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National Forest Inventory and forest observational studies in Spain: Applications to forest modeling

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ABSTRACT

According to official statistics, forest and other wooded lands cover 54.4% of the Spanish national territory. However, approximately 39.2% of Spanish forest lands are under different types of protection and only 18.4 million ha (36% of the country) are true forests or plantations. Four main forest ecoregions can be distinguished in Spain: Mediterranean, Atlantic, Alpine and Subtropical (Macaronesic). The particular characteristics of these eco-regions determine the particular types of forest resource utilisation. Three objectives are dominant: (a) biodiversity conservation (main objective in the Macaronesic area), (b) timber production (important in the Atlantic region) and (c) multifunctionality as well as non-timber products (important in the Mediterranean and Alpine ecoregions). In the second half of the 20th century, the combination of new Permanent Plot Networks (PPN), silvicultural trials (covering a wide range of species and site conditions), and the National Forest Inventory (NFI), made possible to develop new forest models, especially during recent years due to advances of statistical software combined with improved field observations. New forest models for different tree species, management purposes and regions have been developed at different scales, including whole stand and individual-tree approaches, and taking into account forest diversity and end-user aims. The combination of PPN and NFI allows further improvement of the models, including additional output functions to estimate tree and stand variables related to specific objectives (e.g. crown fire risk). The advantages and disadvantages of Forest Observational Studies (FOS) and National Forest Inventory data for developing forest models are discussed. Finally, an example of synergy between FOS and NFI observations for developing dynamic growth models for intensively managed forest in the Atlantic ecoregion is presented.

1. Introduction

Forest management decision making and effective long-term planning are based on information about current and future forest conditions. Models which describe forest dynamics accurately, are essential for decision-making and sustainable forest use (Vanclay, 1994; Burkhart, 2008; Garcia et al., 2011). This is especially important in intensively managed forest plantations where forest dynamics is significantly influenced by silviculture.

Growth and yield studies began in Spain in the early 20th century when different permanent plots were established in *Pinus sylvestris* L. and *Pinus pinaster* Ait. stands in central Spain. The first forest growth models in Spain were yield tables developed in the 1940s for *Pinus radiata* D. Don and *P. pinaster* plantations in the Atlantic area (Echeverría, 1942; Echeverría and Pedro, 1948, respectively). New efforts were made during the second half of the 20th century to establish permanent plots, which made it possible to construct new yield tables. However, during the past 15 years the combination of previous data collection efforts with improved statistical applications and new computer technology has revolutionized forest modeling in Spain. New models were developed for different species, management purposes and geographical regions (with the exception of the Macaronesic area) and at different scales (including whole stand and individual-tree models). A variety of modelling approaches and specific tools relating to forest diversity and end-user aims emerged. A comprehensive review of forest models developed in Spain in recent years for both timber and nontimber applications and forest dynamics (including regeneration and mortality) is presented in Bravo et al. (2012).

All the models developed in Spain for practical uses are parametric models and their parameters must be estimated from observations. Since estimation accuracy and usefulness of a model depend on the quality of data, the first step in growth model construction is to ensure that the available observations are suitable for a specific purpose. When the observations are

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inadequate, a suitable data collection process must be designed (Curtis and Hyink, 1985; Rennolls, 1997).

In recent decades, the automatic capture of forest state variables by various remote sensing techniques has substantially increased the amount of data available on stand dynamics. Even so, sample plots and stem analysis of felled sample trees continue to be the two basic data sources for developing growth models. Felled-tree sampling provides information similar to that obtained when re-measuring permanent sample plots. However, this is expensive and some important variables cannot be reconstructed. Thus, the majority of the data used for growth modeling is obtained from sample plots. Examples of different networks of sample plots that could be used for growth analysis and designed according to resource management needs are:

(1) Resource inventory plots: The design is based on temporal plots, where the number of sample plots is calculated to achieve a desired precision for a given set of target variables. The spatial distribution of the sample grid is usually oriented across environmental or physical gradients to maximise within-plot variation and thus reduce between-plot variance.
(2) Field experiments: Growth data can be obtained from different field trials (spacing, thinning and pruning trials, fertilizer trials, growth trials, etc.). In Spain, these trials are established and maintained almost exclusively by government research organizations (Montero et al., 2004) or university research groups (Bravo et al., 2004; Torres Álvarez et al., 2004; Diéguez-Aranda et al., 2009). The design is based on permanent sample plots and the size, shape, number and distribution of sample plots depends on the objectives of the field experiment.
(3) Permanent Plot Networks (PPN): First attempts to establish a permanent plot network in Spain were made in 1915 when researchers from the former '*Instituto Central de Experiencias Técnico-Forestales*' established a set of plots to study timber production in Scots pine stands in the Central Range and to study resin yield in *P. pinaster* stands in the Northern Plateau. A second big effort to generate a PPN was made in the 1940s and another in the 1960s. Currently, different plot networks belonging to universities and national and regional research centers are maintained across the country.
(4) Continuous Forest Inventory (CFI): The main objective is to assess and monitor the extent, state and sustainable development of forests at the national or regional level in a timely and accurate manner. The design is based on permanent plots in different types of forest and stand conditions in proportion to area. Sampling is done by passive monitoring. As with resource inventory, precision is gained by reducing between-plot variance.

The most important database of CFI in Spain is the National Forest Inventory (NFI). The First National Forest Inventory (NFI1) was conducted from 1965 to 1974. The main motivations for that inventory originated from the need to provide forest data for statistics and policy development at regional and national levels, and to estimate the forest growing stock, forest areas, and increments as a guide for establishing new forest enterprises. NFI1 covered all the national forest areas. The assessment units were the 50 Spanish provinces which have a mean surface area of 1 million ha and a total of 50.6 million ha for all of Spain. The following methodology in each province was used: (i) a stratified double sampling design with allocation of the field plots to minimise the variance of volume estimates; (ii) estimation of forest areas by assessing the forest/non-forest status of points at the intersections of a systematic sampling grid, overlaid on aerial photographs of 1:30,000 scale; (iii) all plots were temporary; (iv) selection of trees on sample plots using the angle count method and (v) three representative standing trees per plot were measured to obtain data for construction of volume and increment models.

The Second National Forest Inventory (NFI2), was conducted from 1986 to 1995. The assessment unit was also the province. The sample methodology considered the following main characteristics: (i) forest areas and strata were identified from the existing agriculture and land use map; (ii) field plots were located at the intersections of a 1-km Universal Transverse Mercator (UTM) grid; (iii) distances and azimuths from the plot centres to trees and diameters at breast height (d), heights and six different tree shapes were registered (e.g. pollard tree, bifurcation at a height of more than 4 m, etc.) to classify trees from the same species into homogenous groups and to use different equations for each of those groups to obtain more precise tree volume estimates; (iv) field plots were marked as permanent; (v) four circular concentric plots of radius 5, 10, 15 and 25 m were used to measure trees of different diameters and (vi) four representative standing sub-sample trees per the whole plot (four concentric plots) were measured for length and width of the crown, bark thickness, diameter increment for the last 10 years and upper diameter at a height of 4 m.

The Third National Forest Inventory (NFI3), started in 1997 with the field work ending in 2007, and covered all forests in all ownership groups. The main methodological characteristics are similar to those of the NFI2 with the following differences: (i) stratification was 'a posteriori' and land cover classification and forest area estimation were based on digital maps and ortho-images; (ii) unlike in the NFI2, no additional tree measurements were performed regarding length and width of the crown, bark thickness, diameter increment or upper diameters; (iii) sub-sample trees were not measured and (iv) a new improved methodology for forest biodiversity assessment was developed and used for some provinces.

The Fourth National Forest Inventory (NFI4) began in 2008. A summary of the Spanish NFIs is given in Table 1 and further explanation of the Spanish National Inventory can be found in Alberdi et al. (2010).

The NFI has provided periodic information on status and trends on a variety of parameters describing forests and forest uses. However, the sampling methodology was not specifically designed to develop growth models, especially for even-aged stands or plantations, and there are four major weakness of the database for forest modelling purpose: (i) excessively long inventory cycles (10 years), especially for fast growing species, which cause long periods of high uncertainty about the forest dynamic; moreover, there are not information about silvicultural treatments between inventories, therefore it is not possible to differentiate the effect of thinnings and mortality in tree number reduction or basal area and stand volume changes; (ii) the most interesting stand conditions to compare different silvicultural alternatives are usually present in only a small fraction of the existing forest and it could be not represented in a systematic inventory; (iii) the sample design could cause larger random errors in those variables obtained in the smallest radius subplots such as ingrowth (Trasobares et al., 2004; Adame et al., 2010); this is especially important when these variables are related to other variables obtained from the largest radius subplot; and (iv) the stand age was not measure or the estimations are unreliable, and this is an important variable for even-aged stand models. Nevertheless this variable has been considered as a key variable and it will be possible to add this information for modelling in the future.

Despite the drawbacks described, the Spanish NFI has the important advantage that the data are drawn from an unbiased, systematic sample of plots that are distributed throughout the complete range of the forest types of interest. Therefore, the NFI