Forest Sector Modelling Conference 2013

Accounting for socio-economic drivers in climate change analysis with the French Forest Sector Model 2.0 (FFSM++)

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Objectives and outlines

Given the importance of anthropogenic determinants in forest growth within Europe, the objective of FFSM++ is to link the evidence arising from biological models with socio-economic determinants, where the expected returns of forest investments represent the main drivers.

Climate change is modelled both directly as productivity changes and indirectly as management response to a different environment.

Hence first an adequate spatial scale is adopted to facilitate models linkage and then a management module is introduced to account for possible variations in forest investments.

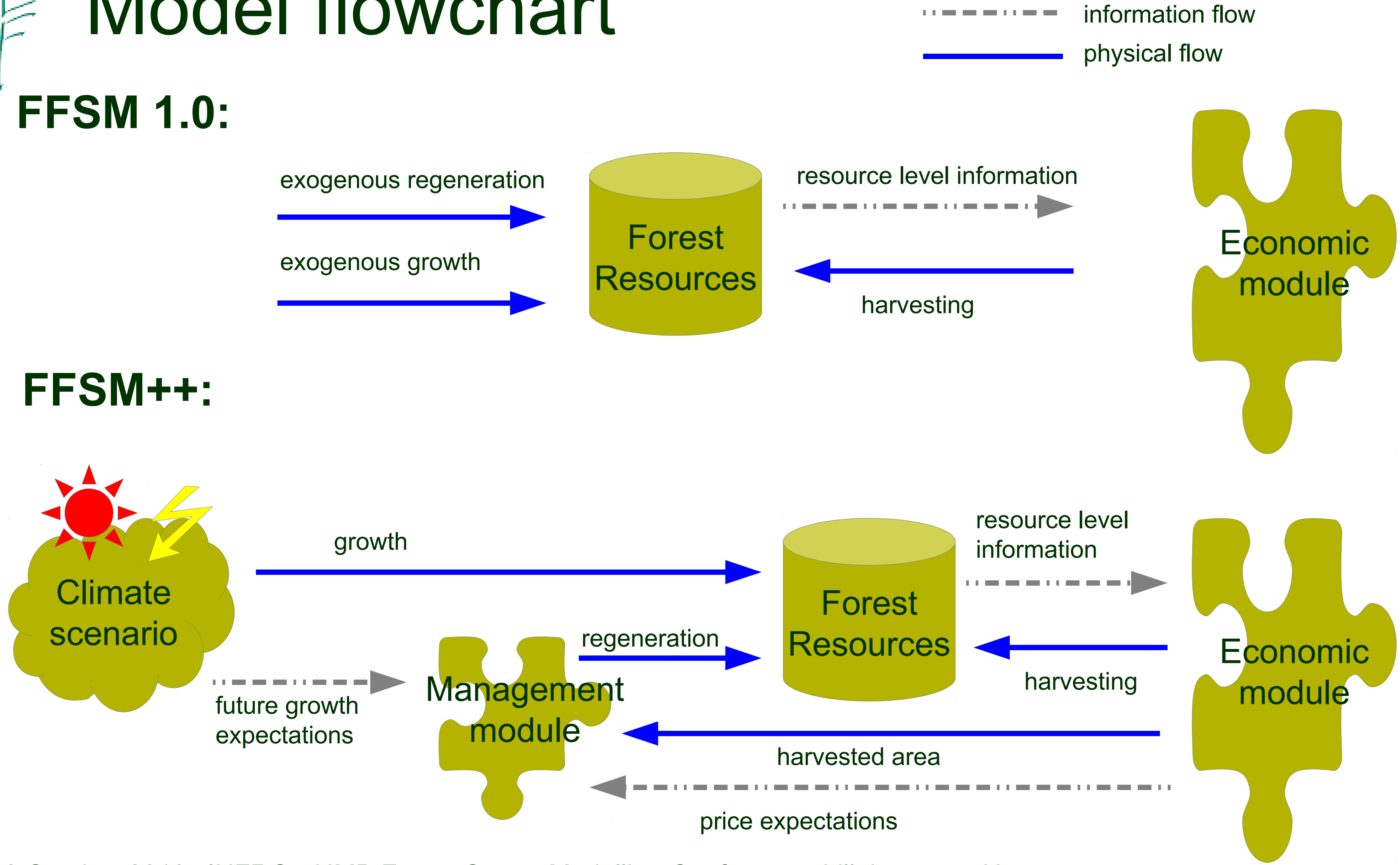
- Modelling framework
  - structure of the model
  - hypothesis, calibration and data issues
- Climate change modelling: “modifiers”
- Algorithm validation

Model key facts

- French Forest Sector Model (FFSM, Caurla et al. 2010) is a recursive simulation model of the French forest sector;
- Developed at *Laboratoire d'Economiè Forestiere* of Nancy, France;
- Adapted to long-term analysis within the ORACLE project;
- Modular approach: Market Module, Resource Module, Management Module *(new)*

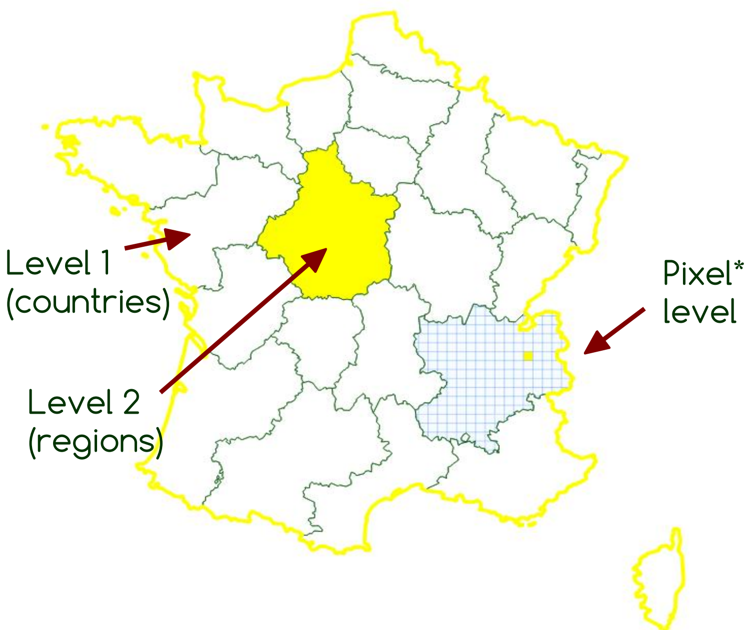
Module	Var Input	Var Output
Market Module (KM)	Inventary, W Price	Supply, Local prices, Trade
Resource (RM)	Supply, Regen. Area	Inventary $_{(t+1)}$, Harv. Area
Management (GM)	Price, Harv. Area	Regeneration Area

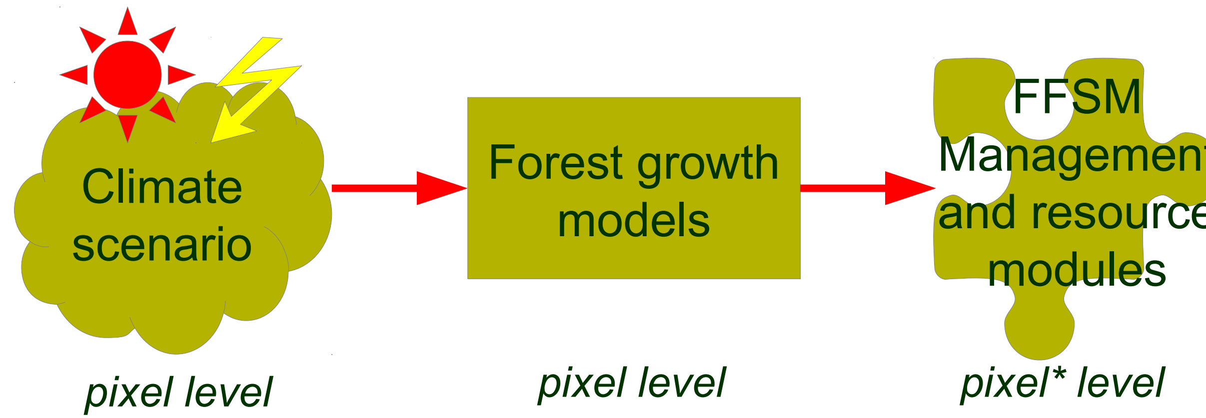
Model flowchart



Spatial representation(1)

- Decoupling the spatial scale of the market module (regional) from those of the resource and management modules (pixel)
  - regional scale reasonably adequate for the market module
- Consistency with vegetation growth models:





Module	Spatial Levels
Market module (KM)	Countries, regions
Resource module (RM)	Counties, regions, pixels*
Management module (GM)	Countries, regions, pixels*

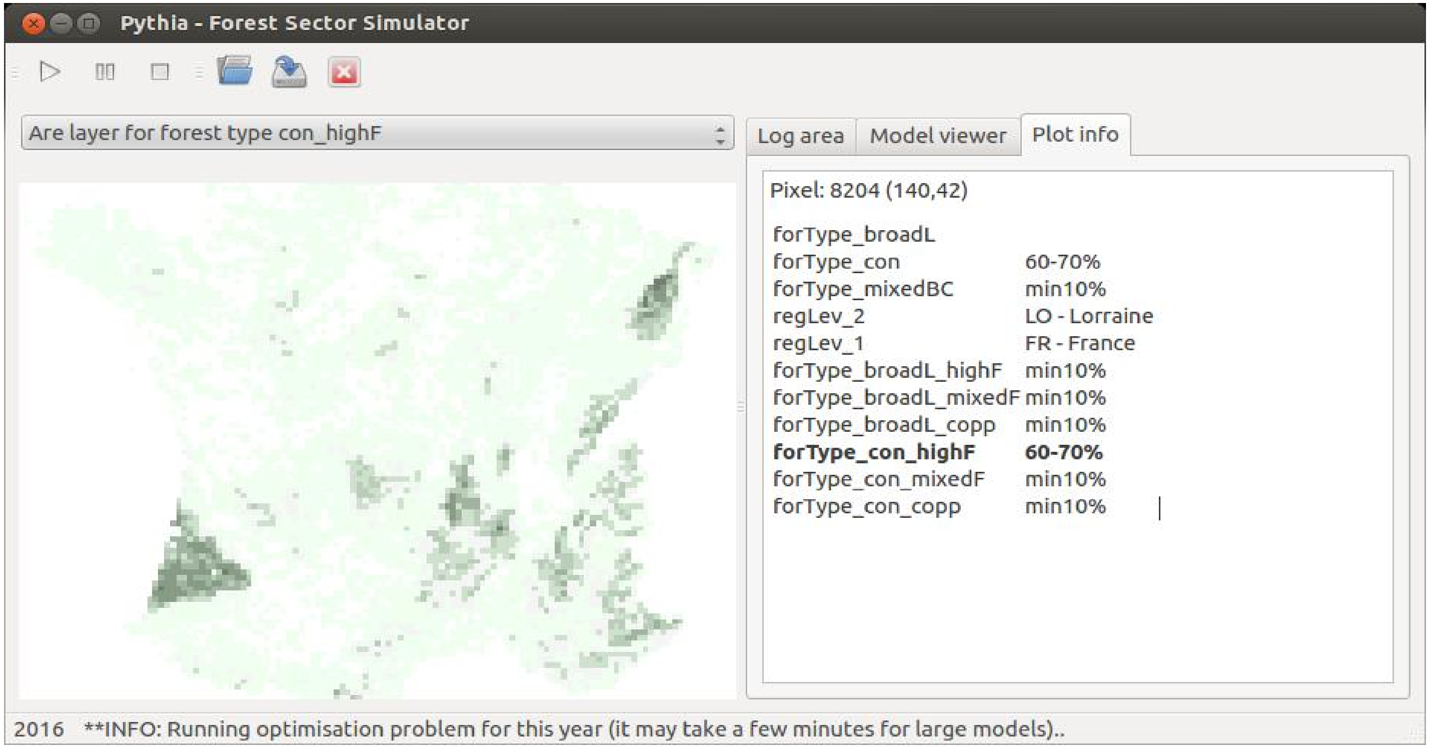
Spatial representation(2)

Intra-regional variances larger than inter-regional one

Relative diameter growth (5-years diameter groth/diameter), data from 2010 France IFN on 3740 trees with D between 45-75 cm ("moyen bois"):

	Peduncolate Oak	Sessile Oak	Common Beech	Scots Pine
AL	0,0880	0,0526	0,0859	0,1208
AQ	0,0742	0,0933	0,1118	0,0573
AU	0,0605	0,0583	0,0731	0,0784
BN	0,0437	0,1127	0,0944	0,0135
BO	0,0614	0,0581	0,0657	0,0597
BR	0,0527	0,0712	0,1006	0,0603
CE	0,0805	0,0445	0,0771	0,0870
CA	0,0337	0,0757	0,0646	0,0882
CO			0,1484	
FC	0,1067	0,0380	0,0614	0,0146
HN	0,0529	0,0629	0,0948	0,2197
IF	0,0882	0,0845	0,0299	0,1069
LR	0,0436	0,0675	0,0678	0,0672
LI	0,0609	0,1034	0,0607	0,0476
LO	0,0643	0,0750	0,0793	0,0801
MP	0,0545	0,0497	0,0782	0,0967
NP	0,0261		0,0236	
PL	0,0641	0,0573	0,0992	0,0485
PI	0,0872	0,0337	0,1404	
PC	0,0584	0,0751	0,0253	0,0471
PA			0,0930	0,0542
RA	0,0682	0,0665	0,0628	0,0663
France	**0,0066**	**0,0058**	**0,0113**	**0,0128**

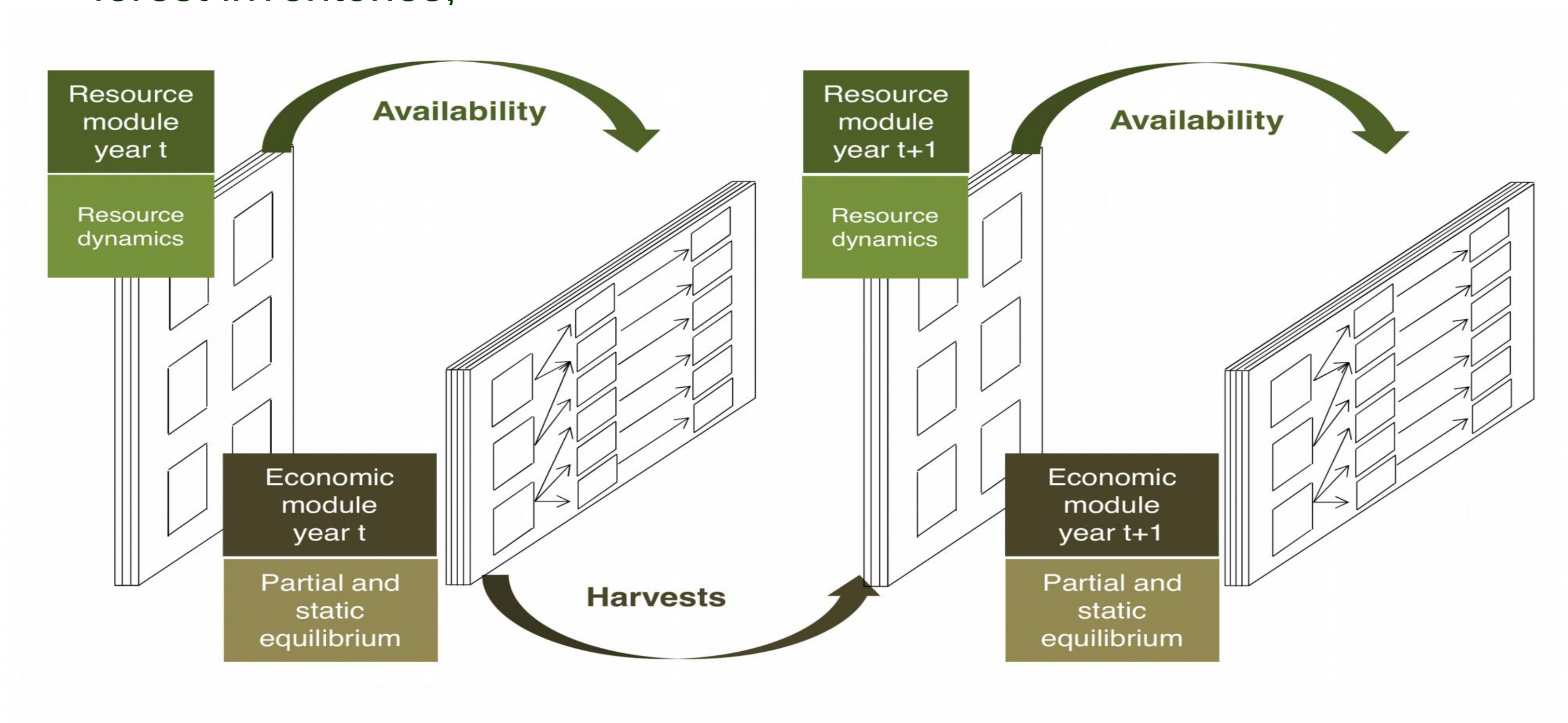
Spatial representation(3)



- Model working on a pixel-based grid with a GIS-layer for each forest type
- Pixel contains information of the amounts of land allocations within but not where it is allocated (that is, soil usage inside the pixel is not represented – *a compromise*)
- Model independent on spatial resolution, currently pixels set at 8x8 km

Forest resources dynamic module (RM)

- Model the regional timber stock dynamics using a diameter-class approach;
- Resource dynamics in each cell is calibrated using data from the 2005-2007 French forest inventories;



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

Market module (KM)

- Spatial partial-equilibrium model of the French forest sector, from timber production to the consumption of first-transformation products (Samuelson, max total welfare);
- Recognises full substitutability of products across regions but imperfect substitutability between international products (using Armington elasticity);
- Uses a simple Leontief production functions: under assumption of perfectly competitive markets the transformation industry makes zero profit at equilibrium;
- 4 primary products local: (regional) prices, **demand**, supply, exports, inter-regional trade;
- 6 transformed products: (regional) prices, demand, supply, imports, inter-regional trade;

Management module (GM) (1)

- Expected returns from a given “forest type” {structure X species group} depend from both (expected) market price of related wood products and (expected) biological parameters;
- 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).

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

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

- Each year an harvested area for each f.t. is computed from the harvested volumes (in turn derived from market demand)

$$harvestedArea_{px,ft,dc,t} = hV_{px,ft,dc=finharv,t} / vHa_{px,ft,dc,t}$$

Management module (GM) (2)

- The 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 is allocated as the regeneration area of the forest type having the highest expected return ($\check{ft}$).

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

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

- A time leg exists between harvesting/regeneration and availability of wood resources

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

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

Forest layers initialisation

Forest Layer	Source
Broadleaves	*Corine Land Cover*
Coniferous	*Corine Land Cover*
Mixed forest (broad/con)	*Corine Land Cover*
Broadleaves, high forest	Computed Layer
Broadleaves, mixed forest	Computed Layer
Broadleaves, coppers	Computed Layer
Coniferous, high forest	Computed Layer
Coniferous, mixed forest	Computed Layer
Coniferous, coppers	Computed Layer

Combination of IFN and CLC datasets

sp = species group

mt = management type (structure)

ft = forest type (sp X mt)

$$area_{px,sp,mt} = area_{px,sp} * \frac{V_{r,sp,mt}}{\sum_{mt} V_{r,sp,mt}} + area_{px,sp=mix} * \frac{V_{r,sp,mt}}{\sum_{sp}\sum_{mt} V_{r,sp,mt}}$$

$$V_{px,ft,dc} = V_{r,ft,dc} * \frac{area_{px,ft}}{area_{r,ft}}$$

- Three strong assumptions implied:
  - density (vHa) is the same for each management type;
  - density is constant within the region;
  - constant distribution of forest in diameter classes within the regions.

Climate change effects: multipliers

- using multipliers$_{px,ft,t}$ key input biological variables can change from the regional average along the spatial and temporal dimensions:
  - time of passage: $cumTp_{px,ft,dc} = cumTp_{px,ft,dc-1} + tp_{r,ft,dc-1} * tpMultiplier_{px,ft}$
  - beta coefficient: $beta_{px,ft,dc} = beta_{r,ft,dc} * betaMultiplier_{px,ft}$
  - mortality rate: $mort_{px,ft,dc} = 1 - (1 - mortY_{r,ft,dc-1} * mortMultiplier_{px,ft})^{tp_{px,ft,dc-1}}$
  - volume per ha: $vHa_{px,ft,dc} = vHa_{px,ft,dc-1} * beta_{px,ft,dc} * (1 - mort_{px,ft,dc})$
- the recursive nature *(by dc)* of these parameters lead the model to compute both an expected version of them (e.g. to be used in evaluating forest investments) and a “real” version for actual use (e.g. for conversion between harvested volumes to harvested areas)
- 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

Algorithm validation 2

- The algorithm in the new version match the one in the first version
- The small differences depends on the different library used (GAMS vs C++/IPOPT/ADOL-C/ColPack)

	3 regions			6 regions			all (22) regions		
	FFSM	FFMS++	*rel err*	FFSM	FFMS++	*rel err*	FFSM	FFMS++	*rel err*
2008	6,3831254	6,3831283	*-4,49E-07*	10,7284	10,7318	*-3,21E-04*	47,75	47,96	*-4,24E-03*
2010	6,4573127	6,4573118	*1,46E-07*	10,8498	10,8532	*-3,11E-04*	48,09	48,29	*-4,09E-03*
2012	6,5210278	6,5210326	*-7,44E-07*	10,9464	10,9497	*-3,05E-04*	48,42	48,60	*-3,66E-03*
2014	6,5870480	6,5870444	*5,43E-07*	11,0457	11,0490	*-2,97E-04*	48,78	48,93	*-3,04E-03*
2016	6,6347580	6,6347631	*-7,74E-07*	11,1185	11,1217	*-2,92E-04*	49,03	49,17	*-2,94E-03*
2018	6,6931214	6,6931193	*3,04E-07*	11,2060	11,2092	*-2,86E-04*	49,32	49,47	*-3,04E-03*
2020	6,7483185	6,7483505	*-4,74E-06*	11,2907	11,2919	*-1,10E-04*	49,59	49,75	*-3,16E-03*

Harvested volumes (Mmc) and discrepancies

Algorithm validation 2

- Test the spatial-explicit algorithm using fixed modifiers equal to 1
- Small differences between the two versions are likely to be due by the way the model handle the formation of expected returns for a given forest types

	2010	2030	2050	2070	2090
Harvested volumes [M mc]					
- *sp. implicit*	48,291665	50,940514	52,664556	53,858612	54,553096
- *sp. explicit*	48,291665	50,940524	52,664606	53,858609	54,553107
- *diff %*	0,000000	0,000019	0,000095	-0,000005	0,000022
Volumes of regeneration [M mc]					
- *sp. implicit*	2,697705	1,358129	1,496011	1,670559	1,763393
- *sp. explicit*	2,697705	1,362416	1,495954	1,670550	1,763348
- *diff %*	0,000000	0,315665	-0,003820	-0,000586	-0,002586
Expected returns [€/ha]					
- *sp. implicit*	16,50544	12,95245	10,50857	8,89961	7,90911
- *sp. explicit*	16,50544	12,95160	10,48988	8,84972	7,82822
- *diff %*	0,000016	-0,006568	-0,177854	-0,560623	-1,022654

Output confrontation between spatial implicit and explicit algorithms

Conclusions

With both biological and economic drivers considered we can try to:

- understand the impact of forward-looking vs conservative forest management;
- forecast the impact of climate change on forest profitability, depending on forest managers strategies;
- forecast the long-term evolution of the French land-use, comparing forests and agriculture profitability.

Upcoming work

- Testing the spatial module working with the spatial/temporal multipliers (from ORACLE project);
- Integration of other local, sub-regional characteristics (e.g. slope → available wood resources, soil maps ??);
- Recognition of forest owner heterogeneity (different risk attitude);
- Sensitivity analysis and validation exercises;

Thank you for your attention

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