Short-term Effects of Forest Fire on Aquatic Systems

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

The initial changes in aquatic systems caused directly by forest fire tend to ripple through time. Direct effects of fire on soils and vegetation, for example, can influence the quantity and quality of water in these systems long after the flames have passed. These changes, in turn, influence the type and number of insects, amphibians, and fish that affected watercourses and water bodies can support in the years that follow fire.

The ripple effects caused by forest fire are far more complicated and unpredictable than the direct effects from heating. Simple differences in post-fire rainfall and snowmelt patterns, for example, can impart considerable variation in the short-term effects of similar burns on similar aquatic systems within the region (Minshall et al. 2001a). Other sources of variation in the short-term effects of fire on aquatic systems include burn size and severity, size and gradient of the affected system, forest type, geology, and topography (Minshall 2003). With an eye toward these and other contingencies, in the following sections we describe a number of ways in which changes initiated by fire can possibly reverberate through aquatic systems in the first 10 years after burning. Possible longer-term influences are discussed in long-term aquatic effects.

WATER TEMPERATURE

By killing or consuming vegetation next to streams and ponds and diminishing the shade it provides, forest fire can have strong and lingering influences on water temperatures (Gresswell 1999, Pilliod et al. 2003). Dramatic effects should be detectable only after fires of mixed or high severity in forest vegetation and will diminish as plant cover increases in the years that follow.

The exact magnitude of any increase in stream temperature caused by loss of forest cover will depend on pre-fire tree density, fire severity, the volume of water affected, and the degree of mixing with unheated waters. Stand-replacement fires in densely forested areas should have a much greater effect on stream temperatures than fires that burn through relatively open forest. Shallow ponds and small, headwater streams are prone to the most extreme heating. Near complete loss of shading from vegetation along small forest streams has been reported to raise average maximum water temperatures by 18°F, with 70°-maxima possible in mid-summer (Brown and Krygier 1970, Helvey et al. 1976). Such effects, however great, should dissipate as water from headwater streams flows into and mixes with cooler waters downstream (Gresswell 1999).

FLOW VOLUME

Increased water yield from recently burned forests invariably leads to elevated water levels within associated catchments and drainages (Benda et al. 2003). All else equal, a high-severity burn in steep forest should effect the greatest increase in water yield. Extreme discharges from small, or low-order, drainages in these areas can lead to flash floods in main channels below (Meyer and Pierce 2003). Low-severity fires on level soil should effect only trivial increases in water yield, if any.

Actual fire-caused changes in streamflow volume in the Northern Rockies have seldom been quantified. Data from the Pacific Northwest and Yellowstone National Park suggest that, while annual peakflows may rise by 50%, the total annual flow volume of large drainages within severely burned watersheds may seldom increase by more than 10% (Anderson et al. 1976, McIntyre and Minshall 1996). Nonetheless, these increases mean that streams can be become more powerful after burning, and greater so with increasing percentage of the watershed burned (Legleiter et al. 2003). Powerful flows can reconfigure affected channels by scouring and widening reaches (Legleiter et al. 2003).

A severe burn can also change the timing of annual high-volume runoff events. Spring thaw and associated peak flows, for instance, are likely to occur much earlier in forests effectively denuded by fire than in unburned stands (Tiedemann et al. 1979). Prior to the Sundance Fire, which severely burned 26% of the Pack River watershed in the Kaniksu National Forest, Idaho, spring thaws and peak runoff from snowmelt invariably occurred in June. In each of the fifteen years that followed, thaws and peak runoff events occurred in March.

INPUTS OF SEDIMENT AND ORGANIC DEBRIS

Much of the ash, soil, and organic debris washed from forests after fire winds up in nearby catchments and drainages. Once incorporated in aquatic systems, the small, inorganic materials are considered sediment (Everest et al. 1987). If smaller than a quarter of an inch in diameter, these inorganic materials are classified as *fine sediment* (Chapman 1988). Typical organic inputs, on the other hand, include leaf litter and woody debris. These materials may range in size from tiny particles to whole trees and are usually charred to varying degrees.

The amount of sediment in a given volume of water is known as the sediment load. Both the sediment load and the concentration of small-sized, or particulate, organic matter accounts for the turbidity, or cloudiness, of the water (Beschta 1990, Minshall et al. 1990, Beaty 1994). High turbidity impedes light penetration, which in turn affects water temperature and plant productivity. High concentrations of particulates and sediments can also suffocate aquatic organisms. For these reasons, turbidity, like temperature and chemistry, is an important component of water quality.

The quality and quantity of post-fire inputs of sediment and organic debris depend on soil type, fire size and severity, the slope of the affected area, and post-fire precipitation patterns (Dwire and Kauffman 2003, Meyer and Pierce 2003). Inputs of ash and charcoal tend to increase with heightened fire severity in vegetation and soils (Minshall et al. 2001a). In general, inputs will be greatest during heavy rainfall and snowmelt events soon after large, stand-replacing fires on steep slopes (Noble and Lundeen 1971, Potts et al. 1985, Minshall et al. 2001a, Meyer and Pierce 2003). Large, woody debris can also be transported into catchments and drainages from affected slopes and streambanks by the sheer force of gravity. During heavy storms and peak flows, materials sloughed from hillslopes and scoured from stream channels can be carried miles from their origins.

Runoff-initiated erosion events tend peak during the first year after forest fire. Sediment pulses generally wane faster in larger streams than smaller ones, with elevated sediment yields seldom persisting longer than 5 years in any case (Legleiter et al. 2003). During that period, affected drainages may produce visibly turbid water during each heavy storm or snowmelt event (USFS 1999).

Landslides, however, are apt to occur 4-10 years after a severe fire (Wondzell and King 2003, Meyer and Pierce 2003). The lag is largely due to the relatively slow decay of roots of fire-killed trees and shrubs. Once these anchors are lost, the soil is more likely to slough from steep slopes when saturated with rainfall or snowmelt (Meyer and Pierce 2003). Slopes steeper than 27°, or 50% grade, are especially prone to landslides (Miller et al. 2003).

However far they are moved, most materials transported into watercourses after fire will be deposited such that they can affect the subsequent flow of water and materials through the affected reaches (Dwire and Kauffman 2003, Benda et al. 2003). Large woody debris, for example, can trap other bulky waterborne materials (also known as *bedload*) and constrict stream reaches. In doing so, these materials can temper the erosive influences of heightened water yield on stream channels.

Massive post-fire sediment deposition can also change the flow of water through forested systems. Such deposition often takes the form of an alluvial fan at the confluence of a steep tributary and a higher-order channel (Benda et al. 2003, Meyer and Pierce 2003). Less-pronounced elevation of channel beds or floodplains due to sediment deposition, a process also known as aggradation, is also common after severe fire (May et al. 2002, Benda et al. 2003, Legleiter et al. 2003).

Post-fire deposits of sediment and organic debris tend to be "reworked" by repeated heavy flows that occur shortly after burning (May et al. 2002). In other words, a given fire will often effect a series of channel-bed adjustments, not just a one-time change. Where channel gradients remain reduced via persistent aggradation or the persistence of alluvial fans, however, the retention of sediment and organic debris will likely increase with time since fire. Benda and others (2003), for example, noted increased sediment storage over thousands of meters upstream of alluvial fans that formed in third-order and larger channels within the Boise River basin one year after the stand-replacing Rabbit Creek Fire.

By-products of the deposition reported by Benda and others (2003) included side channels and pools, which are important refugia for many aquatic invertebrates, amphibians, and fish (Benda et al. 2003). The input and retention of large woody debris into stream channels after fire is especially important for pool formation and persistence (Benda et al. 2003). Other possible by-products of fire-caused changes in the transport and storage of sediment and debris are gullies, terraces, floodplains, and boulder deposits. All of which are "habitats not formed during more quiescent times" (Benda et al. 2003).

WATER CHEMISTRY

The nutrient content and alkalinity of water in catchments and drainages may increase periodically during the first several years that follow intense or severe forest fire in the Northern Rockies. These pulses are due largely to increased sedimentation and post-fire leaching and therefore tend to coincide with heavy rainfall or snowmelt events (Beschta 1990, Minshall et al. 2001a, Spencer and Hauer 2003).

Total inputs of a variety of nutrients, including inorganic forms of nitrogen, phosphorus, potassium, calcium, magnesium, and sodium, have been found to increase after certain forest fires (Tiedemann et al. 1979). Increased water volumes invariably dilute these inputs such that only marked nutrient additions reliably translate into increased nutrient concentrations in affected watercourses and water bodies (Tiedemann et al. 1979, Beschta 1990). Post-fire influxes of potassium, calcium, magnesium, and sodium are seldom sufficient to raise the concentrations of these cations in aquatic systems. Nitrogen and phosphorus inputs, on the other hand, are often large enough to raise the concentrations of these nutrients in affected waters.

The nitrate form of inorganic nitrogen is the most mobile in soil-water systems. It readily leaches through forest soil and into catchments and drainages. It is the form that reliably increases in aquatic systems after heavy runoff events that follow forest fire. Nitrate concentrations in undisturbed forest streams seldom exceed 1 mg/L (Tiedemann et al. 1979). Levels have risen an order of magnitude in the years following slash fires in northern Idaho forests (Snyder et al. 1975). In the five years following the 1988 Red Bench Fire, which severely burned thousands of acres of mixed conifer forest in Glacier National Park, Hauer and Spencer (1998) documented pulses of dissolved nitrate exceeding five times the baseline level in third-order streams.

Inorganic phosphorus readily binds to organic compounds or other chemical elements in the soil. It may wind up in aquatic systems by adhering to materials that wash from burned forest. Alternately, it can be leached from soil that has lost much organic matter to fire. Once in the water system, plant-available phosphorus is called soluble reactive phosphorus. In their study of third-order streams affected by the Red Bench Fire, Hauer and Spencer (1998) noted fivefold increases in concentrations of soluble reactive phosphorus that waned during the early years after burning in steep terrain. In more level terrain, lesser influxes of soluble reactive phosphorus were evident for 3 to 5 years after burning (Hauer and Spencer 1998).

Elevated nitrogen and phosphorus concentrations in aquatic systems tend to enhance the growth of aquatic plants and microbes (Kiffney and Richardson 2001). These effects are exacerbated by any increase in water temperature and sunlight levels that may follow forest fire (Spencer and Hauer 2003). Populations of algae, for example, are readily stimulated by these conditions.

Algae are single-celled plants known as *periphyton* when attached to rocks, logs, and other submerged objects or as *phytoplankton* when suspended or floating in water. They form the base of the aquatic food chain and are therefore indispensable to other forms of life in these systems. Given ample sunlight and nutrients, however, populations of these little plants can "bloom" to extraordinary sizes. Excessive algal growth can be harmful to other aquatic organisms, as the mass of plants depletes the supply of dissolved oxygen through respiration and decay.

Simply by reducing shade from forest vegetation, a severe fire can stimulate algal growth, but seldom to problem levels. Extraordinary algal blooms in post-fire forests are most likely to occur in drainages and catchments of low physical disturbance that have been cleared of most vegetation and effectively fertilized with nitrogen and phosphorus. Indeed, Spencer and Hauer (2003) found puddles, ponds, and rivulets bright green with dense algae blooms immediately after snowmelt in the first spring following the stand-replacing Red Bench fire of September 1988.They had not witnessed comparable blooms in their several decades of work in Glacier National Park, nor did they witness any in subsequent years.

Even without algal blooms, dissolved oxygen levels may still drop in recently burned catchments and drainages due to water heating. Cold water holds more oxygen than warm water. As water temperature rises, dissolved oxygen necessarily decreases. Optimum dissolved oxygen levels in the cold-water fisheries of the Northern Rockies are between 8 and 13 mg/L. The combined influences of moderate water heating and algal growth in the several years following forest fire could result in suboptimal dissolved oxygen levels within certain aquatic systems. However, this suite of fire effects has not, to our knowledge, been documented in the field.

All else equal, the magnitude and persistence of fire-caused changes in water chemistry should increase with increasing fire severity and decrease with stream or pool size. Generally, as vegetation redevelops, fewer nutrients will be available for leaching, the erosion potential will diminish, and nutrient concentrations in affected waters will return to pre-fire levels (Gresswell 1999).

INVERTEBRATES

As a whole, aquatic invertebrates are sure to respond to any dramatic fire-caused changes in food availability or physical condition of watercourses and water bodies that take place in the decade after burning. Marked die-offs or out-migrations, however rare, are most likely to occur in the first year after fire, when water quality is apt to be poorest (Minshall 2003). Most first-year changes appear to be caused by physical changes in streams, such as major channel cutting and sediment scouring, resulting from enhanced spring snowmelt runoff or summer precipitation, rather than from chemical or thermal changes (Minshall et al. 2001a,b). The heavy sediment inputs that can follow severe fire, for example, can depress numbers of aquatic insects in burned areas to levels akin to those in polluted streams (Minshall et al. 2001a).

Different groups of invertebrates, however, vary in their sensitivities to fire-caused changes in aquatic systems. Both generalist insects (which can live under a range of physical conditions and eat a wide range of foods) and mobile insects (which can readily flee intolerable conditions) tend to be least affected by burning (Minshall 2003). A number of mayflies and stoneflies fit this bill (Minshall 2003). Some specialist invertebrates can likewise withstand burning and may even thrive in the first 4-5 years after a severe forest fire. These include the few invertebrates that can eat charred materials, the shredders and scrapers that feed on algae and mosses, and the miners (e.g., midges) and filter feeders that can subsist on fine sediments (Mihuc and Minshall 1995, Kiffney and Richardson 2001, Minshall et al. 2001a,b). In contrast, invertebrates with mouthparts specialized to ingest loose organic matter and those that require stable riffles or relatively slow-moving streams often decrease in abundance after severe fire, only to rebound with the redevelopment of forest vegetation (Gresswell 1999, Minshall et al. 2001b).

In sum, the abundance of aquatic invertebrates is likely to differ little from that in unburned streams shortly after forest fire. A severe fire that causes substantial changes in water quality, quantity, or both, however, may effect a short-term die-off or out-migration of these important animals and change the composition of the invertebrate community considerably (Jones et al. 1993). We have noted some potential changes above. However, with regard to the precise nature of community change after any given fire, Minshall (2003) cautions:

Strict adherence to a patterned sequence of feeding group replacements generally has not been observed because physical factors, particularly turbidity, sedimentation, and scouring, have an overriding influence on invertebrate occurrence, and furthermore, most stream invertebrates are not narrow food specialists.

AMPHIBIANS

Amphibians spend part of their lives in water and part on land and are notoriously sensitive to changes in either type of environment (Maxell 2000). Their extraordinary sensitivity is due in large part to their highly permeable skin, which readily "breathes" in any toxins they contact.

While on land, amphibians must keep their breathable skin moist and are therefore usually found in humid environments not far from watercourses or water bodies. Individuals are generally faithful to certain breeding, feeding, and wintering locations and rely on particular migratory corridors when they must travel from one place to another. By changing the availability of areas suitable for these critical activities, fire can affect amphibian populations for years after the flames have passed.

There have been only a handful of studies of fire's effects on amphibians in the Northern Rockies (Bury et al. 2002, Pilliod et al. 2003). This limited research suggests that: (1) from an amphibian's perspective, forest fire can cause both good and bad changes in the environment, (2) a change that is good for one species may be bad for another, and (3) the more severe the fire's effects on forest vegetation and soil, the more dramatic and lasting these changes are likely to be. In other words, fire's indirect effects on amphibians are highly varied.

In this section, we consider the ways in which fire can possibly affect amphibians of Northern Rocky Mountain forests in the short term and review findings from case studies conducted within this region.

Amphibians of the Northern Rockies generally require: (1) relatively warm pools with large woody debris or plants that rise above the water's surface for breeding, (2) plenty of algae or insects for feeding, and (3) burrows, leaf litter, or freeze-resistant waters in which to spend the winter (Maxell 2000). If any of these resources are widely spaced across the landscape, the animals must have safe migratory passages to complete their life cycles.

A fire that increases surface-water flows can create new pools and destroy others. Moreover, changes in water quantity and quality can improve existing pools and streams while degrading others. Elevated levels of fine sediments, for example, can be detrimental to amphibians like tailed frogs and giant salamanders, which lay eggs, feed, and hide in the spaces between rocks in streambeds (Bury et al.

2002, Pilliod et al. 2003). Increased sedimentation rates after fire can also lessen reproductive success of other species, if inputs are timed such that they smother eggs. On the other hand, species like long-toed salamanders that rely on water plants or large woody debris to lay eggs, feed, or hide, can be favored by the opening of the forest canopy and increased deadfall and debris flows that generally follow more severe burns.

Changes in water temperature that stem from burning can also affect forest amphibians in positive and negative ways. High water temperatures (e.g., >60°F) can stress or kill individuals of species like tailed frogs that thrive in relatively cold streams and ponds (Bury et al. 2002, Pilliod et al. 2003). Slight increases in average water temperature, however, can speed larval growth in a range of amphibians (Harkey and Semlitsch 1988, Marian and Pandian 1985). Fast growth tends to lessen the chance of being eaten and the chance that breeding pools will dry up before the tadpoles or larvae have morphed into their adult forms (Skelly 1995). Modest temperature changes can be mixed blessings, though: if breeding pools are warmer after fire because they are less shaded, they are also exposed to greater ultraviolet radiation, which can kill or cause defects in young amphibians (Anzalone et al. 1998).

Fire-caused changes in water chemistry can be mixed blessings as well. High concentrations of nitrate-nitrogen in water (e.g., >2.5 mg/L), for example, can stress or kill amphibians (Rouse et al. 1999). Fires that effect heavy flushes of this nutrient or other chemicals could render watercourses and water bodies uninhabitable for years after fire. On the other hand, nutrient inputs can stimulate production of the algae and insects upon which amphibians feed (Kiffney and Richardson 2001). In doing so, non-lethal nutrient influxes after fire could benefit the frogs, toads, and salamanders of Rocky Mountain forests (Pilliod et al. 2003).

The land-dwelling forms of forest amphibians are also affected by fire-caused changes in forest vegetation and soil. Patches of severely burned forest are apt to be hot, dry, and largely devoid of the safe havens beneath downed wood and leaf litter that these animals depend on not only in the heat of summer but also during the winter cold. Without such shelter, land-dwelling amphibians are more likely to fall victim to the weather and predators as they feed, hibernate, and travel between their wintering and breeding grounds (Naughton et al. 2000, Pilliod et al. 2003). These adverse effects should wane as forest vegetation re-develops and litter and woody debris re-accumulate in the years after burning.

In sum, the frogs, toads, and salamanders of northern Rocky Mountain forests can be indirectly affected by fire in a multitude of ways. Actual responses, however, have been documented only rarely.

In the summer of 2001, David Pilliod and Steve Corn compared numbers of Rocky Mountain tailed frogs in streams running through forest severely burned by the Diamond Peak Fire of 2000 in the Frank Church-River of No Return Wilderness, Idaho, to those in comparable streams within nearby unburned forest. Streams in burned forest were less shaded, had higher daily maximum and lower daily minimum water temperatures, greater nutrient loads, and more fine sediment, and supported fewer tailed frogs than streams in the unburned reference areas (Pilliod and Corn 2003). Similar data from the Bitterroot Valley, Montana, after the fires of 2000 likewise indicate lower numbers of tailed frogs in burned versus unburned watersheds, apparently attributable to "low reproductive success during the year of the fire" (Pilliod and Corn 2002).

In a subsequent and rather serendipitous study, Steve Corn and his colleagues observed essentially the opposite response from boreal toads. This time Corn's team had data on toad populations for two years leading up to the stand-replacing Moose Fire in Glacier National Park, which burned a swath of their study area in summer of 2001. A year later, the researchers found boreal toads breeding in seven ponds within the burned forest that had not supported breeding toads in the previous years of study. They also found boreal toads breeding in three additional ponds that had been dry before the fire (Pilliod et al. 2003).

Corn discussed the boreal-toad study in a Missoulian interview (Jamison 2002):
Having the old data to compare to was critical... Unless you just happen to be studying an area before it burned, you'd have no way of knowing whether the toads had been there all along or whether they had

just moved in.

....One of the interesting things that showed up right away was the arrival of the toads. We were surprised by the magnitude of the invasion.

Corn attributed the "invasion" of severely burned forest to the boreal toad's preference for warm, unshaded pools: "They like to soak up the sun, like to bask in it. They like open areas with lots of light. A dense lodgepole forest is just not very good toad habitat" (Jamison 2002).

In a July 2003 interview that aired on the radio program, Living on Earth (available online), Corn further explained the boreal toad's affinity for warm pools:

The length of time [boreal toads] spend as eggs and tadpoles is hugely dependent on water temperature. The boreal toads lay their eggs in the shallowest water they can find, typically. The warmer they are, the faster they develop. And the sooner they get out, the better they are able to survive the winter, because if they can put on a little weight, they'll likely survive a little better over winter.

FISH

Fish, too, are sensitive to the lingering effects of forest fires. Elevated water temperatures, for example, can stress or kill cold-loving fishes like our native trout and salmon (Rieman and Chandler 1999, Sauter et al. 2001), while heavy nutrient and sediment inputs can be toxic to all (Minshall et al. 1989). In the face of such changes, the fish are apt to seek refuge in unaffected waters, leaving burned areas poorly stocked until conditions become favorable once again (Minshall et al. 1989, Riemann and Clayton 1997, Gresswell 1999). Fish isolated from safe havens due to the extent of the burn or the lack of connectivity between affected and unaffected waters, however, must suffer any ill effects of burning on their habitat. Thus, the short-term effects of fire on fish populations are a function of both the degree and duration of fire-caused changes in water quality and quantity as well as the proportion of each inhabited stream network affected by burning. All else equal, an isolated, or fragmented, fish population will recover far more slowly from any adverse effects of burning than will a population inhabiting a widespread and well-connected stream system.

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