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Research article

From leaves to landscape: A multiscale approach to assess fire hazard in wildland-urban interface areas

Luciana Ghermandi [a, *], Natacha A. Beletzky [b], Mónica I. de Torres Curth [a, c], Facundo J. Oddi [d]

[a] Laboratorio Ecotono, INIBIOMA (CONICET-UNComa), Pasaje Gutiérrez 1125, 8400 Bariloche, Prov. de Río Negro, Argentina
[b] Centro Regional Universitario Bariloche, Universidad Nacional del Comahue, Quintral 1250, 8400 Bariloche, Prov. de Río Negro, Argentina
[c] Departamento de Matemática, Centro Regional Universitario Bariloche, Universidad Nacional del Comahue, Quintral 1250, 8400 Bariloche, Prov. de Río Negro, Argentina
[d] IRNAD (UNRN, Sede Andina), Mitre 630, San Carlos de Bariloche, 8400 Río Negro, Argentina

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ABSTRACT

The overlapping zone between urbanization and wildland vegetation, known as the wildland urban interface (WUI), is often at high risk of wildfire. Human activities increase the likelihood of wildfires, which can have disastrous consequences for property and land use, and can pose a serious threat to lives. Fire hazard assessments depend strongly on the spatial scale of analysis. We assessed the fire hazard in a WUI area of a Patagonian city by working at three scales: landscape, community and species. Fire is a complex phenomenon, so we used a large number of variables that correlate *a priori* with the fire hazard. Consequently, we analyzed environmental variables together with fuel load and leaf flammability variables and integrated all the information in a fire hazard map with four fire hazard categories. The *Nothofagus dombeyi* forest had the highest fire hazard while grasslands had the lowest. Our work highlights the vulnerability of the wildland-urban interface to fire in this region and our suggested methodology could be applied in other wildland-urban interface areas. Particularly in high hazard areas, our work could help in spatial delimitation policies, urban planning and development of plans for the protection of human lives and assets.

1. Introduction

Housing development adjacent to shrublands and forests increases the fire hazard of wildland-urban interface (WUI) areas due to an increase of ignition sources (Chas-Amil et al., 2013) and due to changes in fuel structure that make houses more vulnerable to fire (e.g. wooden roofs, plantation of trees near houses) (Gill et al., 2013).

This vulnerability is an increasingly serious social problem (Bar-Massada et al., 2013; Gill et al., 2013; Prior and Eriksen, 2013). Many fire-prone regions, principally but not only those with Mediterranean climate, have suffered significant losses of lives and property in recent years due to increasing urbanization and fire frequency (Pausas et al., 2008; Veblen et al., 2008; Gill et al., 2013; Penman et al., 2013; Keeley et al., 2012). The alteration of fire regime in fire-prone systems can be a consequence of the climate change, but fire is a complex phenomenon and fire activity depends on interactions among many variables (Krawchuk et al., 2009). Even in developed countries where great social and financial effort is invested in fire control and prevention, WUI wildfires can be very destructive (Gill et al., 2013; Penman et al., 2013).

Fire hazard assessments can help to prevent and manage wildfires in WUI areas because increase awareness among the general public, policy makers and managers about the fire danger and create a framework for discussion about future urban planning (McAneney et al., 2009). These assessments usually include the estimation of dead and live fuel load, the spatial arrangement of vegetation, and the flammability of individual species (Hardy, 2005), but they should ideally include both social and ecological variables (Hardy, 2005). However, even in developed countries, social factors such as land use planning, homeowner actions and improvement in building regulations are rarely included in fire management plans (Prior and Eriksen, 2013; Syphard et al., 2013).

Flammability is a complex trait that can be defined in different

* Corresponding author.
E-mail address: lghermandi@yahoo.it (L. Ghermandi).

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ways and measured at varying spatial scales, from leaves to landscape (Pausas and Moreira, 2012). The breadth of this concept has generated linguistic uncertainty (Thompson and Calkin, 2011) based on different conceptions of flammability in fire ecology and in wildfire prevention and management. Flammability can be measured at different spatial scales, including vegetation type (e.g.: grasslands, shrublands, forests), individual plants, or components of plants (generally leaves or litter). Fuel load (live vegetation along with fallen branches and logs) and the spatial arrangement of vegetation (vertical and horizontal distribution) contribute to landscape flammability and modify the capacity of fire to spread. Little is known about flammability at leaf level because the flammability changes among species and these values are not available for all species. However, increases in foliar moisture content consistently reduce leaf flammability (Santana and Marss, 2014).

In South America, 86% of fires have anthropogenic origins (FAO, 2005). Vulnerability of WUI areas to fire is determined by climate, ecological factors and land use changes, and is influenced by the high number of human-caused ignitions (de Torres Curth et al., 2012; Curt et al., 2013). In many fire-prone areas land-use planning policies fail to consider the risk of mega-fires and people are living in dangerous locations without accurate fire protection measures (Stephens et al., 2014).

In Northwestern Patagonia, most fires reported are of unknown cause, probably because the investigation of the causes is still rare, but few fires have natural origins (de Torres Curth et al., 2012). Regardless of ignition source, fire spread and fire severity are influenced by local topography and vegetation structure. For example, fire can threaten neighbors and property if vegetation and terrain have specific characteristics. Forests with low horizontal continuity will have a low probability of fire spread; forests with high vertical continuity will have a greater chance of high intensity crown fires and fire spread more readily on steep, dry slopes (Lampin-Maillet et al., 2010).

In regions with Mediterranean climates, meteorological or climatic variables are important factors in the fire hazard assessment, because most fires occur during the warm and dry seasons (late spring, summer and early autumn) (Keeley et al., 2012). In our study area, fires normally occur from October (late spring) to March (early autumn). A previous study has shown that drought and high temperatures influence fire hazard (by drying vegetation) and fire spread (de Torres Curth et al., 2008). Further, if a wildfire develops in extreme meteorological conditions, spread is difficult to control because of high fire intensity and windblown embers that readily cross firebreaks.

Andean-Patagonian native forests are located in a region with a Mediterranean climate and frequent fires (de Torres Curth et al., 2008). The forests provide a variety of ecosystem services, including direct (wood, firewood, fruits, hunting and fishing, tourism) and indirect uses (water regulation, habitat conservation, genetic resources) (Chauchard et al., 2008).

Populations of the major cities located in or near these forests are increasing as people seek better economic opportunities or quality of life; this population growth significantly increases the anthropogenic pressure on the WUI areas. Catastrophic fires are still relatively uncommon, but the increasing probabilities of ignition (mainly due to the growing population) enhances the probability of catastrophic events (de Torres Curth et al., 2012). Several big fires have occurred in the past two decades in WUI areas of NW Patagonia cities, endangering lives and houses, and affecting extensive natural areas. For example, in January 1996 (summer in the southern hemisphere), a big wildfire that started in Catedral mountain burned 675 ha and caused the evacuation of Villa Los Coihues, a neighborhood of Bariloche. However, little research on WUI fires in the region has been conducted (de Torres Curth et al., 2012; Dondo et al., 2013; Mundo et al., 2013) and no previous research had developed a methodology to assess fire hazard.

Our study was inspired by the 2006 Villa Los Coihues neighborhood fire. Our goal was to evaluate the fire hazard of this periurban area through a protocol that could be replicated in other WUI areas of Argentina and worldwide. A careful knowledge of how local environmental and social-ecological variables influence the fire hazard in WUI areas is necessary to deal with fires and to define adequate natural resource management policies. Studies about WUI fire hazard generally do not integrate different scales of analysis, likely because this approach greatly increases study complexity. However, in this study, we included a large number of variables that we assumed *a priori* were important in fire ignition and spread. The general objective was to assess the WUI fire hazard combining three scales (landscape, community and species) in Villa Los Coihues, a WUI sector of Bariloche (Patagonia, Argentina) through the analysis of environmental variables, live and dead fuel, and leaf flammability and produce a fire hazard map that integrated all the variables.

2. Materials and methods

2.1. Study area

Bariloche is located along the southern coast of the Nahuel Huapi Lake in Patagonia, Argentina. The Nahuel Huapi National Park (700,000 ha) surrounds the 22,000-ha municipal district, creating a very long perimeter of contact (more than 40 km). In this WUI area, vegetation contacts and intermingles with housing and other infrastructure. The climate is Mediterranean with dry summers and precipitation in autumn-winter. The average annual temperature is 8 °C and annual accumulated precipitation is 1344 mm. Winds are strong and frequent with an average annual speed of 4.5 km/h with maximum average values of 64.4 km/h (DPA, 2011). Bariloche is located in a very fire-prone region (de Torres Curth et al., 2008) where fire causes have been related to social-economic problems (de Torres Curth et al., 2012; Dondo et al., 2013).

Due to the vastness of the perimeter of the municipal district, our study focused on a 378-ha portion of the WUI around Villa Los Coihues neighborhood (41° 10′- 41° 15′ S, 71°10′ - 71° 23′W, Fig. 1). This neighborhood is entirely surrounded by native and exotic vegetation. The landscape of the study area is heterogeneous and the vegetation types are related to topography and soil type. *Nothofagus dombeyi* and *Austrocedrus chilensis* forests dominate southwestern sectors whereas *Nothofagus antarctica* monospecific shrublands and *N. antarctica*, *Lomatia hirsuta* and *Schinus patagonicus* mixed shrublands share northeastern sectors. Disturbed grasslands occupy a marginal area of the landscape and exotic species like *Pinus* spp., *Pseudotsuga menziesii* and *Cytisus scoparius* occupy very degraded sites (e.g. shoulders of the main road).

In the study area, there are some scattered houses but urban pressure is increasing, including illegal settlements located in *N. dombeyi* and *A. chilensis* forests. The study area is mostly used for recreation and tourism, but also shows clear evidence of disturbance, due to illegal logging and landfills.

2.2. Methods

We performed the study at three interconnected scales: landscape, vegetation community and species (Table 1). At the landscape scale, we used Google Earth images, fieldwork and a vegetation map (Naumann and Sancholuz, 2000) to identify 11 vegetation units (VUs): *N. dombeyi* forest, *A. chilensis* forest, *N. dombeyi - A. chilensis* forest, *A. chilensis* mixed forest, *N. antarctica*