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Introducing forest management in forest sector models: impact of active management and risk attitude on forest resources in the long term

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Abstract

Given the importance of anthropogenic determinants in forest ecosystems within Europe, the objective of this paper is to link the evidence arising from biological models with socio-economic determinants, where the expected returns of forest investments represent the main driver. An inventory-based forest dynamic model is hence coupled with a market module and a management one in a national level forest sector model for France (FFSM++). Running long-term scenarios (until 2100) we show the implications on the forest composition of an active management: when the most

profitable option drives forest investments, coniferous forests are generally preferred over broadleaved ones. This result is however reappraised when the risk aversion of forest owners is explicitly considered in the model, given the higher risk associated with the former. We further show the strong stability of forest ecosystems that, due to the very long cycles, undergoes very small variations in volume stocks even in scenarios where the initial forest regeneration is strongly influenced.

Key words: Forest sector modelling, Investment, Risk Aversion.

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1 Introduction

Forest ecosystems are characterised by very long delays between any perturbation is introduced and the system responds with measurable effects. For example, timber production, biodiversity capacity and CO_2 accumulation are all processes that can be measured only decades after any policy devoted to interact with them is implemented. Hence, it is not surprising that the forest sector has long been the subject of careful planning initiatives. Historically this planning has took the form of normative, empirically derived rules. With the increased complexity of accounting for multi-purpose objectives on one side and the better availability of simulations tools on the other side, these planning methods have switched from normative rules to the usage of mathematical models, able to forecast in the future the status of forest ecosystems conditionally to agent's today actions. This switch was also due to major price variations after the two first energy shocks in the 70's. Simple 'gap analysis' models were not sufficient and more integrated tools were required.

Within the multitude of forest models (Buongiorno et al. 2003; Kallio et al. 2004; Sjølie et al. 2011 among others), the French Forest Sector Model (FFSM, Caurla et al., 2010) distinguishes itself by explicitly considering both international and interregional trade, accounting for the full heterogeneity of regions and, using the Armington theory (Armington, 1969), of products. It also aims to combine the modeling part of the forest dynamic, taking into account each forest specific conditions, with those of forest markets, using a partial equilibrium approach.

In order to achieve its goal, the traditional FFSM (FFSM 1.0) considers two separate modules: the first one simulating the forest dynamics, the "Forest Dynamics (FD) module"; the second one determining wood market prices, demand, supply and trade: the "Market (MK) module". These two modules are combined together and exchange informations as detailed in section 2. This version of FFSM has been used to forecast the impact of climate public policies of the forest sector at a t+20 horizon. However, the model was not fit to make long term projections (t + 100). Indeed, the FD and MK modules do not take into account long term decisions of forest managers such as the choice of species and management choice on the land that is cleared by forest harvesting: this cleared land was supposed to be reproduced identically. It follows that, while the Forest Dynamic module has been designed to forecast the status of the current forests, it was particularly weak in making long-term projections. In order to include possible changes in environmental (*in primis* climate changes) and economic (e.g. timber prices) conditions, and incorporate forest managers response to these changes, a third module, namely the "Management module" (MG), has been introduced to allow for possible switches in forest types (species composition and/or management type) given expected market and ecological conditions.

The objective of this paper is therefore to understand how an explicit introduction of forest management choices modifies the landscape of forest resources in the long run. Two important considerations have to be considered in this manner. First, the degree of forest management is unobserved, and there is high uncertainty about its implications. Thus, we introduced a forest management rate in order to assess the implications of this management intensity on the forest sector. Second, given their long time to maturation, forest investments are particularly subject to stochastic events. We hence introduce risk aversion of forest managers, in which the risk of tree mortality influences the forest management choices.

This paper is organized as follow: section 2 presents an overview of FFSM as a viable method to produce forecasts of the forest sector at a national and regional level, highlighting its history and providing a short bibliography of results already published. It also shortly presents the work done to spatialise forest resources inside regions. Sections 3 is devoted to describe the management module. Once the model has been presented, section 4 objective is to make evident, looking at the model results, the implications of the enhancements described in the previous section. Simulations focuses in particular on two aspects: (a) the role of an active management, where results from FFSM++ are compared with those derived using exogenous forest regeneration; (b) the effect of heterogeneous risk aversion within forest managers. Finally section 5 concludes.

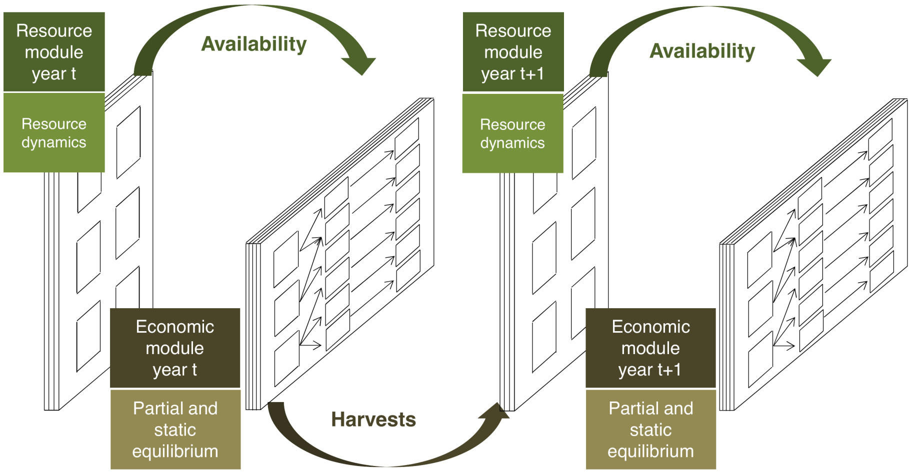
2 Overview of the model

2.1 FFSM 1.0

The French Forest Sector Model (FFSM, Caurla et al., 2010) is a recursive simulation model of the French forest sector. It articulates two modules: a Forest Dynamics module (FD) and a Markets module (MK). At each period (year), given available timber resources, timber supply functions, transformation technologies and capacities, and demand functions for (first-transformed) timber products, the MK module computes all market equilibria in the forest sector, from which it deducts the annual harvest. Harvest then enters the FD module, which computes available timber resources at year t + 1. In turn these enters the MK module, and so forth (see Figure 1). The first version of FFSM was implemented under the General Algebraic Modelling Software (Bussieck & Meeraus, 2004), and runs for periods of 10-20 years.

The FD module (Wernsdörfer et al., 2012) simulates regional timber stock dynamics using a diameter-class approach. Since French forests are very diverse in terms of climate, soils, species and types of management, the FD module breaks down timber resources into 2574 cells differing by region

Figure 1: The Markets module of FFSM



(22 administrative regions), type of management (high forests, coppices, mixed), species (coniferous and broadleaved) and diameter classes (13 total). Resource dynamics in each cell is calibrated using data from the 2005-2007 French forest inventories (Colin & Chevalier, 2010).

The MK module is a partial-equilibrium model of the French forest sector, from timber production to the consumption of first-transformation products. There are four raw timber products: fuelwood, pulpwood, hardwood and softwood roundwood, and six processed timber products: hardwood sawn- wood, softwood sawnwood, plywood, pulp, fuelwood, and fiber and particle board (Table 1).

Three groups of agents are represented in the model: wood suppliers (either forest owners or forest managers on behalf of forest owners), transformation industry and consumers (either final consumers or second- transformation industries). The transformation industry is modelled using Leontief production functions. Under our assumption of perfectly competitive markets, the transformation industry makes zero profit at equilibrium (Caurla et al., 2010).

The MK module distinguishes 22 administrative regions within France, and inter-regional trade is modelled assuming perfect competition and full substitutability of products across regions, à la Samuelson (1952). International trade (exports of raw products and imports of processed products) is modelled assuming imperfect substitutability within the Armington (1969) framework. The MK module is calibrated using literature data and specific estimates, as presented in Caurla et al. (2010) and Sauquet et al. (2011).

So far, FFSM 1.0 has been used to assess the impact of climate mitigation policies on forest sectors (Delacote & Lecocq, 2011, Delacote et al. (2013)) at a relatively short-term horizon (2020): a comparison of sequestration and substitution policies (Lecocq et al., 2011); an assessment of the impact of fuelwood stimulation policies (Caurla et al., 2013*b*); an economy-wide carbon tax and potential substitution effects (Caurla et al., 2013*a*).

Along this paper the following indexes will be extensively used:

Table 1: Commonly used index symbols

Notation	Definition	Values
t	time	[2005-2100]
c	country	{France}
r	region	[22 administrative regions in France]
px	pixel	
sp	forest species group	{Broadleaves, Coniferous}
mt	forest management type	{High forests, Mixed forests, Coppices}
ft	forest type (including management)	[sp × mt] (e.g. coppices broadleaved or high forest coniferous)
dc	diameter class	{0, 15, 25, 35, 45, 55, 65, 75, 85, 95, 150}
pp	primary product (that is, deriving directly from forest resources)	{Hardwood Roundwood, Softwood Roundwood, Pulpwood and Fuelwood}
tp	transformed products	{Fuelwood, Hardwood Sawnwood, Softwood Sawnwood, Plywood, Pulpwood, Pannels}
prd	products	[pp ∪ tp]

2.2 Spatial representation

The spatial representation of FFSM++ is organised along three levels (Figure 2). Of these, the first two (Countries and Regions) are used in the market module while the pixel level is used only in the resource and management modules (Table 2). Each pixel encompasses the information of the area share for each forest type within the pixel, but the exact land allocation inside the pixel is not defined. While the model itself is independent on the spatial resolution, pixels in the simulations proposed in Section 4 has been set using a 8x8 km resolution.

Adopting this approach, FFSM++ is able to represent ecological and social phenomena at the scale that is more appropriate for their analysis. In particular, with the inclusion in the model of a micro-economic management module, a detailed spatial representation is essential to describe the conditions in which the economic agents operate. Indeed, in a homogeneous region (and with homogeneous agents), the “optimal” forest investment would be wherever the same, and the model would not be able to represent the indisputable richness in forest types that exists within each region.

Space affects the model in all of its modules: in MK the Euclidean distance between regions drives the formation of transport costs in the market module; in FD and MG heterogeneous ecological conditions influence the forest dynamic, both observed and expected, and hence the investment decisions.

The spatialisation of FFSM is presented in detail in Lobianco et al. (2014), where the forest layers initialisation and the aggregation and disaggregation functions of forest resources from regions to pixels are explicited.

Figure 2: FFSM++ spatial representation

Table 2: Modules, spatial levels and interface variables

Module	Levels	Var Input	Var Output
Market (MK)	Countries, regions	$Inv_{r,pp,t}$	$Supply_{r,pp,t}$, $Price_{r,pp,t}$
Forest Dynamic (FD)	Counties, regions, pixels	$Supply_{r,pp,t}$, $RegArea_{px,ft,t}$	$Inv_{px,pp,t+1}$, $HArea_{px,ft,t}$
Management (MG)	Countries, regions, pixels	$Price_{r,pp,t}$, $HArea_{px,ft,t}$	$RegArea_{px,ft,t}$

3 Management (MG) module: introducing long-term decisions in FFSM

3.1 Introduction

The forest dynamic module, using inventory data and exogenous modifiers, is able to forecast the forest status and to consider environmental changes that affect the forest system. The market module of FFSM can already be used to account for economic and policy drivers that impact forest usage, for example an increased fuelwood demand (Caurla et al., 2013*b*) or a substantial change in wood prices.

The management module under risk integrates the FD and MK modules recognising the role of forest management and the interaction of these bio-physical and economic drivers in forest dynamics.

The FD module is responsible for accounting the volumes of wood available for any given forest type and region. Every year it calculates the available volumes recursively from the volumes of wood of the previous year, taking into account natural tree growth, mortality and harvesting.

In the original version of FFSM, the calculation of new volumes reaching the first productive diameter class (that is, the result of the regeneration of the forest after the harvesting) is taken exogenously from inventory datasets. The objective of the MG module is to make endogenous this regeneration, explicitly linking it on one side to the level of harvesting activity and on the other side to the expectations that forest agents would make at replanting time given current market prices of wood products and expected forest growth. In order to achieve this objective, the harvesting volumes computed in the resource module are transformed in harvesting area and then expected returns are computed for each forest type to allow its allocation among the most profitable forest type. This regeneration area will then became the regeneration volumes (Figure 3).

While this section is devoted to detail the above methodology, the role of an active forest management is the focus of the simulations run in Section 4.1.

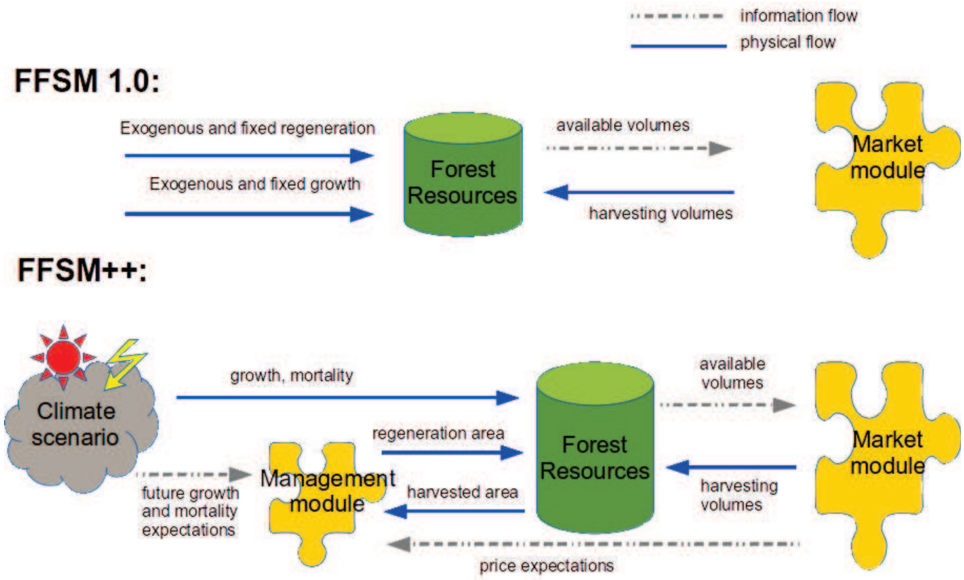
3.2 Computation of regeneration volumes

The management module is responsible to compute the wood volumes entering the first production diameter class for each forest type.

The first step is represented by the conversion of wood demand from the market module into harvested volumes hV (eq. 1). The share of these volumes arising from final harvesting is in turn converted to harvested area ($harvestedArea$).

$$hV_{px,ft,dc,t} = \left(sum_{pp} sflag_{ft,dc,pp} * \frac{supply_{pp,t}}{inv_{pp,t}} \right) * V_{px,ft,dc,t-1} \tag{1}$$

Figure 3: Flowchart



$$harvestedArea_{px,ft,dc,t} = hV_{px,ft,dc,t} * finHrFlag_{ft,dc} / vHa_{px,ft,dc,t} \tag{2}$$

where $sflag$ is a binary variable that links each wood product with its possible sources in terms of forest types and diameter classes and $finHrFlag_{ft,dc}$ is a binary variable that indicates if a harvesting of a given diameter class and forest type has to be considered as a final harvesting (thus, freeing land for potential regeneration) or a thinning (that is not supposed to free any land).

For each forest type the model computes the expected returns as:

$$expReturns_{px,ft,t} = \max_{dc,pp} \frac{PW_{r,pp,t} * vHa_{px,ft,dc,t} * finHrFlag_{ft,dc} * sflag_{ft,dc,pp} * r}{(1+r)^{cumTp_{px,dc,t}} - 1} \tag{3}$$

where PW is the observed price of primary products that can be realised from the forest resource, r is the chosen discount rate and $cumTp$ is the (expected) cumulative time for trees to reach a certain diameter class. An important hypothesis here is the assumption that prices at time t represent the expected prices in the future. In reality, agents are likely to make different expectations of future prices. Nevertheless, the objective of this paper is to focus on the influence of forest management and risk aversion of forest resources, with a constant environment. Thus this myopic behavior of forest managers is not our main concern here. The influence of prices expectations will be investigated in future studies.

Expected returns are given as an equivalent annual income (EAI) to consider forest types with different production cycles. It is important to note here that possible change in tree species or forest management is made at no cost. In reality, it is very likely that such a choice presents positive (and potentially high) costs, meaning that the influence of more intensive forest management is probably over-estimated in our results.

Any direct comparison between *expReturns* and agricultural gross margins should be taken with caution, as the former includes revenues only from final harvesting overly simplistic assuming that revenues from thinning compensate exactly forest management costs [1]. Nevertheless the trend of the ratio between them could still give insight on possible changes in the relative convenience between these two broad land uses.

Once all the expected returns for any forest types have been computed, harvested land is allocated to the forest type with the highest one ($\hat{ft}$):

$$regArea_{px,ft,t} = \sum_{dc} harvestedArea_{px,ft,dc,t} * (1 - mr) \tag{4}$$

$$regArea_{px,\hat{ft},t} \mathrel{+}= \sum_{ft} \sum_{dc} harvestedArea_{px,ft,dc,t} * mr \tag{5}$$

where mr is the management rate, a coefficient [0,1] that reflects the consideration that not all the forest is managed according to strictly economic criteria. Instead, a share of the harvested area (1-mr) is allocated according to ecological considerations. While in the scenarios described in section 4 this area is simply reallocated on the same harvested forest type, a probability of presence function, derived from ecological and biophysical data, could also be used. This management rate allows for considering the uncertainty about the implication of economic drivers in forest managers choices. By letting mr vary, we can therefore assess how a larger importance of economic drivers influence forest resources, compared to a situation in which natural regeneration dominates.

Finally the regeneration area for a given forest type is then converted back in wood volumes entering the first diameter class using the vHa of the first productive diameter class (an exogenous parameter that has been estimated from national inventory data):

$$vReg_{px,ft,t} = regArea_{px,ft,\tau} * vHa_{px,ft,dc=1,t} \tag{6}$$

It is important to note that there is a time lag between the harvested year and the one when the new shrubs enter the first production diameter class:

$$\tau = t - tp_{px,ft,dc=0,t} \tag{7}$$

[1] A proper comparison of gross margins would require to include in the expected returns also informations on the cost side, while currently the management module works with information only on the revenues side, assuming similar costs between forest types. Using the supply function as an indicator of marginal costs may be a way to deal with this issue.

Due to this time lag between harvesting and regeneration, in the first $tp_{px,ft,dc=0,t}$ years the model doesn't have enough information to compute the regeneration volumes, hence it is forced to use exogenous regenerations. This is the reason leading to many parameters being very similar across scenarios on the initial years of the simulations.

4 Simulations: the influence of forest management and risk aversion on forest resources

Figures 4 and 5 present the numerical output of simulations run under scenarios selected to highlight specific topics. Variables are reported in the order they influence each other in the model: expected returns drive forest investments in specific forest types leading to regeneration volumes (forest recruitment) that in turn dynamically increase the stock of volumes for a given forest type and finally the volume stocks influence the harvesting levels through a positive elasticity of supply (described in Caurla et al., 2010).

Harvesting levels represent the raw material supply within the market module. As FFSM++ does not introduce any modification to the market module, we didn't include any market-based scenario and consequently market results are not discussed in this section[2].

Due to the initial time lag in regeneration of Equation 7 some curves show an initial "S" shape that lasts for the first 20-30 years and hence comparisons between scenario, when not otherwise stated, are given as average for the period 2030-2100 for flow variables (expected returns and volume regenerations) and on the last year of the simulations (2100) for stock variables (forest volumes), the exception being the harvesting volumes that while being a flow variable depend on the stock volumes and hence they are reported for 2100.

4.1 Active management

As mentioned before, there is large uncertainty on the actual level of forest active management. In order to deal with this uncertainty, we run simulations in which the degree of forest management mr varies. Effects of an active management, where profit maximisation drives the forest investments, are shown in Figure 4, based on scenarios of Table 3.

[2]The full set of results, including regional ones, is however available in the digital archive that come along with this paper.

Results for forest dynamic and markets are available in the attached ZIP archive under the files "data/output_{scenario_name}/results/forestData.csv" and "data/output_{scenario_name}/results/productData.csv" respectively and as pre-formatted tables and charts in file "ffsm_output.pdf".

Input data is located in the "data/ffsmInput.ods" speadsheet and in the gis maps under "data/gis".

Table 3: Active management scenarios

scenario	mr	description
vRegFixed	–	exogenous regeneration (derived from national inventory data)
vRegFromHr	0.0	regeneration linked with the harvesting activity but without the possibility to switch between forest type
reference	0,5	intermediate level of active forest management
vRegEnd070	0,7	stronger importance to economic drivers

The first plot on Figure 4 shows the clear economic superiority of coniferous investments over broadleaved forest at national level, with the former showing over double expected returns than the latter.[3] At regional level the distance between coniferous and broadleaved expected returns vary, but the broadleaved never overtake the coniferous in any of the discussed scenario, with the exception of two regions in the North of France, namely *Picardie* and *Nord-Pas-de-Calais*, where forest is very rare and therefore the input data is much less reliable.

Since coniferous are more profitable than broadleaves, forests managers with active management switch their tree portfolio toward a larger share of coniferous. When the degree of forest management increases (`vRegEnd070`), a larger share of forest managers apply this type of behaviour. This increase in the share of coniferous (and thus decrease in the share of broadleaved) increases in the long run the supply of coniferous (and decrease supply of broadleaves). This result, at national level, in a long-run decrease in coniferous prices and increase in broadleaved prices. However Table 5 shows that impacts vary much across regions. In general the incremental coniferous production is concentrated in regions that are currently minor producers. Due to the spatial nature of the market equilibria, regions that are currently strong coniferous producers may end up with both an increase in production and in price. When the regional prices for coniferous products drop the corresponding expected returns for coniferous forest fall as well, as these strictly depend on the observed prices.

Regeneration volumes are even more influenced by the scenario, as result of the different algorithm used. Compared with `vRegFromHr` in the `reference` scenario broadleaved forests suffer a reduction of 0.49 $Mm^3/year$ while coniferous benefit of a increase of an average of 0.65 $Mm^3/year$ (Table 4). If we increase the quota of forest managed according to economic criteria (`vRegEnd070`) we see this effects to amplify (-0.67 and +0.90 $Mm^3/year$ respectively). While this switch is evident at individual forest type, the aggregated effect is much lower and due uniquely to the higher productivity of the coniferous.

[3] It is important to recall here that expected future prices are observed prices at the time of the forest management choice. Assuming different types of price expectation may provide different results.

The central variable that differentiate the four scenarios is the regeneration of new volumes. However in the model, it is produced only as a consequence of an harvesting operation, and moreover after a consistent delay. As harvesting rate remains relative low, the effect on the forest stock remains in all case very limited even after a century. In 2100 the effects on forest volumes of the `reference` scenario over the `vRegFromHr` one are of -140 and +398 Mm^3 for broadleaved and coniferous respectively.

As expected, the increasing coniferous (decreasing broadleaves) stocks influence the harvesting volumes in the same direction with coniferous harvesting that in 2100 outmatch broadleaved harvesting in the `vRegEnd070 scenario`.

Table 4: Management effect [avg. 2030-2100]

	vRegFromHr	reference	difference	vRefEnd070
Expected returns (€/ha)				
- 00_Total	20.432	23.666	3.235 (15.832%)	24.783
- 01_Broadleaved	14.129	14.591	0.462 (3.269%)	14.902
- 02_Coniferous	34.755	37.183	2.428 (6.988%)	37.494
Regeneration Volumes (Mm^3)				
- 00_Total	1.828	1.989	0.161 (8.806%)	2.056
- 01_Broadleaved	1.037	0.546	-0.490 (-47.310%)	0.368
- 02_Coniferous	0.791	1.443	0.651 (82.319%)	1.688
Forest Volumes (Mm^3)				
- 00_Total	5664.200	5781.992	117.792 (2.080%)	5830.2
- 01_Broadleaved	4149.085	4084.636	-64.449 (-1.553%)	4058.6
- 02_Coniferous	1515.115	1697.356	182.241 (12.028%)	1771.6
Harvested Volumes (Mm^3)				
- 00_Total	52.896	53.683	0.788 (1.489%)	53.927
- 01_Broadleaved	29.429	28.271	-1.158 (-3.934%)	27.876
- 02_Coniferous	23.466	25.412	1.945 (8.290%)	26.051

4.2 Risk Aversion

In the above scenarios, the investment choice is determined only by the forest type showing the highest expected return, without any consideration for the risk that the investment bears. In this section, we investigate the tradeoff that can be made by forest managers, between expected returns and mortality risk.

Risk indeed is a fundamental element of a forest investment decision and in `withRiskXX` scenarios[4] the overall mortality rate at time of cutting is interpreted as a risky element that it is tried to be avoided by forest managers. [5]

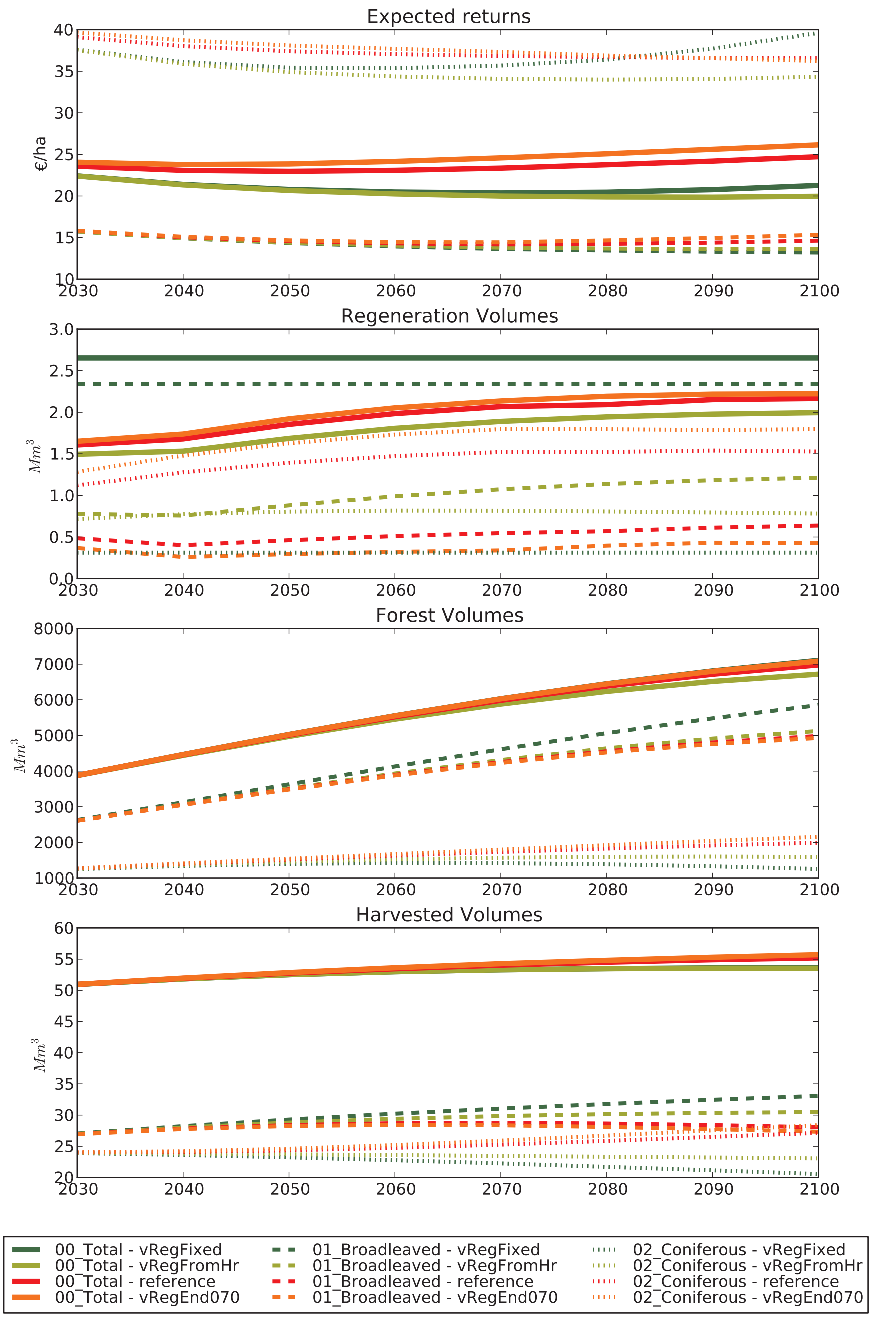
[4] The management rate mr is set to 0.5 here, for all scenarios.

[5] Other types of risk may be investigated in future studies, like price risks or risks on timber growth. However, analyzing mortality risk is the most straightforward, and

Table 5: Regional impacts of `reference` over `vRegFromHr` [2100]

Region	Softwood Roundwood			Coniferous
	Production		Price	Exp. Ret.
	Mm^3	Var %	Var %	Var %
France	17.20	11.75	-0.74	6.60
Aquitaine	3.95	18.58	9.34	9.34
Rhône-Alpes	2.46	0.96	-0.84	-0.84
Auvergne	1.63	7.77	6.89	6.89
Franche-Comté	1.41	12.65	6.44	6.44
Lorraine	1.37	13.19	5.80	5.80
Alsace	1.07	11.26	7.19	7.19
Limousin	0.97	25.43	6.44	6.44
Bourgogne	0.86	32.14	5.49	5.49
Midi-Pyrénées	0.73	3.59	-7.99	-7.99
Languedoc-Roussillon	0.53	7.19	-2.64	-2.64
Bretagne	0.49	0.00	-19.28	-10.67
Centre	0.39	0.00	-17.26	-17.26
Champagne-Ardenne	0.31	14.45	-22.26	-22.26
Pays de la Loire	0.29	1.18	-21.49	-5.50
Provence-Alpes-Côte d'Azur	0.17	0.63	-2.50	-0.75
Basse-Normandie	0.16	58.11	-23.99	-23.99
Poitou-Charentes	0.15	0.00	-37.48	-37.48
Haute-Normandie	0.14	39.57	-35.28	-28.22
Corse	0.05	0.00	-3.77	-2.13
Picardie	0.04	69.80	-38.53	-27.82
Île de France	0.03	0.00	-53.64	-3.02
Nord - Pas-de-Calais	0.00	-67.21	-35.48	-11.79

Figure 4: Active management simulations, France



potentially the most interesting when dealing with climate change, which is likely to have an impact on tree mortality.

Mortality rate is already accounted in the expected returns of forest investment in all scenarios, but economic agents decide uniquely on the base of the expected value (that is, they are risk neutral). In `withRiskXX` scenarios instead we suppose that agents have utility functions with harmonic absolute risk aversion (HARA) and more specifically a constant relative risk aversion (CRRA), that is the relative risk premium that the agents are ready to pay to escape the risk doesn't depend on its wealth (Gollier, 2001). The equivalent risk-free investment expected return is computed as:

$$expReturns = origExpReturns * (1 - ra * cumMort); \tag{8}$$

where ra is an individual specific risk-aversion coefficient sampled from a normal distribution $\mathcal{N}(\mu_{ra}, \sigma_{ra})$ with parameters constant within the scenario. As pixels are in FFSM++ the minimum level at which forest investment decisions are applied, at each pixel in `withRiskXX` scenarios corresponds an agent.

Figure 5 compares the reference results with the μ_{ra} coefficient set to 0.6 (`withRisk06`), 0.8 (`withRisk08`) and 1 (`withRisk10`). As we increase the risk aversion coefficient, we notice that the equivalent expected returns drop significantly, especially for coniferous (broadleaved: -8.77%; coniferous: -14.19%). Since the impact of risk mortality is larger on coniferous than on broadleaves, forest managers are confronted to a classic risk/yield tradeoff in which coniferous play the role of the risky/profitable asset, while broadleaves play the role of safer/less profitable asset. Larger risk aversion is then expected to influence the tradeoff toward a larger share of broadleaves in the forest manager portfolio.

However this large drop in expected returns leads only to minor effects to the rest of the model (Table 6), and the reason is possibly in the small standard deviation used to build the normal curve from which the agents ra are sampled (0.2). Hence, even if the expected return of the two group of species get much closer, they do not intersect and hence the switch from the decision to replant coniferous to replanting broadleaved is very limited.

5 Conclusions

In France forests, as well as in most temperate climates ones, socio-economic drivers works on top of (conditionally to) biophysical drivers and hence represent an important determinant of forest distribution, composition and structure. In models that aim to predict the status of forest ecosystems the role and interaction of both these drivers must be represented, as market forces depend on and influence forest resources. Often however, the two domains are modelled separately resulting in either forest-dynamic models on one side and forest markets models on the other, with their linkage obtained running them in iterative steps, with the data produced from one model

Table 6: Risk effect [avg. 2030-2100]

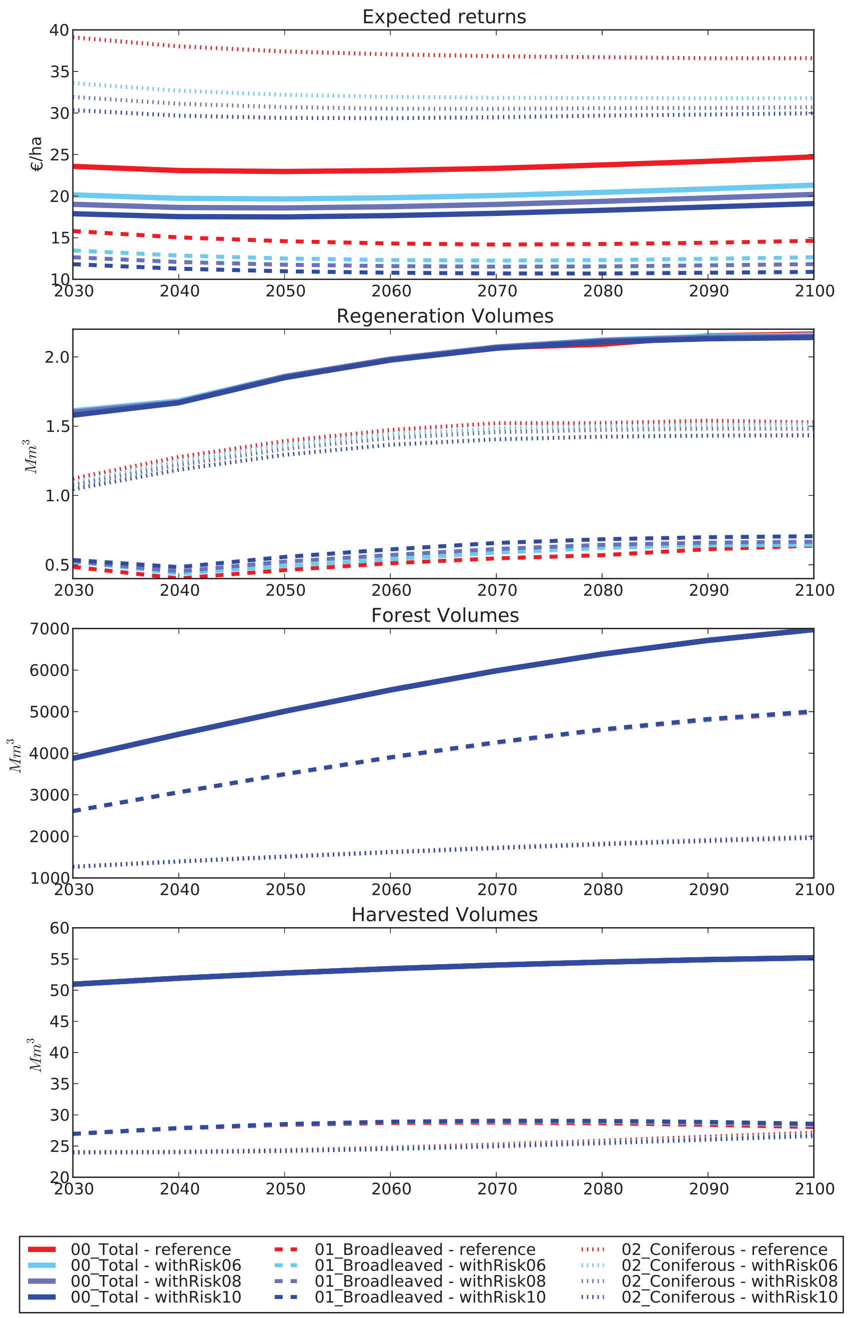
	reference	withRisk08	difference
Expected returns (€/ha)			
- 00_Total	23.666	19.245	-4.422 (-18.684%)
- 01_Broadleaved	14.591	11.794	-2.797 (-19.170%)
- 02_Coniferous	37.183	30.790	-6.393 (-17.194%)
Regeneration Volumes (Mm^3)			
- 00_Total	1.989	1.989	0.000 (0.000%)
- 01_Broadleaved	0.546	0.601	0.054 (9.968%)
- 02_Coniferous	1.443	1.388	-0.054 (-3.773%)
Forest Volumes (Mm^3)			
- 00_Total	5781.992	5781.173	-0.819 (-0.014%)
- 01_Broadleaved	4084.636	4093.008	8.372 (0.205%)
- 02_Coniferous	1697.356	1688.165	-9.191 (-0.541%)
Harvested Volumes (Mm^3)			
- 00_Total	53.683	53.685	0.002 (0.004%)
- 01_Broadleaved	28.271	28.510	0.238 (0.843%)
- 02_Coniferous	25.412	25.175	-0.236 (-0.930%)

used as input data for the other model and the opposite, until a satisfactory integration is obtained. For example, the European Forest Sector Outlook (EFSON) II (UNECE/FAO 2011; Van Brusselen et al. 2009) uses this approach to link together the EFISCEN (Nabuurs et al., 2002; Schelhaas et al., 2007) and the EFI-GTM (Kallio et al., 2006) models. [6]

The aim of FFSM 1.0 was to couple a consistent forest dynamics (FD) module with a market (MK) module. If this simple relation is acceptable for short-term analysis (with a time horizon of more or less 20 years), it couldn't fit with longer-term simulations, as forest management choices where not explicitly considered (only regeneration of identical forest was considered). The objective of this paper was therefore to present a management (MG) module, in which forest managers consider expected returns and risk in their choice to manage forests. In FFSM++, the three modules can hence continuously exchange information and the model is able to catch the effects of their iteration. Moreover, this analysis takes into account uncertainties about the real level of forest managers active management. We then focus in this paper on the influence of the degree of forest management in forest in the long run.

[6] One of the reasons of this dualism in forest modelling is that the tools used are themselves different. Ecologists often use a general programming approach to build their models (C++, matlab, python..) while economists often use programs specialised in solving equilibrium problems like GAMS (Bussieck & Meeraus, 2004). Our approach has been to utilise instead a generic programming language (C++) that gives us the flexibility required to build a complete forest dynamic and management module with specialised software libraries, namely IPOPT (Wächter & Biegler, 2006, ADOL-C (Walther & Griewank, 2012) and ColPack (Gebremedhin et al., 2013), used to solve the Samuelson equilibrium and hence build the market module.

Figure 5: Heterogeneous risk aversion, France



Two interesting results emerge from this study. First, the combined model assess the clear prevalence in the profitability of the coniferous forest in comparison to broadleaved forests strongly emerges. However, this result implies a general equilibrium effect: when forest managers are more active, they increase the share of coniferous in their tree portfolio, which result in smaller expected returns. The long-term impact on timber stock is relatively low, due to the long-term nature of the forest dynamics and the low level of timber harvesting compared to the forest stock. Second, when we consider the risk aversion of forest managers, the preference for broadleaved forest investments increases due to the lower mortality risk associated with them.

The introduction of the MG module opens the floor for further studies. First, environmental conditions are assumed to be fixed in this paper. However, climate change is likely to influence the dynamics of forest resources in the future. Taking into account the impact of climate change on forest resources would then bring important information about the potential adaptation of the forest sector, depending on the degree of active forest management, where the presence of an inter-regional and international market of forest products would allows the model to simulate cascade effects between neighbouring regions and between the ecological and economic components of forest systems. Second, the influence of price expectation has to be investigated further. Finally, the risk analysis can be undertaken forward, considering price risk and risk on tree growth, and not only on tree mortality.

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