Effects of High and Low Severity fire on Aquatic Ecosystems

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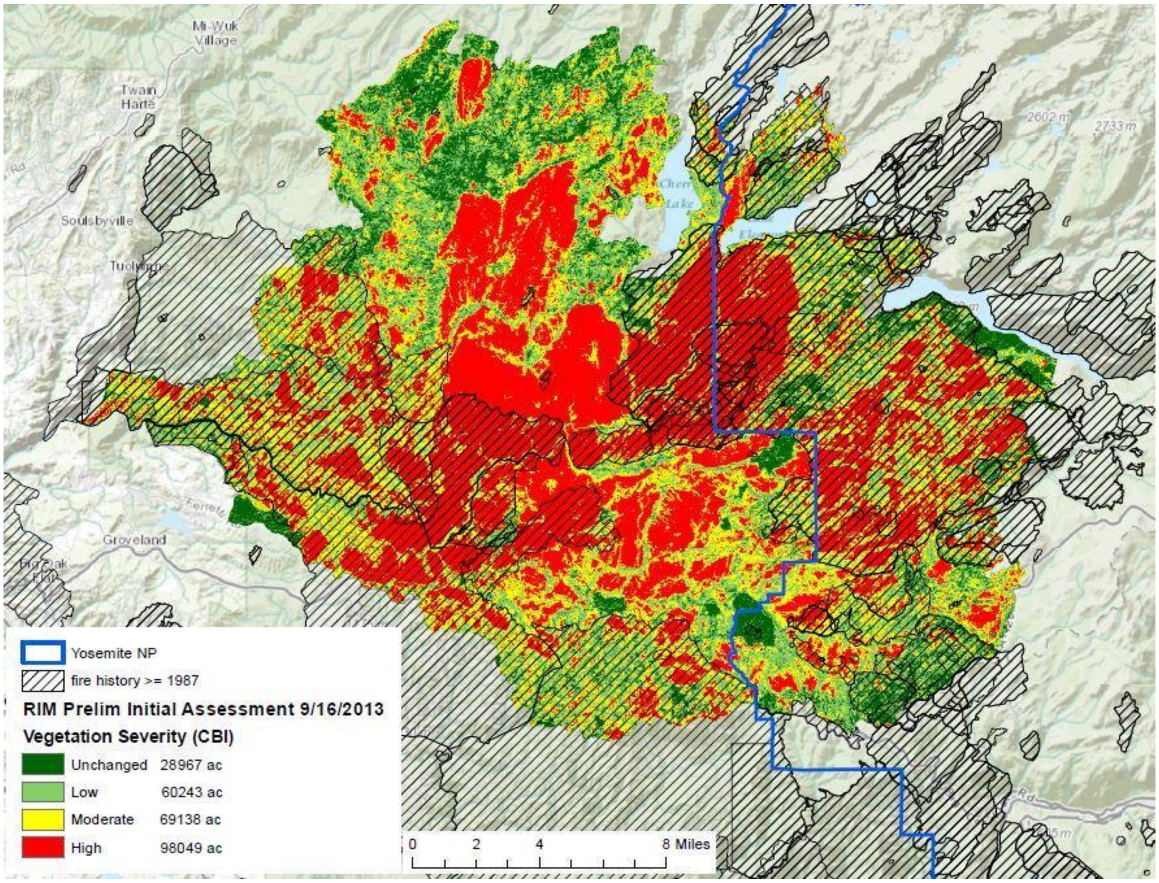
Introduction

Following a massive fire in Idaho, Montana and Washington in 1910, the USFS lobbied for more strict forest management policies, which included the suppression of all wildfires, no matter the severity (Agee and Skinner 2005). Low severity fires are defined as those in which fire dominates the understory, and less than 20% of the over-story trees are burned to mortality (Perry, Hessburg et al. 2011). Low severity fires essentially reduce the amount of “ladder fuels” that, if left unmanaged, allow fire to climb to the tree crown. High severity fires are defined as those where 70% or more of the over-story trees are burned to mortality (Perry, Hessburg et al. 2011). The dendrochronological record is able to show the historical record of Sierra Nevada wildfires. Burn scars on trees in three locations within the Sierras indicate that the historical mean fire return interval was about 17 years (Van de Water and North 2010). However, due to the United States’ 100-year fire suppression policy, there has been an increase in high severity wildfire in the Sierra Nevadas (Agee and Skinner 2005). In 2007 the high-severity Angora fire burned 254 homes and 1243 hectares of Jeffrey pine and other mixed conifers in the Lake Tahoe basin due to heavy understory fuel (Safford, Schmidt et al. 2009). In 2013, the Rim Fire in Yosemite National Park was the largest fire on record in the Sierra Nevada and burned 101,131 hectares. Lydersen et al. (2014) showed land that had already burned within the last 14 years (close to the historical burn return interval) burned at low severity during the Rim Fire (Lydersen, North et al. 2014). Wildfire is a natural process and low severity burns are important to ecosystem function; however, high severity burns can have undesirable effects on aquatic and riparian ecosystems.



2013 Rim Fire severity map from http://inciweb.nwcg.gov

Physical Effects

Forest fires affect terrestrial animals and vegetation by destroying habitat and altering the trophic cascade, but their impact on soils and geomorphic processes are less evident. Fires have been shown to have varying effects on how water moves through the watershed, how much sediment is supplied and transported, and how nutrients are cycled. The impact on these physical parameters is directly related to the fire’s severity. The severity of a fire is composed of two variables: fire intensity and fire duration, which are affected by the fuel availability and moisture content, topography, and climate (Sugihara

2006). The heating that occurs during a fire has immediate and long-term effects on soil properties, mainly its structure, hydrophobicity, and nutrient content, all of which affect the health of the watershed as whole (DeBano 2000).

Soil structure is a critical component of ecosystem health. The upper layers often consist of partially degraded organic material and mineral particulates, which naturally form pockets of open space. These spaces allow water to percolate down through the soil, which can then be used by plants or stored in water tables that feed nearby rivers (Childs, Shade et al. 1989). As fires burn, they either combust or volatilize the organic matter, causing the pores to collapse, resulting in soils that have poor water storage capabilities, and therefore have higher run-off than more porous soils. Increased run-off can then lead to increased rates of erosion. Compounding this problem, the removal of detritus and aboveground cover by fire causes the soil surface to be exposed to the impact of raindrops, causing additional compaction of soils (Neary, Klopatek et al. 1999). Surface erosion can drastically alter hydrologic processes in the watershed by causing higher flood peaks, increased sediment loads and increased large woody debris (LWD). After a series of intense fires in Yellowstone National Park, Mishall et al (1997) found that small streams in burned watersheds had a larger post-fire annual discharge, and subsequently had greater alterations in channel area, width/depth ratio, and increases in LWD compared to unburned watersheds. Aside from soil structure, fires can also disrupt nutrient cycling within both the aquatic and terrestrial environments (Sugihara 2006).

Nutrients can be removed from the soil by erosion, volatilization, and transportation by smoke columns or wind. The amount of carbon and nitrogen lost to volatilization is different for low versus high severity fires (Neary, Klopatek et al. 1999).

At high temperatures, much of the organic nitrogen that remains is converted to inorganic forms like ammonia and nitrate, which are leached into the ground water where they can end up in streams (Weston and Attiwill 1996). Multiple studies have observed transient pulses in ammonia and nitrate concentrations in burnt watersheds following the first post-fire precipitation event (Minshall, Robinson et al. 1997; Bêche, Stephens et al. 2005). Nitrates and phosphates are just some of the nutrients that can also be returned to the soil or transported to streams as ash carried by convection columns (smoke) and winds (Certini 2005). All of these processes have the potential to export nutrients from the burn site to nearby rivers and streams where they can alter the productivity of ecological communities.

Biological Effects

Fires occurring in riparian landscapes, such as the Angora and Rim fires, trigger critical effects in the biological aquatic communities as well as the physical landscape, and as these fires range in severity so do their effects. While low severity fires have been shown to “renew and rejuvenate,” high severity fires can “truncate or retard,” (Sugihara 2006). Oliver, Bogan et al. (2012) used a reference point to assess the changes that occurred in the years post fire in Angora Creek. They found that there was a decrease in overall abundance of shredders and scrapers, while there was an increase in the abundance of collectors due to the increased sediment load in the river (Oliver, Bogan et al. 2012). Furthermore, aquatic macro-invertebrate populations in the creek experienced a decrease in species richness, EPT richness, density, and percent of sensitive taxa (Oliver, Bogan, et al. 2012). They attributed these declines to canopy loss and the subsequent increase in solar radiation, changes in vegetation inside and outside of the stream, increases in sediment load, and a dramatic increase in in-stream temperature. Using the Eastern sierra-index of biological integrity (ES-IBI)—a tool used to assess the health of a stream—they found that Angora Creek fell from a “very good” state with a score of 89.5 to just a “good” state with a score of 67.5 in the first year after the fire, and to a “poor” state with a score of 50.6 in the second year (Oliver, Bogan et al. 2012). This illustrates that high severity fires have major effects on aquatic macro-invertebrate assemblages within a watershed.

Fires induce more variable responses in fish populations than in invertebrate populations. Dunham et al. (2003), suggest that fish with narrow habitat requirements and fragmented populations are at a high risk of long-term extirpation. This phenomenon was observed in New Mexico where a fire extirpated a Gila trout population from its native range. Conversely, fish that have a less stringent habitat requirements and a more dynamic--existing in a greater number of interconnected areas--population are more resilient to recovery. In Idaho, a fire extirpated a bull trout population from its local habitat; however, it was recolonized within a year due to the connectivity of the populations across the entire watershed (Dunham, Young et al. 2003). Evidence suggests that a fish population’s recovery is due in part to life history strategies and timing of fires. Novak et al. (1989) found that one year after a fire, rainbow trout, which are spring spawners, recovered rapidly while brown trout, fall spawners, had a much longer recovery due to reduced fall flows and habitat modifications (in the form of dams, which act as connectivity barriers) by beavers.

Fires can also mitigate or exacerbate non-native fish invasions (Dunham, Young et al. 2003). Many native, anadromous fish species in the Sierras have a biphasic life cycle which allows them to quickly recover from small perturbations such as low severity fires that cause temporary physical changes to the associated streams. These changes negatively impact all the fish in the stream; however, the native, anadromous fish with a biphasic life cycle will recolonize the following year while the non-natives may be extirpated (Dunham, Young et al. 2003). High severity fires create long-term impacts on a watershed that make it hard for native fish species to recolonize, leaving other, more tolerant species to exploit the area (Dunham, Young et al. 2003).

Discussion

The Tuolumne River passes through the burn area of the Rim Fire that occurred in 2013. Two years after the fire, we can expect to see the aquatic ecosystem still responding to fire effects. Increases in sediment, LWD and changes in aquatic invertebrate assemblages may be evident. Fish assemblages may also have changed in response to fire, possibly favoring invasives such as bass and sunfish. Aside from a just a few moderate winter storms, drought conditions in 2014 and 2015 have reduced run-off, resulting in decreased erosion and nutrient transport into the Tuolumne. It’s likely that the small amount of precipitation in winter of 2015 could be allowing new vegetation to root, possibly curbing some of the more severe erosion in burn areas. Overall, the Tuolumne river ecosystem will continue to change over time in response to the Rim Fire.

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