Which models are needed for Pinus pinea forests? A review on current state and potential use

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Which models are needed for *Pinus pinea* forests?
A review on current state and potential use

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Abstract. We aim to make a critical review of the current state of the art of modelling in Mediterranean stone pine forests, focusing on the stakeholders and end-users criticisms and points of views. To do this we first present an exhaustive review and analysis of the currently available literature on the topic, in order to detect gaps in knowledge. In a second part of the study, we analyze whether the stakeholders involved in stone pine managements make use of the existing models. We also analyze which are the characteristics and requirements that the potential end users demand to the models. Our results show an extraordinary development in the modelling activity for the species, identifying more than 109 scientific references, of whom 72 are published in JCR® journals, although some gaps are observed. Despite this large availability of models, potential end-users of the models currently don´t make an in-depth use of these tools, since in many occasion their demands are not met by the expected outputs.

Keywords. Type of models – End-users – Simulation tools.

I – Introduction

A forest model is an abstraction, or a simplified representation, of some aspect of forest dynamics and functioning, or of any of the components and relations defining the system (Weiskittel *et al.*, 2011). Forest modelling activity started in Central Europe by the end of the 19th century, with the construction of the growth and yields tables based on normal forest principles, and since then they have been considered basic tools for supporting forest management at different scales. The interest of foresters in models for predicting, explaining and describing forest systems, together with the advances in statistics and computation, have resulted in a recent increasing effort in the modelling activity worldwide.

The Mediterranean stone pine, *Pinus pinea* L. can be considered a paradigmatic example of this evolution. In the last 25 years stone pine has evolved from being a species with a scarce knowledge concerning growth and yield dynamics to being nowadays a well-known species in the Mediterranean forests ecosystems (e.g. Mutke *et al.*, 2012, 2013). This widening of the scientific knowledge was the necessary basis for the considerable effort in constructing models to explain and predict ecologic processes and yield of stone pine forests.

Currently there are models available for the species working at different spatial, temporal and functional scales, with geographical validity in different countries and regions within countries. Classical empirical models for predicting growth and yield (Castellani, 1989; Calama *et al.,* 2007a) now coexist with climate-driven models (Calama *et al*., 2014a), physiological based models predicting photosynthetic activity (Calama *et al.*, 2013), models attempting to predict different dynamic processes, as natural regeneration or decay (Manso *et al*., 2014), or large scale process-based models (Pardos *et al.*, 2015). Apart from timber and fuelwood production, existing models for stone pine aim to simulate cone production (e.g. Gonçalves and Pommerening, 2012), nut quality and content (Morales, 2009), and the provision of other ecosystem services, as CO_2 fixation (Correia *et al*., 2010). Temporal scale of different models ranges from the second (Calama *et al*., 2015) to the multiannual scale (Mutke *et al*., 2005), while spatial scales extent from the leaf (Correia and Freire, 2014) to the region (Nanos *et al.*, 2003). Moreover, the existing models aim to cover the wide range of stand conditions and forest management objectives, including high-cone producer grafted plantations (Mutke *et al*., 2005c; Carrasquinho and Gonçalves, 2012), naturalized afforestations focusing on protection (Calama *et al.*, 2009), or mixed stands oriented to recreational uses (Madrigal, 2014) or agroforestry uses (Palma *et al.,* 2007). Finally, the modelling activity is going on, with new models and approaches being currently under construction in different countries (Sghaier *et al*., 2013; Loewe *et al*., 2015).

All this modelling effort necessarily relies on good quality datasets. In this sense, specific nets of permanent plots and experimental trials have been installed in different countries to analyze growth and yield dynamics for the species. Among those are noteworthy to mention the nets of permanent plots for timber and cone production and thinning trials (covering wide areas of Spain and Portugal), natural regeneration essays (Valladolid) or the irrigation and fertilization trials installed in Portugal. A specific issue concerning the species is the need to obtain sound information on cone production, which can only be afforded in detail by collection the cones directly from the trees.

This extraordinary evolution is more remarkable taken into account that, unlike other timber focused species, the main production from stone pine stands is the pine nut, extracted from cones collected from standing trees. Modelling cone production deserves a real challenge due to some issues: (i) large interannual variability in the production (masting) at tree, stand and regional scales, (ii) abundance of zeroes in some regions (e.g. in Valladolid province more than 50% of trees present null crops), (iii) patterns of spatial dependence, (iv) asymmetric and skewed distribution, with the main part of the production located in a few trees, and (v) lack of physiological knowledge of the flowering-fruiting process.

Despite the wide offer of modelling tools nowadays available, existing models seem not to be perceived as fully useful to answer many of the questions, demands and concerns that stone pine forest managers, forest owners, policy makers and industrials are facing with. Our models are often criticized for being oversimplifications leading to unrealistic results; at the same time, they show complex formulations where the demanded inputs are not easily available. Spatiotemporal scales usually do not match with those required by the users, and outputs from the models are far away from those expected. Meanwhile, some basic questions seem not to be adequately answered by existing models. Many topics remain uncovered by model predictions, such as: cone and timber production in the next decades; how to manage stone pine forests under an uncertain climate; how to optimize cone production for a given stand; how to make a small property profitable; what is the expected impact of an extreme drought event; what to do with the mixed stands… and many others.

In the present study we aim to make a critical review regarding the current state of the art of modelling in Mediterranean stone pine forests, focusing on the stakeholders and end-users criticisms and points of views. To do this we first present an exhaustive review and analysis on the currently available literature focusing on the topic, in order to detect gaps in knowledge. In a second part of the work, we analyse whether the stakeholders involved in stone pine management make use of the existing models. We also analyse which are the characteristics and requirements that the potential end users demand to the models, and focus on identifying which could be the best type of model for each end user.

II – State of the art on modelling for *Pinus pinea* forests

1. Methods

To carry out our review on currently available models for *Pinus pinea*, it was necessary to define first which would be our objective population. We focused uniquely on tools that fulfill the following conditions:

- constructed with the aim of describing, explaining and/or predicting some aspect of forest dynamics and functioning, or of any of the components and subjacent relations of the system;
- the attributes of the system are mainly described by numerical values;
- the dynamics and relationships are expressed by means of mathematical functions;
- specifically constructed for the species *Pinus pinea* L.

We orientated our search towards two different groups: (i) models already published in journals included in JCR®, and (ii) models published on non-JCR® journals, technical reports, academic dissertations and conference proceedings. JCR® query was carried out by means of a Boolean search in Web of Science (www.webofknowledge.com) using as topic keywords the following:

[“Pinus pinea” or “stone pine”] + [“model” or “dendrochronology” or “growth” or “cone”]

In a second step we made a subjective filtering over the whole database in order to match the previously defined conditions. Additionally, to those limiting conditions, we deliberately skipped out all the references related with modelling *Volatile Organic Compounds*, a discipline largely developed by the end of the 90’s of the last century, which on many occasions used *Pinus pinea* as a case species, but which falls far from the scope of the interest topics for our review.

Search on non-JCR® literature was based on consulting books of proceedings of different scientific meetings (e.g. 1st Agropine, Spanish and Portuguese National Forest conferences, MEDPINE...), non-JCR® journals (Montes, Options Méditerranéennes, Cuadernos SECF…), phD & MSc thesis and others sources. Criteria for selection matched those previously presented. In the case of tied references –e.g. a preliminary version of the model presented in a proceeding and thereafter published in a JCR journal– we just included the later one into the database.

2. Results and discussion

Our query resulted in 109 references, of which 72 correspond to models published in JCR journals, while 37 were found in other scientific and technical literature (see Annex I for the complete reference list). Due to the nature of non-JCR literature, it is obvious that we have missed several references from this group, especially from national technical reports, national meetings and others.

A. Temporal analysis

First analysis over the database will focus on the temporal evolution of the effort on modelling for *Pinus pinea* forests (Fig. 1). A clear increasing trend is detected, with only ten references (only two in JCR) covering the 34-year period elapsed between the first reference (Pita, 1966) and 2000 while in a single year (2015), twelve references on modelling in *Pinus pinea* forests were published (eleven in JCR). Although this is a common issue for all the forest species (see Weskittel *et al.,* 2012), we must mention some peculiarities in the case of *Pinus pinea*.

The first of all is a clear delay with respect to other species, even within the same Mediterranean region. Except for the seminal works by Pita (1966, 1967) focusing on site index curves and volume equations, no effort was carried out up to the end of the decade of 1980’s. By that time, on the

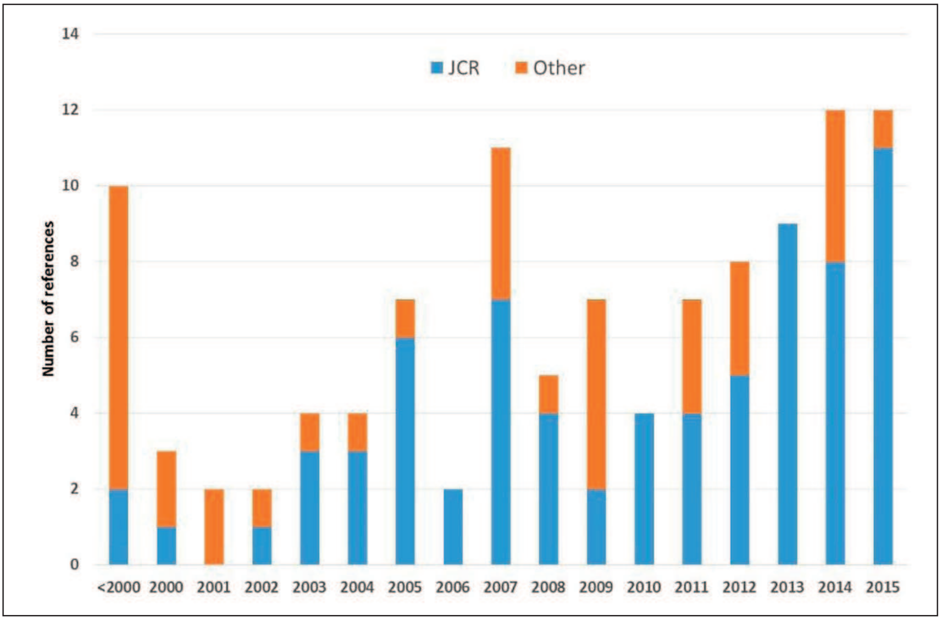

Fig. 1. Temporal evolution in the number of references focusing on "modelling + *Pinus pinea*" in JCR and other literature.

exhaustive revision of the existing growth and yield tables for the Spanish forests species presented in Madrigal *et al.* (1999) the unique main-species non represented was *Pinus pinea*. This situation was similar in other countries with available tools for other species, as Portugal, France or Italy.

Main reasons for this delay can be related with the lack of timber productive interest of *Pinus pinea* forests if compared to cone production, while classical growth and yield tables uniquely focused on wood-biomass production. Related with this, in order to promote cone production *Pinus pinea* forests resulted in low stocking density of the stands, which refutes the basic principle of normal complete stocking basic for the construction of traditional growth and yield tables. The lack of knowledge on the fruiting process in *Pinus pinea* also prevented the inclusion of cone production into classical tables. Due to this the first growth and yield tables –including cone production– for the species were only published in 1989 in Italy (Castellani, 1989).

As mentioned before, the study of the species has progressed over the last 20 years to make *Pinus pinea* one of the best known species in the Mediterranean ecosystems. A factor triggering this was the interest that the species arose in the FAO meetings at the end of the 1980's, which resulted in activities such as the installation of a net of permanent plots for studying cone and timber production in the Spanish forests. This net was installed and maintained since 1992 by the INIA-CIFOR in cooperation with the Regional Forest Services of Castilla y León, Andalusia, Madrid and Catalonia (https://sites.google.com/site/regeneracionnatural/proyecto-rta2013-00011-c02-00/difusion-y-transferencia). A result directly derived from this net was the construction of the first diameter-distribution and tree level models for the species (García-Güemes, 1999; Cañadas, 2000), the first interregional models with validity in Spain (Calama *et al.,* 2003), the integrated model PINEA2 (Calama *et al.,* 2007a, b) together with its associated stand-level simulator. Joint use of this net together with annual recordings of cone production at forest scale permitted the construction of spatial (Calama *et al.,* 2008a), temporal (Mutke *et al.,* 2005) and spatiotemporal (Calama *et al.*, 2011) models for cone production. In Portugal, a similar evolution resulted in the publication of the first integrated tree-level model for the species (Freire, 2009), also incorporating a cone production model (Rodrigues *et al.*, 2014).

Finally, in the last years the modelling effort for the species has been oriented to new topics such as heterogeneous stands (de-Dios-García *et al.*, 2015), natural regeneration processes (Manso *et al.*, 2014a), physiological traits (Mayoral *et al.*, 2015a, Calama *et al.,* 2015), dendrocronological models (Natallini *et al.*, 2014) or the calibration of process-based models for the species (Pardos *et al.*, 2015).

B. Geographical analysis

With respect to the geographical distribution of the modelling activity in *Pinus pinea* there is a clear dominance of the references focusing on works developed in Spanish forests, amounting more than 70% of the total (77 out of 109 records). Portugal and Italy accounts for 9% and 7% of the total, with Portugal showing a recent effort in developing growth and yield models for the species (Freire, 2009; Correia *et al.*, 2010), while in Italy, where the first yield tables were constructed, the modelling activity for the species focuses nowadays on dendrochronology (Piraino *et al.,* 2007). It is noteworthy to mention the recent research carried out in Tunisia (Sghaier *et al.*, 2012). These results contrasts with the lack of models –up to the knowledge of the authors– in countries with such a large modelling tradition, as France, or in two of the countries with larger potential for cone and nut production, as Lebanon or Turkey. Once more it is necessary to mention the lack of information concerning non-JCR in many of the countries, especially in other languages different than English, which surely affects these results.

C. Model objective

Modellers tend to present different classifications of models, according to degree of empiricism, spatiotemporal scale of application, minimal unit of simulation. In this study we adopted a purpose-oriented classification, according to the objectives to achieve. In this sense we classified the selected models into:

- Growth and yield: models focusing on the evolution / growth/ allometry / production of a given forest unit or each of their components.
- Dynamic processes: models focusing on other dynamic processes apart from growth, e.g., regeneration, mortality, competition.
- Dendrochronology: models focusing on climate-growth relations and sensitivity.
- Physiological: models focusing on specific physiological traits, e.g. stomatal conductance, net assimilation.
- Optimization: models aiming to optimize forest management in terms of a given output.
- Genetics: models devoted to identify best genotypes.
- Niche: models identifying optimal sites for species establishment, growth and performance.
- Wood quality: models focusing on the prediction of wood traits (stem rot, mechanical attributes).

Focusing on the 109 models for *Pinus pinea* identified (Fig. 2), almost 50% (53) were classified as growth and yield models, which will be presented in detail later on. Concerning models devoted to other dynamics processes, they account for 19% of the total, mainly orientated to describe and predict the different phases involved in natural regeneration (seed dispersal, germination and survival) under different climate and management scenarios (Manso *et al.,* 2012, 2013a; Carnicer *et al.,* 2014). On the contrary, we detected a clear gap on models describing and predicting mortality for adult trees.

Twelve dendrochronological models were identified, covering different regions from Portugal, Spain, Italy, France, Tunisia and Turkey, aiming to describe climate-growth relationships and identify key climate factors driving secondary growth at a regional scale (Akkemik, 2000; Campelo *et al.*, 2007; Cutini *et al.,* 2013; Natalini *et al.*, 2015). Finally, the fourth main group is that of physiological models (8%), with special attention to photosynthesis and gas exchange processes (Evrendilek *et al.,* 2005; Mayoral *et al.*, 2015a).

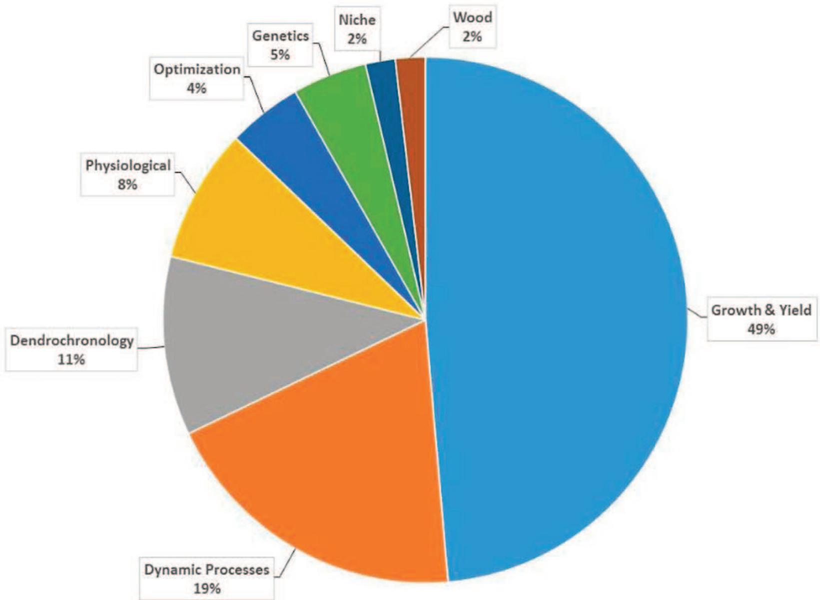

Fig. 2. Percentage of type of models for *Pinus pinea* according to their main objective.

We proposed a subdivision of growth and yield models into different categories, once again with a purpose-oriented aim (Fig. 3). The main group (15 references) was the one devoted to models for cone and nut production with validity on different regions of Spain, Portugal and Tunisia. These models include pure spatial models describing spatial correlation at different scales (Nanos *et al.*, 2003, Gonçalves and Pommerening, 2012), empirical functions predicting cone production at tree level using stand, tree and climate attributes as predictors (Calama *et al*., 2008a, 2011), and regional scale models (Mutke *et al.*, 2005). We also found twelve references presenting allometric relationships for the species, including volume, stem taper (Calama and Montero, 2006) and biomass equations (Ruiz-Peinado *et al.*, 2011; Correia *et al.*, 2008), height-diameter functions and crown equations (Cañadas *et al.*, 2001). Diameter increment functions, with special attention to the effect of intra and interspecific competition accounted for other six references (Ledo *et al.*, 2014). Additionally, six site index curves with validity for different regions and countries have been published (Calama *et al.*, 2003; Bravo-Oviedo *et al.,* 2005; Sghaier *et al.*, 2012).

Some of these functions were included in the integrated stand-level models, yield tables and tree level models which represent other twelve references. In an independent way, these complete models also include cone production, site curves, growth and/or allometric functions not previously published. These complete models have been either implemented as yield tables, stand density management diagrams, as well as on stand level simulators. The most complete models are the tree-level model PINEA2 (Calama *et al.,* 2007a, b), with validity in different regions in Spain, originally fitted for pure-even aged stands, and currently extended to uneven-aged stands and afforestations, and the stand-level model ORGEST_Pinea (Piqué *et al.*, 2011, 2015), with validity on Catalonia.

A main drawback of the aforementioned growth and yield models for *Pinus pinea* is that they are not climate-sensitive. In this regard, some effort in annualizing estimates by including climate drivers (Calama *et al.,* 2014) are currently under development.

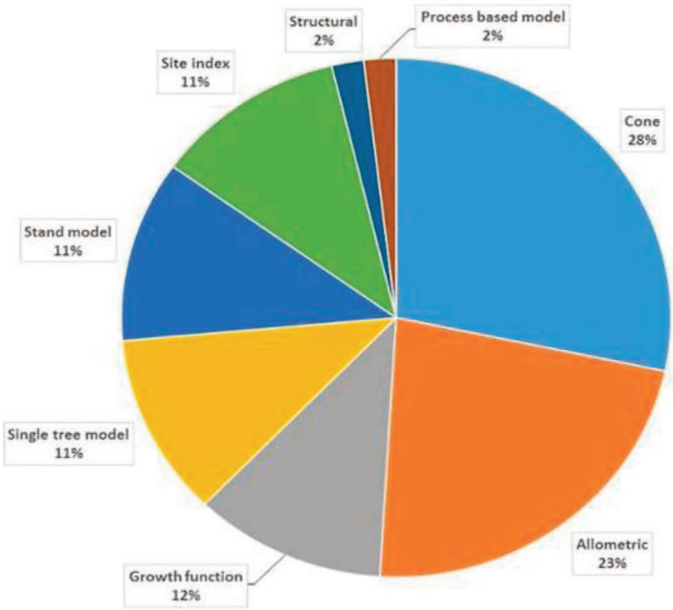

Fig. 3. Percentage of type of growth and yield models for *Pinus pinea* according to their main objective.

D. Empiricism vs *process based models*

The majority of the 109 models and function analyzed must be defined as empirical models, since they rely on statistically fitting mathematical functions over observed data, where predictors are actually variables acting at different spatio-temporal scales (climate drivers, stand and/or tree level attributes, competition, provenance…). The combination of these functions and variables do not represent basic chemical or physical processes at the basic organisational levels of the individuals, but they rather aim at describing phenomenological responses to the environment. In this sense even though many physiological process (e.g. photosynthesis, gas –exchange parameters, etc.) are modelled, these models rely on an empirical formulation.

We only found three exceptions to this general trend, with the first being the crown development model by Mutke *et al.* (2005b) which entirely falls within the category of structural models, defined as those aiming to describe plant growth based on the development of the different organs. Pardos *et al.* (2015) succeeded in calibrating and validating the model PICUS v1.41, a model combining elements of a 3D patch model and a process-based forest production model, for *Pinus pinea* in the Spanish Northern plateau, incorporating the empirical spatiotemporal model for cone production by Calama *et al.* (2011). The model provides estimates of timber and cone production, as well as vulnerability for the species under different climate scenarios and management alternatives. Finally, Calama *et al.* (2015) propose a hybrid model for predicting seedling survival using as predictors daily rate of net assimilation and water status, derived from specific physiological based models.

III – Current use of the identified models

Goodness of fit, statistical correctness and predictive accuracy of a model do not mean success from a practical point of view. As we should expect that not all the models are useful for all the potential users, cooperation among model builders and model users is required. Model building means an iterative process where modellers and potential end users should define the main objective in building the model, design the model structure and agree the expected uses and outputs of the model.

Models are constructed with the aim of describing, explaining and predicting. While in essence all the models are constructed focusing on these topics, the reality indicates that when focusing on the main use of the model, one is commonly dominant. In this sense, we can classify models from the end-use point of view as:

- Descriptive: the main aim of the model is to describe the state of the system and identify relationships among attributes.
- Predictive: the model is used to forecast information required to help in any decision related with management of the forest at different scales.
- Explanatory: the model is used to contrast hypothesis about causal relationships, thus mainly an academic / knowledge building use.

An overview over our 109 models and functions reveals that 14% of the models show a main descriptive use, 35% can be classified as explanatory models, 42% as predictive models and the remaining 9% are proposed for a joint predictive / explanatory use. According to the different categories, growth and yield models are mainly constructed for a predictive or an explanatory/predictive use, while dendrochronological models, physiological models and models describing processes as regeneration aims to an explanatory use. According to previous figures, at least 51% of the models were constructed focusing on a predictive use in order to help management of the forests at different scales, and we would expect that they were nowadays used for potential end users. The main aim of this section is to evaluate the current state of use of the available models.

1. Methods

A short discussion was carried out with a small number of stakeholders (at least one per group) related with *Pinus pinea* forests representing five different groups of potential end users of the model: forest managers, forest planners, policy makers, forest owners and nut and timber industrials. Questions focused on general knowledge of the existence of models for the species, current use of models, need of models in their task, expected outputs, spatio-temporal scale and interface.

In a second phase we selected five different models for the species, representative of the different model types but oriented to predictive or explanatory / predictive use, in order to check whether these models will cover the required demands presented by different end-users group. Selected models were the growth and yield tables by Montero *et al.* (2004), ORGEST_Pinea (Piqué *et al.*, 2015), PINEA2 (Calama *et al.,* 2007a), natural regeneration multi-stage model (Manso *et al.*, 2014a) and hybrid model PICUS_PINEA (Pardos *et al.,* 2015).

2. Results and discussion

Table 1 shows the current state of use and demands from potential end-users of the models for *Pinus pinea*. Forest managers and policy makers reported to make little use of the models, even if they declared to be aware of their state of development. Forest planners, owners and industry usually neglect existing models. Concerning the demands, managers, planners and owners require tools projecting real forest management units, while policy makers need to carry out estimates at national or regional level. Planners and owners require simple guidelines and friendly interfaces. In general stakeholders are interested on timber, cone and biomass production, although managers are highly concerned for the regeneration of the forests, and policy makers on topics as species substitution and fire hazard. Industrials focuses on quantity and quality of raw materials, as cone and timber.

Table 1. Use, demands and requirements of the different groups of potential end-users of models for stone pine

	Forest manager	Forest planner	Policy maker	Forest owner	Nut & timber industry
Knowledge	Wide	Little	Wide	Little	No
Use	Little	No	Little	No	No
Main demands	Project real block units Predict annual cone crop Economic evaluation	Project current state of the forest Simple guidelines Yield tables	Raw estimates at regional level Compatible with NFI Compatible with international demands	Early annual estimates of cone Management to increase cone production	Timber quality and saw classification Pre-crop nut yield & quality
	Identify vulnerable sites Timber and biomass quantification Sensitive to management	Cover all forest tipologies Compatible with management invetories	Species substitution Focus on forest typologies	Simple guidelines	Global forecasting of annual cone production Low cost methods
Output	Cone Timber Biomass Natural regeneration	Cone Timber Biomass	Biomass & CO2 Timber & Cone Vulnerability Fire risk	Cone Timber	Timber Cone Nut yield Wood quality
Spatial scale	Block	Block	Region	Forest	Forest Region
Temporal scale	Annual	Annual Decennial	Annual Decennial	Annual	Annual
Interface	Simulator	Flexible Compatible with large databases	Flexible & homogenous	Friendly apps	Compatible with factory systems

Growth and yield tables represent a simple-orientated guideline, valid as an average value of the observed silvicultural system proposed in a region giving raw estimates on timber an average cone production (not annual cone production). These tools do not consider stand heterogeneity, and are not sensitive to management, thus its validity for managing at block or forest scale is limited. Main current use is in forest planning, thus present simplified guidelines easily implemented, as well as for policy makers, given their large scale utility.

Stand and tree level models, as ORGEST_Pinea and PINEA2 are tools sensitive to silvicultural decisions, thus easily applied at block or forest scale. ORGEST is valid for any type of structure, since the model is calibrated for the whole set of typologies identified in Catalonia. On the contrary, PINEA2 is only valid for pure stands, though calibration for mixed stand is under development. PINEA2 allows annual estimation of cone production, thus useful for owners and forest managers, and it is sensitive to climate, while ORGEST_Pinea uniquely gives average output on cone production. PINEA2 is implemented in a stand level simulator, which give total flexibility for adapting any initial condition of the stand, which makes it compatible with NFI data. While being capable of simulating any different silvicultural schedules, the main limitation is that it requires the simulation of each block/stand within the forest. In the case of ORGEST_Pinea, uniquely a limited number of initial conditions and silvicultural schedules, defined according to forest main objective, are available, but permits to easily define a silvicultural orientation for each block on the stand. PINEA2 permits to estimate end-use of timber production, and can be adapted to include nut yield equations (Morales, 2009), thus can have a moderate interest for industrials.

Process based model PICUS_PINEA allows for annual estimates of cone, timber, biomass and CO_2 fixation at large spatial scales, and it is sensitive to management and climate scenarios. In this sense, it is useful for managing at regional and national scales, as required by policy makers. Its main limitations are linked with complexity of the interfaces, complex inputs and lack of accuracy on cone and timber estimates at small scales, which prevent its use by forest owners, planners and managers working at management unit – forest scale.

Finally, a model focusing on dynamic processes, as the multistage model for natural regeneration, allows identifying the factors governing the whole process and the main bottlenecks that prevent successful regeneration, and permit to estimate the probability of occurrence of established seedlings given a silvicultural schedule. In this regard, models for dynamic processes are useful tools for guiding forest managers and planners in identifying priority areas for regeneration, or proposing specific regeneration techniques. Table 2 show the adequacy of each model to the demands and requirements expressed by the type of potential end-user.

Table 2. Level of adequacy of the different models to each end-user group (ranging from XX minimum adequacy, to √√, maximum adequacy)

Model	Forest managers	Forest Planners	Owners	Nut industry	Policy makers
G&Y table	X	√	X	X X	√
ORGEST	√	√√	√	X	√ √
PINEA2	√ √	√	X	√	X
PICUS	√	X X	X X	X	√ √
PINEA Regeneration	√ √	√	X X	X X	X

IV – Conclusions

Our results confirm the considerable modelling effort carried out with the species *Pinus pinea* in the last 20 years, identifying more than 100 references in the scientific literature. Despite this main progress, several gaps in knowledge have been detected. We observed a geographical gap in the presence of models for the species in countries such as Turkey or Lebanon, where the large production of cone justifies the use of tools supporting management. Also, recent models for the species in European countries as France or Italy are missing. The lack of climate-sensitive growth and yield models, models focusing on processes as mortality or regeneration, as well as process-based and physiological-based models can be referenced as another main gap. In this sense, a main topic of further research should focus on study physiological traits beyond floral induction and cone phenology and development, as well as on the influence of water and nutrients availability in the allocation patterns for roots, leaves, wood and cones for the species.

While the modelling effort has increased in the last two decades, the use of models by final users has not experienced a significant advance. Although a single model cannot meet all the required demands and outputs of every group of users, there are enough models as for covering all these demands. Model users should define their demands, and search among the available models which ones are better suited for their requirements. Forest managers and planners demand growth and yield models, acting at stand or tree level, sensitive to management, climate and flexible to include any initial state, and implemented in friendly interfaces. Forest owners require very simple tables that provide accurate estimates of cone and timber production. Policy makers focus on regional and national estimates, sensitive to climate, which means that simple tables holding large geographical validity, as well as process-based models would meet their requirements. Finally, models focusing on nut yield and quality is a demand from nut industry still uncovered. In any case, apart from this end-user oriented modelling effort, it is important to work on knowledge transfer and continuous feedback between researchers and stakeholders, which should be carried out by means of technical reports in native languages, divulgation sheets, workshops and seminars, web tutorials...

On modellers' side, there is a need to consider the demands from potential users during the modelling design phase. The observed gap on knowledge transfer between modellers and end-users should be taken into account. Modelling design should consider what the expected use of the models is. As a general conclusion of this work, before building our new model, we need to carefully think of why to construct the model, and who is going to use it. Providing that there are still gaps in modelling activity, future models aimed at *Pinus pinea* forests, should be developed with that idea in mind.

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