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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).

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.

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

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):

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

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

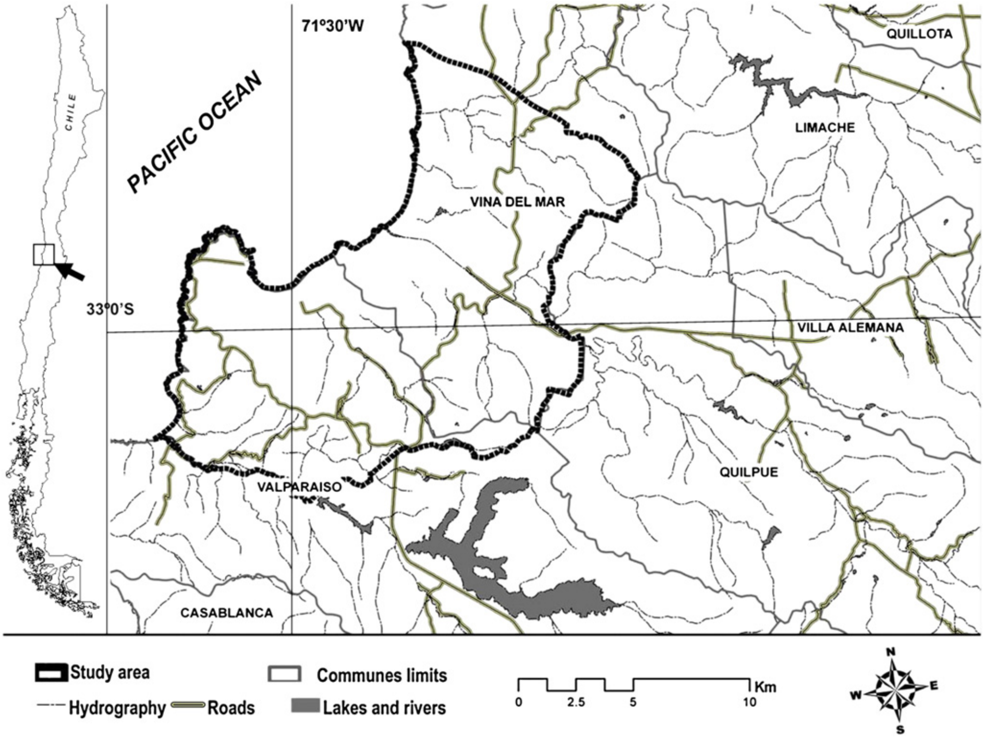

Fig. 1. Area of study: Central region of Chile. This is the area (22,213 ha) with the country's highest concentration of forest fires, which mainly affect areas of urban–wildland interface.

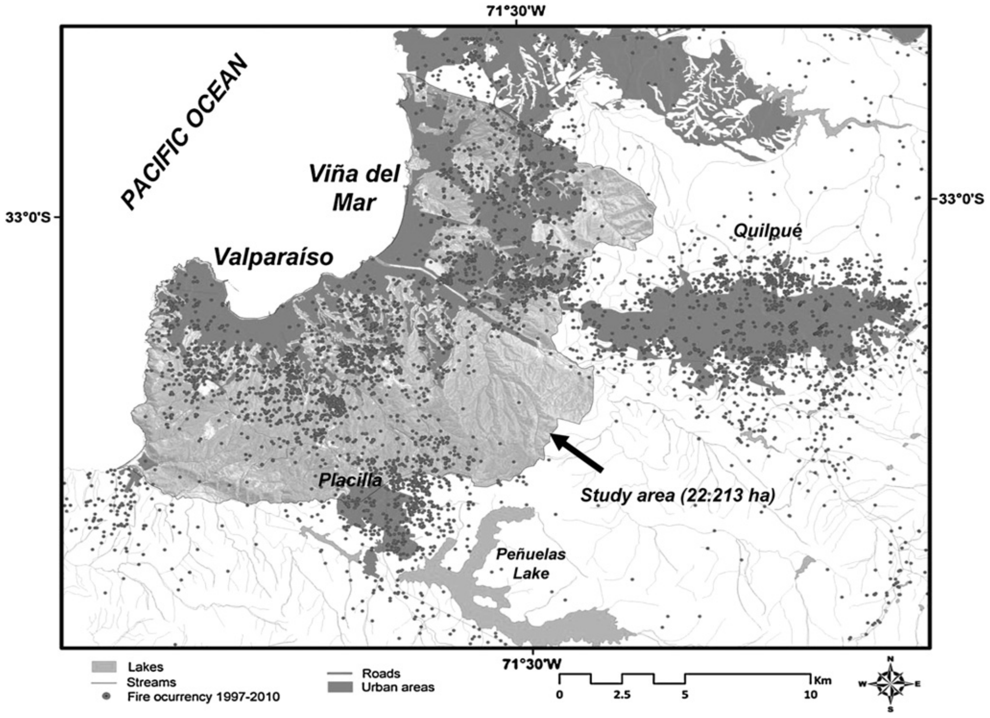

Fig. 2. Map showing density and spatial distribution of forest fires for the area of study. The region of Valparaíso and its surrounding area are constantly affected by a high occurrence of fires, particularly in urban–wildland interface zones. The areas of highest density are concentrated in the urban sectors of Valparaiso, Viña del Mar and Quilpué.

vulnerability in interface areas. Risk, danger and damage potential inputs were generated in a different manner, using historical records, data for roads, weather, forest fuels, a digital terrain model, vegetation maps and interface area maps generated using empiric methods, neighborhood analysis and V-Kitral simulations (Table 2).

2.3. Risk

Risk variables are linked to human activity, through negligence, premeditated or intentional actions, given that approximately 99% of fires in Chile are caused by humans (Castillo, 2006; Julio, 2007). The

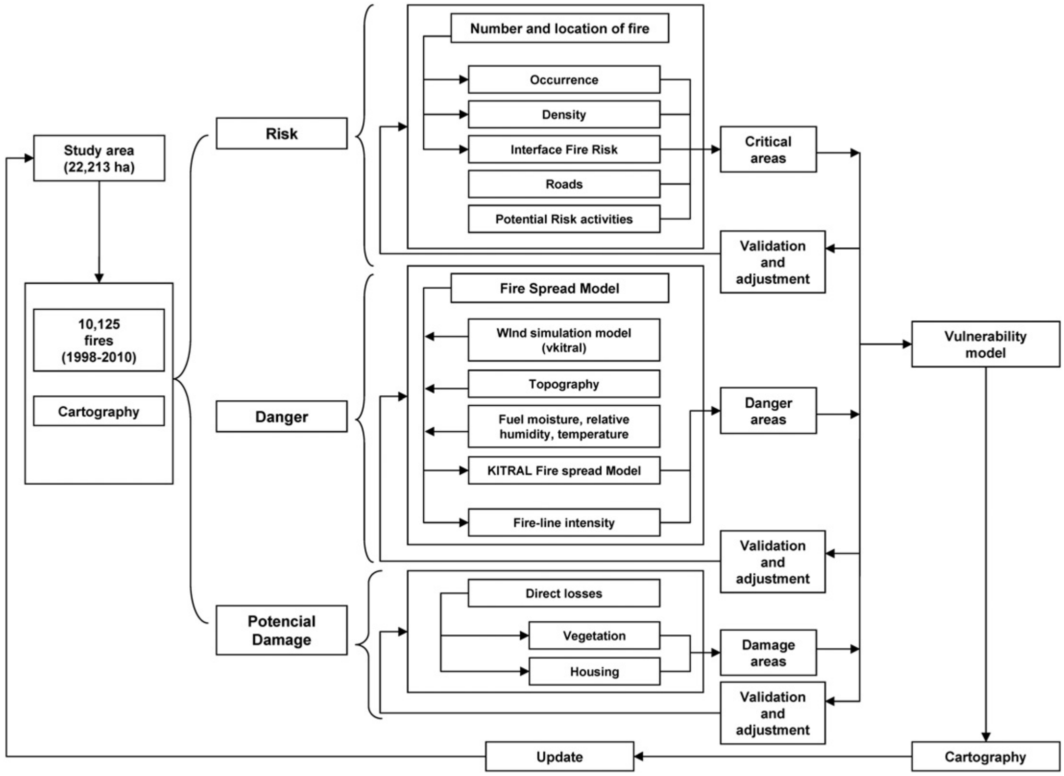

Fig. 3. Diagram of the process leading to the determination of the final fire vulnerability map. Analysis is broken down into three components: risk; danger; damage potential.

Table 2
Entrance factors for the vulnerability model. Spatial representation of all SIG information layers, defined in 25 m^2 cells.

Factor	Entrance data	Method
Historical incidence (Julio, 1992)	Database for forest fires	Empiric models
Potential incidence (Julio, 2007)	Road network Field studies for interface areas Agricultural and wildland activities	Raster analysis of proximity
Danger of fire spread (Julio, 1992)	Weather data	V-Kitral simulation
Flame longitude (Albini, 1976)	Forest fuels	Kitral simulation
Calorific intensity (Byram, 1957)		
Scorch effect (Chase, 1981)		
Slope factor (Julio et al., 1997)		
Moisture content factor (Simard, 1968; Brumm (1970), Fosberg and Deeming (1974), Deeming and Brown (1975), Fosberg (1977), (Cheney (1978), Rothermel (1983).		
Fuel factor model (Julio et al., 1997)		
Resistance to control (Julio et al., 1997)		
Linear fire propagation (Van Wagner, 1987; Julio, 1992)		
Land slope factor (Julio et al., 1997)	Digital terrain model	Topogrid/kriging
Socio-economic values (Rodríguez y Silva, 2004, 2009)	Vegetation fuel map for Chile	Empiric model
Commercial vegetation values (Rodríguez y Silva et al., 2010; Julio, 2007).		
Housing valuation and fire impact levels (Conaf, 2011).	Urban–wildland interface areas and field studies	

Geographical Information System (GIS) was used to identify areas of urban–wildland interface, areas surrounding roads and zones of potential risk. Fire records were divided into two parts: 75% of the data (from the 1997 to 2006 period) was used to construct the model and the other 25% of information (from the 2007 to 2010 period) was used to validate the spatial incidence trend. For both samples, fire density and areas most susceptible to fire as regards presence of urban–wildland interface areas, road proximity and risk activities were identified in areas of high fire incidence.

2.4. Danger

Potential fire behavior was estimated by applying the Kitral system propagation formulas (Julio et al., 1997), designed specifically for Chile forest fuels. This system is based on two equations to explain the spread and intensity of a fire:

$$VP = (Fmc)(Fch)(Fp + Fv) \quad (2)$$

Where VP represents the speed of linear spread ($m\ s^{-1}$), Fmc is the fuel model factor ($m\ s^{-1}$), Fch the moisture content formula for fine fuel and dead fuel (one-dimensional), Fp the slope factor (one-dimensional) and Fv the wind factor (one-dimensional). VP was validated by Castillo (1998), finding that it correlated directly with the size of the simulated fire. Reliability was up to 86.5% for fires greater than 60 hectares.

$$I = H * w * VP \quad (3)$$

Where I represents calorific intensity ($kcal\ m^{-1}\ s^{-1}$); H is the fuel's calorific power per unit of weight ($kcal\ kg^{-1}$), w the load or weight of available fuel ($kg\ m^{-2}$); and VP the speed of lineal fire spread ($m\ s^{-1}$). The application of these equations via Kitral is based on these parameters as well as topographical and weather information. The use of remote analysis, photo-interpretation and countryside routes (Rodríguez y Silva et al., 2010) to identify vegetation allows models of forest fuel available in Chile (native woodland, pasture, scrubland and wildland plantations among others) to be assigned. The fuel model factor ($m\ s^{-1}$), whose load was expressed as dry weight ($kg\ m^{-2}$) was applied as well as calorific power ($kcal\ kg^{-1}$), and resistance to control for each type of vegetation when faced with fire suppression i.e. the number of linear meters which may be built upon following manual clearance of vegetation (to a point where mineral soil is reached); usually, this value varies according to the type of fuel used. The slope effect is incorporated in the Kitral fire spread model, starting from a digital terrain model (from 25 m spatial resolution). Weather information was obtained by analysis of 10,125 fires (in the period from 1997 to 2010), simulations were undertaken in accordance with dynamic conditions of speed and wind direction, using the V-Kitral wind model (Julio et al., 1997), and taking into account the time elapsed (in minutes) from start to the inspection point (simulation time). Quotas for fire spread were obtained in the previous stage which permitted variables of speed and fire intensity to be estimated. Following analysis of each fire, wind intensity and speed variables were also obtained which had previously been used in the Kitral fire simulator to calculate the surface area affected in the fires studied The "VP" value for each cell is an average of the successive simulations for fires recorded in the study area. Validation results and graphic projections of this algorithm may be found in Castillo (1998).

2.5. Damage potential

Damage potential was characterized by the direct effect of potential fire spread across vegetation (native woodland, scrubland and commercial plantations) and the damage to housing situated in urban–wildland interface zones. Commercial values were updated to Chile's national currency, loss antecedents in relation to past fire damage in the area of study and the National Woodland Corporation of Chile's official statistics (CONAF). Results were validated by the creation of a linear regression model, which considered vegetation areas affected by fire up to 2006 as a sample area for construction of the model and the background data of burnt areas up until 2010 as a validation test. As for housing, interface areas were identified and classified into two categories based on population density, average house surface area, habitants per house and average value (Table 3), consistent with the earlier study by Rodríguez y Silva et al. (2010) for the study area and the average value of material loss of homes recorded

Table 3
Average house value (building and contents), for the two interface areas identified in the area of study.

Class of interface	Residential density (houses ha^{-1})	Average house surface area (m^2)	Inhabitants/house	Average value (US$)	No. of houses	No. of people
1	26	120	4	32.202	16.745	50.235
2	37	56	7	18.575	35.649	142.596

Table 4
Jenks classifications for areas of forest fire incidence. The values represent the number of fires which occurred in the area of study in 625 m^2 (cells).

Class	1997–2006	2007–2010
	75% (sample)	25% (test)
1	4–12	1–3
2	13–22	4–6
3	23–34	7–11
4	35–48	12–16
5	49–65	17–22
6	66–87	23–29
7	88–119	30–36

Table 5
Correlations for fire risk in the study area; deviances for x and y are shown, corresponding to periods of analysis.

Relationship between period 1997–2006 (y), with 2007–2010 (x)	Equation	r	Std. dev. x	Std. dev. y
Fire density	0.192185 + 0.570239 x	0.759	1.37	1.03
Road proximity	1.083392 + 0.770242 x	0.711	1.02	0.88
Fires in interface areas	1.124415 + 0.432433 x	0.672	0.98	0.74

by the National Office of the Ministry for the Interior (ONEMI) in Chile.

Economic impacts were subjected to an earlier test of statistical distribution so that results could later be compared with antecedents published by Julio (2007) and Pedernera (1999) for the same study area, considering fires in the period 1986–1998.

3. Results

3.1. Risk

Ignition points were entered in a raster (*grid*) format using a cell size of 625 m^2 (25×25 m), in order to assess the number of fires and identify areas of greater frequency. Results were classified (Table 4) following Jenks segmentation criteria (1963), in the same way for the model sample (1997–2006) as for the validation sample (2007–2010). The most critical areas tended to be concentrated in areas around roads and the urban–wildland interface zones (Table 5; Fig. 4).

3.2. Danger

Fires were simulated in the study area using the Kitral system, based on weather information, topography and forest fire characteristics as well as wind information. Five qualitative levels were generated based on propagation and calorific intensity (Table 6) using the method of Jenks (1963), and subsequently geo-referenced using GIS. Burnt area data was obtained by counting cells simulated in eight propagation paths, resulting in a statistical comparison between actual and simulated values (Table 7).

Fire behavior simulations were validated with actual fire spread using the Mann–Whitney test and Spearman's rank correlation coefficient (Table 7) for different-sized fires, weather conditions, vegetation and topography.

3.3. Damage potential

a) Vegetation
Direct losses on vegetation for the area of study were determined via the assessment of different plant coverage in line with average market prices. The proportion of damaged vegetation and consequent economic impact fluctuated as regards fire intensity level, which for this study used an average from the University of Chile Forest Fire Laboratory registry (Table 8).
Average plant coverage losses were logged to GIS for areas burnt by fire during the period 1997–2010. As with risk and danger, 75% of data was used to create the model and the remaining 25% for validation. A correlation of 72.9% was attained by reclassifying damaged pixels into ten intervals (Table 9), using the statistics model $y = 0.413146 + 0.613358x$, where y corresponds to the period 1997–2006, and x, to the period 2007–2010. Deviances in x

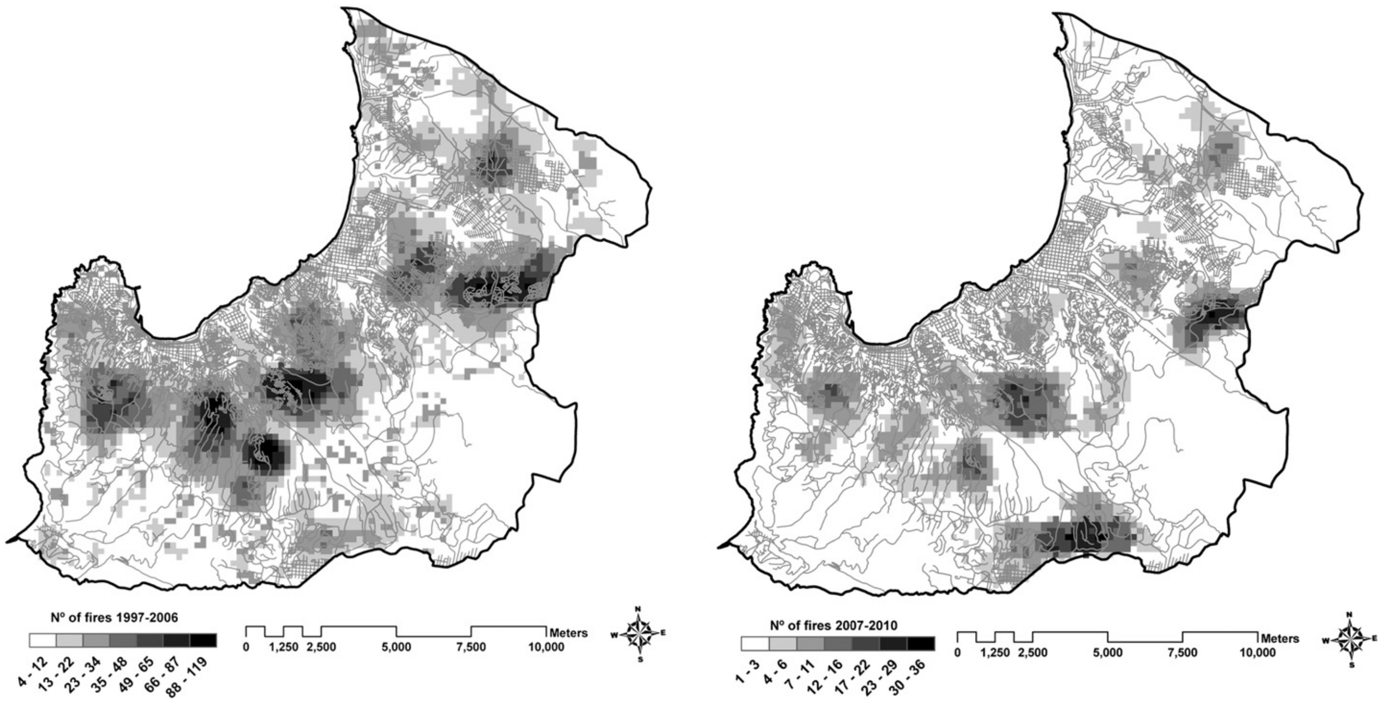

Fig. 4. Areas with incidences of wildland fires, for the area of study. The diagram on the left shows all fires which occurred in the area during the period 1997–2006 (sample). The map on the right (period from 2007 to 2010) was used for validation of results. Spatial correlations of both maps are presented in Table 5.

Table 6
Fire propagation values (VP) and calorific intensity (I), according to the Kitral model.

VP range (m/s)	Observed average	Level	I ranges (kcal $m^{-1}s^{-1}$)	Observed average	Level
0.0010–0.0060	0.0035 ± 0.0004	Mínimum	0.0010–50	25.00 ± 8.17	Mínimum
0.0061–0.0100	0.0081 ± 0.0028	Low	50.1–100	75.05 ± 6.77	Low
0.0101–0.0400	0.0251 ± 0.0017	Medium	100.1–500	300.05 ± 22.04	Medium
0.0401–0.1000	0.0701 ± 0.0014	High	500.1–1000	750.05 ± 26.41	High
0.1001–0.4000	0.2501 ± 0.0031	Extreme	1000.1–16.500	8750.05 ± 111.03	Extreme

(2.06) and y (1.74) indicate a high statistical association between both periods for direct damage to vegetation.

b) Housing

A screening of forest fires occurring within the interface area of influence was carried out for the period 1997–2010. Statistics of annual fires for each type of interface, burnt area and their relationship to direct material loss of homes were obtained (Table 10).

The number of fires in the interface area was analyzed using the Kolmogorov–Smirnov normality test with the help of statistics software. Results indicated that distributions for interfaces 1 and 2 follow a normal type tendency ($p<0.05$) (Table 11), as with the value sequence for direct losses.

Direct housing loss was obtained as a weighted number between the average value of houses found in areas of interface 1 (US$32,202/house) and 2 (US$18,575/house), and their relationship to the number of fires in each pixel or sub area. Analysis of burnt area for each fire allowed a scale or range of loss to be drawn up, which took the form of normal distribution. Direct housing losses were passed to SIG using a raster layer reclassified into six levels.

4. Discussion

The results explained here are based on a spatial resolution of 25 m^2, and a temporal resolution of 14 years (1997–2010). Fires studied for the simulation of fire behavior have enabled more precise estimations due to the larger size of these fires. The Kitral model used and its spatial expression in SIG were well-adapted to the cases studied, especially in terms of the calorific intensity and fire spread speed values.

Table 7
Similitude values calculated using the Kitral system in line with the linear fire propagation model. Results were grouped into six classifications to best illustrate the similitude percentages between actual and simulated values.

Range (ha)	Average surface area (ha)	% Of similitude[a]
0.01–0.50	0.22	34.18
0.51–2.00	0.99	51.15
2.01–5.00	2.23	74.08
5.01–20.00	7.28	83.00
20.01–60.00	37.33	84.67
>60.00	404.75	90.75

[a] Values calculated through comparison of actual and simulated values (size and form of each fire), based on the Mann–Whitney test and Spearman's rank correlation.

Table 8
Direct vegetation loss values in the area of study. Vegetation groups listed here are those which are frequently affected by fire.

Category	Values (US$/ha)
Radiata pine plantations	4.491
Eucalyptus plantations	3.098
Dense native Woodland	2.187
Native open and semi-dense woodland	1.459
Semi-dense scrubland	208
Scrubland and Woodland	599
Open/semi-dense pasture	137
Pasture and dense scrubland	231
Pasture and native woodland	797
Horticulture and golf courses	918
Cereal crops	1.149
Vines	4.711
Agricultural and wildland waste	281
Vegetation bordering water, quarries and roads	141

By integrating risk, danger and damage potential components, it was possible to obtain a global territorial model of economic vulnerability to forest fire (Chuvieco et al., 2010). In Chile, risk areas tend to be concentrated on the periphery of urban interface sectors with high population density and around the main road network. This result is in line with the permanent historical threat which has affected these sectors for the past 40 or more years and which has caused serious damage and impact, including loss of human life and the destruction of hundreds of homes in more critical times. Revision of records of accumulated fire incidences has confirmed critical situations, with densities of up to 74 fires in a 25-hectare area in the period 1997–2010, which undoubtedly reflect the high recurrence in the same territory and reflect the trend established by Pedernera (1999) for the period (1986–1998), regarding damage in interface areas (Fig. 5).

Danger variables reflect the effects of fire behavior (propagation speed and calorific intensity) and resistance to control as a consequence of topographical, climactic and vegetation conditions present in the study area (Julio et al., 1997). Unlike the case with the risk component, it can be seen that danger presented a greater dispersal of problem zones, with the most critical sectors being concentrated in transverse ravines along the coast, which directly connect the hills from interface areas to slopes with a steeper incline.

From the antecedents explained in this study, it may be seen that despite significant differences between annual burnt areas, total losses remain in a relatively homogenous range. On analysis of the data in Table 12, it may be seen that there were no losses caused by fire for about three quarters of the total area during the period 1997–2010. Furthermore the size of the fire is directly related to loss distribution in the sense that greater damage was concentrated in small areas, especially when associated with interface fires. Moreover, around 97% of direct losses occur on a surface area of less than six per cent of total area affected by fire. It is important to note that in some

Table 9
Jenks classification ranges for commercial value of vegetation damage. Values, expressed in thousands of dollars, represent those in the study area in cells of 625 m^2. Validation considered 25% of data for the period 2007–2010.

Class	1997–2006	2007–2010
	75% (sample) 1000s of US$	25% (test) 1000 s of US$
1	0–3.51	0
2	3.51–14.05	0–6.23
3	14.05–28.11	6.23–15.58
4	28.11–42.17	15.58–34.28
5	42.17–66.77	34.28–43.63
6	66.77–108.94	43.63–112.20
7	108.94–224.91	112.20–283.62
8	224.91–347.90	283.62–383.35
9	347.90–446.30	383.35–607.76
10	446.30–896.17	607.76–794.75

Table 10
Fires in urban–wildland interface areas and their relation to direct material loss in the area of Valparaíso, period 1997–2010.

Year	Fires in interface class		Total	Burnt area (ha)	Direct loss (US$)	Year	Fires in interface class		Total	Burnt area (ha)	Direct loss (US$)
	1	2					1	2			
1997	54	94	148	199	14,011,025	2004	47	97	144	1955	14,251 ,918
1998	65	144	209	132	13,886,999	2005	35	97	132	212	11,817,665
1999	60	141	201	345	15,738,692	2006	44	100	144	251	8,732,358
2000	78	190	268	96	7,787,011	2007	53	86	139	247	12,166,183
2001	78	149	227	139	6,420,698	2008	43	58	101	406	8,839,517
2002	105	208	313	162	17,419,926	2009	39	40	79	518	8,766,313
2003	65	143	208	922	16,245,587	2010	29	60	89	713	10,640,011

Table 11
Kolmogorov–Smirnov test for interface data and economic losses (1997–2010).

N (years 1997–2010)		Interface 1	Interface 2	Losses
		14	14	14
Normal parameters	Average	56.79	114.79	11,908,850.21
	Typical deviance	20,389	49,446	3,462,429.32
More extreme differences	Absolute	0.129	0.189	0.169
	Positive	0.129	0.189	0.169
	Negative	−0.086	−0.131	−0.145
Kolmogorov–Smirnov Z		0.484(a)	0.707(a)	0.634[a]
Asintotic (bilateral) significance		0.974	0.699	0.816

[a] Greater than critical level 0.05. The normality hypothesis is accepted for these data.

areas, the economic impact of fire may be under or over-estimated, due to the use of an average loss value.

In the particular case of loss of homes, these were calculated with the help of GIS, using the few antecedents available. It will be necessary to collect more specific data in successive investigations and to identify a wider typology of interface. Economic values employed are in response to average costs estimated by public organizations in the V Region of Chile and those calculated in Australia (Handmer et al., 2008) for cost of replacing homes and most important goods of those affected. Even though Ashe et al. (2007), reported figures for the effect on human lives, it was decided not to include a value for deceased persons in the case of Chile, due to a lack of reliable background data.

The vulnerability model allows critical fire risk areas to be identified in order to prioritize actions. Classification of vulnerability categories using *Método de los Séptimos* (Julio, 1992), prioritized 1/7 of the territory with highest vulnerability (first category) and identified 2/7 as medium vulnerability (second category) and the rest of the area as low vulnerability third category). These vulnerability categories allow areas of supply and demand for protection against forest fires to be established, providing an initial approach to assessment of fire

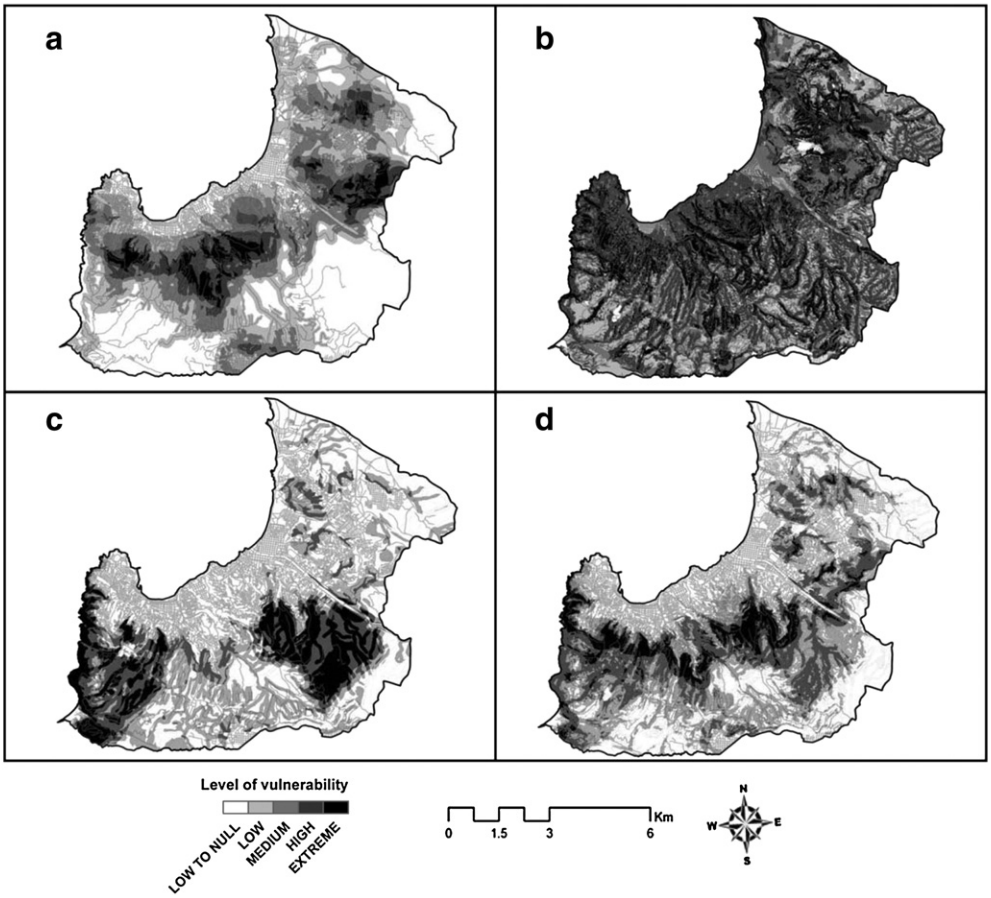

Fig. 5. Final forest fire vulnerability map across components of risk (a), danger (b) and damage potential (c). The result of the vulnerability model is the map (d), categorized into five classes.

Table 12
Distribution of direct losses caused by fire for the area of research. Results are classified into six categories.

Loss range (US$/ha/year)	Affected area (%)	Total losses (US$)	Loss distribution (%)
0	73.29	0	0
0.01–100	15.24	331,761	0.23
100.1–1000	5.71	3,963,845	2.74
1000.1–5000	2.79	12,141,812	8.40
5000.1–15,000	1.67	25,347,227	17.54
>15,000	1.29	102,708,556	71.08

spread impact and losses. Generally, research into the socio-economic effects of forest fire has been practically non-existent in South America and the application of models used for other countries (Molina et al., 2009) is complicated due to the particular conditions of South American Mediterranean ecosystems found in areas of urban–wildland interface, or due to the lack of information reliable enough to create an integral vulnerability model.

Within the context of South America, references reported in Julio (2008) demonstrate the precarious information which exists in the majority of countries regarding the number of losses caused by fire incidence and spread. This is why there are no in-depth studies or scientific publications tackling this issue, which undoubtedly presents an important limitation for development of plans leading to effective management of territory at risk from fire. This research may therefore contribute to the study of similar problems in neighboring countries.

5. Conclusions

The application of the economic vulnerability model in Chile constitutes a reference model for prioritization of suppression activities against forest fires, even when allowing for the lack of information about material losses and the limitations of the damage potential component, which only includes direct damage. The model introduced using GIS may be easily adapted to other South American Mediterranean ecosystems, where forest fire problems exist at the urban–wildland interface due to the high density of fires, mainly caused by humans.

The vulnerability model is totally flexible as regards lack of information for some variables or the inclusion of new variables, the criteria against which this is analyzed and its statistical validation. The reliability of the model—especially in the cases of risk and danger components—should be evaluated periodically through statistical checks of the study sample, even when the experiment shows that the type of problems caused by forest fires tends to be concentrated in the same places. Size and form should be varied depending on the population growth dynamic, especially in urban–wildland interface areas.

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