Immediate Effects of Fire on Aquatic Systems

Source: http://www.northernrockiesfire.org/effects/aqimme.htm

Forest fire often directly affects water quality in nearby streams and other bodies of water. These direct influences are also considered immediate effects, as they are manifest either during fire or very shortly thereafter. Here we describe the direct effects of forest fire on water temperature and chemistry that have been observed by scientists in the Northern Rockies. We then discuss expected and observed responses of aquatic invertebrates, amphibians, and fish to these fire-caused changes in water quality.

WATER TEMPERATURE

As fire burns in surrounding vegetation and woody debris, it can raise the temperature of water in forest streams and ponds (Cushing and Olson 1963, Hall and Lantz 1969, Feller 1981, Spencer and Hauer 1991). However, water has the highest heat capacity of any common substance. It takes a great deal of heat to raise the temperature of water by a single degree. Think of how long it takes to heat a small pot of water. Now imagine how much heat it might take to warm an entire stretch of forest stream!

Clearly, the ability for a forest fire to change the temperature of any particular watercourse or water body depends on the amount of water subject to heating. More precisely, it depends on the affected unit's surface-area-to-volume ratio. In essence, this means that temperatures rise faster in smaller and shallower drainages and water bodies than in larger and deeper ones. All else equal, the magnitude of any temperature change depends on both the amount of heat directed at the water surface per unit time and the duration of heating.

While we know that the heat generated from a forest fire has the potential to affect water temperature, with small and shallow streams and ponds subject to the most pronounced changes, few people have ever had the opportunity to measure peak water temperatures during fires in the forests of northern Idaho and western Montana. In just a handful of cases, researchers happened to be collecting water temperature data when a wildfire passed through their study areas. Most recently, such serendipity allowed researchers to characterize fire-caused changes in temperatures within at least two relatively large (third-order) streams in Montana forests. (Stream size is generally differentiated into "orders", with the source, or headwater tributary classified as a first-order stream. When two or more first-order streams join, they form a second-order stream, and so on [Minshall and Brock 1991].)

Forest scientists were recording temperatures in Laird Creek (near Darby, Montana) every 2 hours and 24 minutes when a crown fire burned through the area on August 6, 2000. According to a subsequent report (Bitterroot National Forest 2000), they "did not record any unusually high water temperatures, which means that either stream heating did not occur,.or heating occurred very quickly and temperatures returned to normal in less than 2 hours and 24 minutes."

In June 2001, Than Hitt began taking water temperature readings every half hour from Deadhorse Creek in the Flathead River system. On August 27, 2001, the Moose Creek Fire entered this watershed, burning approximately 2250 forested acres upstream of the water temperature gauge (Hitt 2003). About 50% of the burned watershed, including the patch of forest in which the gauge had been placed, was classified as having experienced high-severity fire. Hitt recorded a maximum temperature of 63°F in the creek as the fire entered the watershed. This peak lasted less than 8 hours and was 14°F greater than the expected maximum temperature for that day based on a comparable set of readings from a nearby, unburned stream (Hitt 2003).

WATER CHEMISTRY

Fire can cause immediate changes in the water chemistry of forest streams and ponds, both as a by-product of heating and from smoke and ash inputs during the burning process (Cushing et al. 1963, Woodward 1989, Minshall et al. 1990, Spencer and Hauer 1991). Elevated water temperatures can reduce the solubility of dissolved oxygen (Russo 1985) and, along with adsorption of smoke and deposition of ash into surface waters, increase pH and nutrient levels in aquatic systems.

According to Hitt (2003), the peak temperatures that he observed during the Moose Creek Fire (see *Water Temperature*, above) would have reduced the concentration of dissolved oxygen from 11.3 to 9.6 mg/L in pure water. Minshall et al. (2001a), however, found elevated concentrations of most other chemical elements soon after the 1979 Mortar Creek Fire, which burned through mixed-conifer forest within the Frank Church River of No Return Wilderness in northern Idaho.

Pulses of inorganic nitrogen and phosphorus into nearby watercourses and water bodies are most commonly noted after forest fires (Gresswell 1999, Spencer et al. 2003). Spencer and others (2003), for example, documented 5- to 60-fold increases in phosphate, nitrate, and ammonium concentrations in third-order streams during the severe Red Bench Fire that burned thousands of forested acres within Glacier National Park, Montana in September of 1988.

Spencer and others (2003) attributed the nitrogen pulses to the diffusion of smoke into stream water, and phosphorus spikes were attributed to ash deposition. Concentrations returned to background levels within a few weeks. As there was no rainfall during this period, none of the nutrient pulses could be due to accelerated water-borne transport (Spencer et al. 2003). Ash and smoke were apparently the sole vehicles for short-term nutrient deposition into watercourses and water bodies during this fire event.

While changes in water temperature and chemistry may be short-lived, even brief departures from baseline can kill aquatic invertebrates, amphibians, and fish.

INVERTEBRATES

Most aquatic invertebrates thrive in water that we would consider cool to lukewarm at best. The incremental rise of water temperature to 70°F or higher has been found to kill several types of aquatic insects, including mayflies, stoneflies, dragonflies, and true flies, in the laboratory (Nebeker and Lemke 1968). A more rapid water temperature increase during forest fire, like that recorded by Hitt (2003; see Water Temperature above), may kill these animals at even lower temperatures or cause heat-shock, leaving the insects immobilized or lethargic and vulnerable to predators. Changes in water chemistry caused by fire can also kill stream invertebrates.

Only a handful of researchers have actually documented direct effects of forest fire on aquatic invertebrates (Minshall 2003). Despite expectations to the contrary (e.g., Spencer and Hauer 1991), the few data from northern Rocky Mountain systems indicate only trivial direct effects of wildfire on stream invertebrates (Minshall et al. 1997, 2001b). Minshall (2003) contends that, regardless of fire intensity, the suite of insects and other bottom-dwelling invertebrates detectable right after burning is essentially identical to that of pre-fire conditions. Exceptional direct mortality is most likely to occur in small or shallow waters and in areas blanketed with dense smoke (Minshall 2003).

AMPHIBIANS

Like aquatic invertebrates, amphibians are known to be sensitive to changes in water quality but have rarely been the focus of fire-effects research (Pilliod et al. 2003). Tailed frogs, for example, are killed by water temperatures in excess of about 85°F (deVlaming and Bury 1970). While there is no evidence that stream temperatures reach this extreme during forest fires in the Northern Rockies, the possibility remains. Frog and salamander eggs and larvae within relatively small and shallow bodies of water are most likely to experience lethal or stressful heating. Overall, as is the apparent case with aquatic invertebrates, heat kill of aquatic life stages during fire is probably a rare occurrence and inconsequential from a population standpoint (Pilliod et al. 2003).

The terrestrial life stages of these animals are less well-insulated from lethal temperatures and are especially prone to heat kill during fire (Bury et al. 2002, Pilliod et al. 2003). However, wildfires in Montana and Idaho forests tend to coincide with dry spells that force terrestrial amphibians underground or push them toward water, where they are most likely to find refuge from the heat (Pilliod et al. 2003). Slow-moving fires may allow enough time for individuals not already in refugia to reach them. Fires that continue into late summer or even fall are apt to kill individuals migrating to new water bodies and those settling into the leaf litter to overwinter (Pilliod et al. 2003).

Changes in water chemistry are probably the most important direct effects of wildfire from an amphibian's perspective. After de-emphasizing the potential for fire-related heat kill, Pilliod and others (2003) offer the following account and explanation of fire-caused frog mortality in Montana:

Within days after a 1998 wildfire and a 2001 wildfire burned across several third-order streams in northwesten Montana, Forest Service biologists observed numerous dead adult and larval tailed frogs (Ascaphus montanus) in the water.The causes of these mortality events are unknown, but they may be associated with ammonium toxicity in the water resulting from smoke diffusion.

FISH

There are many reports of fish killed during or shortly after forest fire (McMahon and deCalesta 1990, Rieman et al. 1997, Rieman and Clayton 1997, Dunham et al. 2003, Pilliod et al. 2003, Spencer et al. 2003). Fish kills tend to be greater with increasing fire severity in the streamside vegetation and decreasing stream size. Complete loss of fish from a stretch of stream, however rare, is most likely to occur in very small tributaries "cooked" by intense fire. After the fires of 2000, Bitterroot National Forest biologists deemed it "...reasonable to assume that the vast majority of the fish survived in the larger streams (3rd order or higher) that were burned with low and moderate severity fire" (Bitterroot National Forest 2000).

A handful of researchers have documented fish kills following forest fire in the Northern Rockies. All reports of substantial direct mortality come from areas recently burned by high-severity, or stand-replacing, fire. Riemann and others (1997) found only dead fish (bull trout and rainbow trout) immediately after a crown fire spread along two small streams in the Boise River Basin, Idaho. In a similar stream affected by similar fire, fish persisted but at lower densities than before burning. Novak and White (1990) describe near-complete extirpation of brown and rainbow trout attributable to the combined effects of a severe wildfire that burned 26% of the lower drainage of Beaver Creek within the Missouri River basin and a severe rainstorm that occurred one day later. Hitt (2003) found westslope cutthroat trout during an electrofishing survey along 300 m of Deadhorse Creek just a few weeks before a crown fire burned through the study area in 2000. A month after the fire, Hitt resurveyed the same reach of the creek and found no fish (Hitt 2003). Also shortly after high-severity fires of 2000, Bitterroot National Forest biologists documented complete fish kills in unnamed tributaries containing "very small westslope cutthroat trout populations (less than 500 individuals) restricted to several hundred feet of stream" (Bitterroot National Forest 2000).

Decreased abundance of fish shortly after fire can be due to fish kill, the aversion of fish to the affected area, or both. Dead fish found immediately fire are often assumed to have been killed by high temperatures, lack of oxygen, or elevated concentrations of volatile compounds, like ammonia (Spencer et al. 2003). These fire-caused changes may also repel fish from affected waters. Tolerances vary by species. In general, upper tolerance limits of trout fall between 73 and 77°F (Cherry et al. 1977). These fish seek cold water refugia once temperatures reach these veritable extremes (e.g., Nielsen et al. 1994).

Fish may die as a result of rapid water heating even if temperatures remain below lethal limits. A rapid rise in temperature may cause lethargy associated with thermal shock. Lethargic fish are particularly vulnerable to predation. Indeed, many nonnative predatory fishes function best in waters warmer than the cold water optimal for salmonids native to the Northern Rockies (Sauter et al. 2001). Rapid water heating can leave these fish at greater risk to predation by nonnative fish and other animals, like birds and mammals (Sauter et al. 2001).

Fire-caused changes in water chemistry may also kill fish directly or repel them from affected streams. Hitt (2003) documented peak stream temperatures during a severe Montana forest fire that could have reduced the solubility of dissolved oxygen to lethal levels. And both Spencer and Hauer (1991) and Hitt (2003) report that the concentration of ammonium in stream water shortly after the severe wildfires in their studies could have been toxic to native fish.

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