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Ignition probability of fine dead surface fuels in native Patagonia forests of Argentina

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Abstract

Aim of study: The Canadian Forest Fire Weather Index (FWI) is being implemented all over the world. This index is being adapted to the Argentinean ecosystems since the year 2000. With the objective of calibrating the Fine Fuel Moisture Code (FFMC) of the FWI system to Patagonian forests, we studied the relationship between ignition probability and fine dead surface fuel moisture content (MC) as an indicator of potential fire ignition.

Area of study: The study area is located in northwestern Patagonia, Argentina, and comprised two main forest types (cypress and ñire) grown under a Mediterranean climate, with a dry summer and precipitations during winter and autumn (~500-800 mm per year).

Material and methods: We conducted lab ignition tests fires to determine the threshold of fine dead fuel ignition at different MC levels. Moisture content of dead fine surface fuels in the field was measured every 10-15 days from November to March for three seasons. We calculated the FFMC during these seasons and correlated it with the measured MC by applying a logistic regression model. We combined the results of the ignition tests and of the regressions to suggest FFMC categories for estimating fire danger in Patagonian forests.

Main results: The ignition threshold occurred at MC values of 21.5 and 25.0% for cypress and ñire sites, respectively. The MC measured varied from 7.3 to 129.6%, and the calculated FFMC varied between 13.4 and 92.6. Highly significant regressions resulted when FFMC was related to MC. The ignition threshold corresponded to a FFMC = 85. We proposed to divide the FFMC scale in three fire danger categories: Low (FFMC ≤ 85), High (85 < FFMC≤89) and Extreme (FFMC > 89).

Research highlights: Our results provide a useful tool for predicting fire danger in these ecosystems, and are a contribution to the development of the Argentinean Fire Danger Rating and a reference for similar studies in other countries where the FWI is being implemented.

Key words: *Austrocedrus chilensis; Nothofagus antarctica;* wildfire; fire behavior; fuel moisture; fire weather index.

Introduction

In northwestern Patagonia in Argentina, vegetation of the forest-steppe region is dominated by forests mainly composed of cypress [*Austrocedrus chilensis* (D. Don) Pic.Serm. & Bizarri] and ñire [*Nothofagus antarctica* (G. Forst.) Oerst.]. Because of the ecological, productive, and scenic values of cypress forests, this species is considered as one of the most important native trees of northwestern Patagonia (Dimitri, 1972). Ñire forests, instead are heavily exploited as firewood and as grazing/browsing areas for sheep and cattle raising (Laclau, 1997). Cypress and ñire forests have historically been affected by different natural or human disturbances, such as earthquakes, high winds, herbivory, livestock grazing, timber and firewood extraction, and fragmentation for human settlement. Summer wildfires, however, are considered the most important disturbance affecting the structural and functional characteristics of these forests (Lantschner and Rusch, 2007). Related to fire disturbance, it is important to mention that these forests grow under a typical Mediterranean climate, in which most of the annual precipitation fell during autumn, winter and early spring, followed by a drought period during late spring and summer. As in any other Mediterranean ecosystem, this drought period generates favorable environmental conditions for, given an ignition source, the occurrence of wildfires of different magnitude. Although some extensions of cypress and ñire forests, protected within national and provincial parks, are in

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climax or near-climax conditions, the majority of these forests in the region correspond to post-fire stands of different ages that are opened to diverse human activities (Laclau, 1997). As a consequence of these activities and many times due to careless actions, wildfires burned 17,500 ha of these forests during the last fifteen years only in Chubut province of Patagonia. Of this total, 35% were cypress and 43% ñire forests and shrublands (Dirección General de Bosques y Parques de Chubut, 2010). To deal with this disturbance, provincial resource administrations and research organizations have dedicated their efforts not only at preventing and combating wildfires, but also to scientifically understand the processes involved in wildfire occurrence and development. Several research programs have been developed to understand these processes, which include from fuel ignition to fire development. Lately, several technological tools are being implemented to predict fire behavior based on the adaptation and application of several fire indexes.

Among all fuel characteristics and properties involved in fuel ignition (particle size, arrangement, chemical contents, etc.), water content of either live or dead tissues is one of the key factors determining the availability of a fuel to burn (Blackmarr, 1972; Ruiz *et al.*, 2009). The moisture content of a vegetal fuel, commonly termed as "fuel moisture content" (MC), is usually expressed as a percentage of dry weight of the plant material (Canadian Interagency Forest Fire Centre, 2002). In general, when MC rises, the amount of energy required for ignition also raises (Rothermel, 1972). Besides their MC, another important characteristic to be considered in ignition probability is the size and shape of the fuels. Fine dead fuels, for example (i.e. dead material whose diameter is lower than 0.6 cm), quickly respond to changes in their surrounding moisture conditions. This fact is mainly due to the high surface area to volume ratio that these types of fuels have. This is the reason why, shortly after a rainfall and if dry environmental conditions prevail, fine dead fuels may rapidly become dry and highly flammable (Cheney and Sullivan, 2008). As it happens in any other Mediterranean ecosystem of the world, these conditions occur during mid- to late summer in Andean Patagonian Forests. During this season, dry winds blow at very high speeds (Defossé, 1995) drying up fine fuels and contributing to high fire intensities and severities if wildfires occur.

The fine dead MC thresholds above which ignition seldom occurs and fire cannot be sustained is termed moisture of extinction (Rothermel, 1972). This value widely varies depending on the species and fuel type considered (small twigs, leaves, pine needles, etc.; (Blackmarr, 1972; De Groot *et al.*, 2005). The relationship between MC and ignition probability has been largely studied in grasslands (De Groot *et al.*, 2005), in surface litter of some forests (Tanskanen *et al.*, 2005; Fernandes *et al.*, 2008), in slash pine litter (Blackmarr, 1972) and in some shrublands (Plucinski and Anderson, 2008). However, no references exist about similar studies in northwestern Patagonian region. The determination of a possible relationship between MC and ignition probability in different ecosystems is not only important as a value by itself, but also because the MC is a basic component of all fire behavior models developed either in the USA (Rothermel, 1972; Burgan and Rothermel, 1984; Andrews, 1986; Andrews and Chase, 1989) or in Canada (Forestry Canada Fire Danger Group, 1992).

One of these models, the Canadian Forest Fire Danger Rating System (CFFDRS; Wotton, 2009), is composed of four subsystems, each one comprising the use of different variables in their respective calculation. One of the sub-systems of the CFFDRS is the Canadian Fire Weather Index (FWI). The FWI uses daily observations of temperature, relative humidity, wind speed, and 24-h accumulated rainfall to estimate the MC of dead fuels and fuel layers of forest soils for three fuel size classes (fine, medium and large fuels, Wotton, 2009). In the constitution of the FWI, fine dead surface fuels are represented by the Fine Fuel Moisture Code (FFMC; Van Wagner, 1987), while the Duff Moisture Code (DMC), and the Drought Code (DC) correspond to medium and large fuels, respectively (Forestry Canada Fire Danger Group, 1992). The FWI was developed using mature jack pine (*Pinus banksiana* Lamb.) and lodgepole pine (*Pinus contorta* Dougl. ex Loud.) as standard forest types (Van Wagner, 1987). However, dead fuels gain and lose water according to the same physical principles, and fire behavior respond in the same way all over the world to variations in fuel conditions, weather, and topography (Taylor and Alexander, 2006). These facts made that these moisture codes were adapted, used, and successfully implemented as relative indicators of fuel moisture in many different ecosystems throughout the world, such as in Canada, USA, New Zealand, Indonesia, Malaysia, China, Mexico, Portugal, and various other countries of southern Europe (Alexander and Cole, 2001; Raínha and Fernandes, 2002; Taylor and

Alexander, 2006; De Groot *et al.*, 2006; Tian *et al.*, 2011).

In Argentina, the CFFDRS is being adapted to its different ecosystems since the year 2000 (Taylor and Alexander, 2006). This process began with the implementation of the FWI sub-system (Dentoni *et al.*, 2007). Preliminary research based on fire statistics of large areas, without distinguishing fuel types, showed a good relationship between fire occurrence and FWI components (Dentoni *et al.*, 2006, 2007). However, output values of the FWI system still need to be calibrated to better indicate fire potential, since the dominant fuel types of this region are significantly different from the standard closed-canopy pine stand in which the FWI system was initially developed (De Groot *et al.*, 2005). Today, the research emphasis in this area in Argentina has been focused in fuel models development for its different ecosystems. The definition of fuel types for some Patagonian shrubland ecosystems constitutes the first results in this direction (Bianchi *et al.*, 2012). However, information about other basic factors used as inputs in this FWI system, such as the correct determination of each one of these codes is still scarce or null. For example and related to this, there is little or none information on ignition thresholds in the literature for Andean Patagonian ecosystems. Besides, the expertise in studying and modeling fire behavior through experimental burns (in which the determination of ignition thresholds is crucial) is still scarce in Argentina (Bianchi *et al.*, 2012; Kunst *et al.*, 2012).

In order to close this gap of information, small-scale experimental fires seems to be a good way to determine ignition thresholds for dead fine fuels in these two Patagonian forests. Small-scale, experimental test fires, modeling ignition processes, have been successfully applied in numerous researches in Canada and elsewhere using either laboratory apparatus or field ignition trials (De Groot *et al.*, 2005; Tanskanen *et al.*, 2005). These small experimental fires are inexpensive, can be conducted under controlled laboratory conditions, with minimal disruption of field site and with less risk (Frandsen, 1997; Beverly and Wotton, 2007), avoiding external factors influencing the ignition (mostly weather and site characteristics).

The aims of the present study were therefore: 1) to study the relationship between ignition probability and MC of fine dead surface fuels and, 2) to calibrate the FFMC as an indicator of potential fire ignition under cypress and ñire forests floors. Results here presented will be a useful tool for Patagonian fire managers, and a significant contribution to the implementation of the Argentine National Fire Danger Rating System. They will also add valuable information for comparison with similar studies developed in either Mediterranean or other ecosystems around the world.

Methods

The study was divided into two stages. The first one consisted in the determination of the threshold of fine dead fuel ignition based on its moisture content, and the other comprised correlating FFMC with the moisture content of fine dead surface fuels. Both results combined allowed to suggest FFMC categories that could be used for estimating fire danger in Patagonian Andean forests (De Groot *et al.*, 2005).

Species and study sites

The study area is located in the Chubut province in northwestern Patagonia, Argentina, in which ñire and cypress forests represent the main vegetation types. Annual average precipitation is about 500 mm in cypress forest, and could reach to 800 mm in ñire forests (Gyenge *et al.*, 2011). About 70% of the precipitation fall during autumn, winter and early spring. Summers are generally hot and dry, with a water deficit that increases in late summer (February-early March), when most big wildfires tend to occur. In this region, cypress and ñire forests grow in the Andean piedmont, limiting to the east with the Patagonian steppe, and conforming a long and narrow strip of about 2,000 km long and 80 km wide (Dimitri, 1972). Latitudinal distribution of cypress in Argentina goes from 37° S to 44°, covering around 140,000 ha (Secretaría de Ambiente y Desarrollo Sustentable, 2005) while ñire forests cover 750,000 ha, from the 37° LS to 56° LS (Dimitri, 1972; Secretaría de Ambiente y Desarrollo Sustentable, 2005; Gyenge *et al.*, 2011; Fig. 1). Specific study sites were selected in Los Cipreses (43° 14' S, 71° 34' W, 550 m above sea level) where cypress stands are, in average, 10-12 m height, with 1,100-1,325 trees · ha^{-1} and Basal Area = 44.2-60.4 $m^2 \cdot ha^{-1}$. Ñire stands in the same area averaged from 4-7 m in height, with 1,000-1,100 trees · ha^{-1}, Basal Area = 26.7-33.7 $m^2 \cdot ha^{-1}$. These are representative of the majority of post-fire ñire and cypress stands of Patagonia (Bianchi

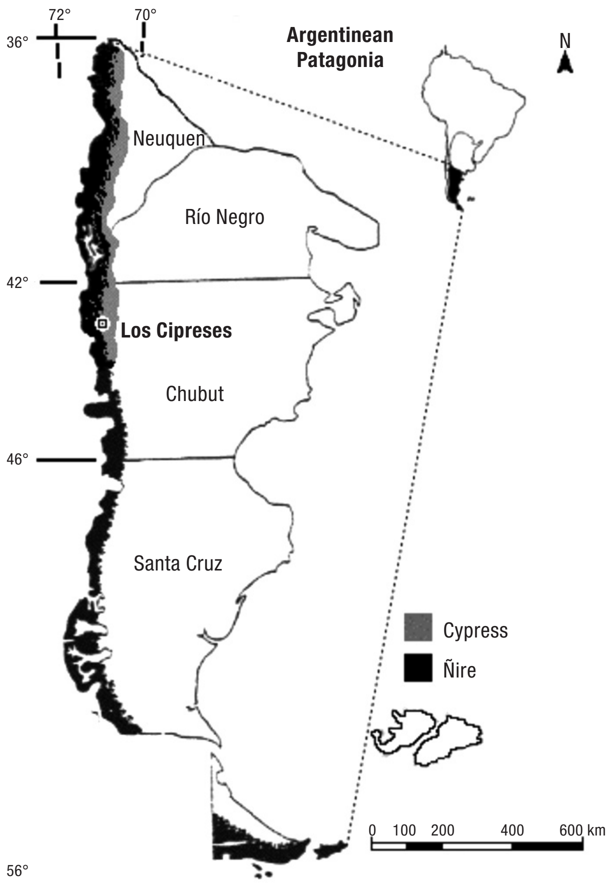

Figure 1. Location of ñire and cypress forests along the eastern piedmont of the Andes in Patagonia, Argentina, showing Los Cipreses study site. This site is representative of both forest structures grown in the Andean region.

et al., 2012). In both areas, litter in the forest floor is mainly composed of dead leaves and small twigs from the dominant cypress and ñire species, and in lesser proportion from those of the understory trees (*Maytenus boaria* Molina), radal [*Lomatia hirsuta* (Lam.) Diels ssp. Obliqua (Ruiz & Pav.) R. T. Penn.], the shrub laura [*Schinus patagonicus* (Phil.) I.M. Johnst. Ex Cabrera var. patagonicus], and the bamboo cane, caña colihue (*Chusquea culeou* E. Desv.). Dead biomass of herbaceous species is also present, but in so low proportions that may be considered as inconsequential in terms of fire danger. Average depth of the litter layer is between 1 and 3 cm and the duff layer is minimal or absent.

Fuel ignition tests

We conducted the ignition test fires in the CIEFAP Fire lab, at different moisture content levels (Wright, 1967; Blackmarr, 1972; De Groot *et al.*, 2005) and sheltered from wind. To conduct the tests we collected ~6 kg (fresh weight) of dead fallen vegetative material in a plastic bag. We randomly divided it in 60 samples of ~100 g (fresh weight) each. These samples were oven-dried at 100°C for 24 hours. Then, to attain specific moisture contents, we transferred the dried material to plastic bags and added water using a squeeze-type sprayer bottle. The amount of water added was determined by placing the sample bag over a digital balance and spraying water until the desired total weight was reached (based on the oven-dry weight and the required MC). The plastic bag was then sealed and placed in an oven at 50°C for 24 hours to ensure equal distribution of the moisture within the sample (Frandsen, 1997; De Groot *et al.*, 2005).

As we detected that in a few occasions after heavy rains, MC raised to values higher than 100% and to ensure that the range of MC during the tests surpassed the ignition threshold, we decided to determine, in a first step, an upper-limit of MC = 60%. We prepared the first set of 60 samples with MC ranging from 5% to 60% in 5% increments. Once we found the MC range of ignition, we prepared another set of 60 samples with MC values in 1 and 2% increments between the range for each species. To conduct the tests we removed the fuel sample from the plastic bag and placed it in a pile of about 25 cm in diameter. In less than 60 seconds, we lit a wooden match and dropped it around the center of the pile from a height of about 10 cm. If the match ignited a fire that spread to 25 cm linear within 1 min, it was considered a positive test and classed as "ignition". If the initial dropped match did not result in a positive test, a second match was dropped and then a third one was dropped if the second one failed. The ignition test was classed as "no-ignition" if the three matches failed to ignite the pile (De Groot *et al.*, 2005).

To define the probability of ignition based on MC, we classified the resulting data obtained in the ignition tests, as ignition (1) or no-ignition (0), and applied the following logistic regression model:

$$P(ign) = \frac{\exp\,(a + bMC)}{1 + \exp\,(a + bMC)}$$

where $P(ign)$ is the probability of ignition and MC the moisture content. We evaluated the goodness of fit of these models with the Nagelkerke R^2 statistic, the area under the ROC curve (c) and –2Log Likelihood statistics.

Moisture content and FFMC

We determined the MC of fine dead surface fuels during three fire seasons (2007-2008, 2009-2010 and 2011-2012), from November to March. Due to weather conditions, we sampled 12-14 times during the first season and 5-6 times in the other two. The main reason was that in order to correctly measuring MC, no liquid water should be present in fuels surface. When rainfall occurred (which happened during different periods in the last two seasons), sampling was postponed until the water over fuels surface disappeared. During each sampling date we collected ten samples of ~100 g (fresh weight) of fine surface fuels under ñire forests and other ten samples under cypress forests. We packed each sample in a hermetic bag and weighed it on terrain to obtain their fresh weight. We took the fuel samples to the lab and dried them at 100°C for 24 hours and reweighed them to obtain their dry weight. Then, we calculated the MC of each sample by applying the gravimetric method. Since MC data were not normally distributed (Shapiro-Wilk test, $p < 0.001$), for assessing whether moisture content means were different between both forest-types we applied the non-parametric Mann-Whitney U test.

The FFMC was calculated with weather data (temperature, relative humidity, wind speed and 24-h accumulated precipitation) registered by an automatic weather station (Vantage Pro2-Davis Instruments, Illinois, USA) installed at 2 km from the sampling sites. We tested the relationship between FFMC and MC by applying a four parameter logistic regression model (De Groot *et al.*, 2005), as follows:

$$FFMC = b_1 + \frac{b_2 - b_1}{1 + \exp\left(\dfrac{b_3 - MC}{b_4}\right)}$$

To evaluate the resulting regression models, we calculated the Pearson correlation coefficient between observed and predicted values. To adjust the model equation we used the *nls()* function of the R statistical software and the default algorithm of this function, which uses a form of Gauss-Newton iteration. We provided approximated initial parameters, and then the adjustment is done by the function through an iterative process (Fox and Weisberg, 2011).

All statistical analyses were conducted with the software R, version 2.15.2 (R Core Team, 2012).

Results

Fuel ignition tests

Highly significant logistic regression models were estimated for ñire, cypress, and for both sites combined (Table 1). The ignition probability in ñire litter increased from P(ign) = 0.01 at MC = 39.1% to P(ign) = 0.99 at MC = 11.0% with P(ign) = 0.50 occurring at MC = 25%. For cypress litter the ignition probability rose from P(ign) = 0.01 at MC = 37.4% to P(ign) = 0.99 at MC = 5.6% with P(ign) = 0.50 at MC = 21.5% (Fig. 2).

It is worth to note that the component of cypress litter that carry the fire are its small twigs, since leaves from this tree can burn but not spread the fire. To test this, we repeated the ignition tests 15 times, but eliminating all twigs from the pile. During these tests, MC ranged from 4% to 20% and even though the ignition occurred, fire did not propagate, unless light winds were simulated with a small portable fan.

Moisture content and FFMC

The MC of litter measured in the field during the three seasons, ranged from 7.3 to 129.6% in ñire sites, and from 8.6 to 111.1% in cypress sites. A comparison of the MC medians of both sites showed that they

Table 1. The estimated parameters (p-value < 0.001) and their corresponding standard error indicated between parentheses of the logistic regression between probability of ignition and fine dead surface fuel moisture content for both forest types combined, for ñire sites and for cypress sites. Ignition tests were classified as ignintion (1) or no-ignition (0). The goodness of fit was measured with the Nagelkerke R^2 statistic, the area under the ROC curve (c) and –2Log Likelihood statistics

Species	a	b	Naelkerle R^2	c	–2Log likelihood
Both sites	6.65 (1.03)	–0.28 (0.04)	0.74	0.94	126.05
Ñire sites	6.47 (1.44)	–0.22 (0.05)	0.80	0.96	68.80
Cypress sites	5.13 (1.26)	–0.24 (0.06)	0.78	0.95	51.55

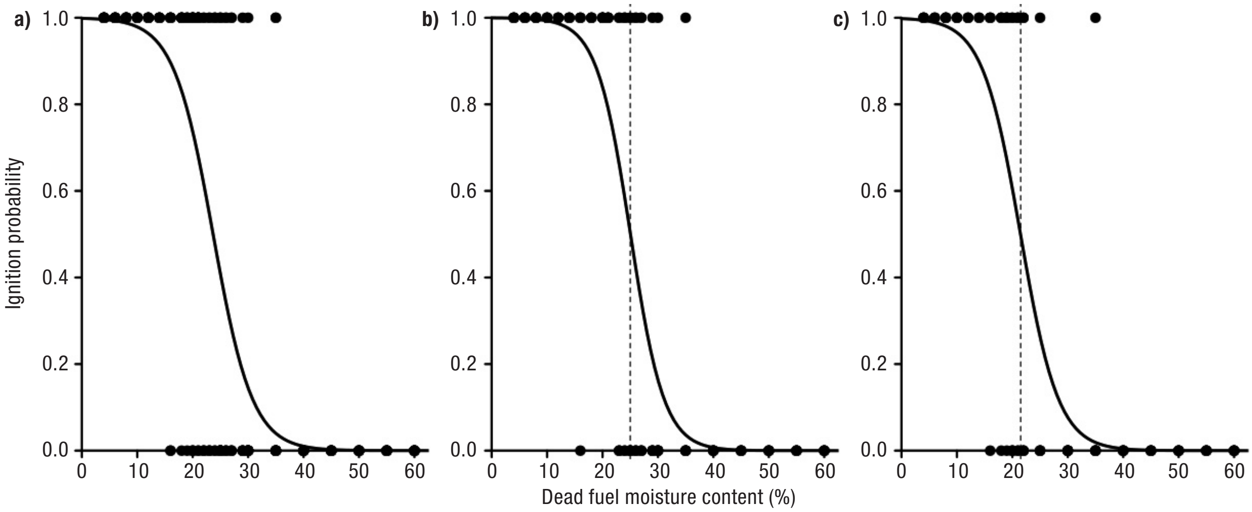

Figure 2. Plots of the logistic regression model (solid line) showing ignition probability against fine dead surface fuel by moisture content, points represents Ignition (1) and no-ignition (0) results and dotted line represent values of moisture content at which ignition probability = 50%. (a) Both study sites combined, (b) ñire (*Nothofagus antarctica*) sites and (c) cypress (*Austrocedrus chilensis*) sites.

were non-significantly different (Mann-Whitney U-test, *p*-value = 0.993). However, MC median was slightly higher in ñire (median = 23.5, mean = 35.4, sd = 20.3) than in cypress sites (median = 20.7, mean = 30.8, sd = 20.7; Fig. 3).

During the three seasons, FFMC ranged from 13.4 to 92.6. Twenty five percent of the days the FFMC was lower than 76, the median was 85, and 25% of the days FFMC was higher than 88. As moisture content increased, FFMC decreased and vice-versa, with an asymptote at higher values of FFMC (Table 2, Fig. 4).

FFMC fire danger scale

Based on the results obtained during the ignition tests, and relating the FFMC code calculated with weather data and the moisture content measured, we propose that the scale of FFMC should be divided in three categories: Low, High and Extreme fire danger. Based on this proposal, the upper limit for the Low category will correspond to FFMC≤85, which according to the regression models can be related to a MC = 38-39%. As the ignition tests showed, at these levels of

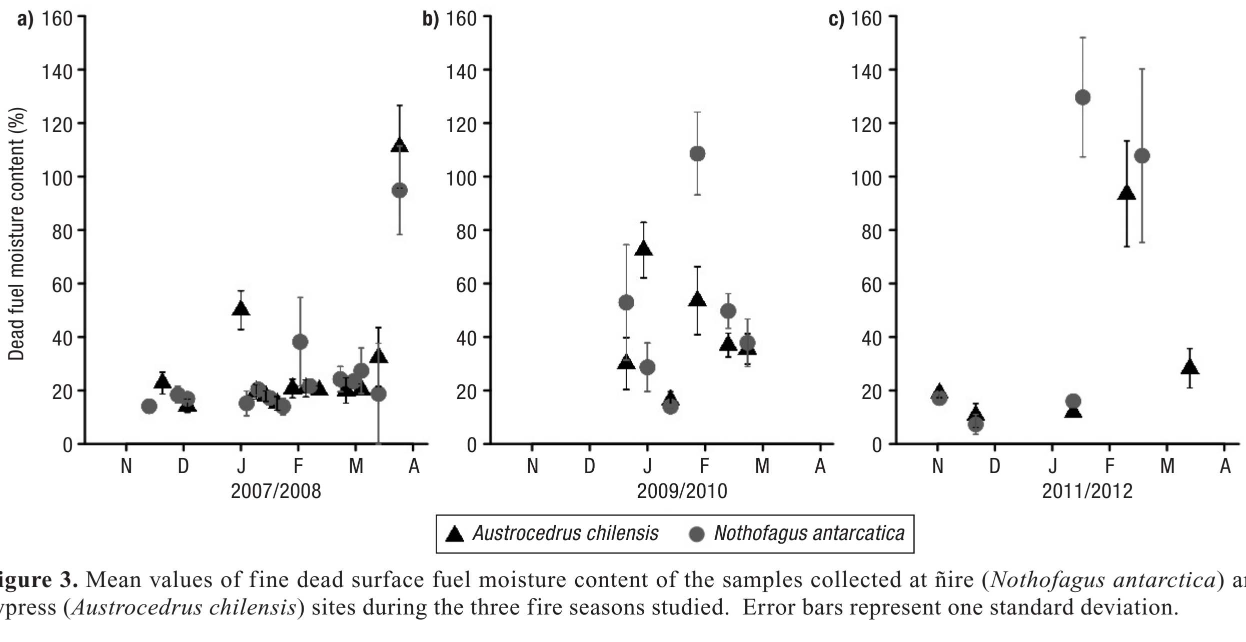

Figure 3. Mean values of fine dead surface fuel moisture content of the samples collected at ñire (*Nothofagus antarctica*) and cypress (*Austrocedrus chilensis*) sites during the three fire seasons studied. Error bars represent one standard deviation.

Table 2. The four parameters of the regression model between FFMC and fine dead surface fuel moisture content with their corresponding standard error indicated in parentheses. The models were valuated with the Pearson correlation coefficients (*r*) between observed and predicted values for each model (*p*-value < 0.001)

Species	b1	b2	b3	b4	*r*
Both sites combined	87.44 (0.32)	58.47 (0.95)	61.25 (1.58)	6.49 (1.02)	0.83
Ñire sites	87.05 (0.61)	61.25 (1.59)	69.26 (3.35)	8.31 (2.91)	0.73
Cypress sites	88.90 (0.64)	47.34 (2.61)	68.74 (2.28)	13.22 (1.78)	0.88

MC fire ignition and propagation probabilities are very low and most of the fires will occur at higher FFMC values (lower moisture content). The lower limit for the Extreme fire danger category that we propose will be FFMC > 89. This value can be associated with a MC = 6-11%. According to the ignition tests we conducted, these values of MC indicate that fires will ignite and spread very rapidly. Values in category High, between FFMC > 85 and FFMC ≤ 89, would indicate that the MC is low and fuel ignition could occur, but fire propagation would be moderate. According to the FFMC calculated for the three seasons, danger would be categorized as Low 49.2% of the days, as High 34.3% of the days and as Extreme 16.5% of the days during a fire season.

Discussion

The ignition tests showed that fires will start and spread under cypress and ñire forests when litter moisture content is below 21.5 to 25.0%, respectively. These thresholds values are similar to those found in other forests litter. For example, a MC = 16-18% was found in mixed pine litter, and MC = 19-29% in red pine litter (Wright, 1967). Moisture contents of 16-20% and 22.7% were reported for litter of different *Eucalyptus* spp. (Plucinski and Anderson, 2008), while MC = 18-30% were reported in slash pine litter (Blackmarr, 1972). In laboratory tests with litter of *Pinus pinaster*, marginal fire propagation was reported at MC = 27% (Gillon *et al.*, 1995). A few results presented higher threshold values. For example, MC~30% was registered in litter of *P. radiata* (Woodman and Rawson, 1982) and MC = 35% was registered to be the threshold for self-sustaining fires in *P. pinaster* with an *Ulex minor* understory in northern Portugal (Fernandes *et al.*, 2008). Research in grass-type fuels reported higher thresholds values of MC for ignition, ~35% for tropical grassland fuels (De Groot *et al.*, 2005) and MC ~ 70% in Tasmanian buttongrass moorlands (Marsden-Smedley and Catchpole, 1995).

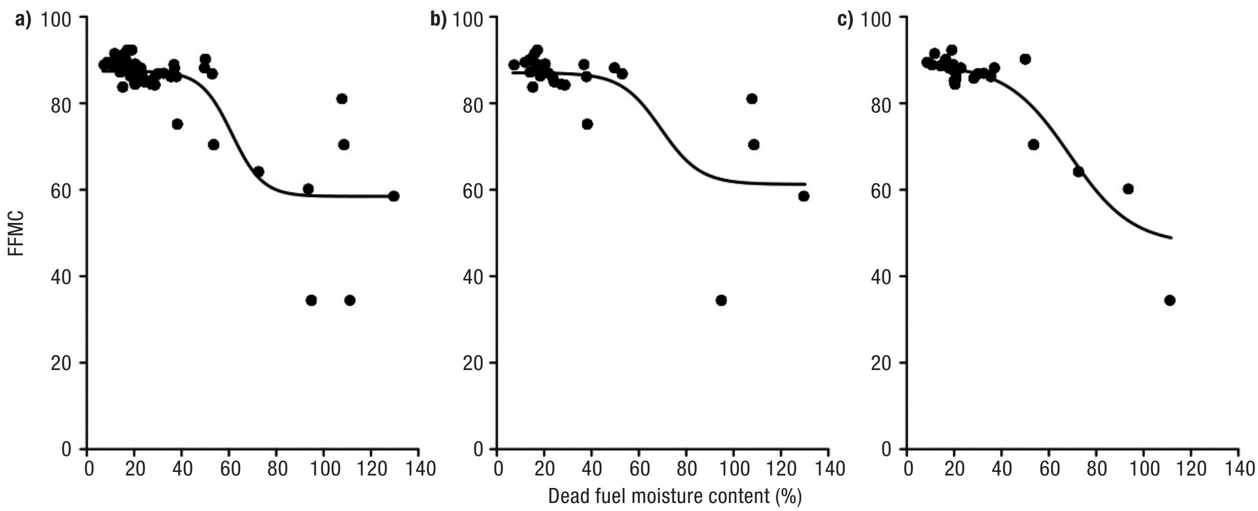

Figure 4. Plots of the four parameter logistic regression model (solid line) relating fine dead surface fuel moisture content and the Fine Fuel Moisture Code (FFMC). (a) Both study sites combined, (b) ñire (*Nothofagus antarctica*) sites and (c) cypress (*Austrocedrus chilensis*) sites.

Fuel moisture content variability was higher in ñire sites than in cypress sites. Ñire stands are more open than cypress stands, and show a random pattern of tree distribution. Cypress forests, instead, show a regular pattern of distribution and have denser canopy cover. These differences could imply that the effects of sunlight and wind, and rain interception and distribution are very variable in the forest floor of ñire stands, and more regular and less variable in cypress sites. This variability in MC, was undoubtedly influenced by these meteorological conditions, and might have introduced some errors when combined study sites models are applied.

It has to be highlighted that the proposed FFMC fire danger scale can be used in the ecosystems where this study was carried out, and with some caution and mainly for comparison in those whose climatic and structural characteristics are similar. The development of FFMC fire danger scale at national level requires new similar studies and validations of the models for each ecosystem. However, fire managers might use the danger scale obtained in the present study, as a tool which would permit to have a brief description of the potential fire occurrence in these widely distributed cypress and ñire forests. We found for this region that when FFMC > 85, conditions are critical for fire initiation and spread. Values of FFMC = 75 (Cheney and Sullivan, 2008), FFMC = 81-83.3 (De Groot *et al.*, 2005), FFMC > 82 (Amiro *et al.*, 2004) and FFMC ≥ 85 (Tian *et al.*, 2011) were defined in other ecosystems as thresholds for fire spread. The FFMC value corresponding to the upper-limit of the lower category defined for the fire danger scale can be related with the results of Dentoni *et al.,* (2006), who analyzed a total of 1882 hot-spots occurred during eleven seasons (1994-2005) in the Andean Patagonian ecosystems. They found that 90% of the hot-spots occurred when FFMC ≥ 85. Although this fire danger scale could represent a valuable tool, it should be complemented with more information (wind speed, topography, etc.) for an accurate assessment of fire danger. While the results here presented could be generalized to other post-fire ñire and cypress forests with similar stand characteristics, caution should be taken when trying to generalize these results to older ñire or cypress stands in- or near- their climax conditions (*i.e.* within National Parks). In these cases, differences in fuel bed loads could lead to different results. This caution could also be extended to other Mediterranean ecosystems with dissimilar stand characteristics.

Conclusions

The results showed that FFMC reflects fine dead surface fuel moisture content and that it can be associated to fire ignition in this region. Besides, the proposed calibration of FFMC presented in this study will provide fire managers with a valuable tool. However, further research would be necessary to complement the results here presented and conduct similar studies to calibrate the DMC and the DC (De Groot *et al.*, 2006; Taylor and Alexander, 2006). The way wind speed affects fire spread has not yet been analyzed for the forests studied. In this sense we found that cypress litter, when it is composed only of leaves, configuring a compact, dense layer, can only sustain ignition, but will carry the fire under the influence of wind. For this reason, more information and probably specific research including the Initial Spread Index (ISI), component of the FWI System, will be required in the near future. Our results are encouraging for further research, and especially in those regions sharing similar Mediterranean characteristics. In other regions of Argentina, this study should be replicated in other fuel types (forests, grasslands, shrublands), to accompany the development of fuel models as a contribution to the adaptation of the CFFDRS to Argentinean ecosystems and to the development of the Argentinean National Fire Danger Rating System.

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