Models for forest growth simulation

From research to sustainable forest practices

From individual stand to Europe level

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- Forestry
  - Forestry is the science, art, business, and practice of conserving and managing forests and forest lands to provide a sustained supply of forest products, forest conditions, or other forest values desired by the forest owner and the society in general

    (Ford-Robertson, 1971)
- Forest management
  - Forest activities imply decisions about the relationship between man and the forest, in particular about the way man modifies the forest in order to achieve its objectives - forest management

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- Forest management decisions occur at different scales of spatial resolution:
  - stand
    homogeneous forest area
  - management unit
    set of stands with a common management plan
  - watershed, landscape
  - region
  - country
  - continent
  - globe

Foresters and private owners

Politicians and public administrators

Evolution of forestry

- Development of forestry (Kimmins, 1997)

	Stage of development	Result
Preforestry	Exploitation	→ Resource depletion
Forestry stage 1	Administrative forestry	→ Failure to achieve conservation and sustainability goals
Forestry stage 2	Ecologically based forestry	→ Sustained production of timber and other conventional products
Forestry stage 3	Social forestry	→ Ecologically based forestry that sustains a wide range of forest conditions and values desired by society

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- Forest management goals increased in parallel with the development of forestry (adap. From Lund & Smith, 1997)

1950's	1960's	1970's	1980's	1990's	2000's
Timber	Timber	Timber	Timber	Timber	Timber
	Multiple resources	Multiple resources	Multiple resources	Multiple resources	Multiple resources
		Biomass	Biomass	Biomass	Biomass
			Global warming	Global warming	Global warming
				Ecosystems, biodiversity, non-wood products	Ecosystems, biodiversity, non-wood products
					Other´s lands?

Sustainable forest management:

- The stewardship and use of forests in a way, and at a rate, that maintain their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfill, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems

source: MCPFE, 2000

Pan-European criteria and guidelines for sustainable forest management (Lisbon Conference, 1998):

Maintenance and enhancement of ...

1. Forest resources and their contribution to global carbon cycles
2. Forest ecosystem health and vitality
3. Productive functions of forests (wood and non-wood)
4. Biological diversity in forest ecosystems
5. Protective functions in forest management (soil and water)
6. Socio-economic functions and conditions

Decision support tools

Models of forest growth and dynamics

- To support decision-making, all forest resources administrators (politicians, public and private land administrators, foresters, etc) require sound predictions on the evolution of the forest under alternative management actions
- Models of forest growth and dynamics are important decision-support tools of sustainable forest management by providing both qualitative understanding and quantitative predictions of the effects of different management practices on forest ecosystem behaviour over different temporal and spatial scales

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Forest growth models

Forest management models

Forest scenario models

Forest growth models

Forest growth models

- Forest growth models predict growth and dynamics of a target forest stand using as input site characteristics and management options
- There are three different types of models:
  - Empirical growth and yield models
  - Process-based ecophysiological models
  - Process-based models of long-term forest ecosystem dynamics

Empirical growth and yield models

- Developed using statistical techniques and calibrated for large data-sets
- Adequately describe growth for a range of silvicultural practices and site conditions
- Some are able to predict wood quality properties
- Most have been extensively validated
- Exist for all of the most important forest types in Europe
- Do not allow for the simulation of forest growth under a changing environment or subject to novel silvicultural practices

Process-based ecophysiological models

- Developed to understand forest behaviour from a description of plan-soil and carbon-nutrient-water interactions
- Are useful for large-scale long-term predictions with particular reference to global-change phenomena
- Are constructed to satisfy mass conservation which constitutes a powerful constraint on sustainable management
- A specific problem with this type of model is the need for detailed input, demanding data which are rarely available at regional or lower levels
- Do not give all the output needed for forest management, some restrict the output to gross or net primary production in biomass

Process-based models of long-term forest ecosystem dynamics

- Tailored to model natural and management induced disturbances in cultivated or natural forests, from a spatially explicit description of recruitment, growth and mortality of individual trees
- A typical example are teh so-called gap models that define and keep track of individual trees competing and growing in a restricted area
- Modelling is based on a global ecophysiological perception of competition for resources and allometric mensurational characteristics of individual trees
- Perform well in reflecting qualitaticve impact of disturbances on forest dynamics but some few models are suitable as decision-support for forest management

What is then the best type of model?

- None of the models presently available do meet all the requirements needed to evaluate the sustainability of forest management practices:
  - Scientifically there is the need to improve the knowledge of the forest ecosystem to be able to predict stand growth and forest development under changing environmental and managerial conditions
  - For forestry practice, there is the need to improve output quality regarding the level of detail as well as the accuracy of predictions; for instance good information on stand structure is essential to assess wood quality or to evaluate harvesting procedures and costs

What is then the best type of model?

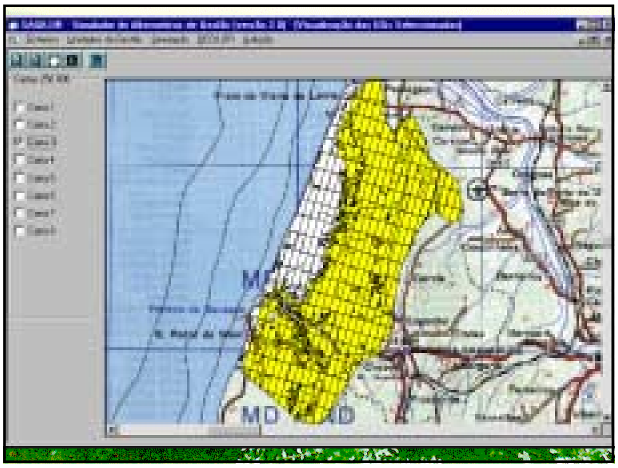
- None of the models presently available do meet all the requirements needed to evaluate the sustainability of forest management practices:
  - Current models usually do not include risk assessment such as storm damage, fire, pests and diseases; nor are they able to reflect the effect of genetics
  - Concentrate output on the development of trees (do not give output on the impact of forests and forest management on soils and water use, on biodiversity, recreational and amenity values, etc)
  - Do not simulate the impact of genetic improvement

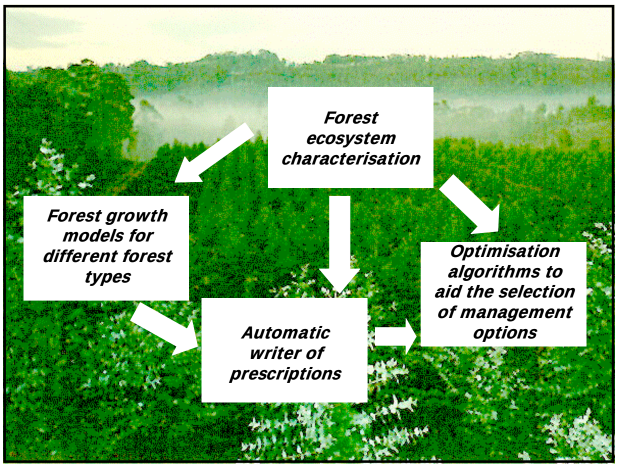
- What do we then need?
  - We need a "mariage" between empirical and process based models in order to obtain hybrid models that
    - can work using forest inventory data as input
    - simulate the effect of global change on tree and stand growth
    - take into account the genetics of the plant material
    - provide information of the effect of different silvicultural alternatives not only on tree growth but also on other forest products and services
    - provide reliable information on stand structure and wood quality
    - account for the possible occurence of several damages

Forest management models

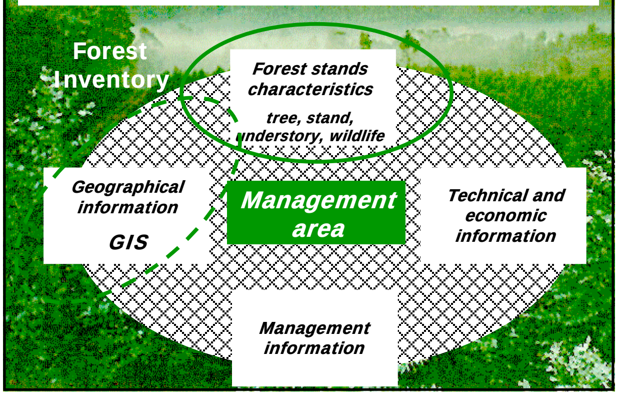
Forest management models

- Forest management models are decision support systems that are used in operational forestry at management unit level, being sometimes usefull for policy making
- Optimising pre-defined goals and criteria, they assist in choosing between management alternatives for each individual stand included in a management unit
- Can integrate models for several forest types as well as models for forest products and other services, being usefull for evaluating sustainability at forest, landscape or regional levels
- Using spatial digital information about the stands in the target area, these models can incorporate a range of spatial, temporal and other restrictions or goals related to minimum or maximum harvest area, adjacency restrictions, etc

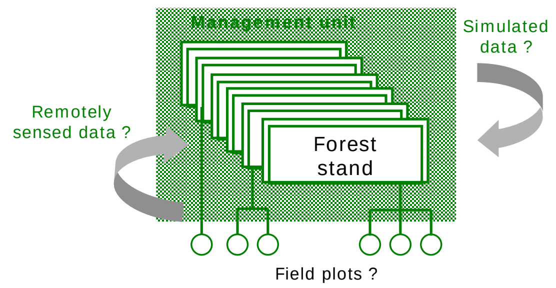


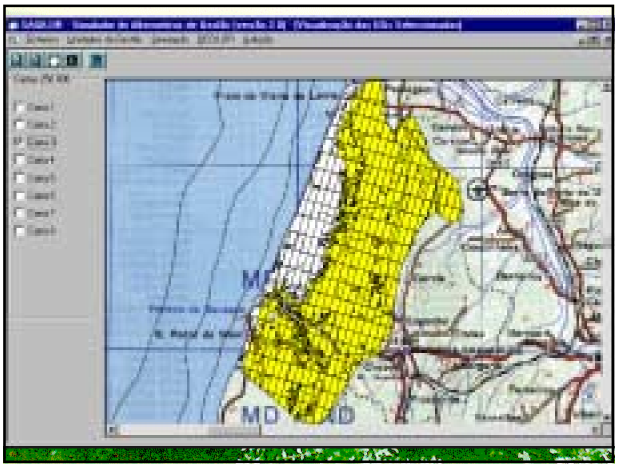


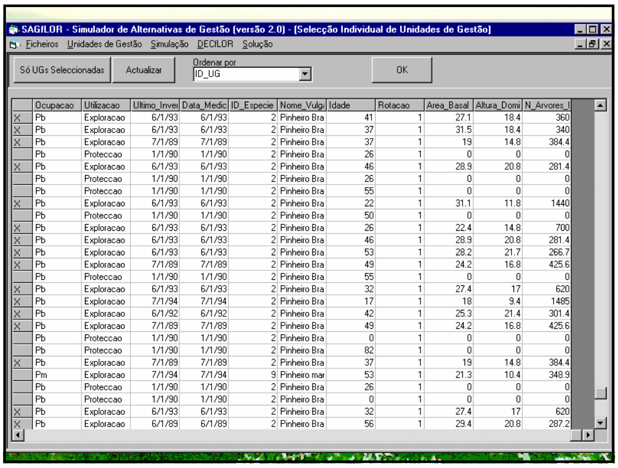
Forest ecosystem characterisation



Information for each stand – how?







	Ocupacao	Utilizacao	Ultimo_Inver	Data_Medic	ID_Especie	Nome_Vulga	Idade	Rotacao	Area_Basal	Altura_Domi	N_Arvores_I
X	Pb	Exploracao	6/1/93	6/1/93	2	Pinheiro Bra	41	1	27.1	18.4	360
X	Pb	Exploracao	6/1/93	6/1/93	2	Pinheiro Bra	37	1	31.5	18.4	340
X	Pb	Exploracao	7/1/89	7/1/89	2	Pinheiro Bra	37	1	19	14.8	384.4
	Pb	Proteccao	1/1/90	1/1/90	2	Pinheiro Bra	26	1	0	0	0
X	Pb	Exploracao	6/1/93	6/1/93	2	Pinheiro Bra	46	1	28.9	20.8	281.4
	Pb	Proteccao	1/1/90	1/1/90	2	Pinheiro Bra	26	1	0	0	0
	Pb	Proteccao	1/1/90	1/1/90	2	Pinheiro Bra	55	1	0	0	0
X	Pb	Exploracao	6/1/93	6/1/93	2	Pinheiro Bra	22	1	31.1	11.8	1440
	Pb	Proteccao	1/1/90	1/1/90	2	Pinheiro Bra	50	1	0	0	0
X	Pb	Exploracao	6/1/93	6/1/93	2	Pinheiro Bra	26	1	22.4	14.8	700
X	Pb	Exploracao	6/1/93	6/1/93	2	Pinheiro Bra	46	1	28.9	20.8	281.4
X	Pb	Exploracao	6/1/93	6/1/93	2	Pinheiro Bra	53	1	28.2	21.7	266.7
X	Pb	Exploracao	7/1/89	7/1/89	2	Pinheiro Bra	49	1	24.2	16.8	425.6
	Pb	Proteccao	1/1/90	1/1/90	2	Pinheiro Bra	55	1	0	0	0
X	Pb	Exploracao	6/1/93	6/1/93	2	Pinheiro Bra	32	1	27.4	17	620
X	Pb	Exploracao	7/1/94	7/1/94	2	Pinheiro Bra	17	1	18	9.4	1485
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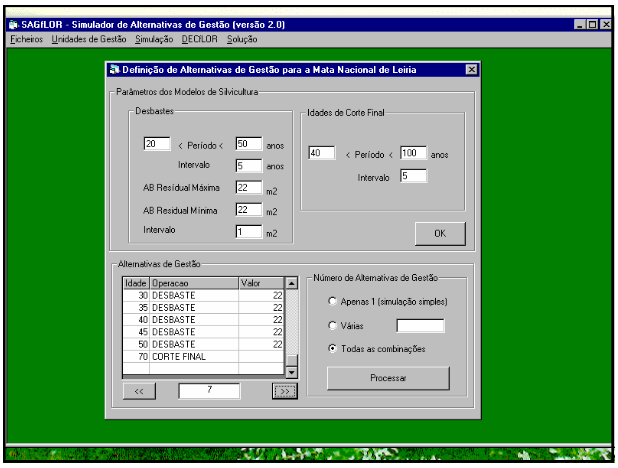
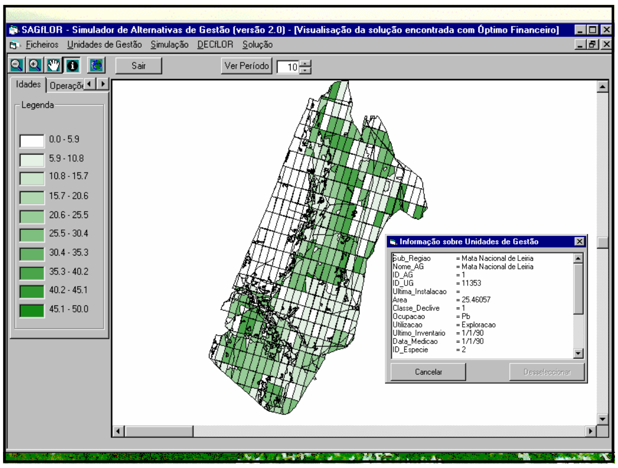
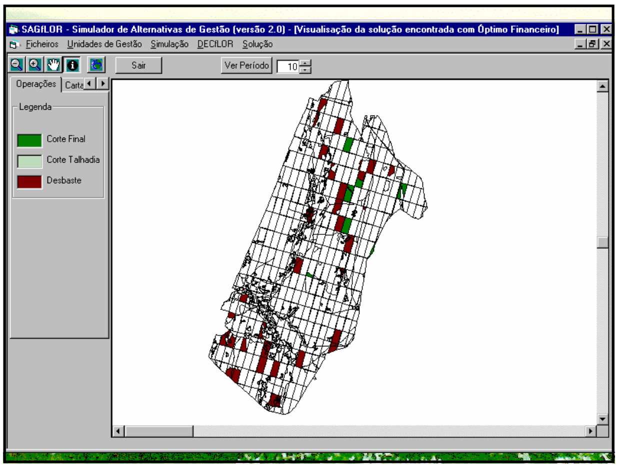
X	Pb	Exploracao	7/1/89	7/1/89	2	Pinheiro Bra	49	1	24.2	16.8	425.6
	Pb	Proteccao	1/1/90	1/1/90	2	Pinheiro Bra	0	1	0	0	0
	Pb	Proteccao	1/1/90	1/1/90	2	Pinheiro Bra	82	1	0	0	0
X	Pb	Exploracao	7/1/89	7/1/89	2	Pinheiro Bra	37	1	19	14.8	384.4
	Pm	Exploracao	7/1/94	7/1/94	9	Pinheiro mar	53	1	21.3	10.4	348.9
	Pb	Proteccao	1/1/90	1/1/90	2	Pinheiro Bra	26	1	0	0	0
	Pb	Proteccao	1/1/90	1/1/90	2	Pinheiro Bra	0	1	0	0	0
X	Pb	Exploracao	6/1/93	6/1/93	2	Pinheiro Bra	32	1	27.4	17	620
X	Pb	Exploracao	6/1/89	6/1/89	2	Pinheiro Bra	56	1	29.4	20.8	287.2



Goals and restrictions (example)

- In an even-aged plantation with several stands of different age:
  - Maximisation of net present value subject to
    - Even-flow of wood products
    - Harvesting can not occur in areas > 30 ha nor < 10 ha
    - Harvesting can not occur in areas with an age < 10
    - Areas to be fertilised (or thinned) in the same year should be concentrated
    - Harvesting should not occur for ages > 15 in order to guarantee a certain amount of extractives
    - Harvesting should not occur before the age of 10





What forest growth models to use?

- Forest management models are not compatible with the use of very detailed models due to the correspondent need of input data
- But the analysis of sustainability demands for outputs that can only be obtained with more complex models
- There is the need to find ways to use, in the forest management model, information obtained from model runs at stand level (complex, detailed models); for some case studies, the results of such methodologies can be tested by using complex models in the forest management model

Forest scenario models

Forest scenario models

- Forest scenario models allow for the prediction of the evolution of all the forests in large areas such as a country or a whole continent
- At the national level, or even for a whole continent, models of forest growth and dynamics provide an indispensable foundation for large-scale scenario modelling.
- Forest scenario models provide an important basis for evaluating sustainability in terms of ecological, economic and social aspects

What forest growth models to use?

- Due to its generality, they usually rely on very simplified forest growth models that work with a high level of aggregation of forest inventory data
- To what extent does aggregation of forest inventory data affect the results of predictions?
- Will it be possible to use stand level models integrated in scenario models?
- Will it be possible to use results from more complex model runs at lower levels as restrictions in forest scenario models?

Identified research topics

Identified research topics

- Better forest growth models
  - One practical challenge lies in transfering the information from detailed, process-based models to empirical growth models that can be easily be used in forest management and scenario models as these are the essential decision support tools for forestry practice as weell as for policy making
  - There are different options to enhance information flow from process-based models to decision support tools:
    1. To use process-based growth indices or growth modifiers to improve predictions from traditional growth models
    2. Simplification and direct incorporation of process-based models
    3. Use of mass balance analysis to generate robust constraints to traditional growth models

Identified research topics (cont.)

- Better forest inventory techniques
  - In forest management models there is the need to characterise each stand with all the information needed as input for the forest growth models used, how to get this information in a reliable and cost-compatible way is an important research topic, using:
    - New sampling procedures
    - Remotely sensed data
    - Simulation techniques
    - ...

Identified research topics (cont.)

- Integration of models of different complexity
  - There is the need to find ways to use, in forest management models, information obtained from model runs at lower levels (complex, detailed models); for some case studies, the results of such methodologies can be tested by using complex models in the forest management model
  - The same type of methodologies may be extended to forest scenario models

Identified research topics (cont.)

- Data aggregation in simulations at higher levels
  - To what extent does aggregation of forest inventory data affect the results of predictions? It will be usefull to use case studies – a country or region, for instance – to compare the results of long-term predictions based on different levels of forest inventory data aggregation