HUMAN AND ENVIRONMENTAL FACTORS INFLUENCING FIRE TRENDS IN DIFFERENT FOREST ECOSYSTEMS

Rosa María Román Cuesta
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Memoria presentada por

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para optar al grado de doctor

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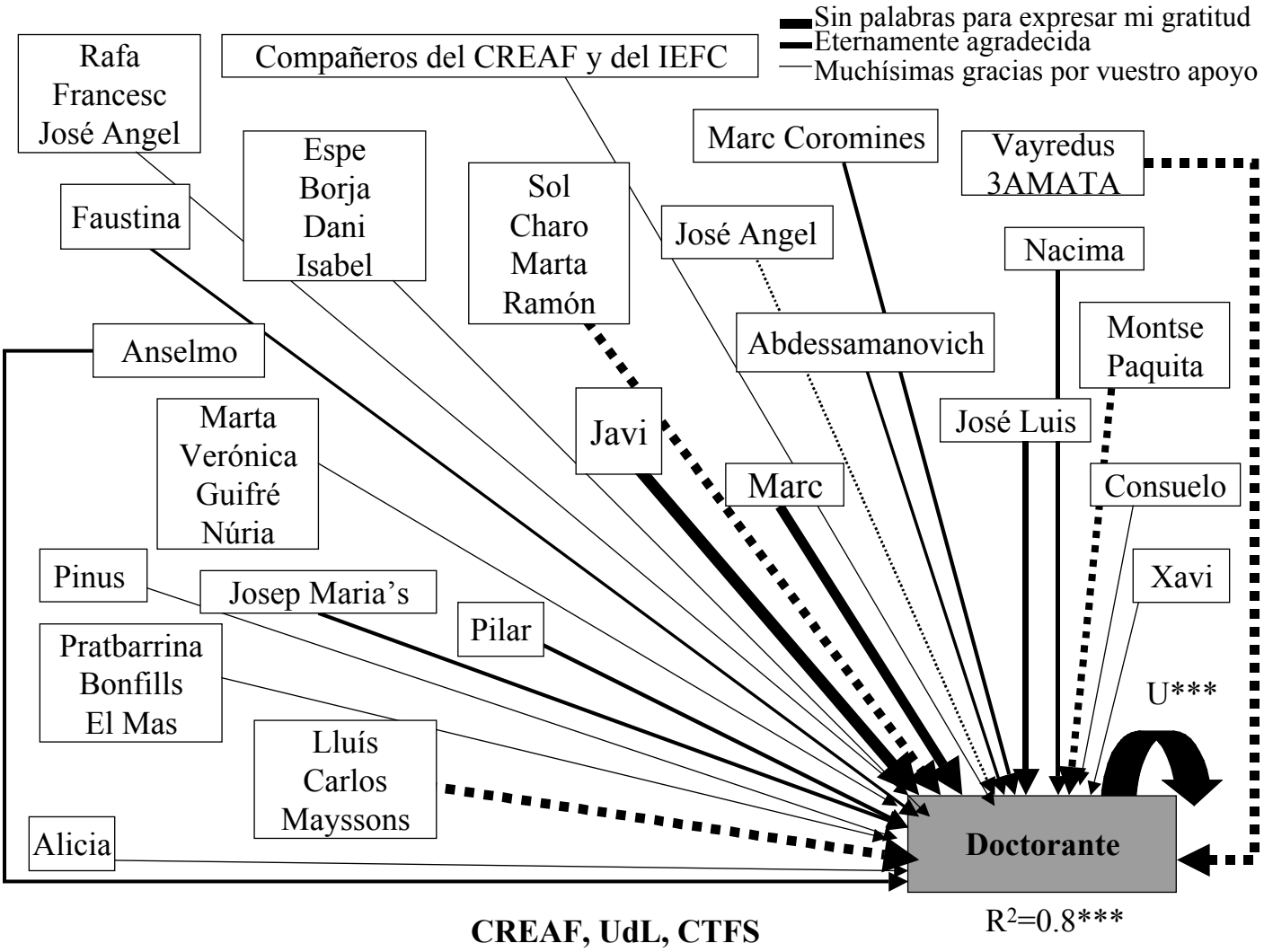
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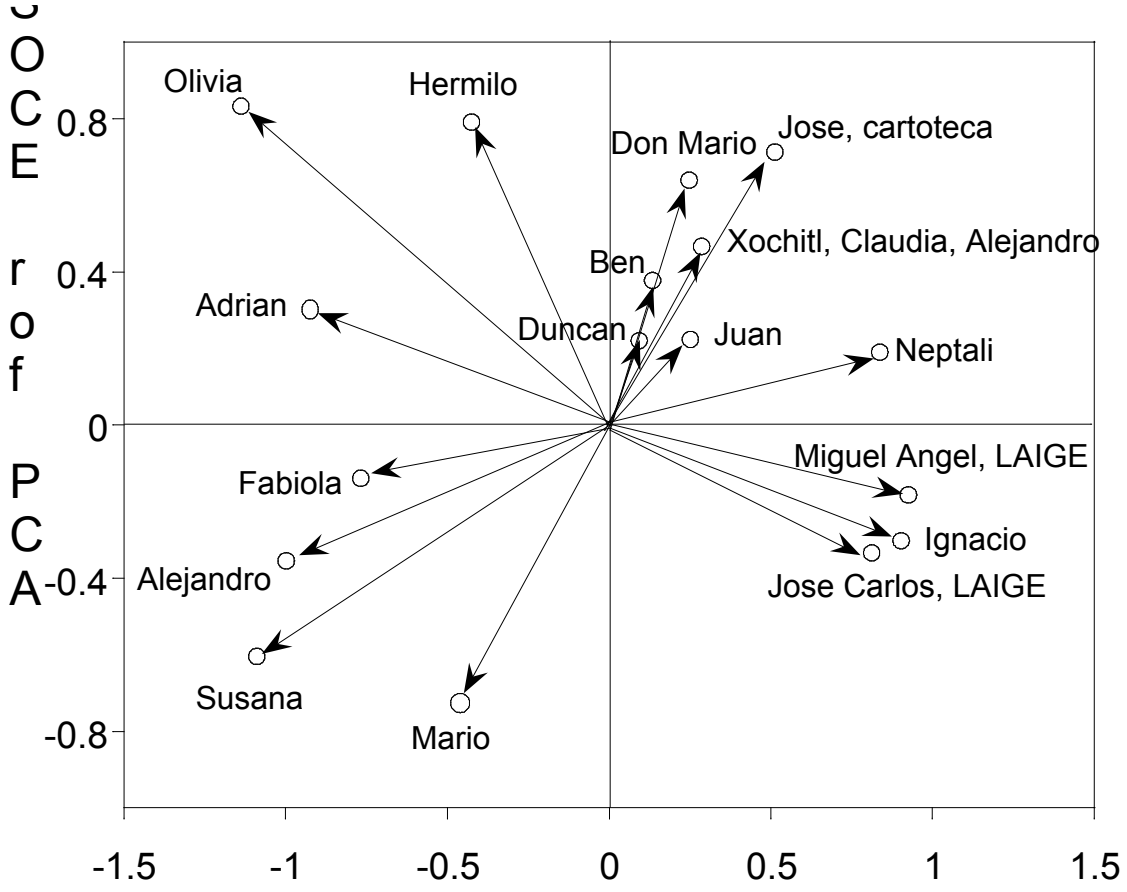

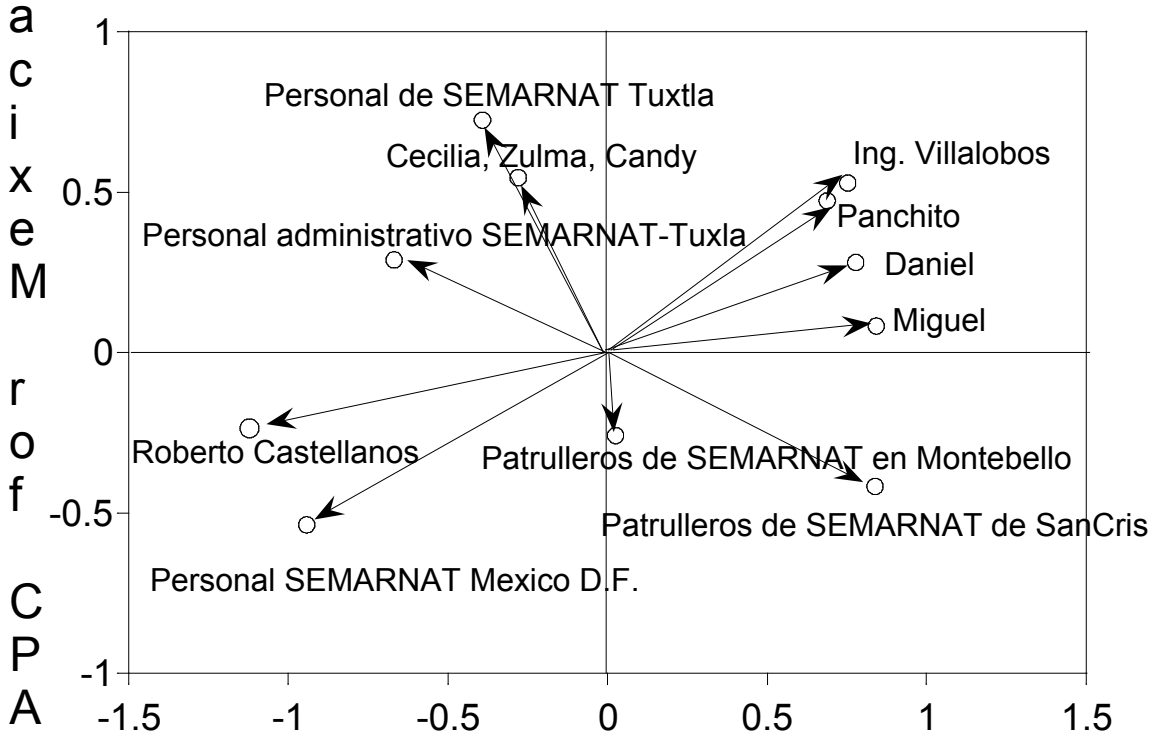

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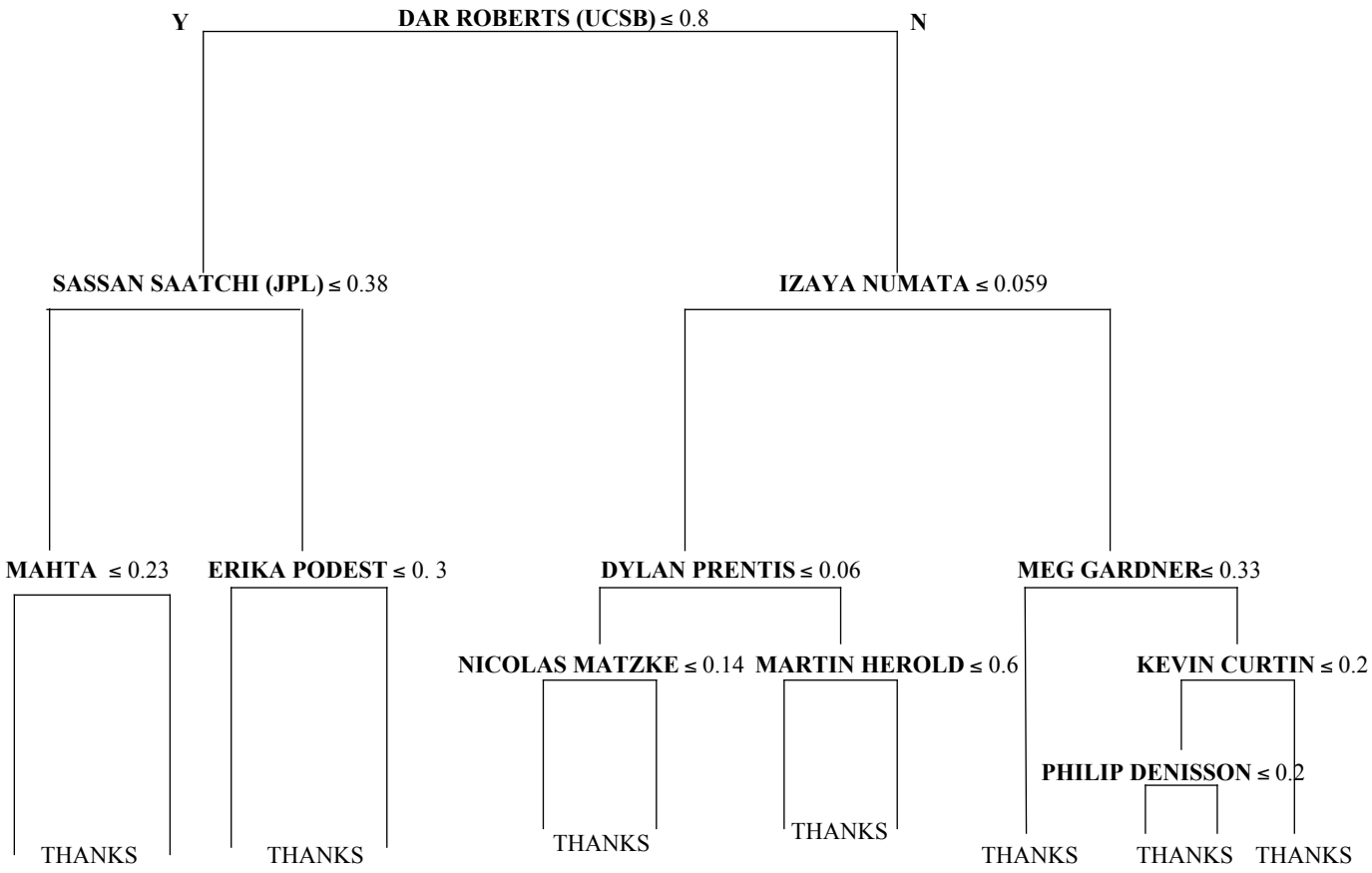

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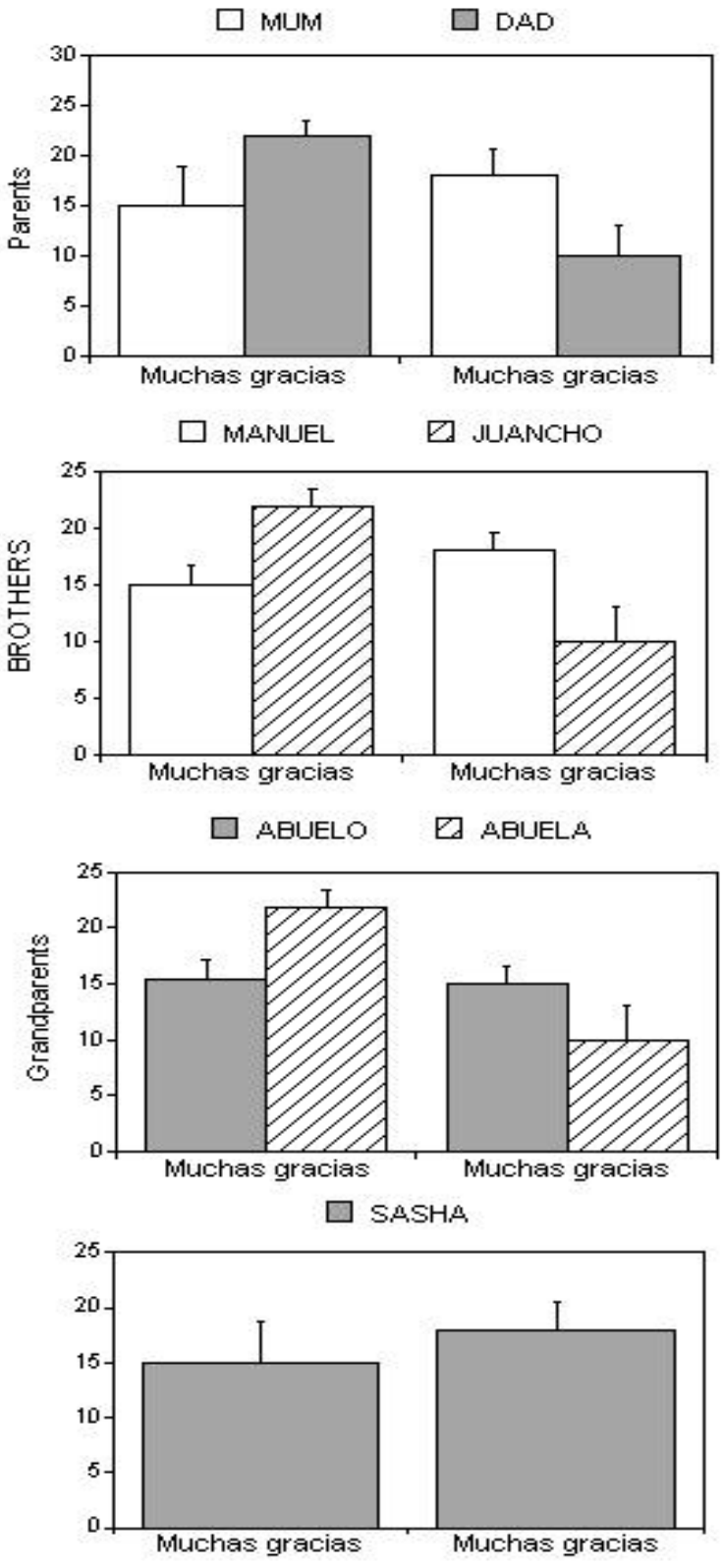
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RELATIVES

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GENERAL INTRODUCTION

Forest ecosystems and fire

The great majority of the forests of the world, excepting perhaps, the wettest belt of the tropics, have been burned over, at more or less frequent intervals for many thousands of years (Spurr and Barnes 1973). Even tropical fires, where the natural humid conditions were thought to preclude fire, have been suffering from periodic forest fires (Saldarriaga and West 1986, Meggers 1994). In the last century however, a combination of human and environmental factors have altered the frequency and distribution of fire, almost everywhere (Pyne 1995). This maldistribution of fire has resulted in an accumulation of this element in ecosystems not adapted to high frequencies of fire (i.e. tropical and sub-tropical areas) (Cochrane et al. 1999, Goldammer 1999, Nepstad et al. 1999), while other ecosystems have suffered the effects of fire suppression policies (i.e. north American temperate forests) (Brown 1983, Fuli et al. 1997).

Among the consequences of these alterations, one refers to changes in the fire regime of several ecosystems: from frequent, low intensity and small fires, to a higher presence of more sporadic, high intensity and large forest fires. These changes in fire trends, and especially the growing importance of large forest fires are related to a series of stressors, where humans play a major role. Among the non-human factors, climate has an important effect on fire at different scales. From a macro-scale perspective, El Niño-Southern Oscillation (ENSO) phenomenon, accounts as a major disturbing factor. Thus, ENSO seasons are characterized by altering the rainfall conditions of many areas of the world, either excluding rain in usually wet areas (Malingreau et al. 1985, Uhl and Kauffman 1990, Cochrane et al. 1999), or enhancing rain in usually dry areas (i.e. greening and flowering of deserts, Holmgren et al. 2001). The role of ENSO has, moreover, a key importance, as it has been suggested that it will increase in frequency and severity, under global warming conditions (Timmermann et al. 1999). From a meso-scale climatic perspective, specific synoptic conditions have been reported to lead to severe fire episodes (Millán et al. 1998). At a micro-scale climatic perspective, variations of wind, temperature and air humidity are responsible for a major part of the resulting heterogeneity of fire severity in the landscape (Bessie and Johnson 1995, Turner et al. 1999, Keeley and Fortheringham 2001). In regard of the human related stressors, fuel alteration, modifications of the landscape patterns, and active fire suppression or fire enhancement policies, are some of the consequences of changes in economical, social and traditional life-styles (Pausas and Vallejo 1999). Among them, the importance of fuels as a factor that influences fire trends -in the long term temporal scale-, and fire severity -in the short term temporal scale-, has long been reported and it constitutes the goal of fuel management (Finney 2001). Thus, larger fuel loads, higher vertical and horizontal continuities and the development of less diverse forests (monospecific tendencies associated to the reduction of disturbances), have lead to the establishment of “unnormal fuel buildups” in some ecosystems (Brown 1983). These fuel trends have lead to lower landscape diversities, and more homogeneous, connected and fire-prone landscapes, where fire patterns depend on the degree of fragmentation and the arrangement of the inner patches (Miller and Urban 2000). At this broader landscape level, the interaction of human activities with environmental patterns, is easily detectable. Thus, some land covers are more frequently found at given topographic locations, where there exist particular microclimatic conditions (i.e. northern aspects versus southern aspects, or higher altitudes versus lower altitudes).

These mentioned environmental and human stresses, and their interactions, let us visualize the wide range of factors that influence fire trends. The understanding of these interactions would be difficulted if other points were considered, such as i) the own ecological complexity, resilience and adaptation to fire of each studied ecosystem, and ii) the establishment of non-linear interactions between fire and the some stressors (i.e. positive feedbacks in the frequency and intensity of fires in tropical forests Goldammer et al. (1999); synergistic interactions between tropical forests and surrounding land covers (i.e. logged forests surrounding tropical remnants Holdsworth and Uhl (1997); or fragmentation processes and fire Cochrane (2001), Cochrane and Laurance (2002).

Different scales in the analysis of fire trends

The revision of ecological patterns can be affronted from different spatial and temporal scales. The selection of the correct scale is a key factor to properly adjust to the research question, and to lead to the correct conclusions. Several factors influence the selection of the scale, among them, the objective of each study is an important conditioner. The complexity of the area under study will also affect the optimum scale of measurement, to adequately represent the phenomenon under study. Low scales are adequate for detailed and intensive revisions of ecological processes at relatively low levels of ecological complexity (i.e. species or populations), but they are time-consuming and expensive methodologies that are unaffordable for large areas. Field Surveys are among the most used methodologies at these low scales. The detailed level of information of these field surveys, combined with their elevated costs and time requirements, makes this method suitable only for very specific (local) situations (Koutsias et al. 1999). Conversely, broader scales offer information about wider processes and patterns, and are more adequate for analysis regarding the heterogeneity of the landscape or the variability of the spatial processes. However, they lack spatial detail and are not appropriate for characterizing the interactions among lower complexity levels (i.e. species level). Among the available tools to investigate broad scale patterns, the use of Geographic Information Systems and remote sensing imagery, appear as two of the best allies. The later development of these techniques has helped the rapid evolution of landscape research, favoring a tendency towards regional, broader scales (Caley and Schluter 1997, Angermeier and Winston 1998). The analysis of fire trends has largely relied on these digital information tools (Justice et al. 1993, Chuvieco et al. 1999).

The combination of these contrasted scales, enriches any ecological research, offering the possibility of integrating diverse perspectives of a similar problem. In the case of fire research, this combination of spatial scales allows a better understanding of the diversity of factors that alter fire trends, and the variety of responses that appear at different scales.

Objectives and structure of the thesis

There exists an extense bibliography that deals with the effects of individual stressors on the resulting fire trends. However, less effort has been done to characterize the relative importance of these factors when they are all considered together. This study will analyse human and environmental factors affecting fire

patterns in two contrasted ecosystems (i.e. Mediterranean and tropical ecosystems). Strength will be given to the landscape scale as it offers a good perspective of the characteristics of these factors and their spatial variations. Narrower will also be considered for those factors that require more intensive research, such as fuels and forest structure. This work is constituted by five chapters, in the format of independent scientific papers. The first two chapters will revise fire trends in the tropical Mexican State of Chiapas, as a case study of these biomes. Chapters 3 to 5 will focus on the resulting fire severity characteristics of a Mediterranean large forest fire occurred in north-eastern Spain, in 1998.

Chapter 1 revises the spatio-temporal variations of fire trends in the southern tropical state of Chiapas. This study represents a first approach to the problem of fire in this state, where, although fire is recognized as a major disturbance, little has been done to quantify and characterize its impacts, nor to identify the factors that lead to that fire situation. The availability of a fire data set obtained from the Mexican Department of the Environment and Natural Resources (SEMARNAT), offers an interesting opportunity to frame this ecological study. A description of fire trends is given, comparing it to the trends of the rest of the Mexican Republic. Fire regime is described in terms of fire sizes and types of fires. Among the factors revised, Chiapas' fire trends are related to variations in rainfall, ENSO variability, fire causality, vegetation flammability, or more socio-economical aspects, such as land tenure. Its results can serve as the basis for future forest management that takes into account the important role of fire in Chiapas ecosystems.

In Chapter 2, a further step is given in order to determine how potential factors affecting fire trends in Chiapas, are influenced by the presence or absence of a strong El Niño-Southern Oscillation (ENSO) episode. An extense and severe fire season during the 1998 ENSO episode suggested the need to revise this factor independently. Three major groups of variables are revised at a municipal scale, for the period of 1993-1999: fire variables (i.e. number of incidences and extent of fires), environmental variables (i.e. rainfall, temperature, diverse land covers) and human-related variables (i.e. poverty levels, density of infrastructures). Causal relationships are searched among these three groups of variables, by means of path analysis. We hypothesize that there will be a shift in the relative importance of the major factors determining fire trends (environmental versus human-related), depending on the existence of ENSO conditions or not. The special sensitivity of rainforests to the presence of fire, and its severe affectation by ENSO droughts, justifies the revision of these factors and will improve management strategies to preserve some of the southern tropical forests of Mexico.

Chapter 3 initiates the studies in a Mediterranean ambience. Due to the importance of large forest fires in these areas, it is important to quickly and efficiently evaluate fire effects in the affected areas. There is a long list of potential methodologies to survey burned areas, but little effort has been done to establish quantitative comparisons among these techniques to determine the most accurate one. To address this deficiency, this study quantitatively evaluates the accuracy and potentials of two broad methodologies: a field survey and four satellite-based techniques (spectral unmixing, vegetation indices, texture and raw reflectance data). Three pure classes were determined by means of a Maximum Likelihood classifier: burned area, unburned vegetation, and soil; and a non-pure class: mixed area. As a further step, classified images

obtained by each methodologies are included into a tree classifier, in order to investigate their partial contribution to the classification process. The revision of the potentials and limitations of each technique enlightens about future problems that one can come across in burned land classifications. It will also guide about the most efficient technique for post-fire assessment, by means of remote sensing techniques.

In Chapter 4, a revision is made of three major factors that potentially affect the characteristics of unburned islands within the fire perimeter. Unburned islands play a major role in all fires, due to their ecological implications in diverse post-fire processes (i.e. seedling distribution, regeneration patterns, fauna redistribution). This chapter relies on the results of Chapter 3, as the classified map obtained by the best performing technique, is used to identify unburned islands. The general study area focuses on the same large forest fire employed in the previous analysis, but the spatial unit of this study diminishes. Thus, slopes with different aspects are categorized as the individual units, by means of a GIS system. “Slopes” are selected as the final landscape unit, due to the importance of microclimatic conditions associated to slopes with different aspects (i.e. north versus south). Topographic features (i.e. aspect, slope), land cover types, and landscape indices are considered as predictor factors of island formation (incidence) and island area. To test the importance of these factors, some general parametric and non-parametric tests are applied. As a further step, classification trees are used to determine the relative weight of each individual factor in the formation of islands (number and area). We hypothesize that the spatial distribution of unburned islands within the fire area does not follow a random pattern, but it will be spatially conditioned by some of our selected factors. The relevance of this study relies on the elaboration of potential management tools to design less fire-prone landscapes, to alter fire advance and to enhance forest survival.

Once the formation of green islands inside the fire perimeter is revised, Chapter 5 analyzes if the structural characteristics of the forests (size factors and fuel continuity) influences the heterogeneity of fire severity. Even though several authors have denied the role of fuels under severe meteorological conditions, fuels represent the major interest from the point of view of forest management, because they are the major factor that can be modified by humans. For this purpose, the spatial scale of this large Mediterranean fire is reduced to two nearby zones (slopes) where fire was affected by similar meteorological (i.e. wind) and topographic conditions. Several plots were established within each slope. A revision of forest structure was then made at a plot and at a tree level. The importance of differentiating between these two spatial levels relies on their different management objectives. Thus, results of the plot level offer information about those forest structures leading to less fuel hazard (i.e. even-aged versus uneven-aged), while the tree level indicate those individual characteristics of trees that enhance its survival. Three categories of fire severity are considered: green, charred, and toasted plots/trees (these last category was affected by radiant heating). Results offered by this study inform whether fuel structure conditions fire behavior in a Mediterranean fire, under moderate weather conditions. It also reaffirms the key role of preventive fuel treatments, as powerful tools to avoid fire ignition, and to difficult the advance of fire in the case it develops.

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