Followup to Large-Scale Forest Fires to Aid in Evaluating Economic Losses[1]

Miguel Castillo S., Patricio Pedernera A., Guillermo Julio A.[2]

Abstract

The KITRAL System Forest Fire Expansion Simulator was used to recreate the conditions of the large fires that affected a forest company in February 1999 in the Octava Region in Chile. The objective of the study was to determine which events affected a specific land plot and at what exact moment, in order to quantify the direct economic damages and to facilitate the decision-making process for a Safety System. In that regard, it was determined that the plot in question was affected by three of the seven fires that touched the area of study.

Introduction

The Octava Region in Chile was severely affected by the ignition and spread of forest fires from February 7 to 11, 1999. According to estimates released by the National Forestry Corporation (CONAF), these fires caused damage to more than 40,000 ha. The problematic situation, which chiefly affected the costal area of the Concepción Province, was mainly produced by the extreme weather conditions present prior to and during said time period. In addition, the cumulative effects of an ongoing drought in the area played an important role. Among the many losses caused by the fires, the losses suffered in the large radiata pine plantations belonging to several forest companies were especially noteworthy. The direct resulting losses of this resource were numerous and unprecedented in the region in the last 30 years, or at least since official statistics regarding forest fires have been kept.

Naturally, the economic, social and environmental implications of such a serious situation called for a detailed analysis of the facts. Indisputably, the forest companies affected needed to know exactly how the problem occurred, and in what way and in what circumstances their plots were damaged. However, it was not possible to clearly identify the fire's spread patterns by visually examining the burned areas. Likewise, the information registered in the operations centres was not sufficient for precisely determining the spread as it devastated the forest plantations. Therefore, in order to know the origin of the damages in each of the affected areas, a study determining the spread models of the different disasters occurred on February 7 and 8th was proposed. The particular plot of interest for the study was deemed to be the Trinitarias plot, property of the forest company Bío Bío S.A.

In carrying out the study, the KITRAL System fire simulator was used. The results of the simulation clearly reveal the spread models of the fires analysed, the

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[2] Académicos, Departamento Manejo de Recursos Forestales, Facultad de Ciencias Forestales, Universidad de Chile, Casilla 9206, Santiago, Chile. (Professors, Forest Resources Management Department, School of Forestry Science).

plots which were affected as the fire advanced, and at what moment the damages occurred.

In accordance with the above, the following objectives were set: to define the spread models of the forest fires that occurred on the dates mentioned above by using the KITRAL System fire simulator, to gather information on the behaviour of the forest fires that affected the Trinitarias plot and other areas belonging to the forest company Bío Bío S.A., and to determine the surface area burned by each of the fires that affected the subject plot.

Methods

The study was carried out through the sequential execution of the following steps: the update of the Digital Information on Forest Fuels, the securing of Environmental Parameters simulating the fires considered in the study and, lastly, application of the KITRAL System fire simulator, the results of which were processed in a GIS.

The KITRAL System

The KITRAL System, which operates by computational means, was completely designed in Chile. The system is based on the construction of diverse independent and interconnected modules allowing the user to easily perform the most frequent activities of an operations centre. The main characteristics of the system, among others, are the ability to predict fire spread at different points in time and the capacity to reconstruct past events and evaluate them in terms of surface area, type of damage, and quantification of the fuels affected (Julio et al 1995).

When simulating a fire—that is, representing in advance the characteristics that a fire will acquire following its ignition or after a given moment in its development—it is possible to obtain an enormous quantity of useful data, such as spread model and spread rate, the amount of energy released, flame length, effects of vertical radiation, extension of the perimeter and effort required for control, just to mention a few of the most relevant data available.

The key factor in simulating fire behaviour is to determine the spread rate and the spread model. Accordingly, if the prevailing environmental conditions in the affected area are known, then from these two variables it is possible to estimate the effect of the other components present in the expansion of a fire (Julio 1999).

The variables that influence the spread model of a forest fire are innumerable, as are those that affect the way in which heart of fire develops horizontally from the moment of ignition onwards. Nevertheless, experience shows that the spread rate depends essentially on four factors regarding the behaviour of the fire: fuel type, fuel moisture, slope, and wind speed (Brown and Davis 1973, Albini 1976).

Several different research studies have shown that although both fuel type and fuel moisture affect the spread rate, they do not influence spread model. That is, for different levels of values or conditions of the above-mentioned factors, different sizes of fires will be produced, but the geometric figure generated by the heart of the fire will remain the same if the other factors (slope and wind speed) are constant. In addition, variations of fuel type and fuel moisture are not present in small surface areas (Anderson, 1983).

The situation is different, however, as regards slope of the land and wind intensity. The relationship of these factors with the speed with which the fire advances is not lineal, and thus variations of their levels will affect the fire's spread model, even if fuel type and fuel moisture remain constant. In addition, the fluctuations in wind (direction and intensity) and in slope (grade of slope and aspect) are very high even in small land areas. Furthermore, significant changes can be observed in their effects depending on the course of the spread (Andrews 1986).

The fire simulator was tested under real conditions by compiling complete and reliable information from more than 120 forest fires of different sizes. The results indicate that KITRAL is capable of providing 90%-correct forecasts for fires where more than 60 ha were affected. However, in fires affecting less than 2 ha, the level of reliability is decreased by approximately 58%. From a technical point of view, this decline is within reason if we bear in mind that the minimum information unit present in the geographic databases of the system is composed of 25 square meter cells for all levels of information (Castillo 1998).

These findings demonstrate the high level of reliability of the simulator, especially in the case of large fires. Together with the processing speed of the system (projection of 12 hours in the future in three minutes), this can be considered a very good standard, given the complexity of the issue and the high number of variables with their respective functions that are involved in the process.

Update of Digital Information regarding Forest Fuels

This stage involved adjusting the fuel maps in the KITRAL system by introducing into the geographic database of the system the data provided by the forest company Bío Bío S.A. regarding the fuels present in their various plots. In that respect, data on the vegetation and tree populations provided by the company was introduced in the database, and the vegetation formations existing within the plots were categorized by fuel types in line with the Fuel Type Classification developed for the KITRAL System.

As a result, a digital map of the fuel covering the total area of study was obtained. This map was then used to carry out the forest fire simulation.

Securing of Environmental Parameters for the Simulation

This stage involved the analysis of the data gathered on the weather conditions observed in the area of study during the days of interest. On the basis of the analysis of the data gathered, the feasibility of using the KITRAL System Wind Field Simulator was evaluated. In line with the data studied, the situation observed for February 7, 8, 9 and 10 clearly shows the existence of favourable conditions for extreme fire behaviour, which is very difficult to control. The existence of high temperatures, together with the presence of a high-speed wind and an ongoing drought (various months), made it difficult to control the spread of the fires throughout the 7th of February. Given the duration of the period of study considered, as a way of equating the value of the simulated environmental variables with the real conditions present in the area, in each of the simulations the value of each was adjusted to truly represent the different day and night-time conditions.

Use of the KITRAL System Fire Simulator

The simulation process was carried out for each fire independently, thu obtaining a map of free spread (not including fire suppression actions) for the perio from the starting time of each event to 10:00 a.m. the next morning. Time wa expressed in minutes and was measured from the moment of ignition of the fir (Minute Zero). Once the ignition points were located geographically, the simulation for each event were conducted until the spread model of the simulated fire mirrore that of the real fire. As a result of this stage, seven maps of spread times wer generated, one for each of the fires considered in the study. These maps covere approximately the same surface area and the same spatial resolution. Subsequentl these maps were transferred to a Geographic Information System for the fina analysis.

Processing of the Simulated Fires in GIS

The KITRAL System contains instruments that allow the simulated fires to b displayed on a screen. The different colour bands used in the display identify th positions of the fire fronts in intervals defined by the user (which in this case wer 60-minute intervals). However, the system does not have the necessary tools t achieve the desired analysis (intergeneration of all the spread models) and thus th entire final processing had to be completed by using the geographic informatio systems Idrisi for Windows and ARC/INFO for Unix.

The processes involved in this stage were: 1) classifying the time maps obtaine into intervals of a common start time and 2) generating all-inclusive maps showin the integrated development of all the fires in one map. For this, time zero (or the sta time for all the simulations) was considered to be the time the Huidanqui fire wa ignited (11:00 a.m. on 7 February 1999), as this was the first of all the fires analysec This process was carried out by adding the necessary amount of minutes to shift th start time in the KITRAL simulation to the real-life start time in relation to the sta time of the Huidanqui fire. Thus, the number of minutes listed in the table below wa added to the initiation time of each fire.

Table 1— Real start times and those used in the KITRAL System Simulator

Fire	Time of real ignition in the simulation	Minute of initiation in the KITRAL simulation	Minutes to be added i the simulation
Huidanqui	11:00	0	0
Hualqui	13:00	0	120
Puente 5	13:10	0	130
Quebrada Honda	14:40	0	220
San Lorenzo	15:50	0	290
Santo Domingo	19:50	0	530
Coihueco	22:20	0	680

After obtaining the adjusted time maps, the time interval (11:00 a.m. on February to 10:00 a.m. on 8 February) was divided further to secure a cleare illustration of how the fires spread overall. For this, the period considered wa divided into five irregular intervals in line with the ignition times of eacl considering that each of the fires should show some spread. The spread was the shown on maps reflecting the situation at 14:00, 17:00, 21:00 and 24:00 on February, and at 03:00, 07:00 and 10:00 on 8 February.

The final step was to estimate the exact area affected by each fire. Due to the fact that for this case the system delivered information on each fire independently, without taking into account its interaction with the other fires, it was necessary to develop a program to analyse the ignition time for each unit of analysis, considering the overall spread of those fires that merged at some point during the analysis period. The program created for this purpose uses an algorithm that examines all the pixels in each of the time plans generated per fire and identifies the first fire to reach said pixel in its spread. This process was necessary to identify the areas within the Trinitarias plot that were affected by each of the fires in question. In this part of the study, only the fires that could have had an effect on the subject plot were taken into account, namely Huidanqui, Hualqui, Puente 5, Quebrada Honda and Coihueco. The San Lorenzo and Santo Domingo fires were discarded, as it was clear that they had had no affect on the subject plot. Thus, a map of the areas burned by each fire within the Trinitarias plot was obtained.

Results

Fire Simulation

With respect to the simulations carried out with the system, the following figures illustrate the spread of the individual fires. Each colour represents the position of the fire front every 60 minutes from the moment of ignition to the time stated as the maximum simulation time (10:00 a.m.).

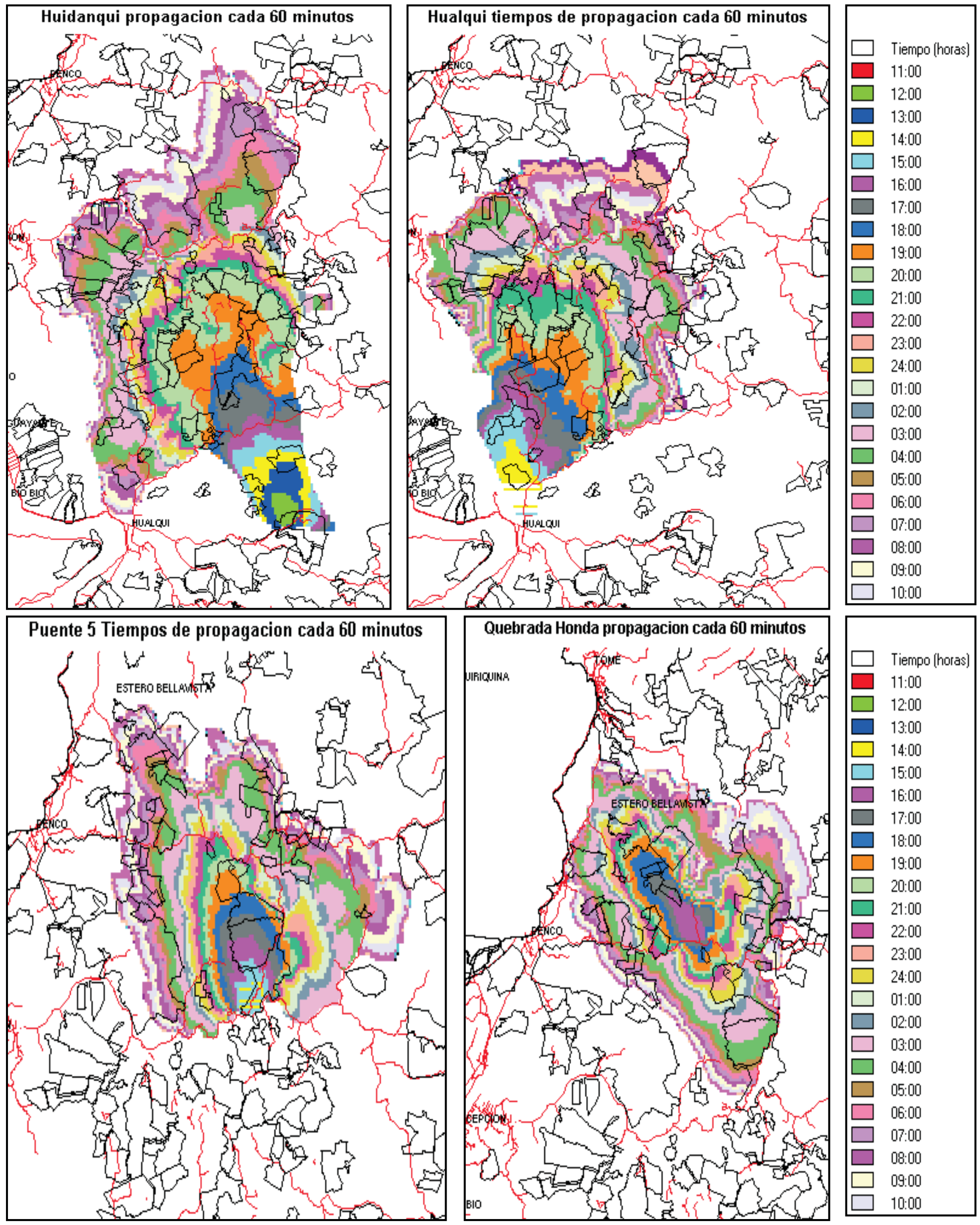

Figure 1— Simulation of forest fires in a 24-hour period using the KITRAL System. The different colours represent the borders of the fire spread every 60 minutes.

All the cases show the violent advance of the fires during the hours immediately following ignition. However, they also show the effects of the environmental conditions of temperature and relative humidity, which acted to slow the fire spread during the night.

Processing the Simulated Fires in GIS

A more general idea of the events surrounding the fires of 7 February was obtained by generating a map showing the global situation at the different time periods following the ignition of the fires.

In that respect, it is important to note that in order to show this situation, time intervals allowing for a relatively clear vision of the fire spread were selected. Care was taken to show some spread time for each fire. Figure 2 shows the global situation three hours after the ignition of the Huidanqui fire and one hour after the ignition of the Hualqui fire.

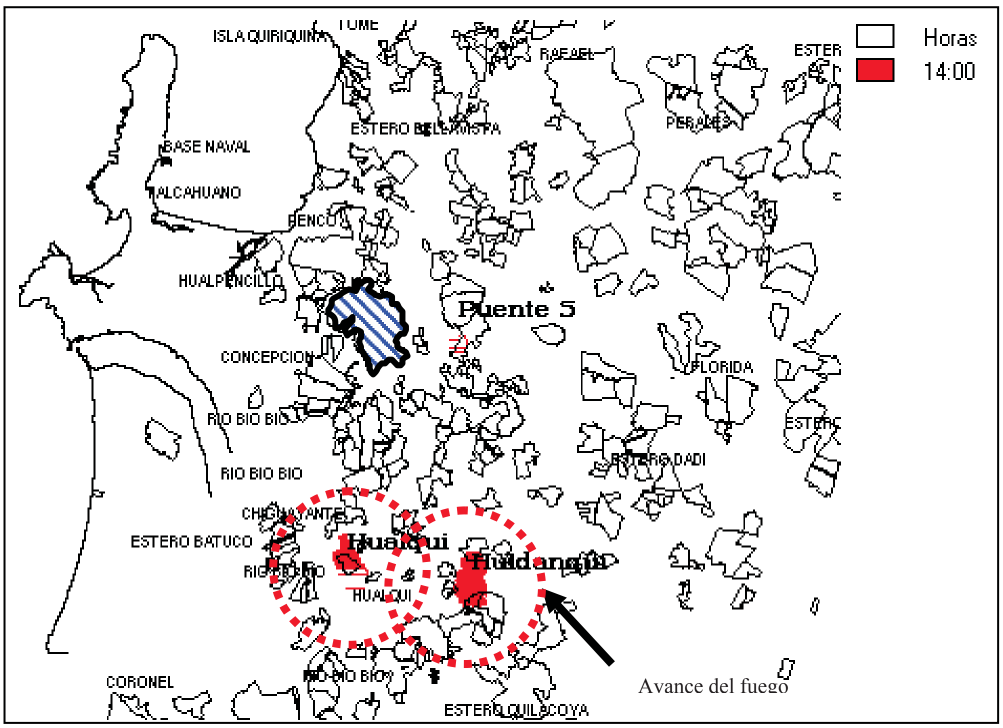

Figure 2—Global Situation at 14:00 on 7 February. The striped area is the zone of interest for the study (Trinitarias). The circles mark the main hearts of the fires, with a N-NE spread.

The figure clearly shows that the Huidanqui fire advanced quickly toward the Northwest, affecting 776 ha, a large portion of which was private land. The case was similar for the Hualqui fire, which advanced in the same direction and affected an approximate area of 423 ha..

Figure 3 depicts the situation in the area six hours later (at 17:00) and shows that the fires continued expanding in the same direction, consuming land belonging to company in question and to the forest company Forestal Celco.

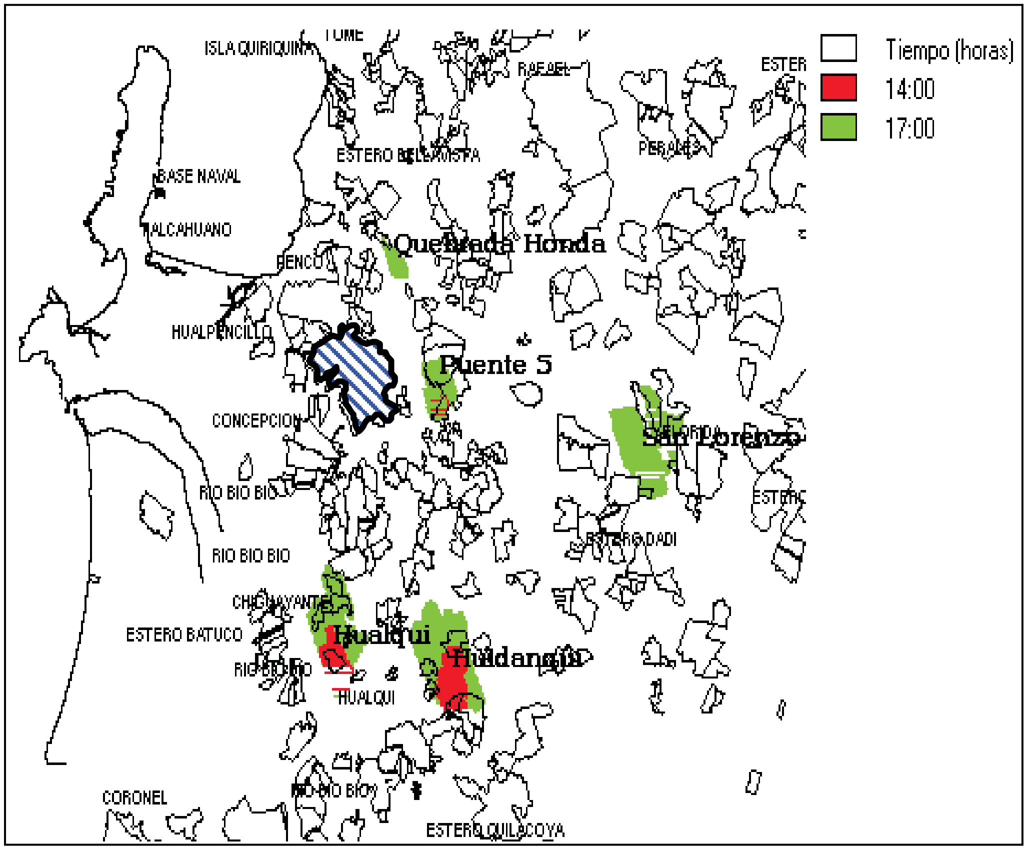

Figure 3—Global Situation at 17:00 on 7 February

In the case of the Huidanqui fire, by 17:00 the fire had affected 2,440 ha. The Hualqui fire had touched 1,780 ha, a large part of which belonged to the company and to Forestal Celco. By this time, the following fires had also been ignited: Puente 5 (736 ha burned), Quebrada Honda (280 ha burned) and San Lorenzo (1999 ha burned). In general, the fires were spreading toward the Northwest.

In addition, the speed with which the San Lorenzo fire advanced its expansion in the Florida area in the simulation was noteworthy. In only 70 minutes the surface area affected was much greater than in the other centres of fire activity. This points to possible problems in the values assigned to the variables determining fire spread in the simulation process.

In the case of the Puente 5 fire, it was possible to note that by this time the fire had already reached the Camarico 1 plot of Forestal Celco, advancing directly toward the adjacent Camarico 2 plot. In the case of the Quebrada Honda fire, the fire advanced directly toward the plot of the same name, accumulating a burned surface area of approximately 280 ha. Figure 4 shows the global situation observed at 21:00 on 7 February.

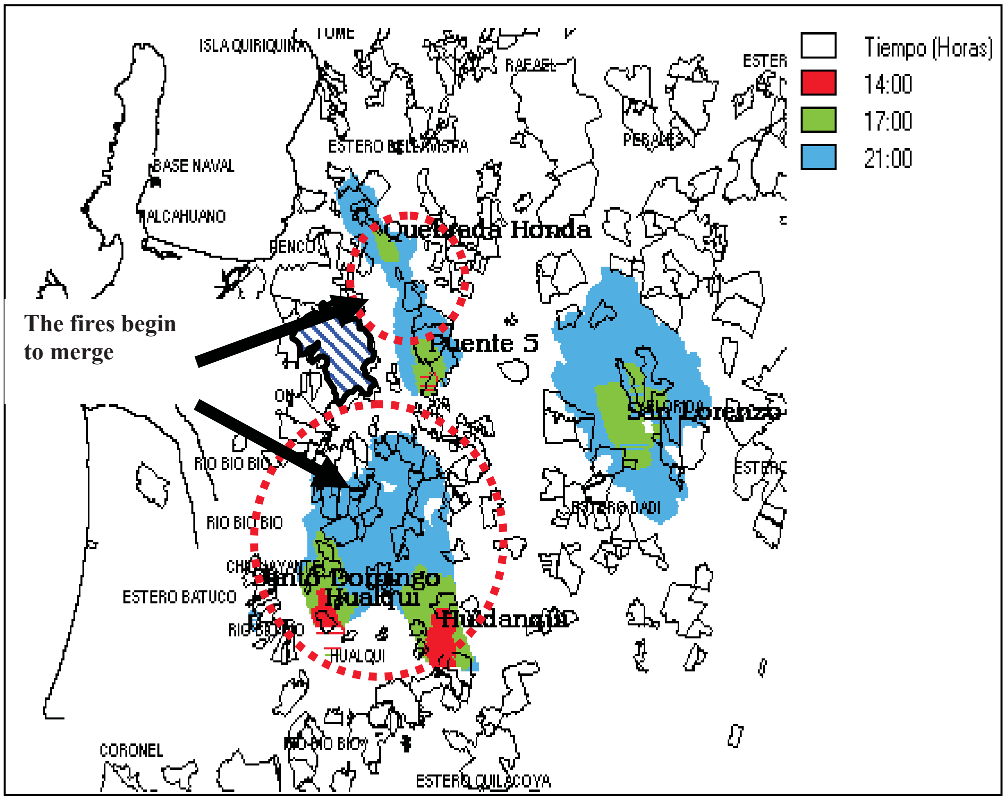

Figure 4— Global Situation at 21:00 on 7 February

Figure 4 shows that by 21:00 Huidanqui and Hualqui, the two main fires, had merged, affecting an overall surface area of 11,500 ha and damaging a large number of plots. The fire continued advancing toward the north, toward Forestal Bio Bio's Trinitarias plot, with a fire front that originated from the Huidanqui fire.

Near the Northern part, the Puente 5 and Quebrada Honda fires also merged, covering an approximate area of 4,700 ha, part of which corresponded to the already completely consumed Camarico 1 plot. As in the Huidanqui-Hualqui fire, the fire continued advancing due northwest. At the same time, the Santo Domingo fire was initiated, affecting an area of 55 ha.

At 24:00 on 7 February, the situation was similar to the previous period, with the fires advancing northwest. However, in the north section of the area the Coihueco fire had ignited and by this time had affected 117 ha of private land. Figure 5 depicts the global situation at this time.

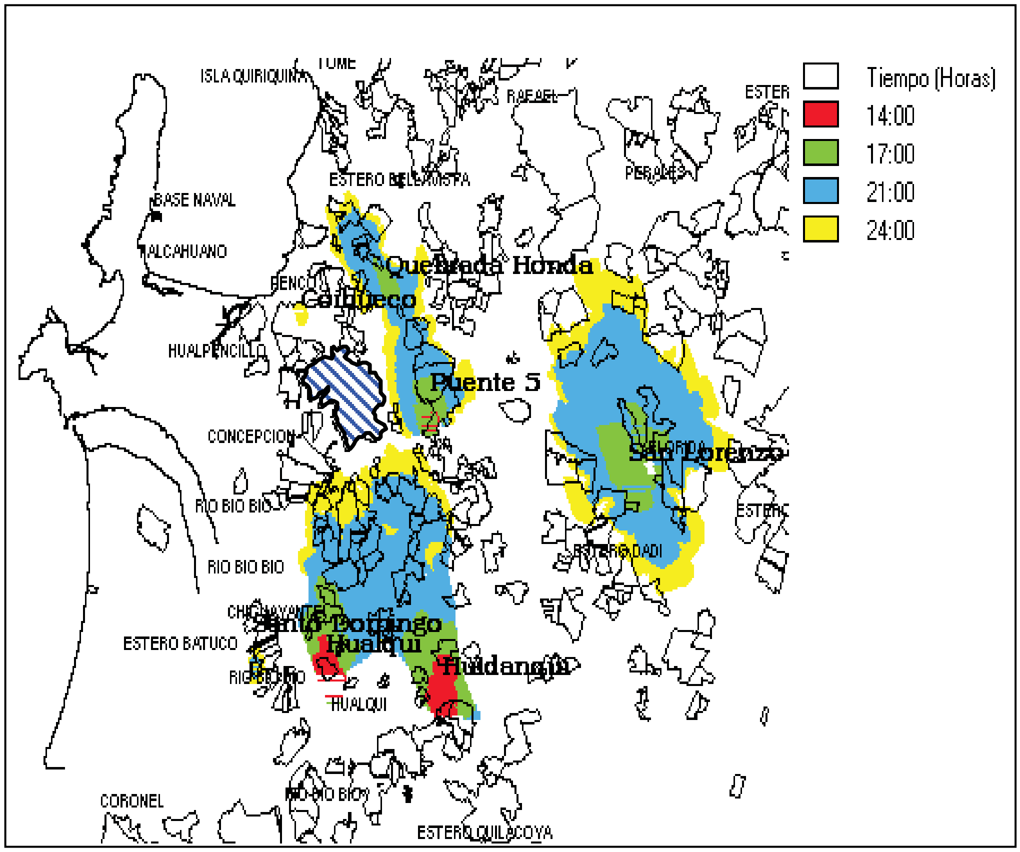

Figure 5— Global Situation at 24:00 on 7 February

By this time, the Huidanqui-Hualqui fire had already consumed approximately 15,400 ha and was nearing the Concepción-Bulnes road. The Puente 5—Quebrada Honda fire had consumed 7,200 ha and was beginning to expand outward. In the following period this would cause these fires to merge with the fire front coming from the south (Huidanqui-Hualqui).

In the case of the San Lorenzo fire, the spread was rather explosive (17,400 ha), which confirmed that there were problems with the parameters introduced in the simulation system.

The graphic clearly shows that by this time the Trinitarias plot was beginning to be threatened by two fire fronts: the Huidanqui-Hualqui fire to the south and the Puente 5- Quebrada Honda fire to the east. The global situation at 03:00 on 8 February is represented in the following graphic.

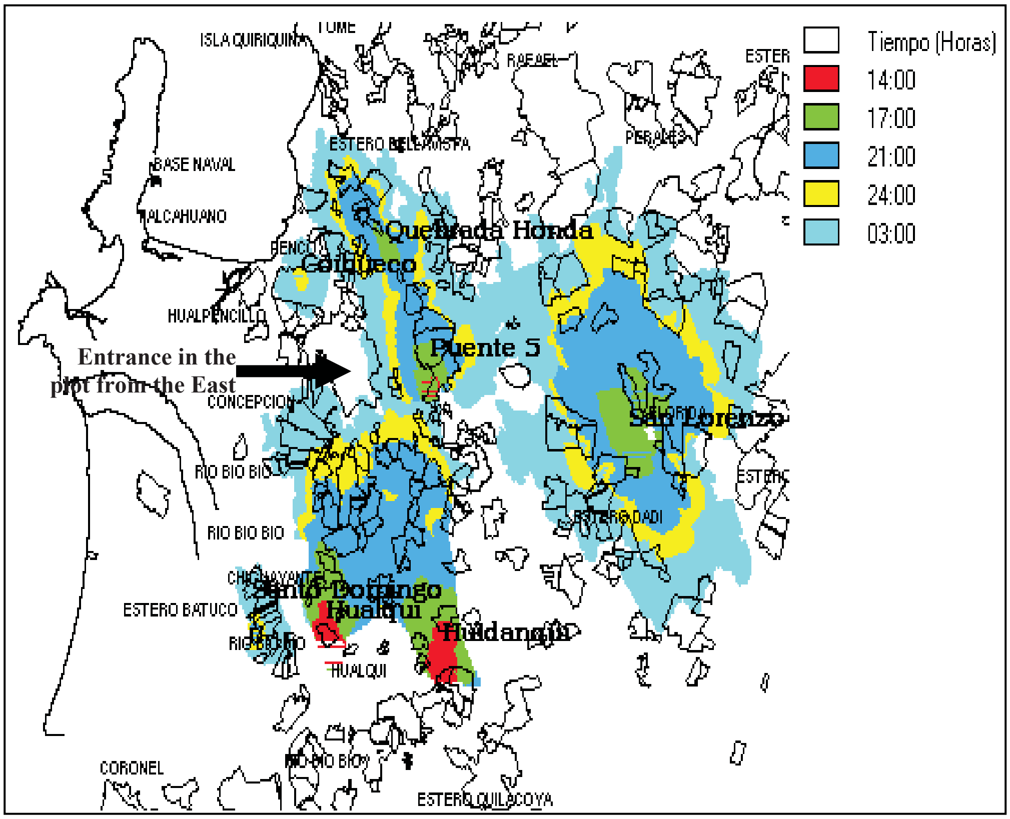

Figure 6—Global Situation at 03:00 on 8 February. The fire begins to enter the Trinitarias plot from the east section.

Figure 6 shows that at this time the fire fronts approaching from the south (Huidanqui-Hualqui) and from the east (Puente 5- Quebrada Honda) were entering the Trinitarias plot. In addition, the two fires were merging to the east and continuing their expansion outward. Upon observing this data and bearing in mind the part of the plot in which the fire entered, the fires that affected the plot at this time correspond to the fire fronts originated by the Huidanqui and Puente 5 fires. The advance of the Hualqui fire was halted by the presence of a watercourse and the Concepción-Bulnes road. In the north sector, at this time the Coihueco fire was not yet more than a threat to the Trinitarias plot, even though the fire front was quite close to the plot boundary. In the south, the Santo Domingo fire continued to expand, affecting 1440 ha. Figure 7, below, shows the situation at 07:00.

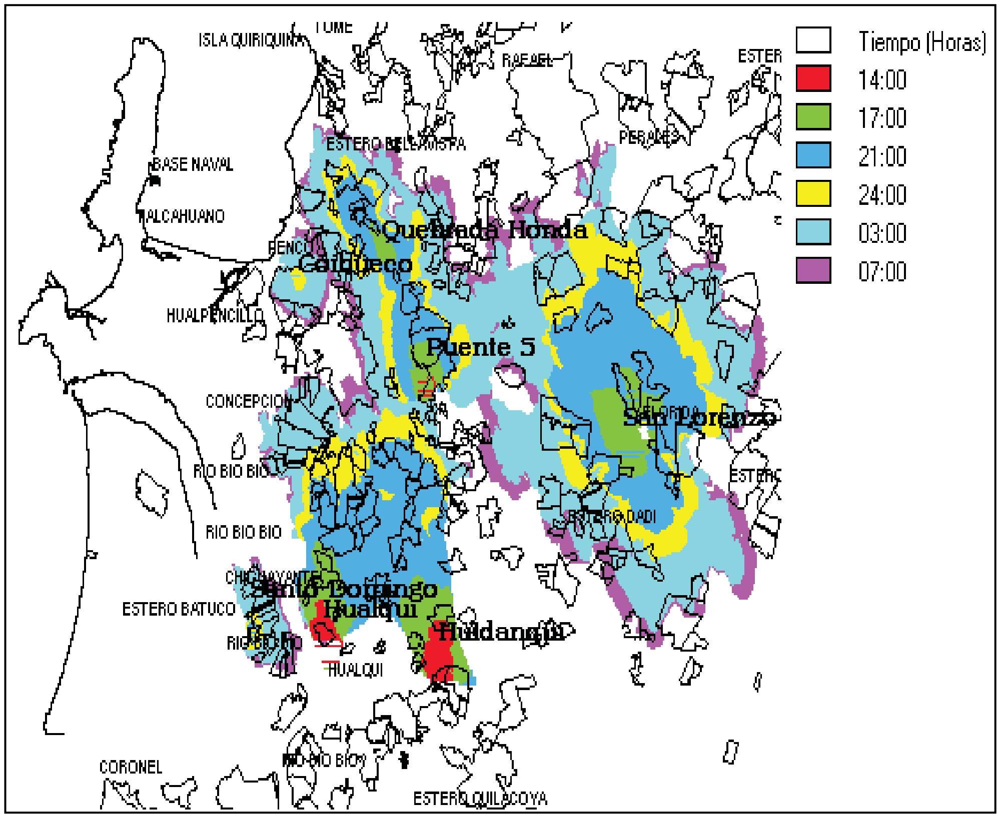

Figure 7— Global Situation at 07:00 on 8 February

During this period, the Huidanqui-Hualqui and the Puente 5-Quebrada Honda fires continued advancing within the Trinitarias plot, and the fire front originating in the Coihueco fire entered the subject plot from the north. In all cases, the fires expanded from the sides outwards. There are no other relevant aspects worth mentioning. The final situation is depicted in Figure 8.

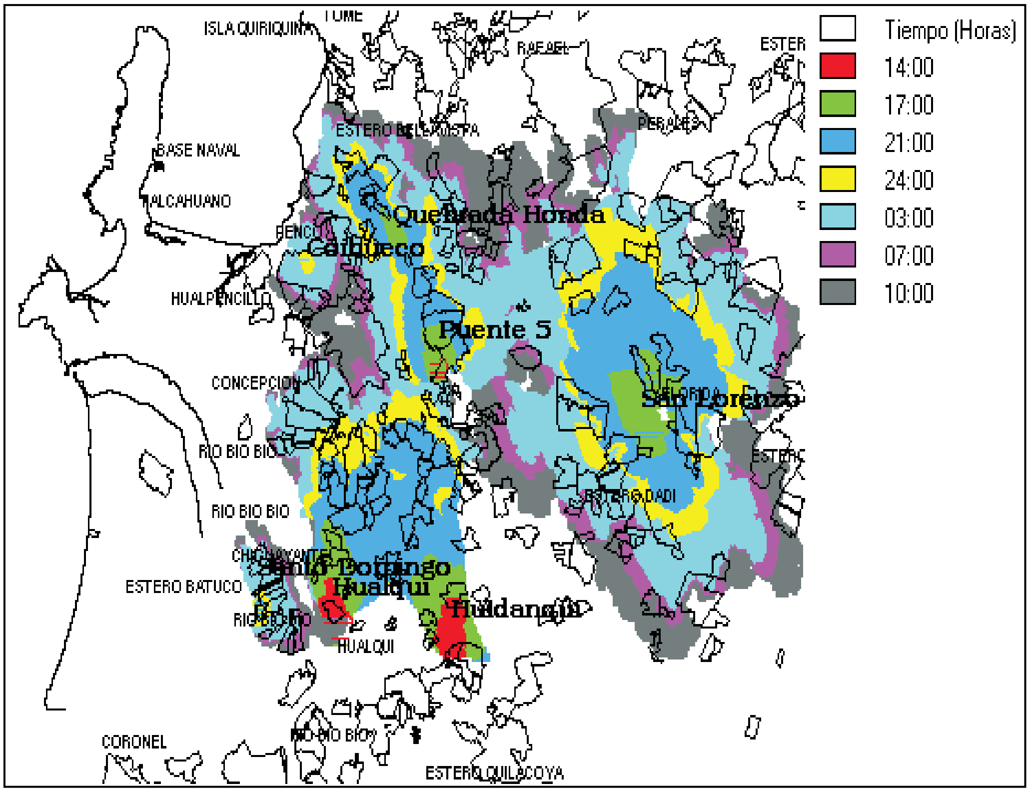

Figure 8— Global Situation at 10:00 on 8 February

The graphic shows that by 10:00 the fires had completely consumed the Trinitarias plot, leaving only a small interior section unaffected. With respect to the other fires in the area, by this time they had merged with the main fires and thus it is rather difficult to clearly evaluate the resulting image.

The project also called for the elaboration of a map showing the surface area affected by each of the fires, especially for the interior of the Trinitarias plot. This map made it possible to evaluate the final situation at the end of the simulation period, specifically to answer the question of how many fires affected the subject plot. The results of this evaluation are shown in Figure 9.

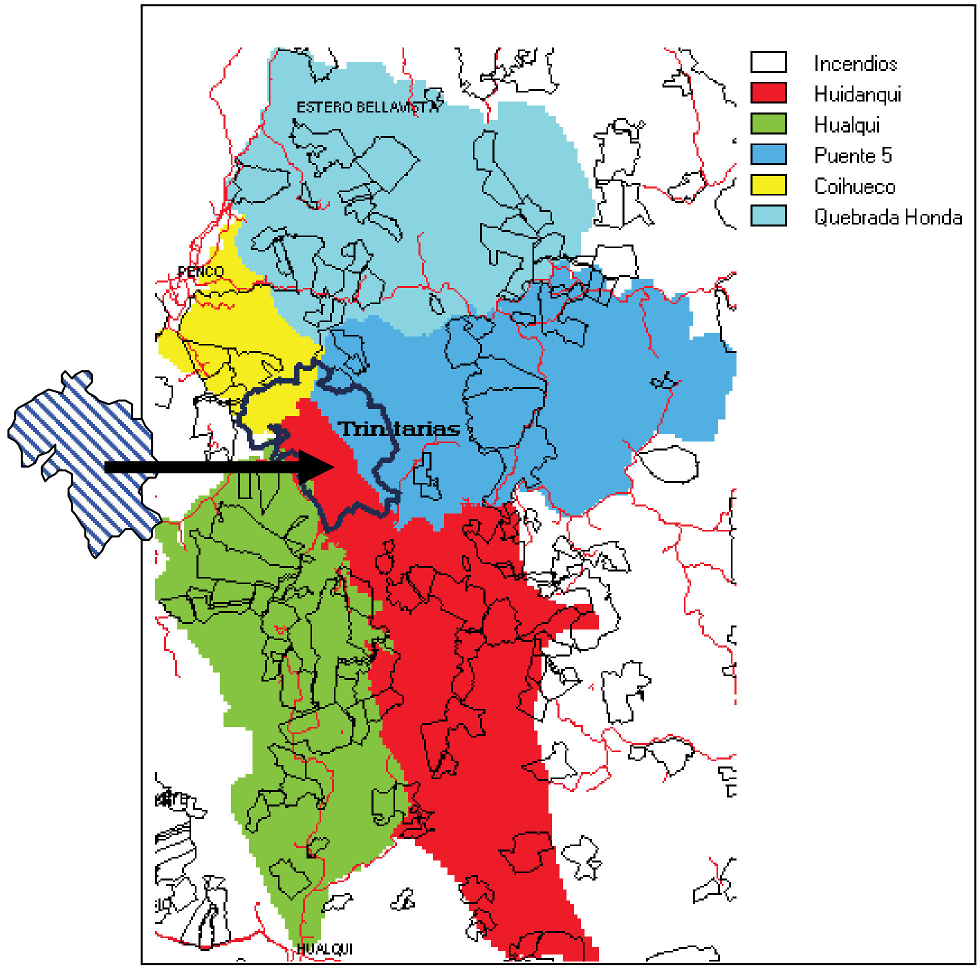

Figure 9—Areas burned by the fires affecting the Trinitarias plot. Each colour represents the area burned by each fire.

The figure, which was obtained by applying a calculation and assignment algorithm, shows that the Trinitarias plot was affected by three fires: Huidanqui in the south, Puente 5 in the east and Coihueco in the north, with 938, 735 and 441 ha of burned area respectively. Toward the southwest, a small sector of approximately 43 ha was left unharmed.

Final comments

From the data provided by the simulation it was possible to reconstruct the events in the Concepción area on 7 and 8 February 1999.

The San Lorenzo fire behaved inconsistently in the simulation, and therefore it was not possible to reach conclusions regarding its true behaviour. This situation could be explained by the lack of reliable data to introduce in the fire simulator, in particular regarding fuels.

Nevertheless, when the information entered is reliable, the post-fire simulation process does make it possible to confirm the observations registered in the field regarding the time the fires reached the subject plot. It was ultimately concluded that for this case study, the Trinitarias plot was affected by three fires, Huidanqui, Puente 5 and Coihueco, which caused damage in 938, 735 and 441 ha respectively.

Lastly, it is necessary to emphasize the performance of the KITRAL system forest fire expansion simulator, whose functional design is highly effective both for predicting how a fire will advance and for recreating true-life situations, as was done in the reconstruction of these large fires. Thanks to the speed with which the simulator provides results and the high degree of reliability, especially for large fires, the system represents an effective contribution to the quantification of damages caused by fire.

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