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Wildfire impacts on aquatic ecosystems

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Abstract: Wildfires are relatively common in many biomes, often being an important vector in forest structuring. Large areas of forest are burned each year, at times causing severe social and economic impacts. Generally, the impacts of wildfires on terrestrial ecosystems are well known, but less information is available concerning the impacts on aquatic ecosystems. The vulnerability of trees as well as forest succession after wildfire can influence response and recovery of aquatic ecosystems to wildfire. Terrestrial inputs into aquatic systems following wildfire can add nutrients and fine sediments with both positive and negative impacts on aquatic communities. Long-term effects can occur when large woody debris are deposited in rivers, causing morphological modifications of rivers with various effects on aquatic communities. The recovery of aquatic ecosystems after wildfire is often associated with the recovery of adjacent landscapes. Mediterranean rivers, typically experiencing major fluctuations in water availability and temperature, tend to show faster recovery rates than rivers from other biomes that have less environmental variation in flow and temperature.

Keywords: wildfires, forest, basin management, lotic ecosystems, habitat morphology, aquatic communities, Mediterranean rivers

1. Introduction

Wildfires, common in forests of many biomes, can result from natural causes, like lightning storms during summer in continental regions, and human causes such as the use of fire to clean fields for agricultural practices (Guyette et al., 2002). Wildfires, whose occurrence and frequency depend on forest type and climatic factors, are responsible each year for the destruction of large forested areas. Although the severe effects, mainly to the human populations, wildfires are often important in the natural successional dynamics of forests and forest ecology in general. Probably no other environmental disturbance is associated with such a dialectic contradiction between destruction and creation. A dialectic already assumed by humans by associating, at the same time, fire as propriety of the Gods as means of punishment (Silva & Rego, 2007). Rivers or streams flowing through burned areas can be influenced by wildfire even during wet periods. Following wildfire, the dynamics of water retention and runoff in terrestrial ecosystems is severely altered. Burned landscapes are unable to retain rainfall water in the upper layers of the forest, increasing the energy of erosional processes. Complete burning of vegetation produces large amounts of fine inorganic particles that once deposited on soils forms a hydrophobic surficial layer that reduces water infiltration (Scott et al., 1992). Thus, the hydrological regime of streams in those basins is often altered (Emmerich & Cox, 1984). Due to less water retention on the landscape, flood events tend to be more intense, occurring quickly and generally for a shorter period of time (Rodrigues & Brandão, 2003). The runoff from rainfall will transport fine sediments, large woody debris, nutrients and pyrogenic components to rivers, thereby influencing aquatic communities. These different inputs can have positive or negative effects on aquatic ecosystems. Consequently, it is quite complex to study the impacts of wildfires on aquatic ecosystems, often requiring an holistic approach, analyzing at the same time the instream communities, river habitat and morphology, landscape features of the drainage basin as well as the frequency and severity of wildfire. All these factors will influence the spatial and temporal scales of wildfire impacts on aquatic ecosystems. In the intermountain west, USA, large wildfires cause impacts on aquatic ecosystems that can take 5-10 years or longer to recover (Minshall et al., 2001), whereas human-controlled fires often show less impact.

In Mediterranean regions, wildfires are common and mainly occur during summer. High temperatures and low air humidity, many times associated with poor forest management, create excellent conditions for wildfires (Wondzell, 2001). These specific characteristics allow Mediterranean regions to have higher wildfire frequencies than other biomes (Chandler et al., 1983). Information concerning the impacts of wildfires on aquatic communities is scarce for Mediterranean regions (Lavabre, 1983; Vila-Escalé, 2007), although recovery rates of forests are expected to be faster and with less impact on aquatic communities than those from continental regions.

2. Frequency and ocurrence of wildfires in Portugal

Historically, wildfires have been an important ecological factor for forest establishment in Mediterranean regions. Several Mediterranean species have evolved strategies to survive wildfire, including fire resistance, seed dormancy that ends following wildfire, and pines that have cones, requirering fire to open and shed seeds (e.g. Fernandes & Rigolo, 2007).

In Portugal, having Mediterranean climatic conditions, wildfires usually occur each year, with highest frequencies during summer from July to September and mainly in central Portugal where large forest areas are found (Damasceno & Silva, 2007). Burned areas during the last decades (Fig. 1) show accentuated fluctuations in area burnt between consecutive years. There has been a general increase in burned area as well as a tendency of increasing occurrences to approximately every five years (Rodrigues & Brandão, 2003). Therefore, depending of local variables, overstory vegetation seems to have cyclic return periods and, after each growing period, an optimal of biomass fire fuel-load is attained (Wondzell, 2001). Therefore, forest vulnerability to fire is also cyclic and, during the more vulnerable periods, human activities seem responsible for most wildfires. Although a linear positive correlation was observed between fire occurrence and surrounding population density (Silva & Catry, 2006), only 30% of the fires were considered human-caused from 2001 to 2006 (Damasceno & Silva, 2007). Other major driving forces of fire occurrence increase include land abandonment and the subsequent shrub encroachment, as well as afforestation of former agricultural land, both leading to increased fuel accumulation (Viedma et al., 2006). Hence, among reasons associated with fire causes in Portugal, many are related with territorial management and planning, important socio-cultural components and forestry strategies.

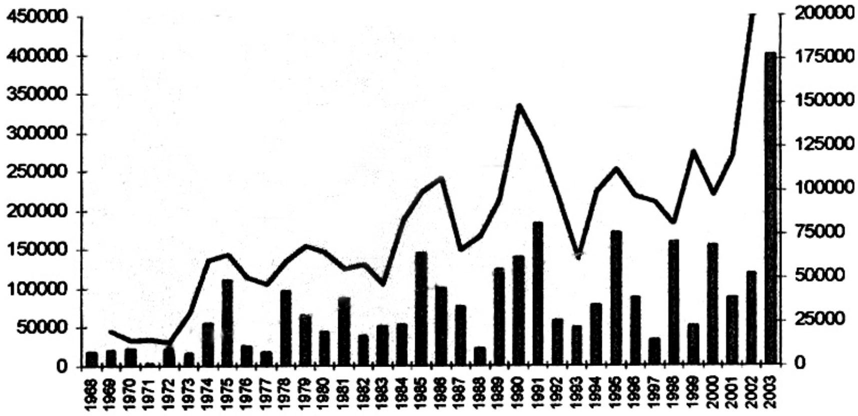

Figure 1. Areas burned (ha) in Portugal by wildfires from 1968 to 2003. Bars: raw data; solid line: transformed data by time averaging for three year periods (adapted from Rodrigues & Brandão, 2003).

3. Behavior of forests to wildfire

Each forest type has specific fire-proneness (e. g. flammability, combustibility) vulnerabilities and post-fire resilience, depending on its structure and species composition. Low density forests composed of large trees are less vulnerable as a result of the discontinuity of combustible matter from the forest floor to the tree canopy (Fernandes et al., 2006). In contrast, more dense forests composed of small trees, shrubs and with much organic matter on the forest understorey are more vulnerable to fire. Due to the continuity of combustible material in these forests, fire intensities also tend to be high. Godinho Ferreira et al. (2006) also describe a tendency of increasing wildfire probability on the bigger forest patches of the forest types that are more likely to burn in Portugal (*Pinus pinaster* forest and *Eucalyptus* sp.), while the contrary happens with other forest stands (e. g. *Quercus pyrenaica*).

Maritime pines and eucalyptus have the highest vulnerability to fire, whereas cork and holm oaks have the lowest vulnerability (see Table 1, adapted from Fernandes, 2007). Following fire, different vegetation survival and recovery rates are observed in the different forest types. While eucalyptus, being vulnerable, has high recovery rates (just after the fire small branches and leaves start growing), cork oaks, being less vulnerable, need several years to recover (Fig. 2). Maritime pines often survive fire, but without a certain amount of needles frequently die later. On another hand, post-fire logging is also a non neglectable activity in Portugal (e. g. Viegas, 1999), intending to salvage some economic value before the decay of burned trees, and also to reduce fuel-load, to prevent bark beetle pests, and to improve the landscape value of the area (e. g., McIver & Ottmar, 2007).

As a result of the relationship between natural vulnerability, recovery, and forestry post-fire management strategies, some trees survive well, while others stay in poor physiological conditions and probably die several years later (Silva et al., 2007). Standing trees, killed by wildfire, start to decompose on the next few years by the joint effects of microorganisms and moisture, then falling as large woody debris. This large woody debris, if not retained, can move further down slope, enter rivers, and be incorporated in river morphology and function for the long-term.

Table 1. Index of vulnerability to fire for different tree species (adapted from Fernandes, 2007).

Tree species	Index of Vulnerability to fire
Maritime pine	20
Eucalyptus	12
Stone pine	9
Other conifer species	8
Other broadleaved species	7
Cork oak	2
Holm oak	1

Figure 2. Different recovery rates of tree species three years after a wildfire in the south of Portugal. At the top, the higher recovery rate of eucalyptus, at the bottom, low recovery rate of cork oaks (photo P. Pinto 2006).

4. Materials exported to aquatic ecosystems after wildfire

4.1. Chemical components

Depending on temperature, large amounts of organic matter are completely or partially mineralized, providing large amounts of nutrients (phosphorous and nitrogen) and inorganic carbon that stay in the soil. During rainfall after wildfire, surface runoff occurs and these chemical compounds are exported to rivers, increasing nutrients, dissolved inorganic carbon and turbidity (Overby & Perry, 1996; Minshall et al., 2001). Under certain conditions, the partial combustion of organic matter in the presence of chlorine can produce polycyclic aromatic compounds; pyrogenic toxicants are also exported to rivers (Barber et al., 2003; Vila-Escalé, 2007).

4.2. Fine and coarse particulate organic matter

Many partially burned leaves will fall to the forest floor or stay weakly attached to tree branches. These leaves can arrive quickly to rivers, providing an extra input of coarse particulate organic matter. This input has different characteristics than the natural one: different composition because most or all volatile components were consumed by the fire, and the input period (during summer) is before the normal one in autumn.

4.3. Large woody debris

Rivers reflect the landscape through which they flow. As such, natural rivers follow a temporal succession that follows that of the surrounding landscape after wildfire. For instance, Minshall et al. (1989, 1997) suggested that streams in the intermountain west of North America show immediate, mid-term, and more long-term affects of wildfire as the forest slowly recovers over 100 plus years. Other biomes show rapid recovery of the terrestrial landscape and rivers show a more short-term impact from wildfire, e.g., eucalyptus forests in Australia have a recovery period of less than 10 years and streams seem to recover in 5 years or so. One reason for the differences in recovery is the output of large woody debris into rivers following wildfire. Trees killed by wildfire can eventually reach rivers if the landscape characteristics dictate downhill movement. In the northwest USA, this may take decades as the half life of a standing dead tree is 15 years.

5. Impacts on aquatic communities

Impacts on aquatic communities can have two principal origins: physical and chemical alterations that act directly on aquatic communities, and on habitat modifications that change the conditions for the establishment of aquatic communities. Both can have negative and positive impacts on aquatic communities.

Periphyton is directly influenced by the increase in nutrients that usually occurs following wildfire. Nutrients, mainly nitrogen and phosphorus, are well known as important factors for increasing periphyton biomass. Jointly with nutrients, an increase in inorganic matter inputs, sediments in more lentic habitats, can cover biofilm layers. A benthic biofilm layer covered by inorganic fine sediments is not optimal for periphyton, and a decrease in biomass is expected. Due to these opposite effects, it is difficult to predict the influence of wildfire on periphyton, and a global relationship seems unclear and dependent on season (Minshall et al., 2001).

Macroinvertebrates can be influenced by several factors. In a direct way after wildfire, water quality tends to decrease due to the input of chemical components and organic and inorganic particles. In this sense, it is expected to negatively influence the more sensitive taxa, affecting diversity, richness and composition. In another way, the increase in particulate organic matter as well an eventual decrease in periphyton biomass has important effects on food webs and trophic structure (Spencer et al., 2003), with an expected increase in collectors and a decrease in herbivores. An indirect influence results from habitat modifications that also can have positive and negative impacts depending on the specific taxa. Generally, the destruction of some habitats is related to an increase in more generalist taxa, whereas the creation of new habitats, mainly as a result of large woody debris deposition, can increase the abundance of more specific taxa. At a coarser temporal scale, wildfires induce modifications of the hydrological regime with more intense floods for shorter periods of time. It is expected that the higher level of perturbation will result in less stable communities. In this way, it is expected to have communities composed of early colonizers and dispersers. These impacts depend on ecological river conditions. Rivers with less variability in the hydrologic regime over the year tend to have impacts that extend for more years, up to 10 years, being much longer than those in regions with higher variability in the year. For the latter, the natural communities, being adapted to a more changing environment, tend to have shorter recovery times and, consequently, wildfire impacts are found for periods of time shorter than two years (Fig. 3).

Macrophytes can experience three different types of impacts from wildfires. The more direct one, concerning helophyte communities and riparian vegetation, is the possibility of being burned. However, this direct impact is dependent on valley form. In very flat valleys, the riparian vegetation is more exposed and can be easily burned. In contrast, in a "V" shape valley, macrophytes and riparian vegetation are difficult to burn. Under this situation, the fire burns only the top of the trees because the generated air currents tend to push the fire up. The second impact is related to the higher concentrations of nutrients with well-known effects on aquatic vegetation, both helophytes and hygrophytes. A third impact is more indirect because it can result from habitat modifications such as formation of pools and debris dams, creating new habitats to be colonized by macrophytes (Blank et al., 2003).

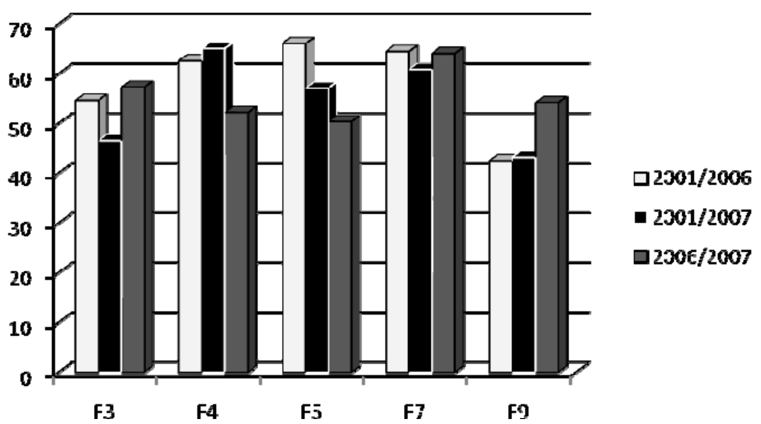

Figure 3. Coefficient of similarity obtained for macroinvertebrate communities at five sites in the south of Portugal (F3, F4, F5, F7 and F9), between pairs of dates with 2001 being before the wildfire and 2006 and 2007 after the wildfire occurred in 2003. The bars show quite similar macroinvertebrate communities before and three years after the wildfire.

Impacts to fishes are less visible because they can move along rivers, and less information is available on this topic. More long-term effects are expected as a result of the accumulation of large woody debris creating new habitats. These new habitats can be quite important as refugia for many fishes. In another way, the possible formation of debris dams can form pools and barriers that reduce longitudinal connectivity with negative impacts on migratory fishes. Lastly, wildfire can have positive and negative impacts on fishes. Due to the scarce information on this topic, it is difficult to generalize the main result of these impacts.

6. Impacts on the morphology of aquatic habitats

Hydrological regime alterations resulting from wildfire (Lavabre et a., 1993) are an important source of habitat modification, both in quantity and quality (Rinne & Neary, 1996; Howell, 2001). Large woody debris is a major structural component of many natural rivers. This large woody debris is incorporated into channels, increasing habitat heterogeneity and providing structural support (Robinson et al., 2005). Large woody debris can directly influence river morphology by being retained and causing shifts in channels. It also is a primary habitat and food resource for some aquatic organisms and refuge to others like fishes. Wildfires increase the amount of large woody debris in rivers as trees breakdown and are transported down-valley by gravity. This input may be retained in the river or transported downstream. The effects of large woody debris inputs and their transport differ by forest type and stream size, although surprisingly little information exists on this topic.

The input of large woody debris may ultimately influence the food webs of impacted rivers by altering habitat conditions and retaining fine organic particles that aquatic organisms can use as food or habitat. Incorporation of large woody debris in rivers following wildfire can alter energy flow and nutrient cycling, that is ecosystem structure and function (Mihuc, 2004). These functional changes will manifest themselves in changes in aquatic communities, changing biological traits of these communities.

7. Final remarks

Effects of wildfires on aquatic ecosystems are complex conducting simultaneously to positive and negative impacts on the different components of the ecosystems. To predict spatial and temporal magnitude of these impacts is complex because they depend from region, fire severity, forest recovery and river hydrology. Concerning Mediterranean regions, where the scarcity of water during the dry season is a key factor to the vulnerability of the aquatic ecosystems, to balance positive and negative impacts after wildfires is very important in order to implement management practices both on rivers and on burned involving drainage areas. Construction of reservoirs is a common strategy to save water to be used during the dry season. A reservoir implanted in a river affected by wildfires cuts the longitudinal gradient and sediments and organic matter, originated by wildfires, can be retained, influencing water quality and life time of the reservoir. For these reasons the study of wildfire impacts on reservoirs must be a future goal on wildfire impacts research.

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