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# Models for sustainable management of Temperate plantation forest

**Bordeaux - 7 9 September 2000**

# PROGRAMME

## *Thursday 7th September 2000*

09:15 – 09:30 Introduction to the workshop. *Jean-Michel Carnus (INRA Pierroton, France).*

09:30 – 10:10 **Introductory keynote address:** Plant-Soil Interactions: key processes for understanding sustainable management. *Mike Proe (Macaulay Land Use Research Institute, Aberdeen, UK). p. 5*

### Session 1 – Carbon and water balance (Chairperson : Jean-Michel Carnus)

10:10 – 10:50 **Keynote address :** Maximising wood yield, carbon storage and efficient use of N. *Melvin Cannell (Centre for Ecology and Hydrology, Edinburgh, UK). p. 6*

10:50 – 11:10 Coffee break

11:10 – 11:40 Simulated effects of tree harvest on C fluxes in $20^{th}$ and $21^{st}$ century temperate forests. *Daniel Rasse (University of Liège, Belgium). p. 7*

11:40 – 12:10 The 3-PG model : matters arising from evaluation against plantation data from many countries. *Joe Landsberg (Landsberg Consulting, Canberra, Australia). p. 8*

12:10 – 12:40 Impact of a $2\times CO_2$ climate scenario on the water and carbon balances and primary productivity of maritime pine. *Denis Loustau (INRA, Pierroton, France). p. 9*

12:40 – 13:00 Pause

13:00 – 14:30 Lunch at INRA, Bordeaux

### Session 2 – Nutrient balance (Chairperson : Roderick Dewar)

14:30 – 15:10 **Keynote address :** Plant-soil models as tools to explain changes in forest productivity and site fertility over successive rotations. *Ross McMurtrie (University of New South Wales, Sydney, Australia). p. 10*

15:10 – 15:40 A model approach to assess the sustainability of the soil nitrogen balance of short rotation eucalytpus in Western Australia. *Marc Corbeels (CSIRO Forestry and Forest Products, Wembley, Australia). p. 11*

15:40 – 16:00 Coffee break

16:00 – 16:30 Nitrogen uptake in young Norway spruce on a fertile site in southern Sweden – effects of fertilization and herbicide treatments. *Urban Nilsson (Swedish University of Agricultural Sciences, Alnarp, Sweden). p. 12*

16:30 – 17:00 Linking production, leaf area, nitrogen use, and soil nitrogen availability in loblolly pine plantations. *Lee Allen (North Carolina State University, Raleigh, USA). p. 13*

## *Friday 8th September 2000*

### Session 3 – Decision support, biomechanics (Chairperson : Denis Loustau)

09:30 – 10:10 **Keynote address :** The use of management-oriented growth and yield models to assess and model forest wood sustainability : a case study for eucalyptus plantations in Portugal. *Margarida Tomé (Instituto Superior de Agronomia, Lisboa, Portugal).* *p. 14*

10:10 – 10:40 Improving the methodology for stand-level assessment of long-term productivity shift : an example in sessile oak high forests. *Jean-François Dhôte (INRA-ENGREF, Nancy, France).* *p. 15*

10:40 – 11:00 Coffee break

11:00 – 11:30 A regeneration model for planted Norway spruce in southern Sweden. *Fredrik Nordborg (Swedish University of Agricultural Sciences, Alnarp, Sweden).* *p. 16*

11:30 – 12:00 Evaluation of different optimisation models to schedule silvicultural operations (in French). *Paulina Pinto (Departamento de Ingenieria Forestal, Pontificia Universidad Catolica de Chile, Santiago, Chile).* *p. 17*

12:00 – 12:30 Simulation of tree growth including mechanics : a new perspective into the investigation of stand stability. *Thierry Fourcaud (Laboratoire de Rhéologie du Bois de Bordeaux, Pierroton, France).* *p. 18*

12:30 Depart for lunch at INRA, Pierroton

14:30 Visit to Pierroton experimental site

18:00 Rendez-vous for visit to Château de Maucaillou, Médoc

20:00 Dinner at Château de Maucaillou

## *Saturday 9th September 2000*

### Session 4 – Synthesis (Chairperson : Michel Arbez)

09:30 – 10:00 **Keynote address :** Workshop synthesis, future prospects. *Roderick Dewar (INRA, Bordeaux, France).* *p. 20*

10:00 – 10:30 Open discussion (led by Margarida Tomé and Roderick Dewar) : Workshop outcomes, future projects and collaborations envisaged

10:30 – 11:00 Coffee break

11:00 – 12:30 Open discussion (contd)

12:30 Depart for lunch in the Landes followed by visit to Ecomusée de Marquèze

# ORAL PRESENTATIONS

# *Plant-soil interactions: key processes for understanding sustainable management*

**Peter Millard, Susan Grayston & Mike Proe**

*Macaulay Land Use Research Institute, Craigiebuckler, Aberdeen, UK.*

Sustainable management of plantation forests is a long-term goal and involves many complex interactions. One of the most significant of these is between the trees and soil. Understanding and modelling plant-soil interactions requires a knowledge of many processes. Within plants, photosynthesis, carbon allocation, growth, root turnover, litter production and nutrient uptake can all be affected by water and nutrient supply. In turn, carbon inputs to the soil (from leaf and root litter and rhizodeposition) can affect soil microbial activity and diversity, nutrient mineralisation/immobilisation, soil organic matter turnover and leaching losses.

There are a number of forest tree growth models in the literature. Within them processes such as photosynthesis and carbon allocation are often well represented, whereas belowground processes are usually represented by a series of ‘black boxes’ (or not at all!). However, the root system can represent the major sink for carbon in the plant and carbon transfers to the soil ultimately regulate tree growth due to nutrient cycling. Tree-soil interactions (and their representation in models) can be considered in terms of both short and long-term responses. In the short-term soil microbial activity and diversity are regulated by the availability of carbon. Evidence for this is presented from a range of experiments which have characterised rhizosphere microbial populations in response to changes such as elevated $CO_2$. However, soil conditioning experiments suggest that the diversity and functioning of the soil microbial biomass might be more affected by the long-term quality of the soil organic matter, rather than the short-term inputs from the plants. Thus a range of soil factors which are site-specific will need to be considered in any models of forest tree growth which represent plant and soil interactions. An example of the complex interactions that need to be addressed in any model aimed at sustainable management will be given, by considering experiments on the impact of whole tree harvesting or second rotation forestry.

# Maximising wood yield, carbon storage and efficient use of N

**Melvin G.R. Cannell & John H.M. Thornley**

*Centre for Ecology and Hydrology (Edinburgh), Bush Estate, Penicuik, Midlothian, Scotland*

Three of the many objectives of forest management are (i) to maximise wood yield, (iii) to maximise carbon storage in biomass, soils and wood products, and (iii) to minimise losses of N as nitrate to ground-waters and $N_2O$ to the atmosphere. These are all aspects of C and N management and involve tradeoffs. The Edinburgh Forest Model, which simulates the flows of C, N and water in forest ecosystems, has enabled the tradeoffs to be explored[1].

Compare unmanaged forests with periodically clear-felled plantations of the same genotype at the same site. Clearly, plantations yield timber, whereas unmanaged forests do not. But plantations 'leak' more N to groundwaters and the atmosphere than unmanaged forests. Also, averaged over time, plantations compare unfavourably with unmanaged forests as carbon stores - unless most of the wood products persist for much longer than the rotation period or unmanaged forests at the same site would have much more carbon in the trees than in the soil. These conditions rarely pertain. Thus, overall, the wood harvested from plantations is obtained at the expense of the environment – in lower carbon storage and more N leaked to the environment. Is there a simple trade off between wood yield and these aspects of the environment?

The Edinburgh Forest Model was used to explore the impacts on wood yield, carbon storage and N leakage of three theoretical harvesting scenarios.

When only 2.5% of the woody biomass of a simulated forest was harvested each year (for example by very light thinning or some form of pruning), less wood was yielded than from a clear-felled plantation, but twice as much carbon was stored and the forest leaked less N to the environment. A similar result was obtained when 50% of the woody biomass was harvested every 20 years – the numerical equivalent.

When 10 or 20% of the woody biomass was harvested each year, not only was the yield greater than from a clear-felled plantation, but more carbon was stored and the system leaked less N. The reasons are given below.

As might be expected, when 40% or more of the woody biomass was harvested each year, the forest was never able to recover sufficiently to maintain a full canopy and productivity, wood yield and carbon storage were all low.

It was concluded that harvesting regimes which regularly remove a fraction of the woody biomass, while maintaining a near-full canopy cover, may offer the best prospects of achieving the three goals stated above. These stands have the following advantages, as revealed by the model simulations.

They have leaf areas indices which are sufficient to intercept most light, but they intercept less rainfall and have lower transpiration losses than the canopies of unmanaged forests. As a result gross canopy photosynthesis is larger.

They are in a condition of constant regrowth, demanding N, depleting the soil mineral N pools and reducing N leaching. Constant regrowth also slightly lowers autotropic respiration by increasing the ratio of growth respiration to other forms of respiration.

As a result of the above, they have high net primary productivities, with a large continuous input of litter to the soil (as well as a high yield) resulting in large pools of soil organic matter, high rates of $N_2$ fixation (if this occurs) and a sustained supply of N for growth.

[1] Thornley J. H. M. and Cannell, M. G. R. (2000). Managing forests for wood yield and carbon storage: a theoretical study. *Tree Physiology* 20, 477-484.

# *Simulated effects of tree harvest on C fluxes in 20th- and 21st-century temperate forests*

**Daniel P. Rasse[1], Bemard Nemry[1] & Reinhart Ceulemans[2]**

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*[2]University of Antwerp - UIA, Department of Biology, 1 Universiteitsplein, 2610 Wilrijk, Belgium*

Tree harvest generates substantial amounts of litter carbon and modifies forest photosynthesis and respiration rates. We used the ASPECTS model, i.e., Atmosphere-Soil-Plant Exchange of Carbon in Temperate Sylvia, to estimate the long-term effects of tree harvest on carbon fluxes in temperate forests. Validation data were obtained from two Belgian experimental forests, one mostly composed of beech (Fagus sylvatica L.) and the other of Scots pine (Pinus sylvestris L.). The beech forest was subjected to normal forest management in recent years, while the stand density of the Scots pine forest was divided by three during the last 17 years. Hourly net ecosystem exchange (NEE) of $CO_2$, were accurately simulated for the beech forest (R = 0.86). Accuracy of the NEE simulation was improved for the Scots pine stand when the history of tree harvest was taken into account, as simulated tree harvest reduced the predicted NEE for 1997 and 1998 by 127 g C $m^{-2}$. We developed synthetic weather data for the period from 1900 to 2100 on the basis of downscaled GCM scenarios and local hourly measurements of climatic variables. We will discuss the effects of a potential increase in forest productivity due to climate change on harvest-generated litter production, and the subsequent consequences on carbon fluxes in temperate forests.

# The 3-PG model: matters arising from evaluation against plantation data from many countries

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*Keywords : PG, parameter values, fertility, species reponses*

The 3-PG model developed by Landsberg and Waring (1997) is a simple process-based carbon balance model requiring few parameter values and only readily available data as inputs. It works on monthly time steps; output variables include stem mass and volume, leaf area index, stem diameter and root mass.

Calibration and evaluation against data from experiments and commercial plantations in 7 countries has provided parameter values and information about model performance in relation to a number of species at a range of sites.

Major factors affecting the performance of 3-PG are: (1) estimates of soil fertility, which affects carbon allocation and canopy quantum efficiency; (2) estimates of soil water available in the root zone; (3) values of Specific Leaf Area. Differences in the performance of species are largely determined by responses to temperature. There is no strong evidence of species differences in carbon allocation. Species responses to fertility and to drought are probably important but there is little empirical information available to evaluate these.

Using the satellite-driven version of the model to simulate forest growth and productivity over large areas has demonstrated very clearly the great variability of forest plot data, and the need for methods of scaling up to appropriate average values.

# *Impact of a regional climate scenario under 2xCO2 on the water balance, carbon balance and primary production of maritime pine in southwestern France*

**Denis Loustau[1], Frédéric Pluviaud[1], Alexandre Bosc[1], Annabel Porté[1], Paul Berbigier[1], Michel Déqué[2] & Victorinne Pérarnaud[2]**

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Using a simple process-based model of Pine forest growth, (GRAECO: GRowth and Allocation based on ECOphysiological processes), we have assessed the possible impacts of a climate scenario with 700 ppmv atmospheric $CO_2$ on the water balance, carbon balance and primary production of maritime Pine in south-western France.

The model GRAECO has been developed since 1991 by INRA Bordeaux. It is a three-layer model describing the radiative transfer, water exchange, carbon assimilation, distribution and respiration and tree growth in a monospecific, even-aged stand of maritime Pine. This model has been run using climate data generated by the ARPEGE climate model of METEO-France which described the local values of climatic variables over a 10-year time series under (i) a standard "1xCO2" climate and (ii) a modified "2xCO2" climate (Déqué et al. 1998) and across a 60 x 60 km grid in Southwestern France. Seven grid points were selected as representative of regional climate variations across the maritime Pine forest of Southwestern France and two age classes (8 and 18 year-old) were simulated.

The main changes in climate under 2xCO2 as simulated by ARPEGE are a mean warming of +2 °C, a shift in the seasonal distribution of precipitation from summer and autumn to winter, and an increase in summer values of the air vapour pressure saturation deficit. Altogether, these changes induced a decrease in gross and net primary production over the six "continental" grid points and a slight increase in the site closest to the ocean which was the most humid, regardless of age class. A sensitivity analysis of the model showed that these responses were mainly due to an increase in vapour pressure deficit and soil moisture deficit, which both impact negatively on assimilation and growth of the pine stand. This negative effect offset the positive effect of $CO_2$ fertilisation which was limited by the poor nutrient status of the sites considered.

# *Plant-soil models as tools to explain changes in forest productivity and site fertility over successive forest rotations*

**Ross McMurtrie[1], Joanne Halliday[1], Neal Scott[2], Kevin Tate[2] & Marc Corbeels[3]**

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Recent experimental studies have observed that soil carbon (C) and nitrogen (N) content often decline following conversion of improved pasture to *Pinus radiata* plantation. This observation has implications for carbon sequestration rates under plantation forestry and potentially for long-term sustainable forest productivity.

We apply a model of C and N cycling in grass and forest ecosystems (G'DAY) to simulate the transition from improved, legume-rich pasture to stands of *P. radiata* at a site near Masterton, New Zealand. Our aim is to quantify biogeochemical mechanisms that can lead to altered soil carbon and nitrogen cycling following afforestation. We run a series of model simulations to investigate the following key questions:

1. Is decomposition of soil organic matter slower under forest because of lower quality of tree litter relative to grass litter? If so, does soil C accumulate under forest relative to pasture? Is soil N availability decreased because of slower decomposition?
2. Is aboveground litter input increased after afforestation because grazing ceases and because the forest has higher net primary production? If so, does soil C accumulate after afforestation? Is soil N availability reduced because of higher soil N immobilisation?
3. Do the answers to questions (1) and (2) change if root C allocation or turnover are lower under forest than under pasture?
4. Do soil N mineralisation and inorganic soil N decline after afforestation due to removal of N fixing plants and grazers? Does total soil N decline? If so, is there a commensurate loss of soil carbon? Or, do soil C:N ratios increase while soil C is unchanged? Alternatively, does soil N loss lead to slower soil decomposition and hence accumulation of soil carbon?
5. Is soil N loss after afforestation beneficial to total ecosystem C storage because it leads to a shift of N from soil pools with low C:N ratios to biomass pools with high C:N ratios? If so, should some loss of soil C and N be encouraged?

We run simulations over single and multiple forest rotations to investigate the relative importance of the above 5 mechanisms and consequences for forest sustainability. Simulations over multiple rotations raise issues of C and N losses in harvested wood and from harvest residue. They also raise the question of how to define sustainable productivity in a modelling context.

# *A model approach to assess the sustainability of the soil nitrogen balance of short rotation Eucalyptus in Western Australia*

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*Keywords: CENTURY, litter decomposition, Eucalyptus, G'DAY, litter, slash residue management*

G'DAY (Generic Decomposition and Yield) is a process-based ecosystem model, that links the BIOMASS plant production model to the CENTURY model of soil carbon and nutrient dynamics. Experimental results on nutrient cycling in *Eucalyptus* forests in south-western Australia were used to test the model's ability to simulate C and N dynamics in plantation forestry under Mediterranean conditions and to predict effects of alternative slash residue management.

The soil organic decomposition submodel was modified based on a more mechanistic concept of soil organic matter decomposition. Three key modifications were: 1) N immobilisation occurs only via the active (microbial) organic matter pool; 2) microbial biomass succession is simulated by a C flow from the active pool feeding back into itself; and 3) the C:N ratio of the active pool is function of litter quality. With the modified version of the decomposition submodel we were able to simulate decomposition of litter and slash residues of different quality. The updated model is then used to assess the effects of different harvest residue loadings on the soil nitrogen balance of short rotation Eucalyptus plantations. The model results are discussed in relation to recommended management options.

# *Nitrogen uptake in young Norway spruce on a fertile site in southern Sweden – effects of fertilization and herbicide treatments*

**Urban Nilsson**

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High production and environmental values may be achieved if biodiversity, recreational values etc. are maintained on a landscape level instead of on a stand level. In such diversified forests, a certain proportion of the area is set aside for intensively-managed stands. However, some environmental restrictions are still important, e.g. no leakage of nutrients is allowed. In northern Sweden, production of Norway spruce can be tripled by yearly fertilization with balanced nutrients, although it is uncertain if the same gain in production can be achieved on fertile sites in southern Sweden. Furthermore, calculations show that yearly fertilization will probably not be economically feasible. A fertilization experiment was installed in a young Norway spruce stand in south-western Sweden and nitrogen budgets were made to test the following hypothesis *i*) nitrogen uptake in field vegetation reduces leakage of nitrogen *ii*) nitrogen that has been immobilized in field vegetation will be available for uptake by the trees after canopy closure. We discuss results showing that nitrogen may be conserved by field vegetation and made available for tree uptake after canopy closure, and illustrate the need for a nutrient uptake model for interpolation of experimental results.

# *Linking Production, Leaf Area, Nitrogen Use, and Soil Nitrogen Availability in Loblolly Pine Plantations*

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*Keywords: nutrition, silviculture, fertilizer*

It is now recognized that the productivity of pine plantations in the southern United States can be at least 2x higher than is currently realized. Through our field trials, ecophysiological research, and modeling efforts, we have determined that mean annual increment for loblolly pine should equal 25 $m^3$/ha/year and that this level of production is not realized because of low leaf areas due to chronic nutrient limitations. Recognizing these limitations, forest industry has dramatically increased operational fertilization programs, so much so that in 1999, 650,000 hectares of pine plantations were fertilized with nitrogen plus phosphorus in the Southeastern United States. The ability to estimating nutrient use and soil nutrient supply in rapidly growing plantations is essential to develop cost effective and environmentally-sound silvicultural prescriptions for ameliorating nutrient limitations. Using growth data from field installations of a regional fertilizer study and NUTREM2 (our Nutrient Use and Removals Model), we estimated annual nitrogen use and soil nitrogen uptake for 40 intermediate-aged loblolly pine plantations. These estimates were then regressed with soil nitrogen, drainage class, and soil texture data to develop a model and practical field guide that foresters can use to estimate soil nitrogen supply.

# *The use of management-oriented growth and yield models to assess and model forest wood sustainability: a case study for eucalyptus plantations in Portugal*

**Margarida Tomé, José G. Borges & André Falcão**

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This paper demonstrates how a management-oriented growth and yield model may be used within a prototype decision support system to assess forest pulpwood sustainability in eucalyptus plantations. The growth model is the GLOBULUS model, a whole stand model that predicts stand development for different combinations of region, initial stand density and site index. The model also includes a series of equations for new stand initialisation, essential for long term prediction of wood availability. It gives more output than it is usual in most management oriented models: growth in dominant height and basal area; stand density along time; total stand volume (over and under bark); merchantable volume to any top limit (over and under bark), total biomass and biomass per components (stem, bark, branches and leaves), accumulation of nutrients and carbon in each one of the biomass compartments, leaf area index. After describing the model, its application within the framework of the decision support system is presented. This application encompasses the simulation of forest growth according to a wide range of management alternatives for each stand within the selected eucalyptus forest area. It further involves using a model that maximizes net present value subject to pulpwood even flow constraints to assign a prescription to each eucalyptus stand.

# *Improving the methodology for stand-level assessment of long-term productivity shift : an example in Sessile Oak high forests*

**Jean-Francois Dhote**

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Exploring the cause of long-term changes in forest productivity is a difficult problem, especially for intensively managed plantations. Along with environmental changes ($CO_2$ increase, N atmospheric input, climate change), the average genetics of stands evolve between successive generations, and silvicultural practices change rapidly (fertilisation, weed management, plantation techniques, early thinnings). This makes it very difficult to isolate the specific contribution of the environment to the shift in productivity which has been commonly observed in plantations (eg. of maritime pine in SW France).

One approach is to improve the knowledge of basic ecophysiological processes and to explore the impact of global change through modelling and simulations. However, some of these processes are still poorly described (eg. carbon allocation), and may be critical for the robustness of model outputs. Furthermore, the heavy experimental approaches needed to calibrate ecophysiological models are generally restricted to a narrow range of ecological situations. For these reasons, semi-empirical models of stand productivity are necessary, provided that they are built on sound ecophysiological concepts, formulated in terms of easily measured variables (such as height and diameter), and fitted on large-scale networks of permanent plots.

The purpose of this paper is to illustrate the potential of such a method to produce long-term records of productivity changes. The basic material is a network of 35 permanent plots in Sessile Oak high forests (in the northern half of France), observed since 1920-30. A model was designed to estimate the contributions of age, site and silviculture to stand basal area increment, and to combine these with periodic fluctuations and a long-term trend (function of date). We observed that the history and magnitude of productivity changes were different between locations, ranging from NW to NE France. In 2 out of the 4 forests analysed, basal area increment increased greatly over the past 60 years (30 to 50% according to the model).

# *A regeneration model for planted Norway spruce in southern Sweden*

**Fredrik Nordborg**

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The initial growth of a Norway spruce plantation is limited by several biotic and abiotic factors. The decreasing number of foresters in modern forestry has raised the need for decision support systems. A model for regeneration of Norway spruce stands is under construction where the growth, survival and homogeneity will be the output Effects of competition, nutrition, water availability, frost damage, row deer browsing and pine weevil damage will be included. The influence of silvicultural methods, such as site preparation, shelters and plant protection, will also be considered in the model.

We present results from experiments studying the effects of site preparation on competition from field vegetation for nutrient and water. Water stress is only a limiting factor for newly planted seedlings or during severe droughts. Nutrient uptake, and especially nitrogen uptake, is a limiting factor for most plantations but established seedlings are good competitors for nitrogen. Therefore, site preparation does not improve nutrient uptake after seedling establishment Nitrogen uptake in Norway spruce often takes place in late summer and autumn, and the amount of nitrogen taken up during the previous year is positively correlated with present-year growth.

# *Evaluation of different optimisation models to schedule silvicultural operations*

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*Key words: operational planning, activity scheduling, labour stability.*

Silvicultural tasks in Chile, due to their seasonal character as well as to their short duration, present the highest level of labour instability among forestry activities, causing a continuous renewal of non-specialised workers. To revert this situation, the number of workers required, considering cost and labour stability simultaneously should be determined in advance; in other words, aim to contract a sufficient number of workers on a fixed term basis, thus reducing monthly fluctuations, but without having an adverse effect on operational costs. The objective of this study was to develop and compare several models that elaborate planning strategies for silvicultural tasks, based on different objective functions and constraint sets. The results were analysed in terms of cost and labour stability. Thus it was possible to determine which factors have greatest relevance with regard to this problem, and to select a practical model which contributes to the effective scheduling of the company's silvicultural activities at an operational level. The results obtained indicate that the analysed models contribute to an effective scheduling of silvicultural activities at an operational level.

# *Simulation of tree growth including mechanics : a new perspective into the investigation of stand stability*

**T. Fourcaud[1,2], P. Ancelin[1], P. Lac[1] & F. Blaise[2,3]**

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The violent storm in France in December 1999 has shown that it is essential to incorporate the role of stand stability into a sustainable forest management. Several studies in tree biomechanics have been carried out in France during the last ten years. A review of modelling developments performed in Bordeaux is presented. This work constitutes a solid basis for which stability at tree and stand levels can be investigated.

The Plant Modelling Program (CIRAD-AMIS, Montpellier, France), in connection with the Laboratory of Wood Rheology (LRBB, Bordeaux, France) develops models to simulate tree growth including biomechanics. This work aims to investigate wood quality with regard to tree growth and tree stability [Constant *et al*, 1999]. Tree and stand level models have been developed in the software AMAPpara and CAPSIS, respectively.

The tree level model is based on a mathematical description of plant architecture. The simulation software AMAPpara includes process based modules allowing the topological and geometrical structure to depend on the tree forest environment *e.g.* competition for space and light, gravitropism [De Reffye *et al*., 1997]. A particular function called AMAPméca, allows the mechanical behaviour of trees to be taken into consideration [Fourcaud and Lac, 1996; Ancelin *et al*, 1999]. The mechanical calculation focusses on the relationships between structure and shape of the stem, introducing righting movement processes, due to cell maturation, in both normal and reaction wood. The evolution of stem form according to the equilibrium of the tree can be simulated and the growth stresses occuring inside the trunk calculated.

The stand level modelling is developed in the software CAPSIS which is a platform dedicated to stand growth models. A module to simulate biomechanical behaviour of simplified trees has been incorporated in the software. This model uses a description of a tree's vital space by Voronoi tesselation, allowing the effect of tree competition on stem shape and structure stability to be investigated.

Stability can be investigated at the tree and stand level with regards to secondary growth and crown development. According to different wind profiles, both distribution and intensity of cumulated wind and growth stresses in the stem can be calculated. Dynamic loading is not considered at the moment, but it can also be incorporated into the models.

## *References*

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## *Workshop synthesis, future prospects*

**Roderick Dewar**

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'Sustainable management', however the term is used, is concerned with the long-term behaviour of plantation forest ecosystems, on timescales spanning several management cycles.

What role can models play in the sustainable management of plantation forests? What has been achieved so far? What are the key uncertainties and prospects for future research? How do we transfer our results to end-users? The objective of our workshop has been to address these questions.

At the heart of the scientific problem lies the complex interplay between tree and soil processes. Here, process-based models of plantation forests have already made significant progress towards understanding how the carbon, water and nutrient cycles in trees and soils are coupled, and the possible long-term effects of various management practices.

Key uncertainties remain, however, regarding our understanding of, for example, how tree growth is allocated to foliage, wood and fine roots, and the fraction of mineralised soil nutrients taken up by trees vs. the fraction immobilised by soil microbes or lost entirely from the system. We may use models to explore various hypotheses about the underlying processes, but ultimately we need more experimental information.

At the same time, foresters require management tools to help them make practical decisions concerning, for example, matching species with sites, or the timing and intensity of thinning and harvesting. The major challenge here is to transfer the information from parameter-intensive, research models into management tools that use only readily available input.

With the above questions in mind, in this talk I will try to synthesise the workshop contributions, and map out some areas for future research.

# POSTER PRESENTATIONS

# SUSTAIN – a forest ecosystem model incorporating hydraulic and nutritional constraints on tree growth

**Roderick Dewar**

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In attempting to quantify sustainable forest productivity, a major challenge for modellers is to predict the time course of tree growth through a rotation, including such key information for foresters as the value of the maximum mean annual stemwood volume increment (m.a.i.) and its time of occurrence. In turn, this requires a description of how growth is allocated to stemwood versus other plant parts.

Recent experimental work suggests that the relationship between sapwood and foliage growth is constrained by the need to avoid catastrophic xylem cavitation (Ryan & Yoder 1997). This hydraulic constraint on growth allocation – which can be viewed as a modification of the old pipe model hypothesis – has recently been incorporated into the HYDRALL model (Magnani et al. 2000, Magnani 2000), and leads to realistic simulations of the age-related decline in tree growth that is well-known to foresters.

The SUSTAIN model combines the hydraulic constraint of HYDRALL with a nutritional constraint between fine root and foliage growth based on the requirement that the tree should match the assimilation rates of nitrogen (N) and carbon (C) – i.e. the functional balance hypothesis. This merger between hydraulic and nutritional constraints – analogous to that proposed by Mäkelä (1986) between the pipe model and functional balance hypotheses – leads to a complete description of growth allocation to foliage, sapwood and fine roots.

Another major challenge in modelling sustainable productivity is to couple tree growth to nutrient cycling in the soil, and to predict the course of maximum m.a.i. and nutrient availability from one rotation to the next. Two key assumptions of the soil sub-model in SUSTAIN are that: (i) the microbial N:C ratio increases with soil mineral N content (reflecting changes in microbial population), and (ii) microbial growth is C-limited but not N-limited. Thus, when mineral N is added to soil, significant N immobilisation in microbial biomass may occur without increased microbial $CO_2$ production, in line with field measurements (Aber et al. 1998).

The poster details the growth allocation and nitrogen cycling components of SUSTAIN, and gives some illustrations of model behaviour.

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# *Topology and geometry measurements of root and shoot architecture of Pinus pinaster*

**Bert D[1], Danjon F, Loustau D, Porté A, Trichet P, Champion I & Godin C**

**Technical contribution : V-M Bernard, JP Chambon, F Courdier, M Guédon, B Issenhuth, F Lagane, C Lambrot, A Lardit, H Lataillade, E Pegoraro, M Sartore & F Vauchel**

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( ☺ indicates an item on the poster)

Process-based models can simulate the resource capture and growth of maritime pines as a function of environmental conditions. Models of photosynthesis and water use (Porté 1995, Granier and Loustau 1994) are currently being developed in parallel with studies of biomass allocation. A good knowledge of carbon allocation enables the accurate conversion of biomass increment into changes in dimension and architecture. Whole-tree measurements give additional insight into the relationship between above- and below-ground parts.

Several stands of different ages (5, 16, 26, 32 yr) were chosen in order to sample a 50 yr rotation, representative of pine management in south-western France. These stands are located 25 km south-west of Bordeaux in the main type of site defined as *humid bent* with a podzolic soil. The small size of the 5-yr-old pines enabled detailed study of the root systems (lower part of the poster), and the above-ground parts were analysed as for the older stands (upper part of the poster). The poster focuses on the 5-yr-old stand, in which 30 representative pines were sampled (mean height = 3.2 m).

The above-ground parts ☺ of this highly multinodal species were described using architectural analysis in order to obtain their topology ☺ (sequence of axis and growth units) and geometry (spatial position). On the trunk and on two branches per whorl, the length and diameter of each annual (AGU) and intra-annual growth unit (GU) were measured. One branch per whorl was then broken-down into Gus, separating wood, needles and buds, which were dried and weighted ☺. The data from 30 trunks (including tree-ring widths), 280 architectural descriptions of branches, 5000 biomass measurements will be analysed and used in conjunction with the models RIRI (Sinoquet and Bonhomme, 1992) and MAESTRO ☺ (Wang and Jarvis, 1990), and the software AMAP ☺.

The root system ☺ was weighed and digitised in 3 dimensions using a low frequency magnetic field digitising device (Danjon et al., 1998) ☺ : the position and diameter of 22000 root segments have been recorded. The measurement was driven by a software taking into account the topological structure of the root segments (Sinoquet and Rivet, 1997). Data were analysed with the "AMAPmod" software (Godin *et al*., 1997). Root axes and root systems were characterised by the number of ramifications, length, diameter, volume, distribution in space ☺ and mean horizontal angle.

In conclusion, estimating parameters of geometry and topology on the whole tree is useful for the construction of process-based models and simulations ☺ : root distribution in the soil for anchorage and water and nutrient absorption, foliage distribution for light interception and photosynthesis, wood quantity and quality prediction. 3D digitising, combined with the AMAPmod software, provides powerful tools for whole tree measurement and analysis.

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# Cartography of the December 1999 storm damage to the Aquitaine region maritime pine forest derived from satellite remote sensing

**Nicolas Stach[1], Guy Gallay[2] & Dominique Guyon[3]**

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Following the storms at the end of December 1999, the National Forest Inventory (IFN) of France was given the task of mapping and estimating the forest damage over approximately half of France's national territory. For the Aquitaine region's maritime pine forest, particularly favorable conditions of geography and species composition made it possible to use a procedure based on remote sensing images to produce a map of the damage at short notice. In this procedure the IFN relied on a method of detecting changes similar to that which it had developed for monitoring the maritime pine forest resource in Aquitaine, supplemented by a stage of spatial aggregation. The map, showing 5 levels of damage intensity, was then combined with the IFN's dendrometric and cartographic data bases to estimate the wood volumes concerned.

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## *GRAECO: a process based model for a maritime pine forest*

**A Porté, A Bosc & D Loustau**

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GRAECO is a mechanistic model of stand primary production and individual tree growth (**GR**owth, **A**llocation and **ECO**physiological processes). It was established for an even-aged maritime pine plantation in SW France. The aims of this new model were (1) to construct a platform for integrating our increasing knowledge of the functioning and growth of the maritime pine ecosystem, and (2) to establish a model capable of simulating tree growth in response to different environmental conditions.

Stand net primary production was estimated as the balance between the assimilation rates of pine and understorey and the respiration rates of pine, understorey and soil. Carbon assimilation was calculated using a light-use efficiency approach. A stand water balance model was coupled to the carbon assimilation model so that primary production and growth are sensitive to water availability. Individual tree growth was estimated using partitioning coefficients between different trees and between different compartments of the same tree.

The model was used first to simulate annual carbon fluxes and growth rates. Carbon isotope discrimination measurements were compared to the stand water-use efficiency estimated from GRAECO. The model was used to study the impacts of climate change on the primary production of a maritime pine forest (Loustau et al., this workshop).

# Modelling Kraft fibre morphology and paper properties from forest data : the example of maritime pine (Pinus pinaster sp.) thinning logs

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*KEY WORDS : fibre morphology, modelling, Kraft process, paper properties, maritime pine, silviculture*

The variability of fibre morphology in conifers is known to be influenced by several factors, including cambial age and position within the log, silviculture and genetics. Preliminary experience has pointed to the large influence of fibre structure and the position of wood chips within the log on Kraft pulp and paper properties. Facing the increasing specialisation of end-products, and therefore pulp and paper products, AFOCEL and industrial pulp mills of SW France have undertaken a research study dealing with the prediction of fibre morphology and paper properties of pulp logs as a function of parameters that are easily accessible to foresters : plantation age, diameter and height within the tree.

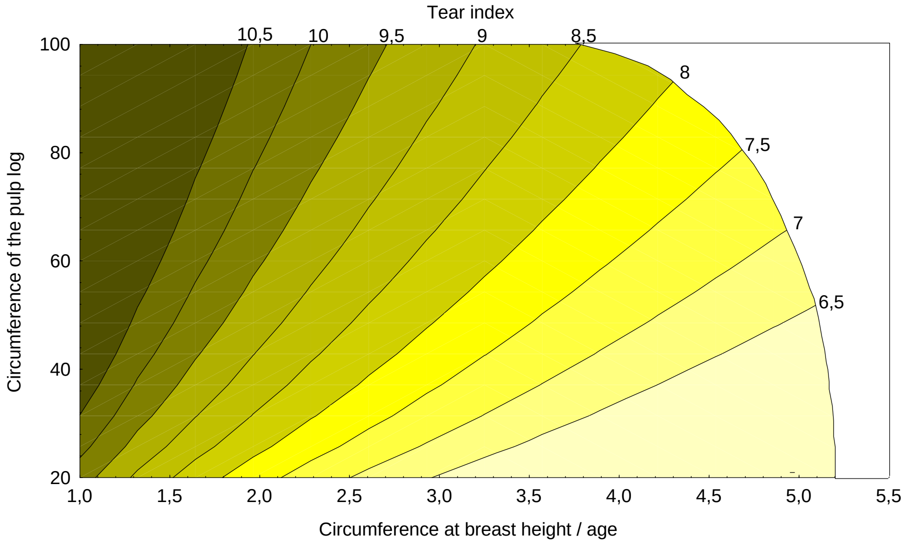
Models are set up in order to link wood structure to the Kraft fibre morphology of maritime pine. The modelling approach relies on two steps : firstly, a theoretical model based on within-ring wood samples, secondly a general model elaborated at the « group of rings » level. This second model is derived from the previous one and is based on a broader sampling basis (age, height, trees). The models show the main influence of cambial age, within-ring wood density traits, earlywood / latewood, and height. These traits can be well-described through non-destructive methods such as X ray micro-densitometry, leading to the prediction of the average fibre morphology. Validation of the « fibre model » is done on a wide range of stands, sites, trees, and sampling heights.

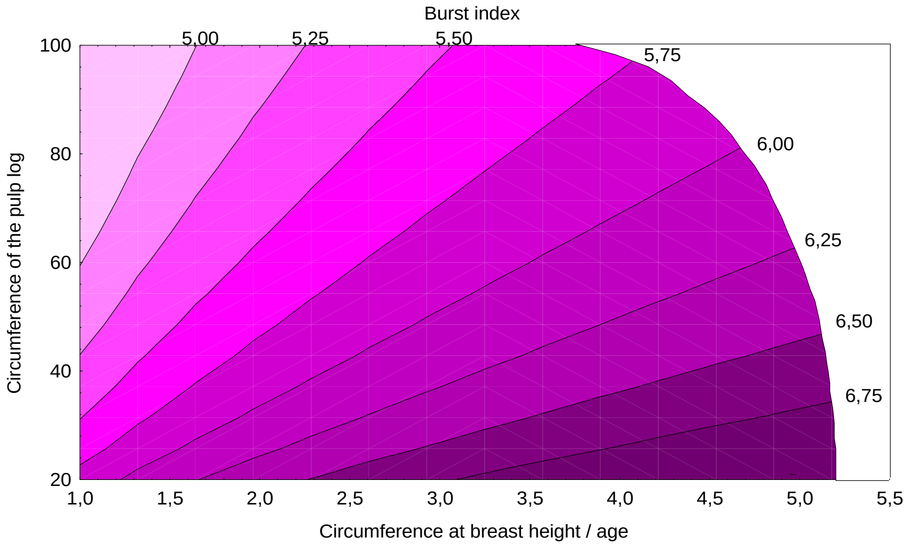
The same approach is applied to modelling paper properties : first at the within ring level, then at the « group of rings » level. Under given process conditions (Kappa index and Schopper degree) it is possible to predict with reasonable accuracy the variability of Kraft paper properties from wood structure traits: tear index, burst index, bulk sheet density, breaking length, and porosity.

Thus, from the analysis of the X ray profiles of 600 maritime pine thinning logs, it is possible to evaluate the influence of simple forest data on fibre morphology and paper properties. Simple charts are then delivered in order to help foresters to meet industrial requirements, within a global wood optimisation chain for the entire French maritime pine resource.

This study can help predict changes in fibre quality in response to changing silvicultural practices or global changes of the maritime pine forest resource. For instance, these models can be useful for evaluating the consequences of the recent hurricane for fibre quality.

Future perspectives include the connection between fibre models and growth models, for the simulation of both tree growth, industrial product distribution (derived from the tree shape model) and fibre quality, in order to simulate the effect of alternative silvicultural schedules.




These charts illustrate the results. From the knowledge of (1) the ratio between the diameter at breast height and the plantation age, and (2) the diameter of the pulp log within the tree, it is possible to predict the average paper properties of various log populations. The forest data are easy to collect either before harvesting or during mechanised harvesting with the help of the computer. In the above charts, the process conditions are Kappa 30-35 on 25°SR beated laboratory handsheets.