Task 4.2 – Simulating the joint dynamics of the French forest resource and sector

– Ongoing ecologic/economic developments

Oracle meeting

Giens – 27-28 Sept. 2012

Jean-Daniel Bontemps, Junfeng Lu (LERFoB)

Philippe Delacote, Antonello Lobianco (LEF)

Task 4.2 : developing the LSFDM-FFSM coupled simulation system

- Forest dynamics model : LSFDM
  - Making the LSFDM climate-dependent…
  - … while expliciting the underlying species composition
  - Projections over the long-term
- Forest sector model: FFSM
  - Introducing long-term choices in forest management
  - Integrating anticipation in forest management

Task 4.2 : Ongoing developments on the LSFDM side (LERFoB laboratory)

1. Some factual news
2. Climate-dependence of the LSFDM
3. Statistical modelling of growth and distribution
4. Projecting forest growth/distribution up to 2100

Task 4.2 : Ongoing developments on the LSFDM side (LERFoB laboratory)

1. **Some factual news** (since meeting of January 2012):

- **Reference scientific/technical roadmap for LERFoB developments** available on Oracle intranet : *Bontemps JD, 2012, Program outline for Oracle, 12p*

- **Junfeng Lu (1-yr post-doc position) arrival in March 2012**. Junfeng is hired for developing **statistical models of tree species distribution and productivity**

- **NFI data for growth and distribution** are available and **ready** (more info in JunFeng slides), modelling starts…

Task 4.2 : Ongoing developments on the LSFDM side (LERFoB laboratory)

❷ Climate-dependence of the LSFDM : a recall

- **Logics presented in Sept. 2012** (see slides on Oracle website)
- **Independent diameter-class matrix models** (9 regions x 2 sp groups x 3 structures)
- In each model, **parameters (recruitment, growth, mortality) can depend on climate**
- **Recruitment (r) and growth (g) explicitly made dependent on climate** :
- **Mortality (m) arises as an « emergent property »** : decline in species frequency (LEF)
  - Degree of freedom to be adjusted in the FFSM modelling choices

Task 4.2 : Ongoing developments on the LSFDM side (LERFoB laboratory)

❷ Climate-dependence of the LSFDM : a recall

- **Modelling recruitment and growth dependence :**

$$r(t) = r(t_0)\ p\{1|env(t)\} / p\{1|env(t_0)\}, \quad p\{1|env(t)\} = \Sigma_{sp}\,\Sigma_{xy}\ p_{sp}\{1|env(t, x, y)\}$$

$$g(t) = g(t_0)\ Prod\ \{env(t)\} / Prod\ \{env(t_0)\}, \quad Prod = \Sigma_{sp}\,\Sigma_{xy}\ Prod_{sp}\ \{env(t, x, y)\}$$

- Tree species models of **probability of presence and productivity are needed !**

$$p\{1|env(x,y,t)\}\ ,\ and\ Prod\ \{env(x,y,t)\}$$

- $\Sigma_{sp}\,\Sigma_{xy}$ = summation over space (continuous) $\rightarrow$ discretized regions
- + summation over species $\rightarrow$ species groups

- Indicators suggested to be **used in the FFSM investment strategy (anticipation, LEF)**

Task 4.2 : Ongoing developments on the LSFDM side (LERFoB laboratory)

❸ Statistical modelling of growth / distribution

- **A review of literature** (first task of Junfeng) to draw a **modelling strategy**
- **Distribution** modelling: a **dynamic field** (ecology), **growth not** that much (forestry)
- **Important issues :** realism of response functions (non-parametric approaches), interactions handling (tree-based approaches), predictive accuracy
- **Profusion of methods**, **no consensus**, many comparative studies, simulation studies on theoretical species, 'ensemble' methods in emergence…

Task 4.2 : Ongoing developments on the LSFDM side (LERFoB laboratory)

❸ Statistical modelling of growth / distribution

- **The 'flaw' of machine-learning** methods (ecological interpretation, data needs)
- **Robustness of simple non-parametric methods** (growth and distribution): e. g. GAMs
- **Promising tree-regression techniques**: e. g. random forests / BRT (boosted regression trees) with a trade-off in bias-variance reduction
- More advanced / marginal techniques (false zeroes, spatial neighbourhood…)

➢ **A review manuscript in prep.**: *Lu et al. Species distribution and growth modelling in climate change research*

Task 4.2 : Ongoing developments on the LSFDM side (LERFoB laboratory)

❹ Projecting forest growth/distribution up to 2100

- **Fit** of statistical models… computation of **growth/distribution projections**…

  space/species aggregation to define modifiers of the LSFDM… **transfer to LEF**…

- **Takes time, and time is fading** (A: we are mid-term ! – B: really ? – A: sorry…, we were !)

- **Format conversions** may also take long

➢ **We now NEED climatic projection definition** (scenarios, models), assessing compatibility with our predictor for “present period”, and **data release (OK, thanks to Christian)**

- **Specification of the reference period** is also important (use for model calibration)

Task 4.2 : Ongoing developments on the LSFDM side (LERFoB laboratory)

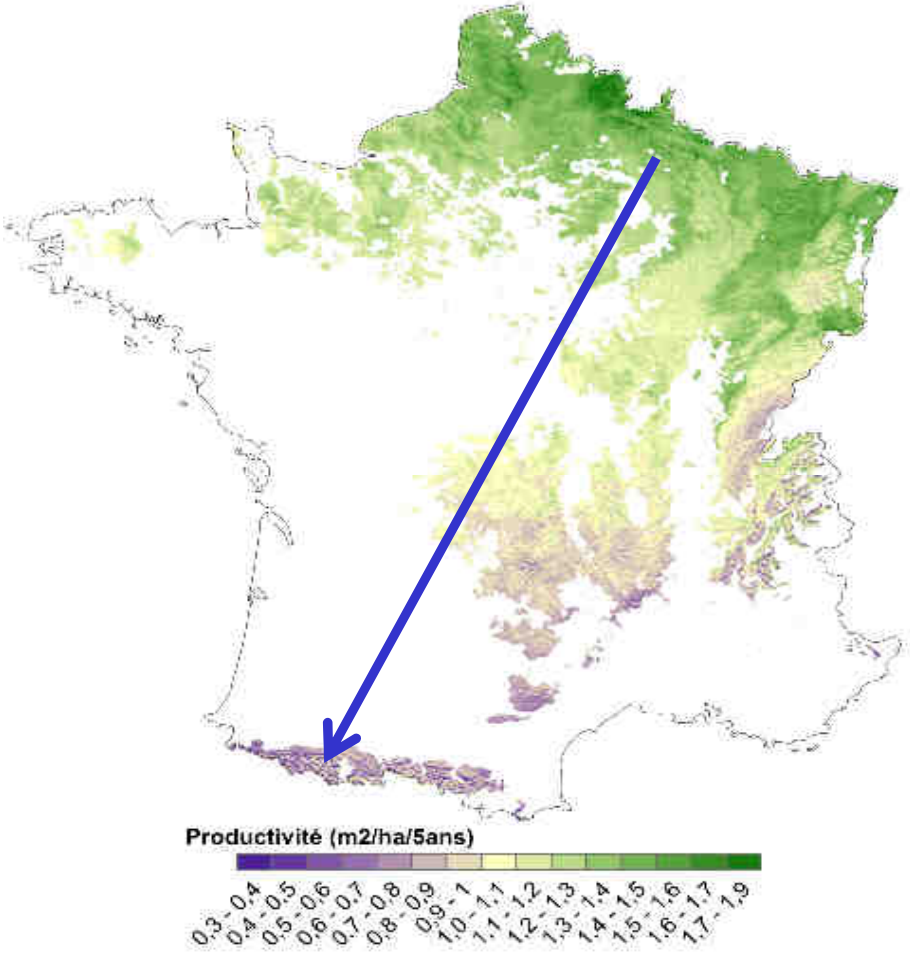
❹ Projecting forest growth/distribution up to 2100

- A suggestion discussed with LEF: **a "version 1" of the LSFDM modifiers early 2013**
- Based on **recent parallel PhD works** (Charru / productivity – Bertrand / distribution)
- Not homogeneous… with a restricted set of species… but **would allow** :
  - **A first rough assessment** of the LSFDM behaviour in the future
  - LERFoB / LEF laboratories to **design/test GIS and FFSM computations / codes**
  - With **alternative climate scenarios** if needed (Climator / Cerfacs)
  - Point out **to important aspects in the properties of statistical models of niche/growth**

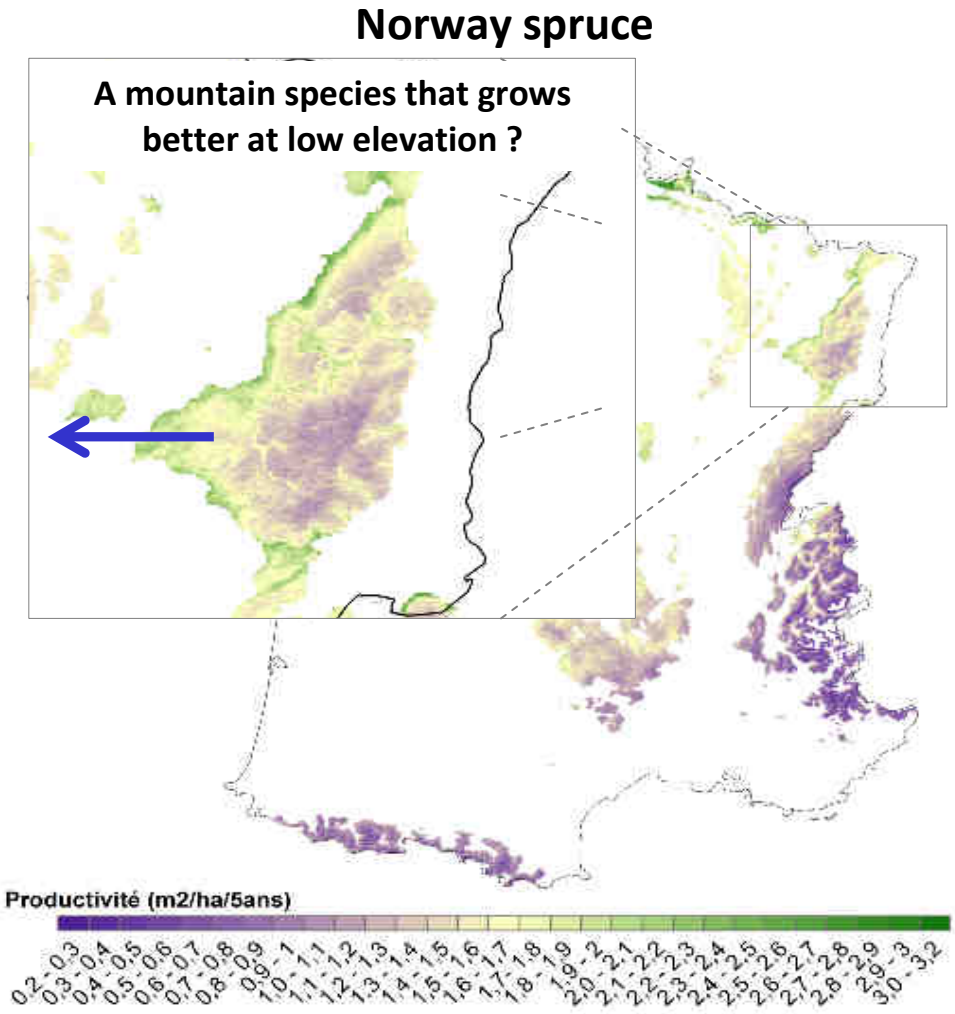
Productivity maps

2 examples : Beech and Norway spruce

Beech



Norway spruce



Overview of NFI data

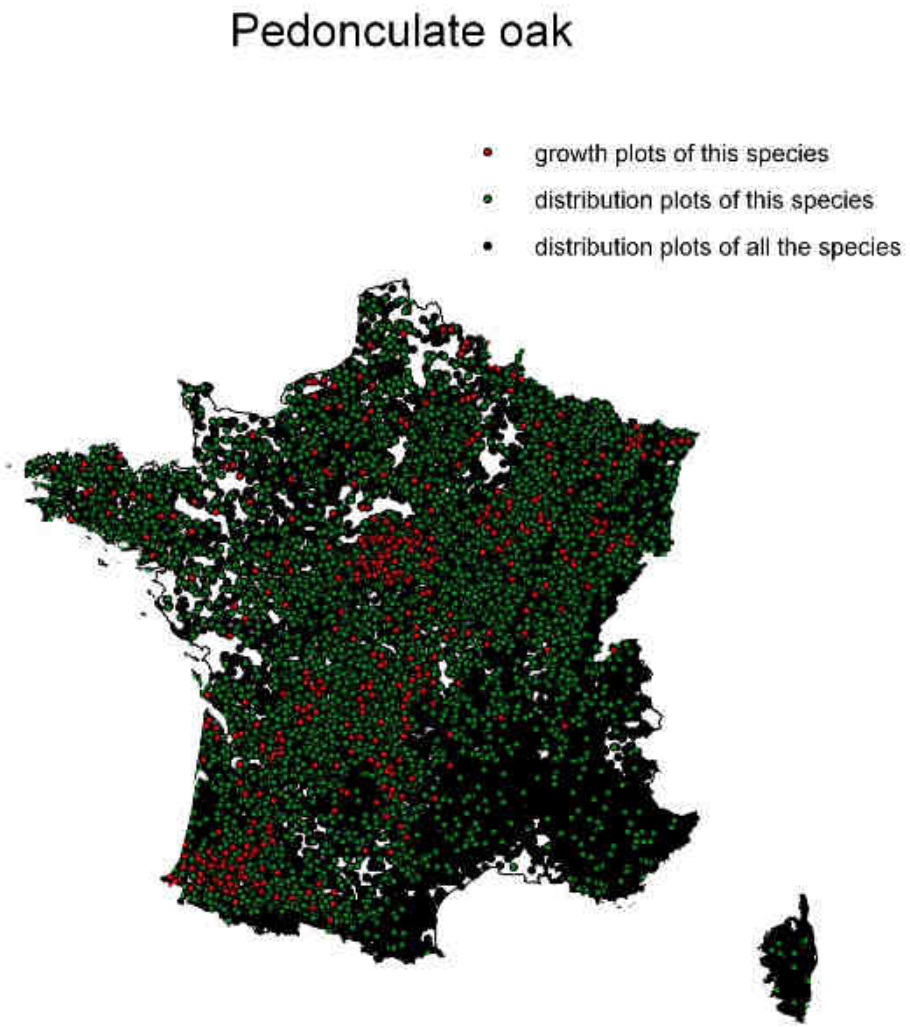
- **National Forest Inventory (NFI) data:**
  - **systematic sampling in 2004-2008 covering the entire French metropolitan territory**
  - plots located in 1.41-square km grid. **33471 plots in total**, and **5014 plots for growth analysis**
  - **8 species selected** (not definitive):
    - **broadleaf**: *sessile oak, pedonculate oak, pubescent oak, common beech*
    - **coniferous**: *scots pine, Norway spruce, silver fir, European larch*
- **Climatic and environmental data:**
  - **climatic**: monthly temperature, precipitation, soil water budget, solar radiation, etc.
  - **trophic and soil**: soil pH, soil nutrients, soil depth, elevation, slope, etc.
  - Projected furture climate data?

Distribution of NFI plots (2004-09, 2 km grid on forests)

Black : all the inventory plots

Green : plots where the species is present

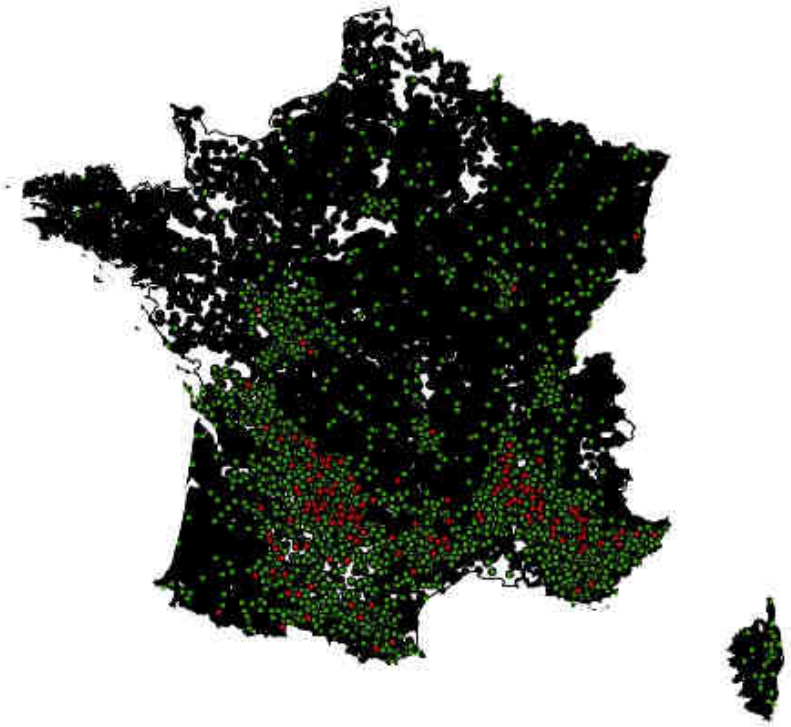
Red : growth plots = plots with pure and even-aged communities (control of stand density, stand phase of development)



Including mountain and mediterranean species

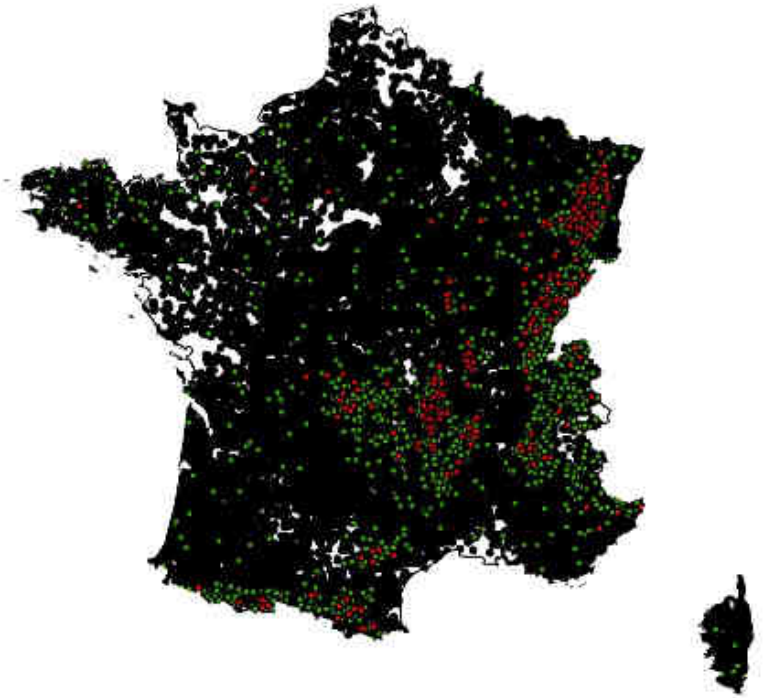
Pubescent oak

- growth plots of this species
- distribution plots of this species
- distribution plots of all the species



Silver fir

- growth plots of this species
- distribution plots of this species
- distribution plots of all the species

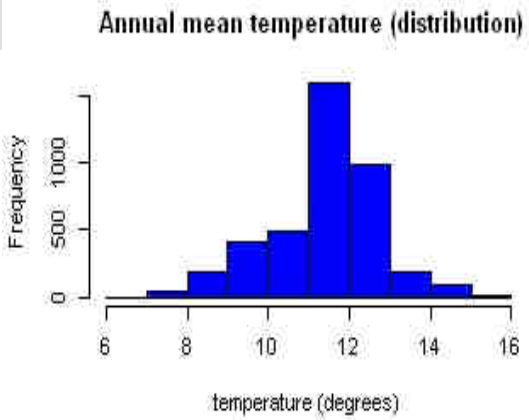


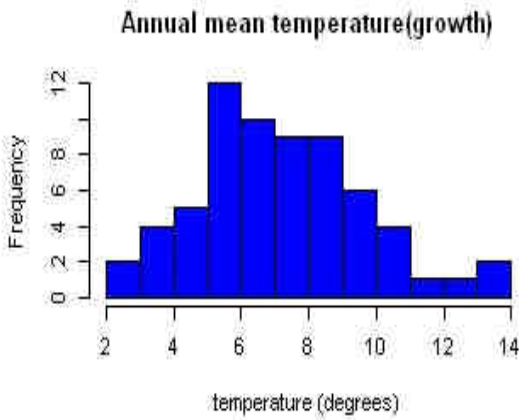
Data structure

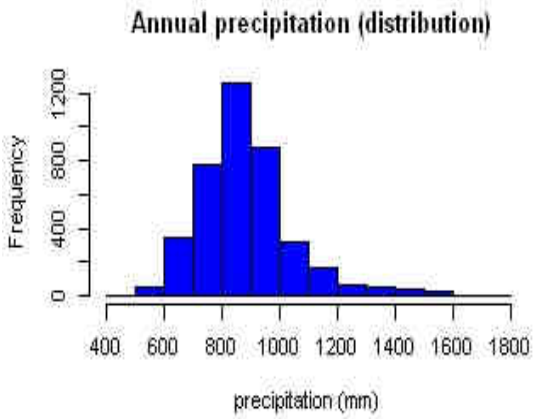
Distribution of climatic and nutrition variables for Pubescent oak

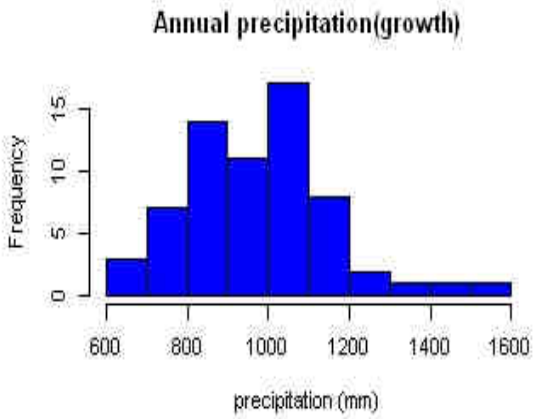
Large gradients (10°C, 1400mm)

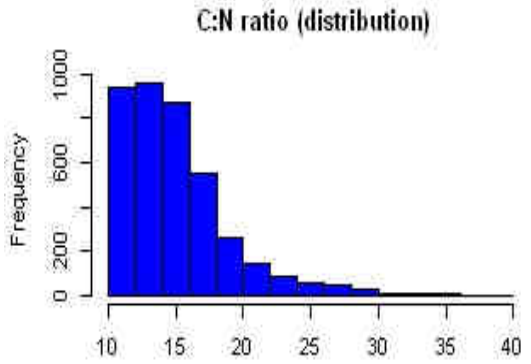
Modal distributions… (capturing the extremes)

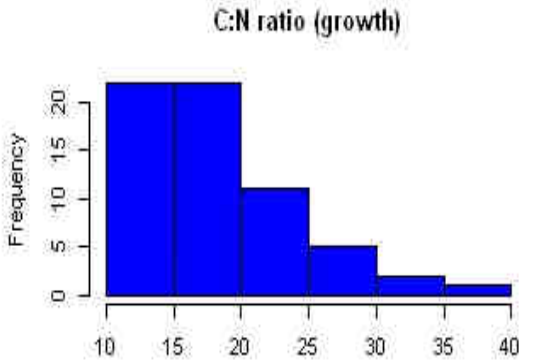












Data structure

Correlation matrix of climatic variables for pedonculate oak's distribution

→ strong seasonal collinearity, but NOT between T and P

	Spring temp	Summer temp	Autumn temp	Winter temp	Spring precip	Summer precip	Autumn precip	Winter precip
Spring temp	1	0.9150657	0.9241134	0.8155226	-0.1307251	-0.4533667	-0.1647794	-0.09195176
Summer temp	0.9150657	1	0.7935547	0.5847457	-0.06194919	-0.264103	-0.1924541	-0.1485677
Autumn temp	0.9241134	0.7935547	1	0.9472389	0.03987083	-0.4352673	0.006159292	0.1009573
Winter temp	0.8155226	0.5847457	0.9472389	1	0.01622399	-0.527288	0.03945708	0.154276
Spring precip	-0.1307251	-0.06194919	0.03987083	0.01622399	1	0.7548509	0.8849141	0.8808361
Summer precip	-0.4533667	-0.264103	-0.4352673	-0.527288	0.7548509	1	0.6602962	0.8849141
Autumn precip	-0.1647794	-0.1924541	0.00615929	0.03945708	0.8849141	0.6602962	1	0.939482
Winter precip	-0.09195176	-0.1485677	0.1009573	0.154276	0.8808361	0.8849141	0.939482	1

Tools for distribution and growth modeling

- Species distribution models (to list a few….):

Model	Category	Representation of relationship	Existing variable selection method	Handling of interaction
GLM	Parametric regression	explicit	yes	Yes, but inefficient
GAM	Nonparametric regression with spline smoother	explicit	no	Yes, but inefficient
Mars	Nonparametric regression with spline smoother	explicit	no	Yes and efficient
Boosting regression trees	Regression/Classification method	Implicit, but obtainable	no	Yes and efficient
Random forests	Regression/Classification method	Implicit but obtainable	no	Yes and efficient
Maxent	Niche distribution modeling	implicit	Yes (weights)	Yes and efficient

Tools for distribution and growth modeling

- Growth models:

Linear regression (empirical)	Nonlinear regression (curve modelling)	Artificial Neural Networks (empirical, strong fit, hardly interpretable)

- Methods to handle collinearity problem:

Principal component regression	Partial least squares regression (PLSR)	PLSR-GLM (for non-gaussian distributed response, i.e., binary, count)

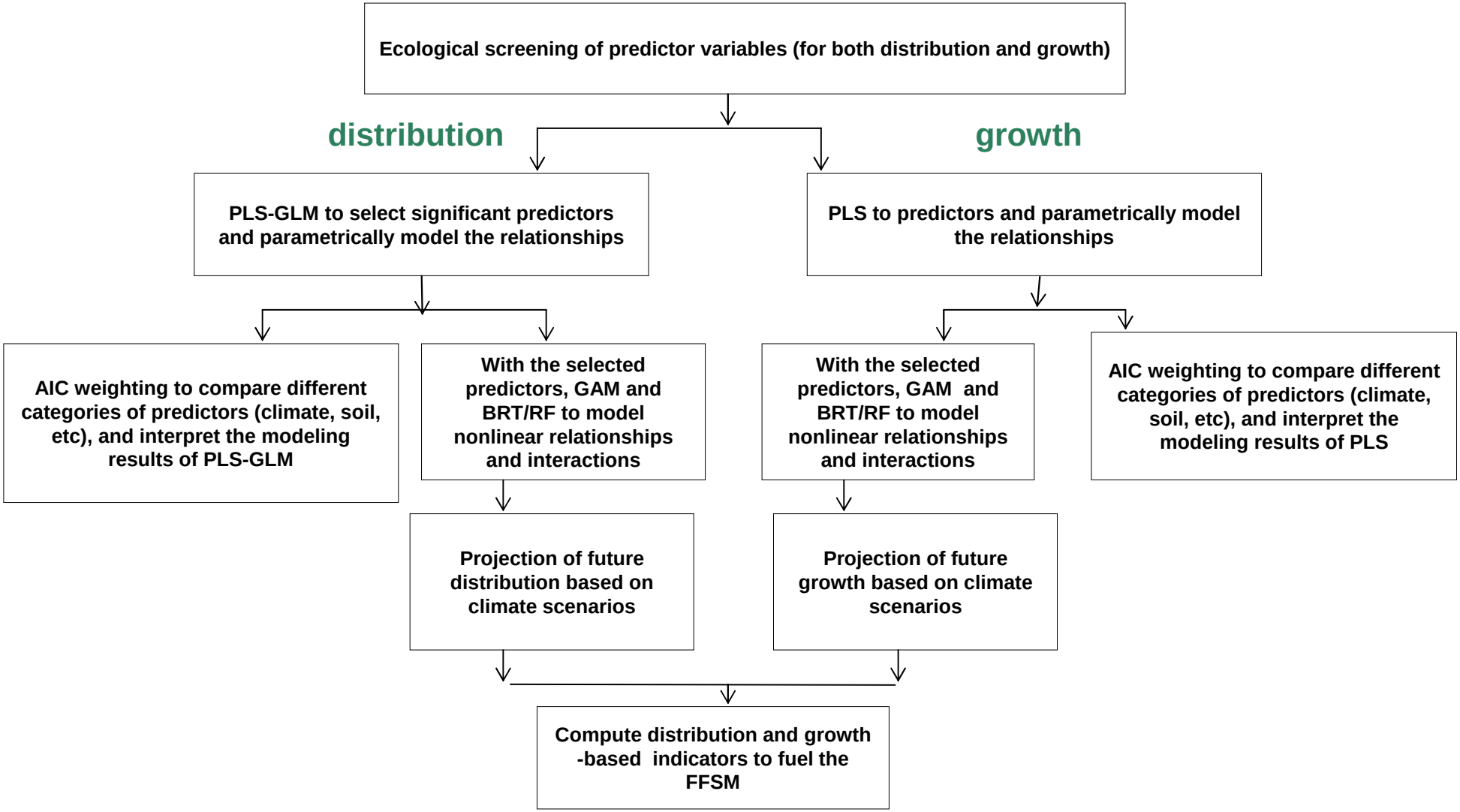
- Which model to choose??

  Unfortunately, consensus does not exist. Many comparison studies and many conclusions. E. g., Marmion et al. (2009) say ANN and RF are the best , but Thuiller et al. (2003) picks GAM.

- Model evaluation:

  Multiple (>50) run calibration-validation with the distribution and growth data to find out the « best » models for the data in terms of predictive accuracy…

Current outline for a modeling Strategy

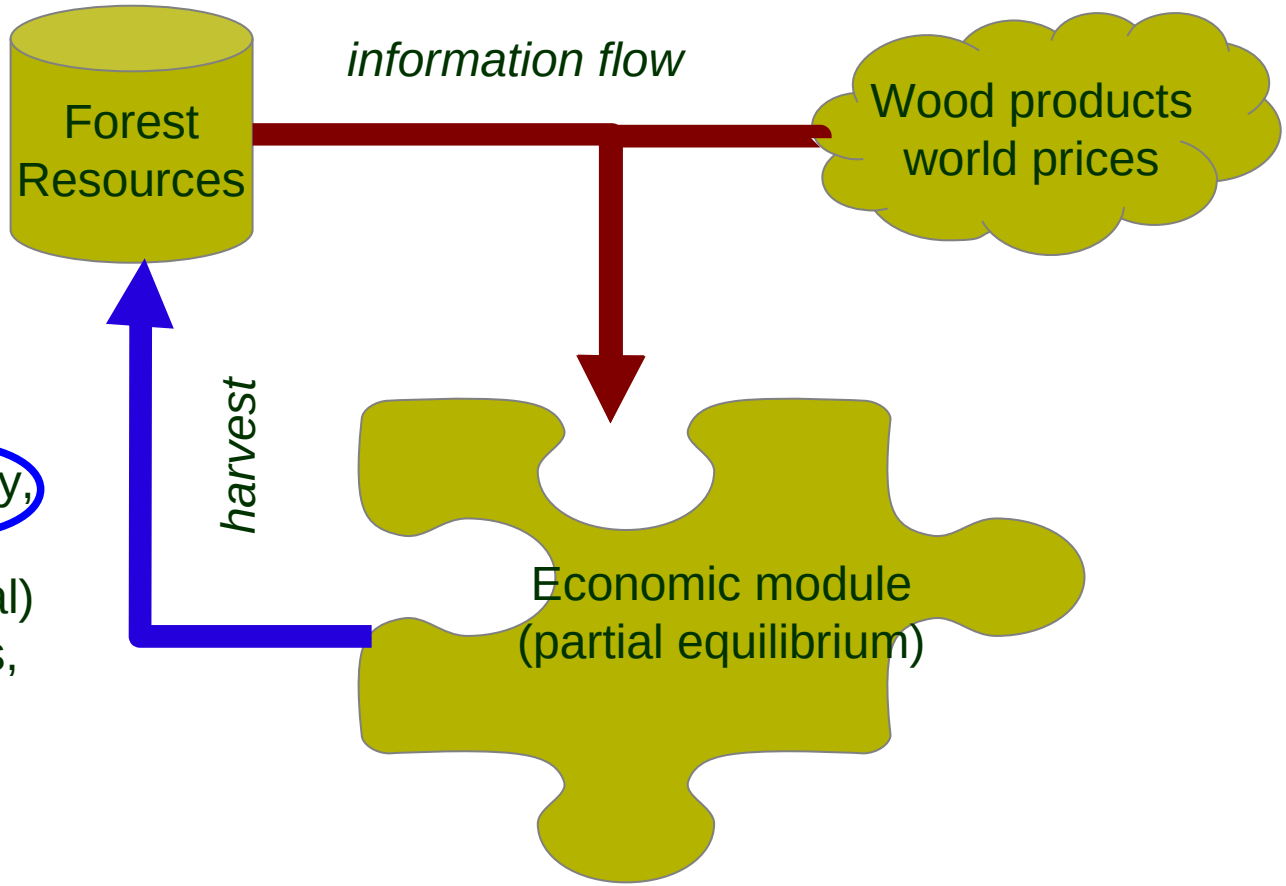


Task 4.2 : Concluding comments

- Up to early 2013, draw a version 1 of the LSFDM modifiers to LEF
- In parallel: statistical modelling of growth and productivity
- Up to autumn 2013: develop modifiers of the LSFDM
- We need specification and release of climatic scenarios !

THANKS FOR YOUR ATTENTION

FFSM: Model sketch



- primary products local (regional) price, demand, supply, exports, inter-regional trade
- transformed products (regional) price, demand, supply, imports, inter-regional trade

$$V_{dc,t} = \left(1 - 1/tp_{dc} - mort_{dc} - hr_{dc,t}\right) * V_{dc,t-1} + \left(1/tp_{dc-1}\right) * beta_{dc} * V_{dc-1,t-1}$$

Aims:

- Integrate the parameter modifiers developed in the forest dynamics model
- Introduce forest management for long-term modelling
  - endogenise forest wood regeneration (depending on harvesting levels)
  - incorporate forest managers expectations
  - model forest investments (replanting)
- Develop indicators of forest overall profitability (land use competition)
- Adopt a more detailed spatial scale

Implementation :

Integrate the extensions of the forest dynamics model

- automatically add a time dimension to any exogenous parameter ;
- switch to a general purpose programming-language (C++) :
  - ad hoc I/O ;
  - ad hoc data management for forest and market data;
  - greater flexibility for increased complexity of the resource module;

Implementation

Endogenise forest wood regeneration

$$harvestedArea_{r,ft,dc,t} = hV_{r,ft,dc,t} \;/\; vHa_{r,ft,dc,t}$$

$$regArea_{r,ft,t} = \sum_{dc} harvestedArea_{r,ft,dc,t}$$

$$vReg_{r,ft,t} = regArea_{r,ft,\tau} * vHa_{r,ft,dc15,\tau}$$

$$\tau = t - tp_{r,ft,dc0,t}$$

- link the new volumes of wood to the harvesting activity ;
- time leg between harvesting/regeneration and availability of wood resources

Implementation

Incorporate forest managers expectations

- expType parameter allows to switch from adaptive expectations to perfect foresight or to use first years observation (for compatibility with legacy GAMS code) for the resource module

Directly affected variables :

- cumulative time of passage ;
- beta coefficient (ratio of V_{dc}/V_{dc-1}) ;
- mortality rate.

Indirectly affected parameters :

- volume per hectare
- discounted expected returns

Implementation

Model forest investments and land profitability (1)

$$expReturns_{ft,t} = \sum_{dc}\sum_{pp} \frac{PW_{pp,t} * vHa_{ft,dc,t} * ponCoeff_{ft,dc,pp,t}}{(1+r)^{(cumTp_{dc,t}-1)} + (1+r)^{(cumTp_{dc,t}-2)} + \ldots + (1+r)^{(cumTp_{dc,t}-cumTp_{dc,t})}}$$

$$ponCoeff_{ft,dc,pp,t} = \frac{hv_{ft,dc,pp,t} * finHrFlag_{ft,dc}}{\sum_{dc}\sum_{pp} hv_{ft,dc,pp,t} * finHrFlag_{ft,dc}}$$

- expected returns from a given forest type depends from both the market price of obtainable products and the biological expected resource;
- converted to annualised valued ;
- each possible combination is multiplied by a weighting factor of the actual harvested for that specific combination to the total harvested for the forest type (only final harvested considered).

Implementation

Model forest investments and land profitability (2)

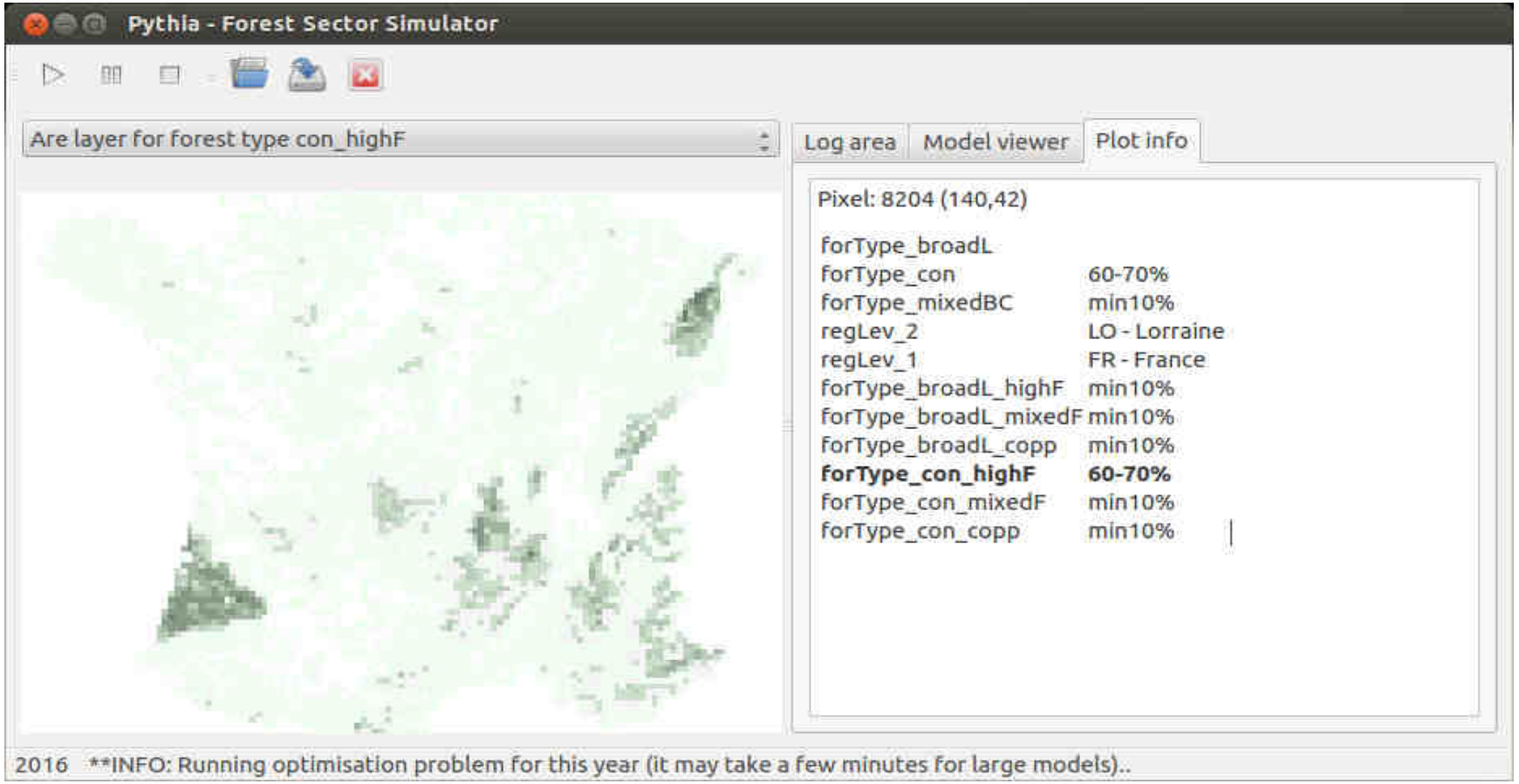
$$regArea_{r,ft,t} = \sum_{dc} harvestedArea_{r,ft,dc,t} * (1 - mr)$$

$$regArea_{r,\mathring{ft},t} \mathrel{+}= \sum_{ft} \sum_{dc} harvestedArea_{r,ft,dc,t} * mr$$

- regeneration area for each forest type is equal to the unmanaged share of the harvested area of its own type ;
- the managed share of the total harvested area increases the regeneration area of the forest type having the highest expected return ($\mathring{ft}$).

Implementation

Adopt a more detailed spatial scale



- model working on a pixel-based grid with forest cover from land use data
- a GIS-layer for each forest type

A preliminary sensitivity analysis exercise

Scenario specification

scenario	regType	mr
vRegFixed	fixed	
vRegFromHr	fromHrLevel	
vRegEnd050	end	0.5
vRegEnd100	end	1

- Forest types (ft): *Broadleaves, high forest; Broadleaves, mixed forest; Broadleaves, coppers; Coniferous, high forest; Coniferous, mixed forest; Coniferous, coppers*
- Primary products: *Hardwood Roundwood; Softwood Roundwood; Pulpwood and Fuelwood*

A preliminary sensitivity analysis exercise

harvesting activities :: harvested volumes

F. type	scenario	2007	2027	2047	2067	2087	2107
3-broadL_copp	a-vRegFixed	100	100	100	100	100	100
	b-vRegFromHr	100	274	342	342	314	277
	c-vRegEnd050	100	275	357	381	381	368
	d-vRegEnd100	100	276	372	420		
6-con_copp	a-vRegFixed	100	100	100	100	100	100
	b-vRegFromHr	100	89	80	70	59	50
	c-vRegEnd050	100	89	79	66	54	43
	d-vRegEnd100	100	89	77	62		

A preliminary sensitivity analysis exercise

forest resources :: volumes of forest regeneration

F. type	scenario	2007	2027	2047	2067	2087	2107
5-con_mixedF	a-vRegFixed	100	100	100	100	100	100
	b-vRegFromHr	100	67	72	74	70	65
	c-vRegEnd050	100	401	526	585	625	649
	d-vRegEnd100	100	735	979	960		
6-con_copp	a-vRegFixed	100	100	100	100	100	100
	b-vRegFromHr	100	41	32	28	23	20
	c-vRegEnd050	100	29	16	14	11	9
	d-vRegEnd100	100	16	0	0		

A preliminary sensitivity analysis exercise

market side :: total supply of primary products

		2007	2027	2047	2067	2087	2107
hardWRoundW	a-vRegFixed	100	100	100	100	100	100
	b-vRegFromHr	100	105	109	112	112	112
	c-vRegEnd050	100	105	109	112	112	111
	d-vRegEnd100	100	105	109	111		
pulpWFuelW	a-vRegFixed	100	100	100	100	100	100
	b-vRegFromHr	100	106	109	111	111	109
	c-vRegEnd050	100	106	109	111	111	110
	d-vRegEnd100	100	106	109	111		
softWRoundW	a-vRegFixed	100	100	100	100	100	100
	b-vRegFromHr	100	106	109	109	108	106
	c-vRegEnd050	100	106	109	109	109	107
	d-vRegEnd100	100	106	109	110		

A preliminary sensitivity analysis exercise

market side :: price of primary products

		2007	2027	2047	2067	2087	2107
hardWRoundW	a-vRegFixed	100	100	100	100	100	100
	b-vRegFromHr	100	88	80	77	76	78
	c-vRegEnd050	100	88	80	77	76	79
	d-vRegEnd100	100	88	80	77		
pulpWFuelW	a-vRegFixed	100	100	100	100	100	100
	b-vRegFromHr	100	87	80	77	77	82
	c-vRegEnd050	100	87	80	77	77	82
	d-vRegEnd100	100	87	80	77		
softWRoundW	a-vRegFixed	100	100	100	100	100	100
	b-vRegFromHr	100	87	81	80	82	87
	c-vRegEnd050	100	87	81	79	81	85
	d-vRegEnd100	100	87	81	79		

Upcoming work

- Further integration with the forest dynamics model (probability of species or growth = anticipation);
- Integration of local, sub-regional characteristics (e.g. slope → available wood resources);
- More sensitivity analysis and validation exercises;

Thanks for your attention