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Competition-induced mortality for Mediterranean *Pinus pinaster* Ait. and *P. sylvestris* L.

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Abstract

A logistic model for determining the probability of survival in the next 5-year period of two of the main species in the Mediterranean area in Spain, Mediterranean maritime pine (*Pinus pinaster* Ait.) and Scots pine (*Pinus sylvestris* L.), is presented. Data were supplied by the Forest Research Centre of the National Institute of Agricultural and Food Research (INIA) of Spain, consisting of a Permanent Sample Plot network (PSP) covering different stand conditions. In this study, 84 plots for Mediterranean maritime pine and 74 plots for Scots pine were used. Several models were tested. Variables concerning tree size, competition and social position of the tree were introduced in stepwise selection. The ratio diameter at breast height versus quadratic mean diameter and the interaction basal area-site index resulted as the most significant variables in the case of Mediterranean maritime pine. For Scots pine, the most significant variables were site index, DBH^{-1} and the interaction between basal area of larger trees and the coefficient of variation of the DBH distribution as a surrogate of structure. Results indicate that competition, tree size and social position within the stand are present in the survival process of both species. One-sided competition in highly structured stands for Scots pine and two-sided competition for Mediterranean maritime pine, are shown to be also important. Model evaluation has been done with data from the PSP not used in the fitting process. The area under the Receiver Operating Characteristic curve is 0.86 for Mediterranean maritime pine and 0.85 for Scots pine. The overall predicted rates of survival and mortality are shown for different cut-off points, indicating that the use of random uniform numbers yields better results. Afterwards, the performance of the model in thinned stands is tested for both species. Results for Mediterranean maritime pine show that it is appropriate to use the same model both for unthinned and thinned stands. However, a new model should be fitted for thinned Scots pine stands.

Keywords: Logistic model; Competition; Survival; *Pinus pinaster*; *Pinus sylvestris*; Mediterranean forest

1. Introduction

Mortality occurs when tree vigour declines due to three possible stress factors (Manion, 1981 in Pedersen, 1998): predisposing factors, such as competition or pollution, inciting factors, such as drought or insect attack and contributing factors, such as pathogens. These factors lead to a wide variety of causes affecting tree survival – environmental, physiological, pathological or stochastic (Yang et al., 2003) – and may help to explain why, of all the events studied under stand dynamics, tree mortality is one of the least understood (Hamilton, 1986) and one of the most difficult to model (Hawkes, 2000). In an attempt to simplify the approach to such a complex phenomenon, mortality has been commonly considered within individual tree-based models either as regular, when caused by competition for scarce resources, or as irregular, when caused by ecological and catastrophic events, such windthrows or fires (Monserud, 1976). Forest gap modellers have commonly dealt with a constant probability of death of all trees depending on the longevity of the species (Botkin, 1993). This is called actual age-independent mortality or intrinsic mortality. Other kind of mortality classes are growth-dependent mortality or competition-mortality and exogenous mortality, such as wildfires and harvest (Keane et al., 2001). Depending on the model strategy, we are dealing with, the assumptions on the causes of mortality are different.

Competition-induced mortality is one of the most frequent case studies done by foresters in individual tree and gap models

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(Keane et al., 2001). Ecological theory defines competition as a kind of interaction which is prejudicial for either species or individuals considered. Frequently the competition is asymmetric, that is, the individuals are not affected equally by the scarcity of resources (Pugnaire et al., 2000). Even more, asymmetric competition may be partial or complete (when there exists a disproportionate rate of available resource according to size or larger trees get all the resources, respectively). Under symmetric competition, all trees would have the same resource level or would have size proportional resource levels (Schwinning and Weiner, 1998). In both cases, the better competitor will succeed over the other, and mortality may occur.

When competition occurs in dense stands the competition-induced mortality is then called density-induced mortality or self-thinning. According to the self-thinning rule proposed by Yoda et al. (1963), mortality occurs when the density reaches a maximum, however, mortality also exists in under-stocked stands. Tang et al. (1994) indicated that competition also exists in low-density stands. If mortality occurs due to competition, then mortality may be reduced by decreasing competition levels or by releasing trees. Thinning is the pre-harvest operation that, among others, looks for an optimum density where trees would be vigourous, and therefore, mortality would be reduced. Mortality models may be fitted separately to unthinned and thinned stands (Avila and Burkhart, 1992; Amateis et al., 1997; Lee and Coble, 2002). Fitting models with data from both, unthinned and thinned stands may mask the effects of the thinning on mortality unless variables affected by management were included (Hamilton, 1986).

Glover and Hool (1979) define three approaches to modelling tree mortality: physiological-based approach, estimation of tree's physiological information and empirical probability of mortality comparing with a random number. On the other hand, Hawkes (2000) reduces the number of modelling strategies to two categories: deterministic or stochastic. Deterministic models consider the death of a tree occurs when a threshold is crossed, e.g. Newnham (1964) and Arney (1972) used changes in tree characteristics, such as crown length and diameter increment, respectively. Stochastic models focus on the probability of occurrence for the event modelled, classifying a tree as dead/live according to the results of a random number generator; in this case, if the probability of mortality is greater than the random number, the tree is considered to be dead.

Mortality/survival is a discrete event that can only take two values: alive or dead. Thus, the problem is reduced to a classification of observations into two groups. Statistics can help us in classifying observations by applying Fisher linear discriminant function which relies on the normal distribution of data. Since this is not the case for most of the variables used in mortality models, a cumulative distribution function bound between 0 and 1 is more appropriate. Exponential, Weibull and Gamma distribution (Moser, 1972; Somers et al., 1980; Kobe and Coates, 1997) are instances of this kind of functions, but the most widely applied one has been the logistic function (Monserud, 1976; Hamilton, 1986; Murphy and Graney, 1998; Monserud and Sterba, 1999; Yao et al., 2001; Yang et al., 2003).

In recent reports, classification tree tools-like CART (Dobbertin and Biging, 1998) and neural networks (Guan and Gertner, 1991; Hasenauer et al., 2001) have been shown as new techniques to determine the dead/live status of a tree. However, none of them have considerably improved the results of a logistic function (Monserud and Sterba, 1999). Another approach for stand level deals with a two-step procedure. First, a probability model of death occurring in stands is fitted with the whole data set. Second, a model that predicts the reduction of stems per hectare over a period, is fitted with data from stand only, where death has effectively occurred. Afterwards, the probability model is used to adjust the reduction of stems per hectare (Woollons, 1998). Within the Spanish Atlantic area this has been the model strategy to predict the mortality in *Pinus sylvestris* and *Pinus radiata* plantations (Álvarez-González et al., 2004; Diéguez-Aranda et al., 2005).

According to the Second National Forest Inventory, the Mediterranean distribution of pure stands of *Pinus pinaster* and *P. sylvestris* is 723,819 and 678,685 ha, respectively, which represent 10% of the total forest surface in Spain. The former lives mainly in the northern plateau and at elevations under 1500 m, with irregular precipitation and high temperatures in summer. The latter grows in mountain ranges up to 2000 m of elevation mainly in the northern aspects, with more precipitations and mild temperatures. Within its habitat, a greater number of growth and yield studies have been conducted for Scots pine (Rojo and Montero, 1996; Bravo and Montero, 2001; Río and Montero, 2001; Bravo and Montero, 2003) than for Mediterranean maritime pine (García and Gómez, 1989; Bravo-Oviedo et al., 2004). Most of these models have been devised to operate at stand level rather than at tree level (Palahí et al., 2003).

Considering that model-based decisions rely on the availability of data, along with desired level for prediction and time horizon projection, stand level information is much more readily recorded. However, with stand level models, it is not possible to know how yield is distributed within the forest and how it correlates with diameter classes, which is one of the most valuable information in forest management, unless a diameter distribution function is fitted. A tree level model is a compound of several equations that, from a tree list, may predict tree growth and, by aggregation, stand level growth and yield. Within this set of equations, a mortality model is needed.

The aim of this work is to develop a survival model in unthinned stands of Mediterranean maritime pine and Scots pine throughout their distribution area in Spain, in order to be further upgraded into a future distance-independent tree level model. A brief discussion on what variables are the most appropriate and on the competition influence in both species is also presented. As thinning is an important pre-harvest operation reducing the number of trees in the stand, the performance of the models will be tested with data from thinned stands to assess if models developed in unthinned stands may be used or not.