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# A territorial fire vulnerability model for Mediterranean ecosystems in South America

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ABSTRACT

A forest fire risk model was designed and applied to a South American Mediterranean ecosystem, taking into consideration three analysis groups: fire risk; danger of fire spread, or propagation; and damage potential over economic threat values. The study area for development and validation of the model was the Mediterranean zone of central Chile and employed data from historical records spanning a 14 year period (1997–2010). Territorial data layers, combined with analysis of the statistical database and wildfire simulation have enabled areas of highest vulnerability to be defined with greater precision, especially in sectors associated with the urban–wildland interface (defined as the zone where man-made structures meet wildland). Maps generated by this model have enabled improvements to be made to the traditional mapping of fires currently undertaken in South American countries. The results shown here are applicable to other Mediterranean areas, where modifications are made to the entrance variables in the risk model.



## 1. Introduction

Forest fires constitute an increasingly complex problem due to the severe social and environmental impacts they produce, more so when residential areas and sectors of the urban–wildland interface zone are compromised, through destruction of housing and the impact on inhabitants, with repercussions and disasters of an unimaginable scale. For example, in the United States, more than 900 homes on average are destroyed each year, as a result of fires in urban interface areas, according to statistics dating back to 1990 (IBHS 2004). In Chile, the problem is concentrated mainly in the municipalities of Valparaiso and Viña del Mar, situated on the coast of the V region of Chile.

This region is characterized by higher incidences of forest fires in densely populated areas and where in the last 40 years, despite the extensive efforts of state bodies responsible for protection and control, a high number of homes destroyed by fire and the subsequent damage to inhabitants, including loss of life, are noted each year. In other countries such as Australia, estimations of human loss have already risen (Ashe et al., 2007), which when added to other loss indicators make it possible to measure the size of fire disasters. In all cases where fire may break out, protection mechanisms must be given maximum priority in order to suppress damage and potential effects caused by fire spread (Rodríguez y Silva, 2009; Rodríguez y Silva and González-Cabán, 2010). With specific reference to Chile, forest fire protection has been restricted by insufficient availability of resources for fire prevention and suppression, which could be due to the lack of awareness of the actual magnitude of material damage, social and environmental impacts which arise from fire incidence. Thus the core objective of this study is to propose and apply an integrated risk model of fire vulnerability for the province of Valparaiso in central Chile, with a base criteria of risk, danger and damage potential, based on the Protection Priority method proposed by Julio (1992) and later refined in 2007, and with the help of the Kitral system forest fire simulator (Julio et al., 1997). The economic vulnerability model is associated with efficient allocation of resources for forest fire prevention and suppression through integration of risk, danger and damage potential. 'Risk' is defined as the factor which causes a forest fire, 'danger' the conflict which can extend the potential spread of fire with regard to weather conditions, topography and vegetation. 'Danger potential' reflects economic losses, both direct (tangible assets) and indirect (intangible assets) resulting from the spread of fire. In this model, only direct losses of vegetation and housing have been included, as there are complementary studies on socio-economic losses caused by intangible assets, such as human health and landscape.

## 2. Material and method

### 2.1. Study area

The area of research was 22,213 hectares which included all the Viña del Mar municipality and the north-central sector of the municipality of Valparaíso, both belonging to the province of Valparaíso in the V region of Chile (Fig. 1). The climate is characterized by the

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presence of mist which moves inland towards the hills to form a temperate zone, with temperatures ranging between 17 and 25 °C, and annual rainfall of 370 mm (DIMECHI, 2005). According to the land registry and evaluation of Chile's vegetation resources (CONAF-CONAMA-BIRF, 1999), native woodland in the municipalities of Valparaíso and Viña del Mar corresponds mainly to Mediterranean woodland, with arboreal-bush and scrub formations, and species adapted to repeated cycles of forest fire in periods of high temperatures.

The region's history of fire activity shows a high concentration of forest fires in the coastal areas of Valparaíso and Viña del Mar. Table 1 demonstrates that the annual incidence of fire was maintained in a relatively homogenous range during the period of analysis. However, a strong fluctuation in surface area affected was observed. Moreover, indicators of fire density and percentage of areas affected show the gravity levels of incidences and fire spread as compared to regional and national averages. Critical areas or zones most affected by fire tended to be concentrated in sectors with high human activity, as is typical of fires occurring in areas of urban–wildland interface (Fig. 2).

**Table 1**
Occurrence of forest fires during the period 1997–2010. The highest density of fire incidence is noted (115.78), with respect to the regional average (17.88), and national average (3.37).

| Year | Number of fires | Surface area affected (ha) | Fire density (No./year/100 km$^2$) | Surface area affected % |
|---|---|---|---|---|
| 1997 | 288 | 171 | 144.52 | 1.07 |
| 1998 | 293 | 127 | 131.90 | 1.32 |
| 1999 | 282 | 340 | 126.95 | 1.53 |
| 2000 | 303 | 94 | 136.41 | 0.42 |
| 2001 | 312 | 137 | 140.46 | 0.62 |
| 2002 | 372 | 162 | 167.47 | 0.73 |
| 2003 | 315 | 922 | 141.81 | 4.15 |
| 2004 | 202 | 1.955 | 90.94 | 8.80 |
| 2005 | 189 | 212 | 85.09 | 0.95 |
| 2006 | 251 | 251 | 113.00 | 1.13 |
| 2007 | 227 | 247 | 102.19 | 1.11 |
| 2008 | 212 | 406 | 95.44 | 1.83 |
| 2009 | 277 | 315 | 77.02 | 1.74 |
| 2010 | 301 | 381 | 67.81 | 1.18 |
| Study area average | 273.14 | 269.06 | 115.78 | 1.89 |
| Regional average | 932 | 8.911 | 17.88 | 0.53 |
| National average for Chile | 5.619 | 52.905 | 3.37 | 0.10 |

### 2.2. Development of the vulnerability model

The vulnerability model consists of three types of variables, grouped according to each of the components: risk, danger and damage potential (Fig. 3). In this diagram, the mapping process uses all infra-structure data supporting these three components. To assess risk, road networks, population centers and human activity were considered. Fuel, topography and climactic data models were used to analyze levels of danger. In order to assess damage potential, background information for urban–wildland interface areas and economic parameters with regard to commercial plantations in the area were considered. Forest fuels correspond to five large groups identified for Chile and used for the Kitral system of fire simulation: native woodland; pasture; scrubland; agricultural and forest plantations; and other terrains. Subgroups exist within each group, forming 34 types of vegetation altogether, associated with fire behavior. Kitral software has been developed in Chile and, among other tasks, considers the possibility of fire simulation using fire spread equations. Entry parameters are described in Fig. 3. Its results allow fire danger to be estimated by consideration of potential fire behavior.

An additional balanced model was created (Castillo, 1998; Julio, 1992) using the Geographical Information System (GIS) with a spatial resolution of 25 × 25 m (cell) and is necessary for a study of this type, due to admissible errors when compiling certain variables, such as ignition point (Castillo et al., 2010):

$$V_i = \sum_{i=1}^{n} X_i * P_i \quad (1)$$

where: $V_i$ is the vulnerability value for each cell; $X_i$ is each of its variables; and $P_i$ its weighting or load. Weight is defined using the background data reported in Castillo (2006), Julio (1992), and Rodríguez y Silva et al. (2010), for the area of Valparaíso through the study of

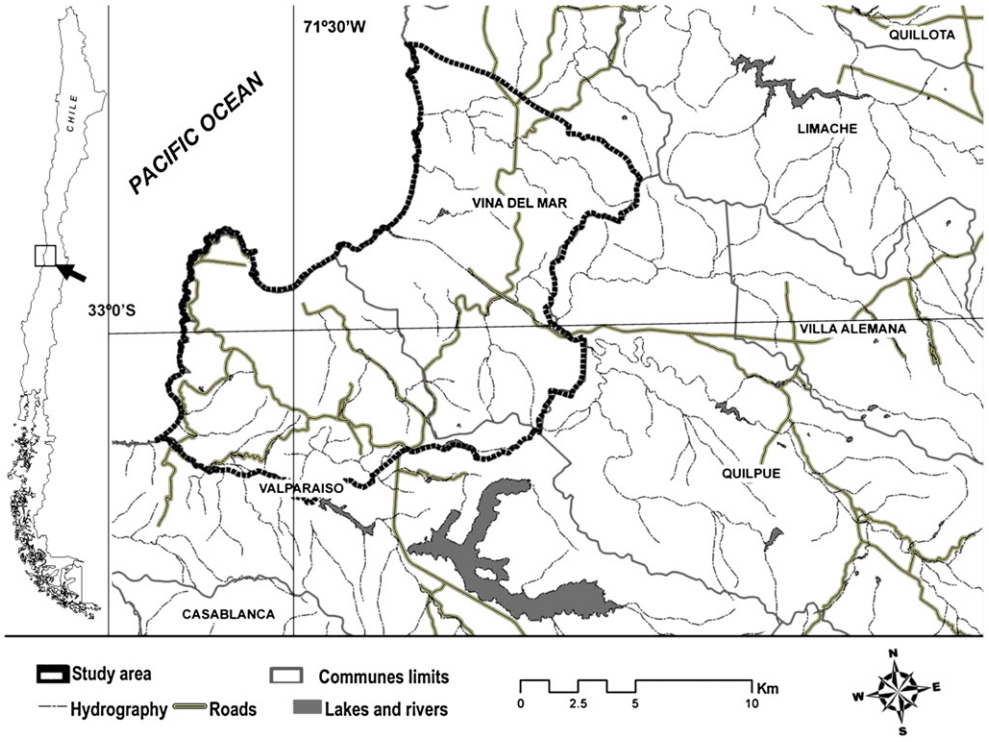


**Fig. 1.** Area of study: Central region of Chile. This is the area (22,213 ha) with the country's highest concentration of forest fires, which mainly affect areas of urban–wildland interface.