Final Report Short Term Scientific Mission within EuroCoppice

Details about the STSM

Title of STSM: Optimizing coppice management under climate change

Date for visit to Instituto Superior de Agronomia, University of Lisbon, Portugal: January 22nd up to February 5th, 2017 (15 days trip).

Information about applicant

Dr. Jordi Garcia-Gonzalo
Forest Sciences Center of Catalonia (CTFC), E25280, Ctra de St. Llorenç de Morunys Km 2, Solsona, Spain.
j.garcia@ctfc.es
Tel: +34676096229

Information about host

Researcher João Palma
Forest Research Center
School of Agriculture (ISA), University of Lisbon
Tapada da Ajuda 1349-017 Lisbon, Portugal
joaopalma@isa.ulisboa.pt
Tel (office): +351 213 653 489

REPORT

Background

Climate is changing and this may impact forest growth and the substantially the forest sector in Portugal. In fact, several studies indicate that in Mediterranean environments, climate change will have a negative impact on forest growth. For example, in Portugal, all climate change scenarios predict less precipitation across the country and a reduction of forest growth (Christensen et al. 2007; Lindner et al. (2010).

The objective of stand-level management planning is to determine the optimal combination of operations (planting, coppice harvest age, stool thinning, number of coppice cuts, final cut), the timing of entries, to best meet the management goals. Optimization typically encompasses an automated search for the best combination of activities. The reader is referred to Valsta (1990) and Hyytiäinen (2003) for comprehensive reviews of numerical methods for the optimization of even-aged stand management. However, optimizing forest management decisions without considering climate uncertainty would lead to non-optimal decisions and overestimation of income. Incorporating uncertainty into forest management planning is a challenging topic.

Empirical models are not suitable for estimating growth under different conditions from those observed during the period for which the inventory plots were measured to develop them (Landsberg and Waring

1997). Thus these models are inadequate to support decision-making under climate change. In this case, process-based models, which are based are based on physiological processes controlled by climatic and edaphic factors (e.g. Kellomäki et al. 1997) overcome the shortcomings of empirical models and may be then used to support forest management under climate change and when developing adaptive management options. In Portugal do exist two process based models that may be used to develop these adaptive management options. One is the process-based model, Glob3PG, that was first developed by Tomé et al. (2004), validated by Barreiro (2011). Glob3PG is a hybridization of the empirical model Globulus 3.0 (Tomé et al. 2006) and the process-based model 3PG calibrated for Portuguese conditions (Fontes et al. 2006; Landsberg and Waring 1997). Glob3PG takes advantage of the flexibility and ability of 3PG to predict the effects of changes in growing conditions (e.g., climate change, fertilization) and the prediction capacity under current conditions of Globulus 3.0 (Barreiro 2011). The second is Yield-SAFE (van der Werf et al 2007) which has been validated for Portugal (Palma et al. 2016)

There are examples of simulation optimization systems developed to optimize stand-level management of forests (Pukkala and Kellomaki 2012; Garcia-Gonzalo et al. 2014) but none has been developed to optimize coppice systems neither under climate change conditions. An example of model presented to optimize eucalypt stand-level management under climate change was presented by Ferreira et al. 2016. They presented a Stochastic Dynamic Programming model. However they did not implement this method in a decision support system.

Objective

The main goal of this STSM was to prepare a prototype of a simulation-optimization system (i.e DSS) for optimizing stand-level eucalypt coppice system management taking into account uncertainty in growth under climate change. This prototype integrates a growth and yield model sensitive to climate change (Glob3PG) and an optimization method (Hooke and Jeeves). The prototype also allows investigating the effects of climate change on eucalypt coppice stands.

Material and Methods

2.1 Simulation–optimization system

A simulation–optimization system STANDOPT was coded to simulate the development of Eucalyptus Globulus stands and to optimize stand management (Fig. 1, 2 and 3). The growth and yield model incorporated is a process-based model calibrated for Portuguese conditions (Tomé et al. 2006) to project stands' growth, while the optimization search procedure was the Hooke and Jeeves direct search method (Hooke and Jeeves, 1961). A second process-based model available in Portugal, Yield-SAFE (van der Werf et al 2007) was programmed into STANDOPT, however it was not used in the optimization because it has not been calibrated yet for coppice cycles.

STANDOPT may be used either for simulation or also for optimizing stand management. If used as simulator, the user must define the prescription (i.e. rotation length, cutting age per cycle, initial planting density, number of cycles to use during the rotation and number of stools ….). The user interface also allows incorporating the interest rate used and the management costs which include:

- The regeneration cost has two components (i.e. fixed costs and variable costs). The fixed costs occurring only once in the beginning of the planning horizon) and includes the soil preparation and the removal of shrubs. The variable component depends on the number of plants.
- Conversion cots, occur only at the end of a full rotation, when the stand is converted, i.e., the stools are replaced by new plants to regenerate the stand.
- Three years after the beginning of the coppice cycle, a stool thinning is performed with a cost that depends on the existing number of sprouts.

When the system is used as optimization system the user must define ranges of values for each of the decision variables (i.e. range of values for the management variables). For example, instead of defining one harvest age the user provides the range of possible harvest ages which will then be used by the search algorithm.

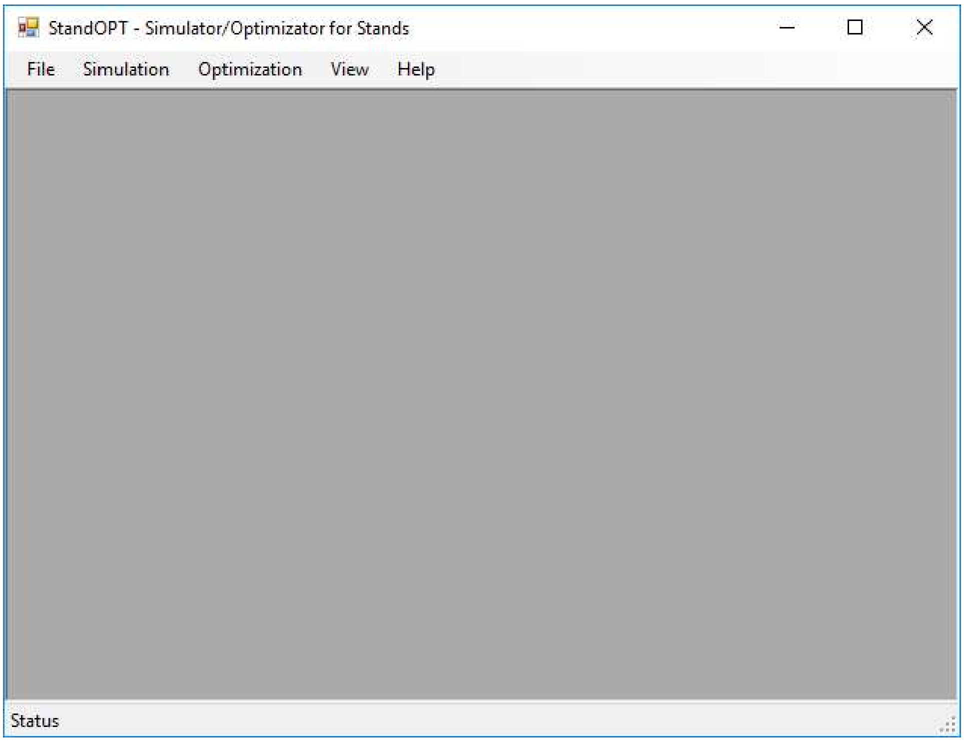

Figure 1. View of the DSS - StandOPT

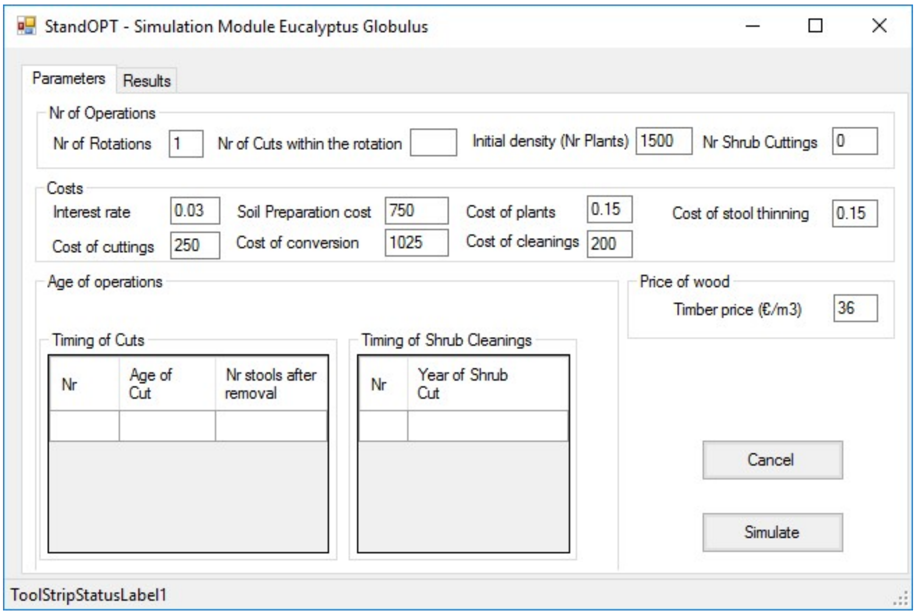

Figure 2. View of the simulation form.

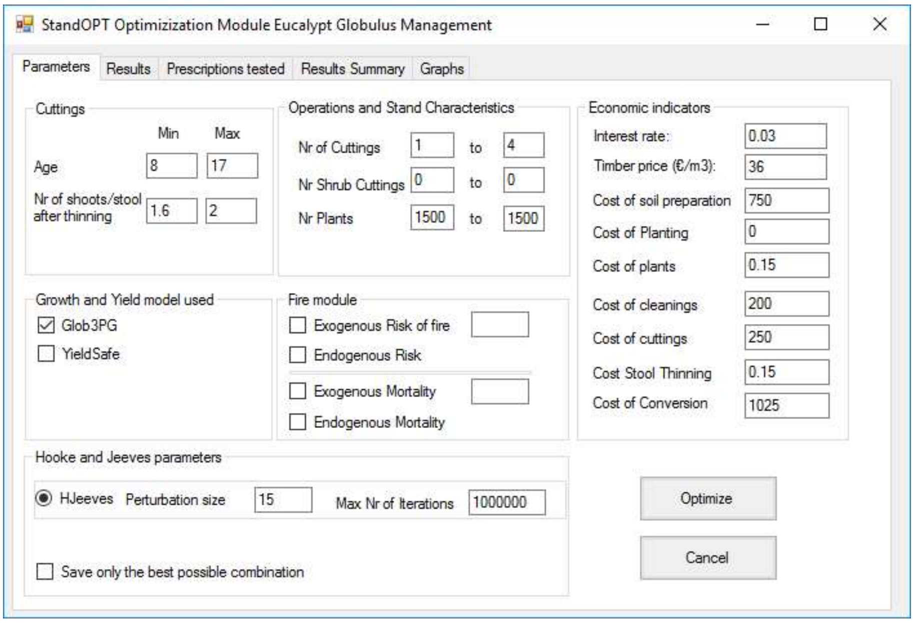

Figure 3. View of the optimization form.

2.2 Initial stand and economic parameters

In order to test the DSS, for the optimization it was considered a Eucalypt stand growing in central Portugal. Eucalypt stands are usually managed as a coppice system and supply key raw material for the Portuguese pulp and paper industry. A typical eucalypt rotation may include up to two or three coppice cuts, with each harvest being followed by a stool thinning in year three of the coppice cycle that may leave the mean number of sprouts per stool ranging from 1.4 to 1.6. Harvest ages range from 9 to 15. For the optimization and in order to give more management options to the optimization system, it was considered a maximum number of 4 coppice cuts with harvest ages ranging from 8 to 18 years, the number of sprouts ranged from 1.3 to 1.7. This research considered a plantation with 1500 trees·ha^{-1}.

The costs considered were based on information from Comissão de Acompanhamento das Operações Florestais (CAOF), and considered:

- Planting cost: Fixe cost (750 euros) and a variable cost (0.15 euros/plant).
- Conversion cost at the end of a full rotation (1250 euros).
- Stool thinning three years after the beginning of the coppice cycle (0.15 euros/sprout).
- Timber price (36 euros/m^3).
- Interest rate (3%)

Climate scenarios were used to see the impact of climate in stand management prescriptions. Climate variables included temperature (mean, maximum, and minimum), raining days, frost days, and solar radiation. Current climate was compared with a scenario were higher temperatures and a lower number of raining days were considered. In fact, precipitation was reduced by 40% and mean annual temperature increased by 4 degrees.

2.3 Optimization

The objective of the optimization was to maximize the soil expectation value (SEV) while finding the optimal number of harvests within the rotation (and harvest ages) as well as optimal number of sprouts per stool after a coppice cut.

2.4 Results

This optimization approach provides the optimal management schedule for each climate change scenario. Results indicate that the optimal solution found considers four cycles within the full rotation for all scenarios. Under current climate the management prescription indicates that first harvest should be performed at age 13, followed by a second harvest 14 years later and the next two harvests at ages 16. However, under climate change the two first harvests are delayed until age 16 and the next two shortened to age 12.

2.5 Discussion

In this research a DSS prototype was developed to optimize eucalypt stand management under climate change conditions. The process-based model programmed allows reading climatic data and projecting tree growth under different conditions which is an advantage compared to classical empirical growth and yield models. The optimization method presented does not need to evaluate all management options which would increase exponentially with the number of decision variables to consider (i.e. number of cycles, number of harvest ages to consider….). This considerably reduces the solution time.

There are examples of simulation optimization systems developed to optimize stand-level management of forests (Pukkala and Kellomaki 2012; Garcia-Gonzalo et al. 2014) but none has been developed to optimize coppice systems neither under climate change conditions. An example of model (Stochastic Dynamic Programming model) developed to optimize eucalypt stand-level management under climate change was presented by Ferreira et al. 2016 which provided similar results to this study. Nonetheless, both methods are not exact methods which may explain why the results may variate between the two studies (i.e. the optimization methods used find close to optimal solutions but there is not 100% certainty that they are optimal). Anyway to the author knowledge this is the first prototype of a DSS to optimize coppice stand management under climate change.

Main activities performed at host institution

During the visit to ISA, Jordi Garcia-Gonzalo will carry out the following activities in direct collaboration with Researcher João Palma (other researchers will be also involved as for example Margarida Tomé and Susana Barreiro):

1. Analyze the Glob3PG and the Yield-SAFE process-based models to decide which one should be integrated/used in the simulation-optimization system to project growth of eucalypt stands under climate change.
2. Programming both growth and yield models. Although in the original proposal it was said that only one model would be implemented, both models (Glob3PG and Yield-SAFE) where integrated in the system. However, only Glob3PG is functional for coppice systems since Yield-SAFE module for the coppice cycles is not ready yet.
3. Progamming/developing a Decision Support System Prototype that combines the process-based model and an optimization algorithm (e.g. Hooke and Jeeves) to optimize stand-level eucalypt management (Figure 1, 2 and 3).
4. Collect climate scenarios to be used in the case study to demonstrate the use of this DSS-prototype and to assess the impact of climate change on Eucalypt growth and optimal stand management.
5. Testing the approach by optimizing stand-level management for eucalypt coppiced stands under different initial growing conditions and climate scenarios. The optimization encompasses finding both the harvest age in each cycle and the number of coppice cycles within a full rotation that maximized Net Incomes.

Main output of the STSM.

The development of this DSS prototype allows optimizing eucalypt stand management depending on climate scenarios. Therefore, it may be used to adapt eucalypt management to climate change.

Literature

Christensen, J.H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., Jones, R., Kolli, R.K., Kwon, W.-T., Laprise, R., Rueda, V.M., Mearns, L., Menendez, C.G., Raisanen, J., Rinke, A., Sarr, A., and Whetton, P. 2007. Regional climate projections. In Climate Change: The Physical Science Basis Contribution of Working Group I to the 4th Assessment Report of the Intergovernmental Panel on Climate Change. Edited by S. Homon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and Miller, H.L. Cambridge University Press, Cambridge, United Kingdom – New York, NY.

Ferreira, L., Constantino, M., Borges, J. G., Garcia-Gonzalo, J, Barreiro, S. 2016. A climate change adaptive dynamic programming approach to optimize eucalypt stand management scheduling. A Portuguese application. Canadian Journal of Forest Research. 46: 1 – 9. Dx.doi.org/10.1139/cjfr-2015-0329.

Garcia-Gonzalo, J., Pukkala, T., Borges, J. 2014. Integrating fire risk in stand management scheduling. An application to Maritime pine stands in Portugal. Annals of Operational Research. Volume 219, Issue 1, Page 379-395

Hooke, R., & Jeeves, T. A. (1961). "Direct search" solution of numerical and statistical problems. Journal of the Association for Computing Machinery, 8, 212–229.

Hyytiäinen, K. (2003). Integrating economics and ecology in stand-level timber production. Finnish Forest Research Institute, Research Papers 908: 42 pp.

Kellomäki S, Karjalainen T, Väisänen H (1997)More timber from boreal forests under changing climate? Forest Ecol Manag 94:195–208

Landsberg JJ, Waring RH (1997) A generalised model of forest productivity using simplified concepts of radiationuse efficiency, carbon balance and partitioning. For Ecol Manag 95:209–228

Lindner, M., Maroschek, M., Netherer, S., Kremer, A., Barbati, A., Garcia-Gonzalo, J., Seidl, R., Delzon, S., Corona, P., Kolstrom, M., Lexer, M.J., and Marchettie, M. 2010. Climate change impacts, adaptive capacity and vulnerability of European forest ecosystems. For. Ecol. Manage. 259: 698 – 709. doi:10.1016/j.foreco.2009.09.023.

Palma, J.H.N., Graves, A.R., Crous-Duran J, Upson, M., Paulo, J.A., Oliveira, T.S., Silvestre Garcia de Jalón, S., Burgess, P.J. (2016). Yield-SAFE Model Improvements. Milestone Report 29 (6.4) for EU FP7 Research Project: AGFORWARD 613520. (5 July 2016). 30 pp.

Pukkala, T., and Kellomaki, S. 2012. Anticipatory vs adaptive optimization of stand management when tree growth and timber prices are stochastic. Forestry, 85(4): 463 – 472. doi:10.1093/forestry/cps043.

van der Werf, W., Keesman, K., Burgess, P.J., Graves, A.R., Pilbeam, D., Incoll, L.D., Metselaar, K., Mayus, M., Stappers, R., van Keulen, H., Palma, J.H.N., Dupraz, C. (2007). Yield-SAFE: A parameter-sparse, process-based dynamic model for predicting resource capture, growth, and production in agroforestry systems. Ecological Engineering 29: 419–433

Valsta, L. T. (1990). A comparison of numerical methods for optimizing even aged stand management. Canadian Journal of Forest Research, 20, 961–969.