	76	55.1	51.9–58.3	110	24.0	21.6–26.4
% Stable streambanks	393	83.0	32.8	na	na	na
Large wood debris (100 m)	593	16.4	14.8–18.0	575	5.4	5.0–5.8

may have reduced local dissolved oxygen concentrations within the stream to lethal levels.

Evidence of fish mortalities during wildfire activity on the Boise National Forest came from direct observations, and from measurements within the streams immediately following wildfire. As shown in Fig. 3, fish densities in one stream, Cottonwood Creek, in the high severity burn area, declined dramatically just after the fire. One sampling site within the severe burn area did not show a reduction in numbers during the fire, reflecting the possibility that these high severity burn areas may contain islands of lighter burning, or unmapped inclusions of low or moderate burning. In high-severity burn areas, fish densities nearly rebounded 1 year later, suggesting repopulation by fish migrating back from less impacted habitats (Fig. 3). Within moderate severity burn reaches intermediate grey fish populations did not decline immediately after the fire, as they did in the severe burn reaches. They did decline in numbers the following year, suggesting a possible re-distribution from the moderate severity burn area upstream into severely burned reaches.

Erosion from post-fire debris floods occurred on high severity burn areas, in headwater drainage channels scoured to bedrock. Debris, including rocks and logs, was transported to lower gradient, higher order channels downstream. These flows are typically initiated as debris slides, caused by soil saturation and loss of soil cohesion as roots decay following fire. Surface erosion, debris slides, and debris flows often result during intense thunderstorms. Thus, their probability of occurrence depends upon the probability of intense storms occurring during periods of increased susceptibility to surface erosion, the first year or two after severe wildfire. In just 8 years, many eroded headwater channels were found to be stabilizing. Moist bottomland sites of small order drainages were observed to be rapidly re-vegetating.

Sediments and debris from headwater channels, were carried downstream to habitats important for spawning and early rearing of salmonids. Two small, non-wilderness redband trout (*Oncorhynchus mykiss gairdneri*) streams, Trapper and Wren Creeks, were associated with uncharacteristic wildfires in 1994. These streams for which pre-fire fish abundance data were available, experienced heavy post-fire erosion and debris floods, and high severity burning over 75% of both watersheds, one year prior to the flood event. Immediately following the debris flood, no fish were found at either monitoring station. Through time, habitat conditions improved (Table 2) and fish recolonized these streams (Fig. 4). Natural riparian revegetation and the addition of large woody debris

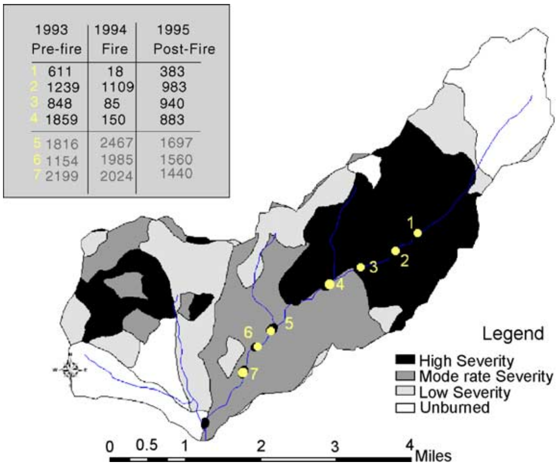

Fig. 3. Fish densities (number per 1.6 km) in Cottonwood Creek showing decreases within the high severity burned area immediately after wildfire in 1994.

from falling dead trees, large rocks carried in by the debris flows, and other products of flooding, apparently helped to restore habitats favorable to redband trout (*Oncorhynchus mykiss gairdneri*). In particular, pool frequency rebounded by the year 2000. Many pools were associated with, and indeed formed by large woody debris in the stream. Prior to the fire, LWD was abundant in these streams. Ater the fire, almost all LWD was exported by the severe floods. After the floods, fire-killed trees falling into the stream, increased LWD.

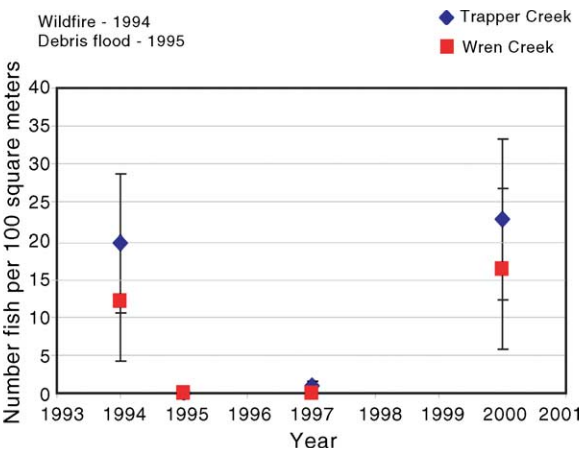

Fig. 4. Redband trout (*Oncorhynchus mykiss gairdneri*) abundance, estimated by electrofishing 100 m segments of stream, at several different segments separated by approximately 1600 m, in Trapper and Wren Creeks, both before and after the debris floods (with 95% confidence intervals). Both streams are located within the Boise River Basin, Idaho.

Others have reported similar responses following wildfire: Minshall and Brock (1991) observed that ‘‘wildfires may result in improved and rejuvenated habitat for salmonids and increased productivity increasing fish populations over the long-term’’. Koelsch (personal communication, 2004) observed the highest densities of bull trout (*Salvelinus confluentus*) in the Little Lost Basin, Idaho, in Smithie Fork, where intense wildfire occurred 20–25 years ago. It is currently shrub dominated with abundant LWD. Rieman et al. (1997) monitored three populations of redband trout (*Oncorhynchus mykiss gairdneri*), and two populations of bull trout (*Salvelinus confluentus*) after intense fires in the early 1990s on the Boise National Forest. Some reaches were devoid of fish after debris flows in those drainages, yet fish densities increased dramatically several years later, and in some cases exceeded those before the fire or densities observed in streams not influenced by the fires. Re-population was likely made possible by higher fecundity, homing instinct, and greater mobility of the larger migratory fish. Thus, in the case of uncharacteristic wildfires, local extirpation of fishes is apparently short-term and patchy, recolonization is potentially rapid, and habitats disrupted immediately after the flood events are often rejuvenated within 5–10 years.

Where surface erosion is increased after wildfire, fine sediments may be transported from the burned lands to stream habitats. In many cases, changes in habitat characteristics were not dramatic and there was no alteration of the basic structure of the channel. The principal effect was to embed the substrate with fines. Subsequent spring floods scoured the substrates and transported most of the fine sands into the floodplain. Substrate monitoring of the 1987 Deadwood Summit Fire indicated a 1 year increase in substrate fine sediments, in the lower reaches of Boundary Creek (Potyondy, 1990), as shown in Table 3. The Boundary Creek watershed experienced characteristic, high severity wildfire in lodgepole pine types, over a large proportion of the watershed.

Where high severity wildfire removed overstory canopy or shade adjacent to streams, we observed increased exposure to sunlight in the riparian zone.

Table 2
Changes in stream habitat characteristics and redband trout (*Oncorhynchus mykiss gairdneri*) densities at the Trapper and Wren Creek monitoring stations

	Spawning fines <6 mm (%)	Pools (%)	Pool frequency (#/km)	LWD[a] (pieces/km)	Redband trout density (#/km)
Trapper Creek					
Pre-fire	40	16	86	259	534
1995–1997	24	1	6	31	20
2000	23	15	52	50	610
Wren Creek					
Pre-fire	33	56	240	120	320
1995–1997	40	2	18	25	0
2000	45	47	166	93	433

[a] LWD is large woody debris—all wood debris within the channel that is submerged or potentially submerged and at least 10 cm in diameter and 3 m in length.

Where the incidence of solar radiation is increased, there is concern for the productivity of bull trout (*Salvelinus confluentus*) in their early life stages. Ott and Maret (2001) recently studied bull trout (*Salvelinus confluentus*) streams in the wilderness areas of Central Idaho, where there has been little or no human intervention. Bull trout (*Salvelinus confluentus*) abundance showed the stongest inverse correlation with stream temperature. For comparison, I examined temperature conditions on two bull trout (*Salvelinus confluentus*) streams in the Boise National Forest, following an uncharacteristic wildfire that decreased canopy shade in one of these streams. Crooked River, was used as the unburned reference for the burned stream, Ballentyne Creek. Both are productive bull trout (*Salvelinus confluentus*) streams, with minimal or no competition from non-native brook trout (*Salvelinus fontinalis*), and bull trout (*Salvelinus confluentus*) densities are among the highest in the Basin. As shown in Fig. 5, temperatures were usually similar in both streams or slightly higher in the burned stream. However, in the summer of 2001, maximum water temperatures were 5 °C higher in the burned stream than in the unburned stream. An analysis of changes in bull trout (*Salvelinus confluentus*) densities during the period of stream temperature monitoring (Fig. 6), indicated that while bull trout (*Salvelinus confluentus*) densities were increasing at monitoring sites in the unburned stream, trends were flat, not increasing or decreasing in the burned stream. Perhaps

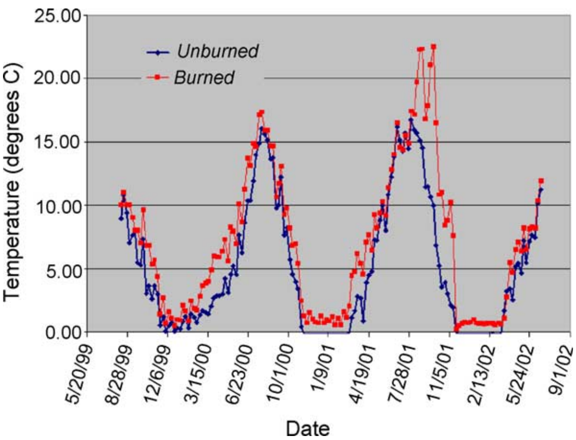

Fig. 5. Seven-day average maximum temperatures observed on Ballentyne (burned) and Crooked (unburned) Creeks from May of 1999 to June 2002. Both streams are within the Boise River Basin, Idaho.

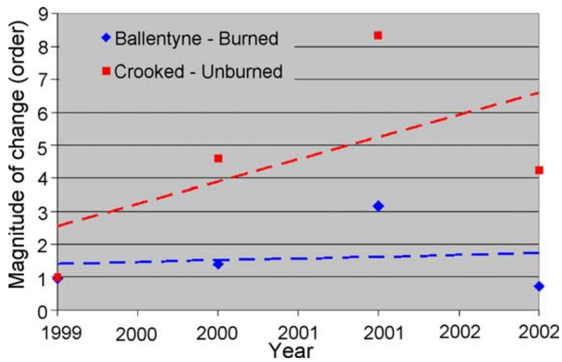

Fig. 6. Changes in bull trout (*Salvelinus confluentus*) densities from 1999 to 2002 in the Ballentyne Creek area, which was burned in a uncharacteristic wildfire in 1994, and on Crooked Creek, a similar unburned stream. Both are in the Boise River Basin, Idaho.

Table 3
Trends in substrate fines (<4 mm) at three monitoring sites in the Deadwood Summit Fire of 1987

Monitoring site	Relative fire impact[a]	Percent fine sediment			
		Pre-fire (%)	1988 (%)	1989 (%)	1990 (%)
Boundary Creek	High	36	63	35	33
Elk Creek	Moderate	15	10	12	na
Sulphur Creek	Low	20	19	8	15

[a] Relative fire impact: high, 66% of the area burned with high severity; moderate, 30% of the area burned with high severity; low, 95% of the watershed burned with light severity.

the adverse affects of higher temperatures in the burned stream are counterbalanced by increased food production, cover, and physical habitat quality. External variables may also affect this difference, however there are no migration barriers, competitors, or fishing harvest of any significance to explain the difference. It is interesting to note that year-to-year changes in bull trout (*Salvelinus confluentus*) density in the unburned stream, Crooked River, are mirrored by similar, annual changes in the burned stream, Ballentyne Creek. Because these trends in bull trout abundance are not significantly different between burned and unburned streams, the results are not suggesting that changes in thermal conditions on Ballentyne Creek, affected by uncharacteristic wildfire, have reduced fish productivity.

2.3. Vulnerability of depressed fish populations to uncharacteristic wildfire

Because fish may be eliminated from streams which experience severe, uncharacteristic wildfire, re-population depends on fish migrating back from downstream rearing or nearby tributary habitats. Populations are more vulnerable if they are unable to move between rearing and spawning habitats. If critical natal habitats are isolated by barriers, re-population may be foregone. Some interesting work by Morita and Yamamoto (2002) on white charr (*Salvelinus leucomaenis*) in Japan shows the potential for extinction among isolated fish populations in small watersheds. In that study, a number of dammed-off streams resulted in local extirpation of white charr, with persistence apparently dependent upon watershed size. The smaller the watershed and the longer the time of isolation, the greater the potential for extirpation, even without disturbance. All watersheds had charr before the dams were built. Watersheds less than 1 km^2 in size were mostly absent white charr, a presumed result of isolation by the dam. Thus, barriers to migration (isolation) may pose significant risks to fishes in small watersheds.

Where uncharacteristic wildfire occurs above such barriers, both short and long-term risks increase. As described above, fish mortalities and habitat alterations can be significant after high severity wildfires, and such burning is typically concentrated in smaller watersheds. Two small forested watersheds burned in the 1990 Dude Fire, Arizona, experienced post-fire ash and flood flows that were fatal to brook and rainbow trout (Rinne, 2004). These populations have not recovered, likely due to isolation from sources of refounding, or because the watersheds are simply too small to support long-term persistence.

3. Discussion

Species at greatest risk from uncharacteristic wildfire, or any major disturbance, include those with populations that are small or isolated. In southwest Idaho, bull (*Salvelinus confluentus*), and redband (*Oncorhynchus mykiss gairdneri*) trout are the species most at risk. Weak populations of such species have been subject to chronic adverse affects of past development, introductions of exotic fishes, and disease. The migratory life-history component may be lacking as a result of migration barriers or poor habitat conditions. In such cases, habitat disrupting events after wildfire could severely depress, and eventually extirpate local populations. Actions to restore forests' resiliency to wildfire, in such cases, would be ineffective for restoring fish. The work by Morita and Yamamoto (2002) suggests that isolation, for at least the species and habitat circumstances they studied, is a significant threat. Thus, even without forest restoration, fish populations would benefit from removal of barriers that cause isolation and prevent refounding after disturbance. Conversely, forest restoration not accompanied by actions to restore fish population connectivity and habitat quality, may provide little risk reduction. Yet given their vulnerability to habitat disruption in the short-term, reducing the risks of uncharacteristic wildfire could provide benefits to small populations, until connectivity or habitat quality is restored. Habitat restoration, barrier removal, and forest management practices designed to reduce wildfire risks may have short-term risks associated with fine sediment production that may temporarily reduce the productivity of the population. Yet the long-term consequences may far out-weigh these risks given the alternative of total extinction. Projects to re-structure forests or reduce fuels to reduce the risks of uncharacteristic wildfire, are essentially balancing short-term risks against long-term benefits to fish. Larger, well-connected populations are at lower risk to uncharacteristic wildfire and may not be benefited by forest restoration. Rieman and Clayton (1997) suggest that restructuring forests to reduce wildfire threats may potentially be a threat to fish. Thus forest restoration associated with large populations may pose short-term risks, not outweighed by long-term benefits.

In a recent field review of pre-commercial thinning to reduce fuel loads, densely stocked fir and ponderosa pine were left within a 61 m buffer adjacent to the streams (Interagency Conservation and Consultation Planning Team, 2003). Local biologists listed concerns about potential high severity fire associated with the remaining heavy fuels along the stream channel, which if it occurs, could lead to stand replacement, loss of shade, and loss of large wood debris (LWD) recruitment. Small diameter pine crowded within the riparian area were preventing the growth and vigor of native shrubs along the stream. Shrubs are important to habitat productivity because they provide cover, nutrient inputs, and pool forming root structures. Where thick stands of pine dominate, shrubs were lacking or absent, LWD was not observed in the stream, and pools were lacking. Where pine had been removed by local wildfire, shrubs were dominant, pools were common, and habitat structure was good. Where there were large ponderosa pine trees on the stream banks, large roots were associated with good cover and large pools. Stream segments in the thick pine zone were dominated by shallow riffles without resting pools that may present a barrier to juvenile salmonids migrating upstream. The review team recommended a test or experiment to evaluate breaking up the continuity of fuels along and perpendicular to the stream, using treatments similar to those beyond the riparian zone, but applied in narrow patches (about 100 m wide), oriented perpendicular to the stream, and extended lengthwise across the full 400 m width of the riparian area. This test would evaluate whether fuels reduction treatments are effective at preventing high severity wildfire from burning continuously along the entire length of the stream. If fuel breaks were staggered along the length of the stream, the narrow patches of treatment would decrease shade, at least until alder (*alnus* sp.) and willow (*salix* sp.) shrubs grow to heights sufficient to provide shading cover to the stream. A simulation using the SSTEMP (Bartholow, 2002), model indicated that for a small stream, fuel breaks totaling 1/10 of the riparian area would increase maximum stream temperature by only 1 °C. Thus, the proposed treatment would likely minimize both the short-term risks of catastrophic fire and risks posed by the project itself. But if this treatment is effective at preventing catastrophic wildfire, would it also prevent the desirable disturbances that may be best for the stream in the long-run? Perhaps the test could also include more characteristic burning between the fuel breaks to evaluate the potential beneficial effects of short-term disturbance, and could also include full thinning in riparian areas to test for hypothesized negative impacts of forest treatments within the riparian zone.

If, in fact, forest disturbance is desirable or even necessary in the riparian zone, a new approach, beyond the current "buffer" strategy for managing riparian areas is needed. Bonar (2004), suggests using forest harvest or thinning and prescribed fire as a means to approximate natural disturbance patterns. This strategy would require maintenance of important ecological functions, such as the need to recruit and maintain LWD in stream channels, the need to maintain stream channel stability contributions of tree roots and large wood, and nutrient flow from trees, shrubs, soils, insects, and animals to the stream.

4. Conclusions

Uncharacteristic wildfires in the forest ecosystem effect changes in fish and fish habitat. Habitats may be dramatically altered and local extirpations are possible. Such changes are usually short-term. Over the long term, wildfires may improve and rejuvenate habitat for salmonids and potentially increase their abundance. Large fires trigger hydrologic events that remove fine sediments from stream channels, and induce debris flows that transport beneficial coarse substrates to the channels. These processes may well provide the materials that maintain productive habitats for fish and other organisms over the long run. Short-term risks of large, uncharacteristic wildfire may be significant and adverse, particularly if the habitat is already degraded or poorly connected to downstream sources of refounding. If, after habitat disruption, external migrants are needed to re-found the population, barriers to migration may prevent re-colonization.

Forest restoration, not accompanied by actions to restore fish population connectivity and habitat quality, will provide little risk reduction when such conditions are limiting the population. As concluded by Dunham et al. (2003), pre-fire management that reduces risks from factors that are already limiting the population, would be a good approach for reducing species vulnerability. Effective pre-fire management planning could address factors that render fish populations more vulnerable to the effects of fire, such as: habitat degradation, fragmentation, and competition with non-native species. Making the local fish population more resilient would reduce risks to fish when such large uncharacteristic wildfires occur.

On the Boise National Forest, riparian forest disturbances associated with uncharacteristic wildfires resulted in increased solar radiation and large woody debris recruitment to stream habitats. Increases in solar radiation and potential warming of the stream, may pose a risk to bull trout (*Salvelinus confluentus*), which are particularly vulnerable to higher water temperatures. There is evidence that such changes may have been beneficial to redband trout (*Oncorhynchus mykiss gairdneri*).

Where fish and fish habitat are at risk from lack of disturbance and the presence of overstocked forests, particularly in the riparian zone, harvest and prescribed burning have been proposed to mimic natural disturbance. However, such management is experimental, and timber harvest may affect the aquatic ecosystem differently than natural disturbance following wildfire (Rieman and Clayton, 1997). The benefits of such restoration projects, need to be carefully weighed against the risks to fish populations.

Past development in the Northwest has resulted in chronic adverse impacts to native salmonids, including barriers (road culverts, diversions, and dams), and the introductions of exotic species and disease. These have resulted in the fragmentation and isolation of many local populations, and the loss of critical life history stages in species with a propensity for migration. Expanding development and forest treatments to reduce the risks of wildfire, must not be done at the risk of spreading chronic effects to the few remaining high quality aquatic habitats (Rieman et al., 1997). Managers must be careful not to prevent wildfires that otherwise are likely beneficial to native salmonids. Our experience suggests that the more intense wildfires, those considered ''uncharacteristic'', may be important to native salmonids, and perhaps critical in the long-term.

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