Tackling climate change. Tours, France. 21 - May 2012

Assessing impacts of climate change in forested landscape planning with advanced decision support tools. A case study in Portugal

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ForChange Forest Ecosystem Management under Global Change

Technical University of Lisbon
The Institute of Agronomy of Lisbon

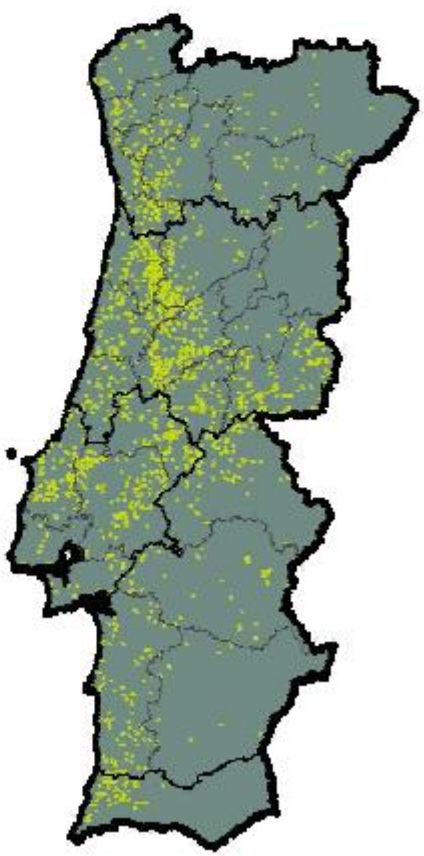
Outline

- I. Background
- II. Aims
- III. Material and Methods
  - A. Decision Support System
  - B. Case Study
    - Study Area
    - Prescriptions used
    - Management Objectives (mathematical model)
  - III.D. Scheme for modelling formulation and solving
- IV. Preliminary Results
- V. Discussion

I. BACKGROUND

- The future climate is expected to change substantially due to the increase of green house gases in the atmosphere, especially CO_2.
- In Portugal, the annual mean temperature (T) is expected to increase by 2-7°C together with a decrease of precipitation by 20-30% by 2100.
- This may impact forest growth, timber yield and accumulation of carbon (C) in our forests.

I.BACKGROUND



- Eucalyptus represents about 23% of the forest cover in Portugal (IFN,2005).
- Main raw material for pulp-paper industry
- Important for the economy (e.g. pulp and paper industry)

What can we do with climate change

- Ignore it and continue doing business as usual?
- Then we will achieve suboptimal solutions or bad solutions (Thorsen and Helles 1998, Pukkala 1998)

FUTURE ???

II. AIMS

- Develop a process-based model, Glob3PG, and integrate it together with optimization techniques.

- Analyse the effect of changing climatic conditions on the production of Eucalyptus plantations.

- Develop a DSS to optimize management plans for Eucalyptus (coppice management) under changing climate conditions.

- Should we change management under climate change?

Why to develp a DSS with OPT techniques and not a simulator?

- What can you do with simulators?
  - Check the outputs from a specified prescription
  - Scenario analysis
  - Answer what if questions…
- What you can not do or would be difficult to do with growth and yield simulators is to answer questions as:
  - What is the optimal plan for a landscape ?
  - Specially when taking into account even-flow of harvests, budget constraints, adjacency constraints…
- Growth and yield models are key in DSS

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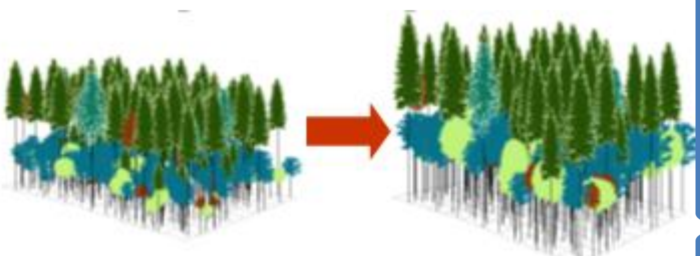
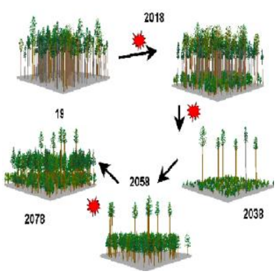
III. A. Decision Support System

User friendly tools

Growth modelling

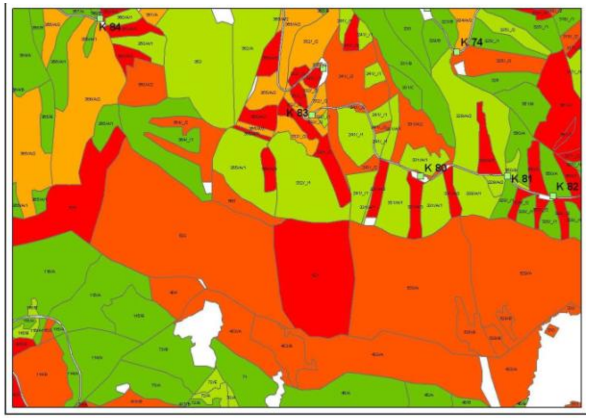


Predict Growth under CC

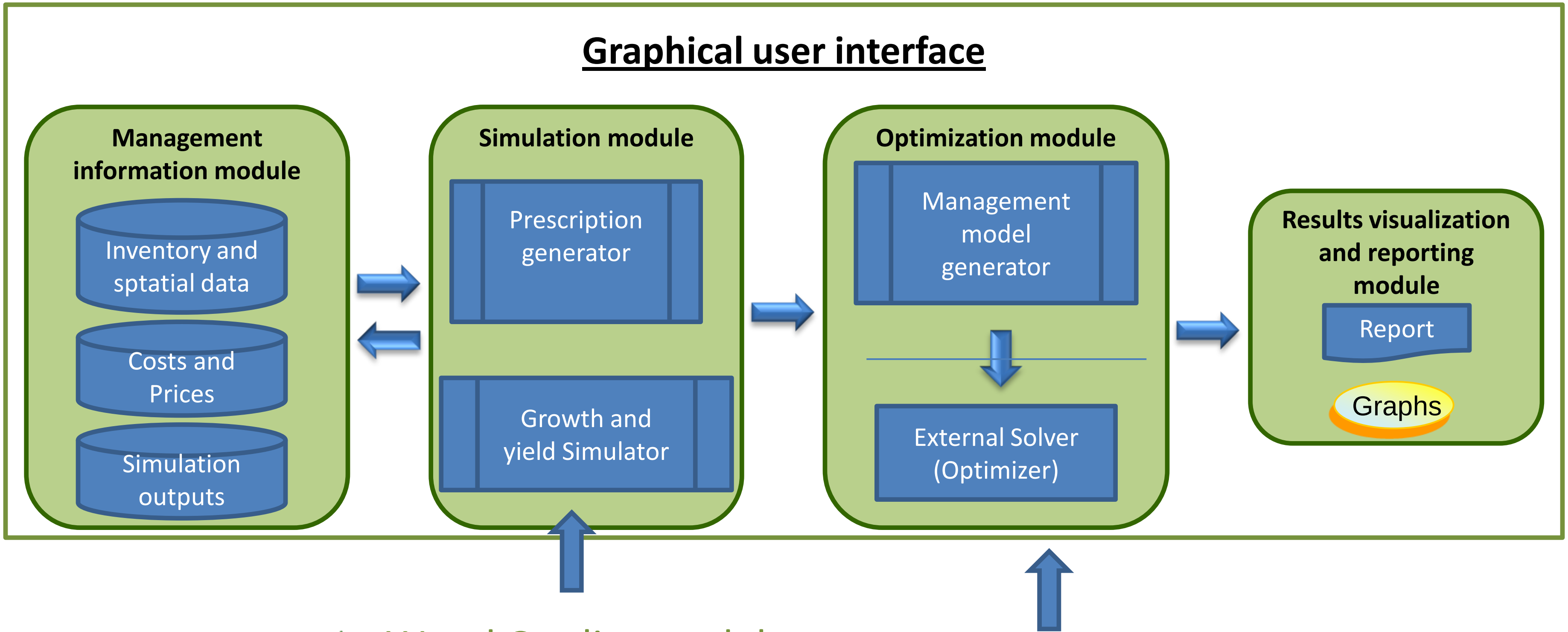


Decision support

Forest management plans



III. A. Decision Support System

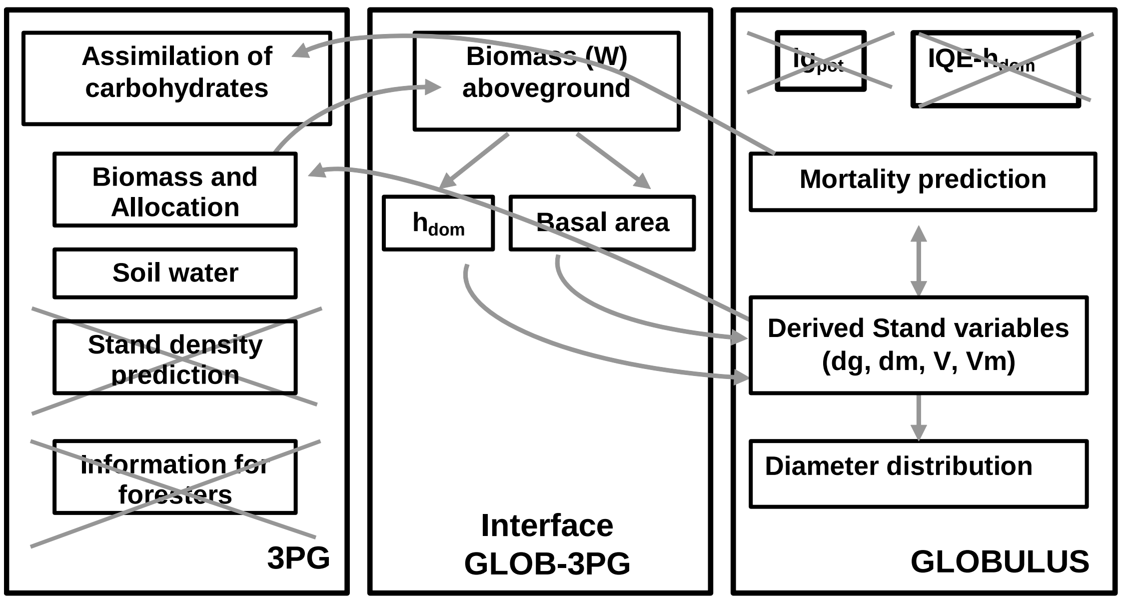


- Wood Quality models
- Risk and damage models…

- A simpler version of this module has been implemented in the MOTIVE toolbox

III. A. GROWTH MODEL

- Methodologies to link 3PG with Globulus were developed having stand variables as linking functions (Tomé et al., 2004):



III. A. GROWTH MODEL

- The result was the GLOB-3PG, a process-based model that:
- 1) is sensitive to climate changes (monthly time step)
- 2) can simulate the effect of intensive silvicultural practices such as irrigation, fertilization, initial stand density
- 3) gives detailed output on stand structure: diameter distributions, merchantable volumes to any top diameter
- 4) gives detailed output on run-off, carbon stocks…

III. A. DSS – SIMULATION/OPTIMIZATION

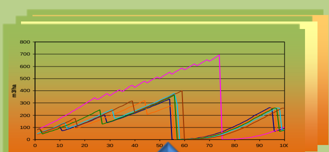
EfLOR- a Forest level Simulation Optimization system for Eucalipt

Precriptions Simulation Optimization About Help

Prices
Costs

Production indicators:

Volume cut
Run-off
Carbon stocks

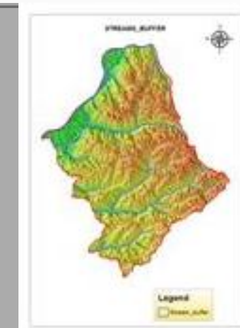


Management models (LP, MIP, GP, Heurist.):

- **Maximization of SEV**
- **Maximization of C seq.**
- **Minimization run-off**

- **Regulation of harvest flows**
- **Budget constraints**

Optimization



Final report with production indicators and preliminary operations scheduling Effects of climate change

Growth and Yield simulations (Process-based model – Glob3PG)

Climate data

Inventory data

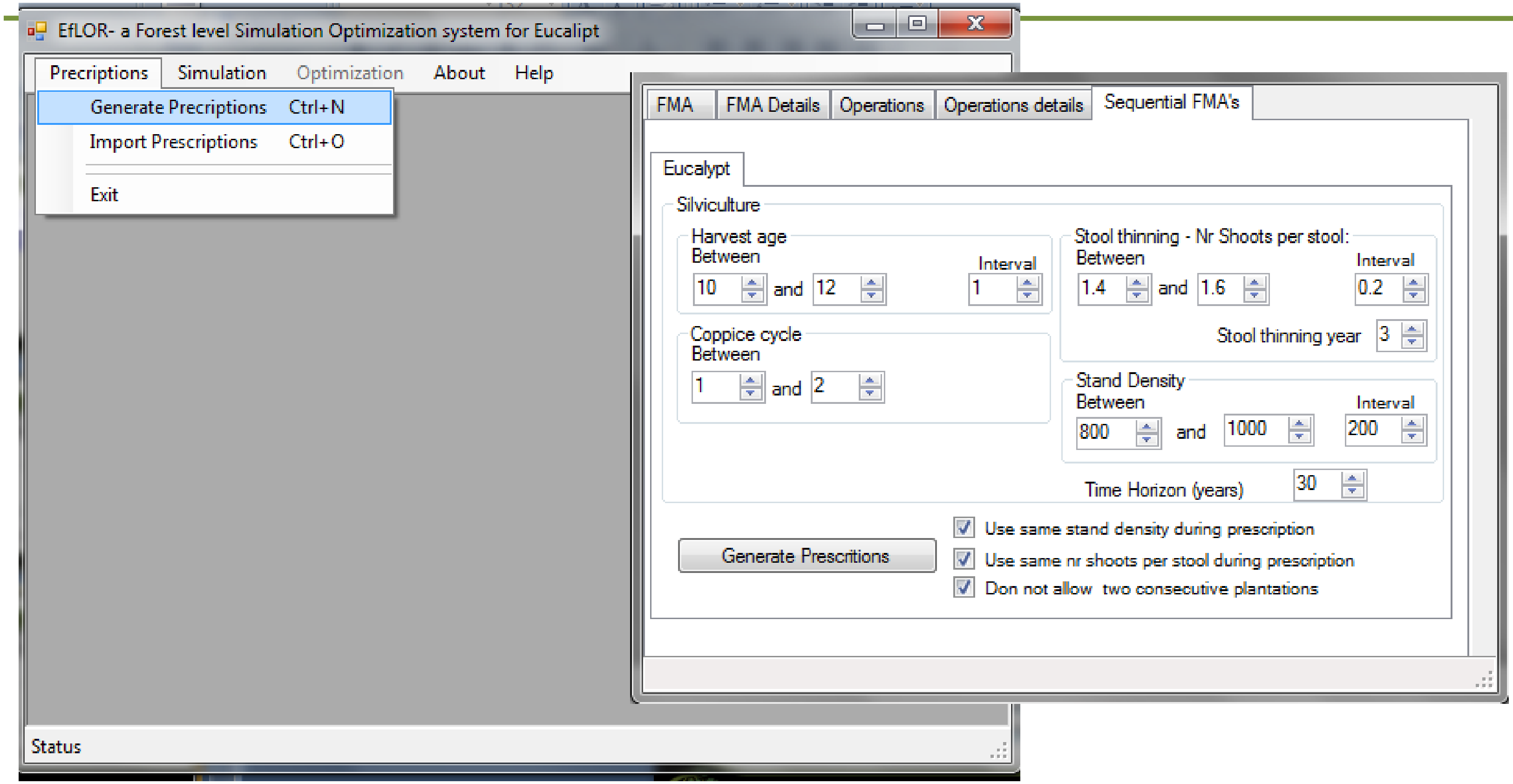
List of Prescriptions

Climate picker

PRESCRIPTION WRITER

Status

III. A. DSS -Prescription writer



- Management rules (Range of possible operations and timing)
- Thus, the prescription writer generates all possible prescriptions for the G&Y model. (this will be improved for efficiency…)

III. B. Optimization

- User constructs the mathematical model:
- 1) Defines the objectives (e.g. Max NPV)
- 2) Defines landscape level constraints (e.g. even flow of harvests)
- 3) Finally it defines the technique used to solve the problem:
  - Exact Methods .- LP, MIP, GP
  - Heuristics . – Simulated Annealing

III. B. MATHEMATICAL MODEL

$$\text{Max SEV} = \sum_{i=1}^{N}\sum_{j=1}^{M_i} sev_{ij} x_{ij} A_i$$

$$\text{Max CARB} = \sum_{i=1}^{N}\sum_{j=1}^{M_i} CARB_{ij} x_{ij} A_i$$

Subject to

$$\sum_{j=1}^{M_i} x_{ij} = 1, i = 1,\dots,N \quad (2)$$

$$\sum_{i=1}^{N}\sum_{j=1}^{M_i} npv_{ijt} x_{ij} A_i = NPV_t, t = 1,\dots,T \quad (3)$$

$$\sum_{i=1}^{N}\sum_{j=1}^{M_i} w_{ijt} x_{ij} A_i = W_t, t = 1,\dots,T \quad (4)$$

$$\sum_{i=1}^{N}\sum_{j=1}^{M_i} carb_{ijt} x_{ij} A_i = CARB_t, t = 1,\dots,T \quad (5)$$

$$\sum_{i=1}^{N}\sum_{j=1}^{M_i} runoff_{ijt} x_{ij} A_i = RunOff_t, t = 1,\dots,T \quad (6)$$

$$W_{t+1} \le (1 + alpha) \cdot W_t, t = 1,\dots,T-1 \quad (7)$$

$$W_{t+1} \ge (1 - alpha) \cdot W_t, t = 1,\dots,T-1 \quad (8)$$

$$x_{ij} \in \{0,1\}, \forall i, j \quad (9)$$

N – Number of stands (1000)

T – Number of periods during the planning horizon (30)

M_i – Number of prescriptions (management regimes) for stand i.

x_{ij} – Binary variable that is set equal to 1 if alternative j is chosen for stand i and to 0 otherwise.

A_i – Area of the stand i.

npv_{ij} – Net present value per ha associated with prescription j and stand i.

sev_{ij} – Soil expectation value per ha associated with prescription j and stand i.

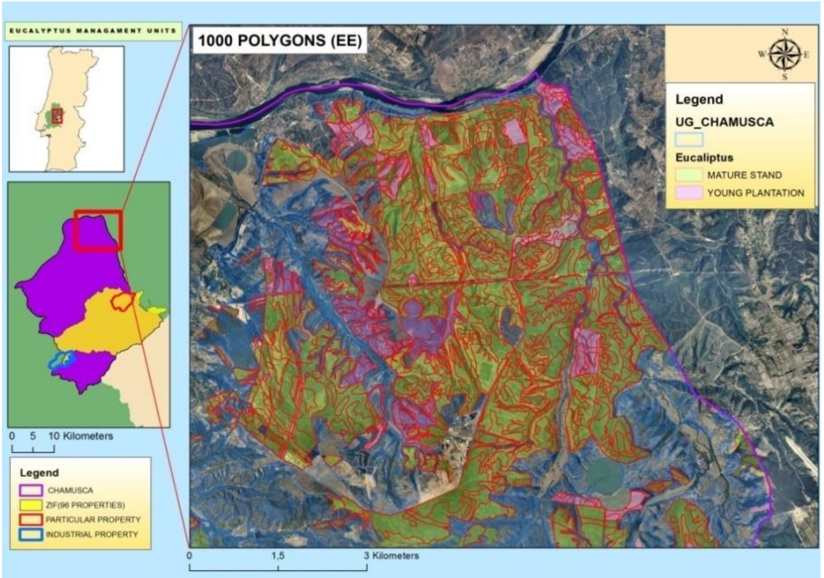
w_{ijt} – Harvested eucalypt pulpwood flow per ha in period t that results from assigning prescription j to stand i.

$carb_{ijt}$ – Average carbon stock per ha in stand i in period t if prescription j is selected.

$RunOff_{ijt}$ – Runoff per ha in stand i in period t if prescription j is selected.

$alpha$ - Deviation allowed from target level (e.g 10% variation)

Output – Management plan



- List specifying which prescription (i.e management alternatives to use in each stand
- Optimal plan for the whole landscape ≠ ∑ best management alternative for each stand.
- This is because you have higher level constraints (landscape constraints)

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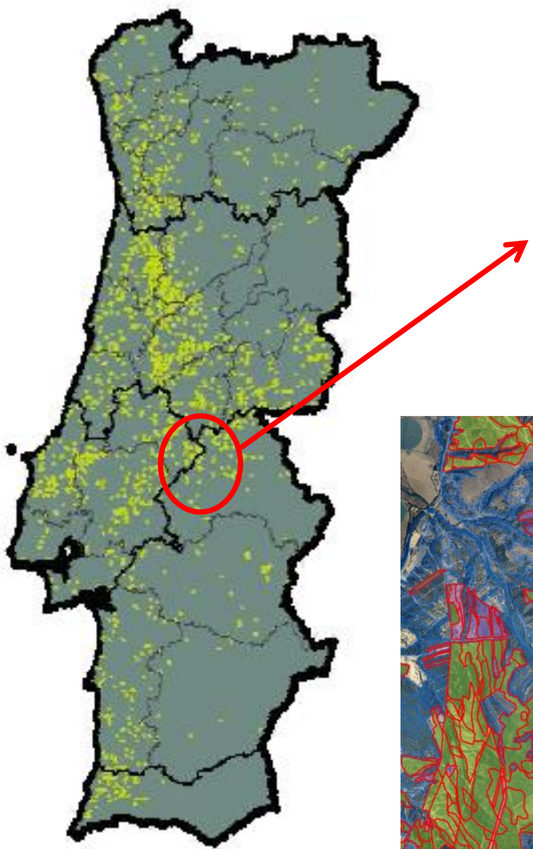
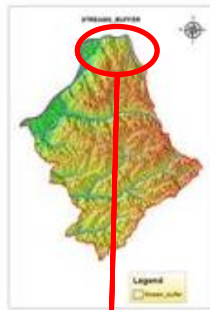
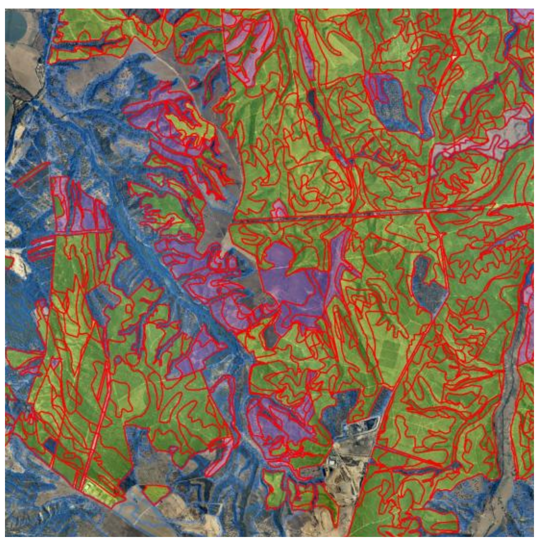
III.B. Case study

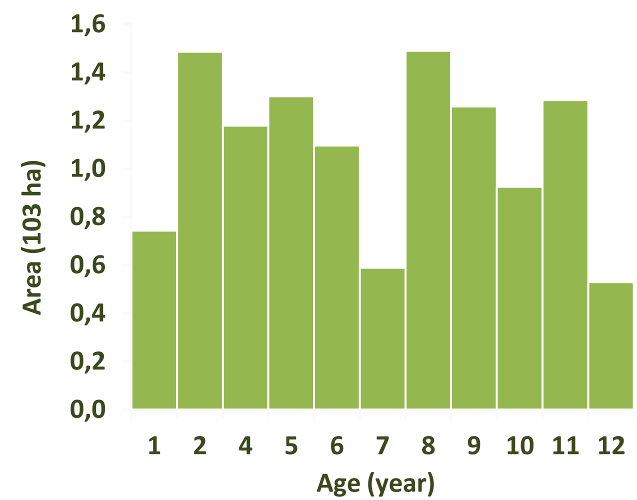
In order to test the use of the proposed DSS



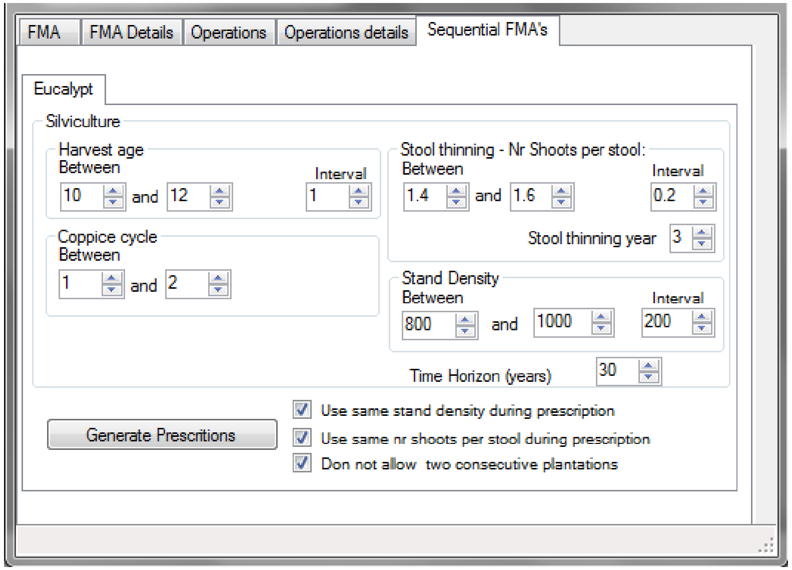


- a case study for eucalyptus forest located in central Portugal
- 1000 stands (11853 ha)
- Real inventory data is used in this study





III. B. Prescriptions used



- In contact with the industry we defined the possible prescriptions:
- 1) A cycle may have up to three rotations
- 2) Rotation lengths between 9 and 15 yr
- 3) In the coppice stands, three years after cutting there is a stool thinning leaving 2 stems per stool

- Thus, all possible prescriptions where generated with the prescription writer (up to 200 possible prescriptions per stand) and projections done for the whole area.

III. Mat and Methods. Study case summary

- Scenarios Generator
  - Forest – 1000 stands, 11873 ha
  - Climate –IPCC scenario A1B (current climate + 2 climate change scenarios)
  - Prescription writer – 198 prescriptions per stand
- Simulation module:
  - Growth and yield indicators – process based model
  - Economic indicators (prices, costs, 4% interest rate)
- Optimization module
  - Maximize SEV (or Max Cstocks) with even-flow constraints (10%)
  - Model I formulation with Horizon planning = 30 years (1-year period for flow constrains)
  - Problem size: 198.000 binary variables, 2000 equations..
  - Solver – model used MIP

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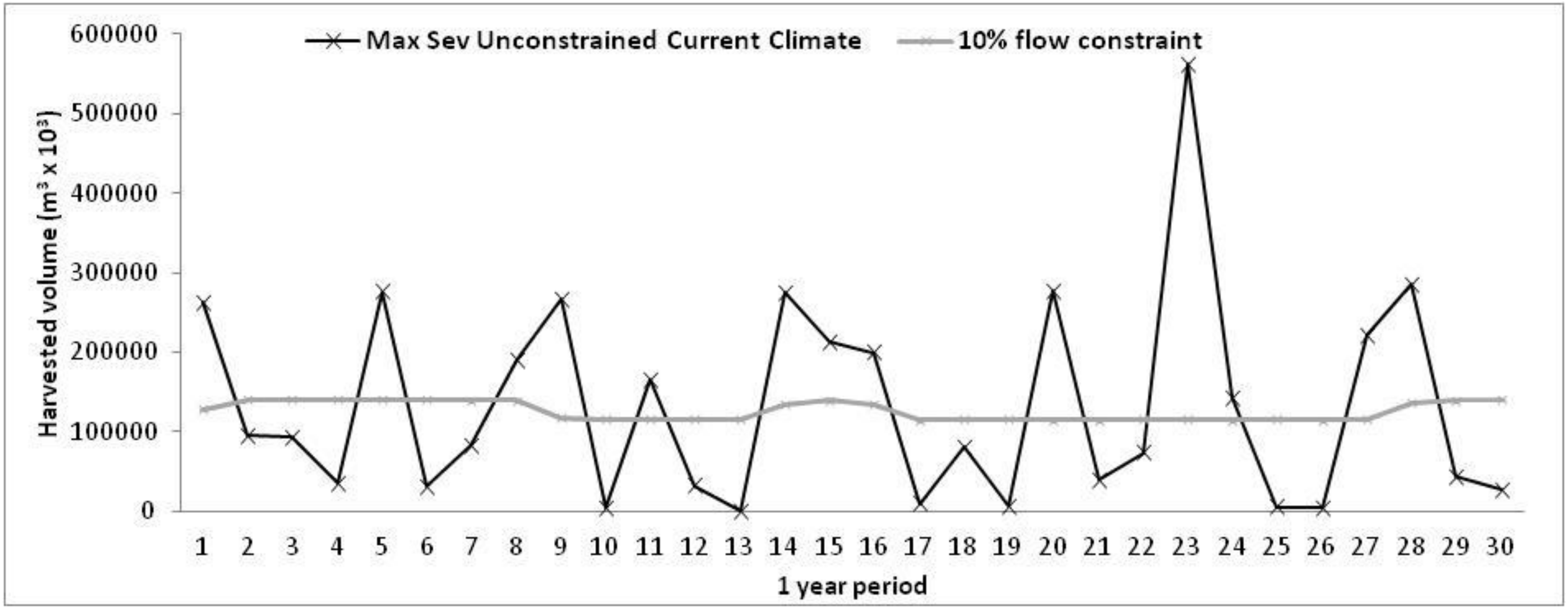
- Optimal plan for the whole landscape ≠ ∑ best management alternative for each stand.



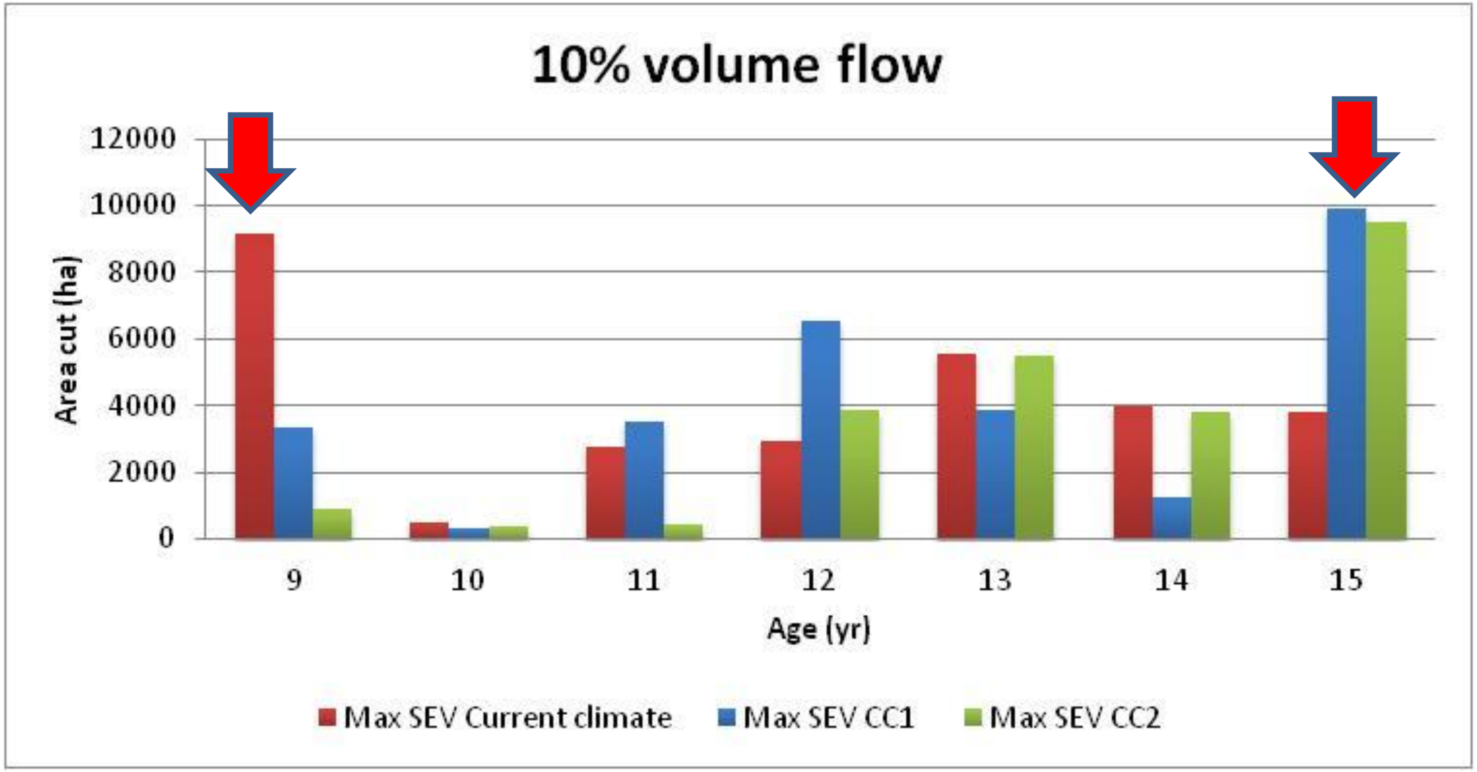
•Selecting the most productive management alternative would give a very unbalanced timber flow.

IV. Results

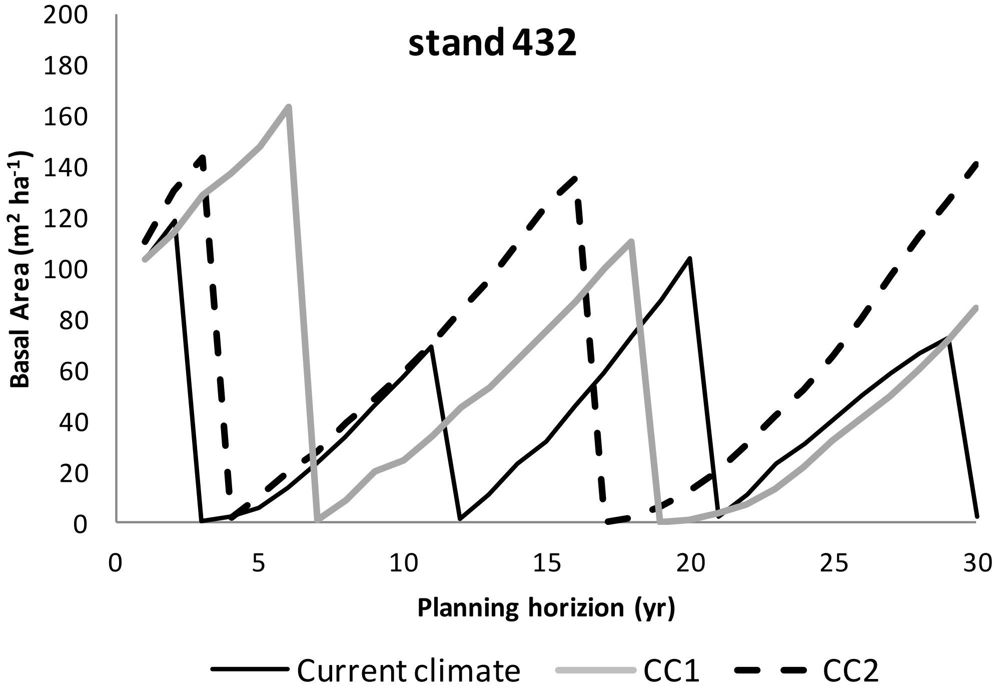
Objective	Constraints	Climate Scenario	SEV
MaxSev	-	Current	158541436
		CC1	147247154
		CC2	130024206

Economic productivity of the study area will decrease between 10 and 20% depending on the climate scenario.

IV. Results – management trends under cc



IV. Results – trends under cc – stand level



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V. Discussion and conclusions

- Results indicate that Eucalipt productivity will be drastically reduced
- Results also indicate that management plans may need to be adapted
- We may delay cuttings under climate change in order to meet flow constraints.

V. Discussion and Conclusions

Good

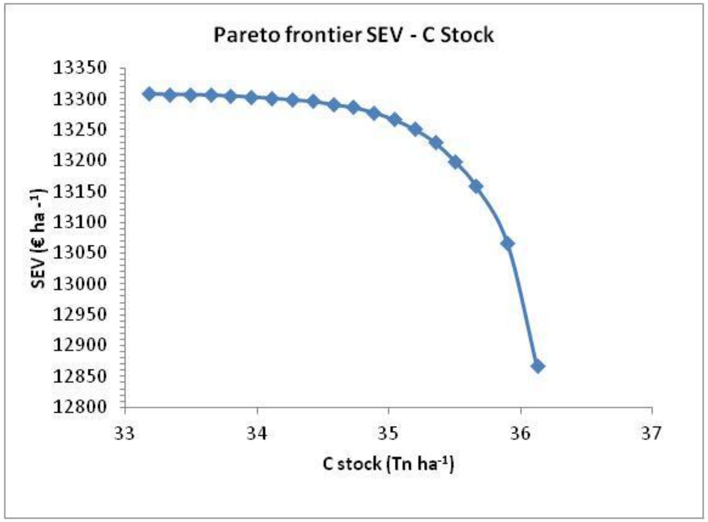
- modular structure gives flexibility to update the different modules
- the structure of this DSS will allows including new growth models and also models for risk assessment (fires, pests etc....)
- Results demonstrated the potential of the proposed approach to provide information and to support landscape analysis and planning under scenarios of climate change.

Bad

- The system does not allow species substitution yet...
- We do not have relation between runoff and erosion

V. Discussion – ongoing work

- We have developed a stochastic mathematical models to include fire risk in the optimization (results not digested yet...)
- This DSS allows constructing Pareto Frontiers for two-compiting objectives (in MIP formulation)



- However, work is ongoing to use FGMethods/Interactive decision maps to show Pareto frontiers for more competing objectives

Sources of funding

- ForEAdapt .- Knowledge exchange between Europe and America on forest growth models and optimization for adaptive forestry FP7-PEOPLE-2010-IRSES-269257
- MOTIVE - Models for adaptive forest management FP7-ENV-2008-1
- PTLYPTUS - Melhoramento genético do eucalipto para produção de pasta e energia promovendo o uso eficiente de recursos naturais QREN SI I&D - Projecto nº 5477 – PT-LYPTUS

THANK YOU!

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