Economic impacts and new control strategies for the pine processionary moth (PPM) in French maritime pine forests

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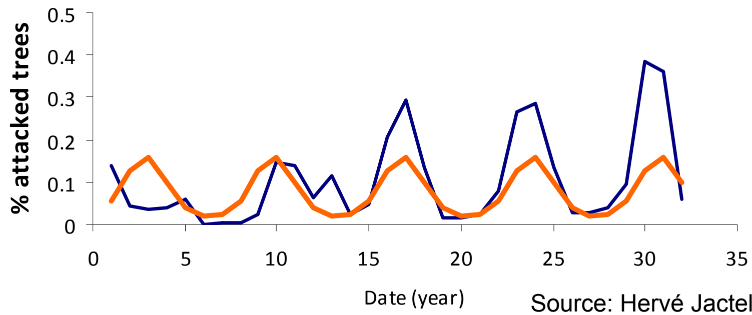
Outline

- Pine maritime in France and Pine Processionary Moth (PPM)
- Optimising the rotation age in presence of cyclical pest outbreaks – theoretical model
- The numerical model
- Results
- Future steps

Background information

- Pine (*Pinus pinaster):* most important conifer in France in terms of wood production (6.4 Mm^3/year)
- Pine processionary moth (*Thaumetopoea pityocampa*)
- Cyclical outbreaks (≈ 7 years period)
- Growth loss up to 93% (Jacquet et al. 2013)
- Nowadays EU regulations and increasing costs limit the aerial spraying of insecticides

Source: http://www.daapv.unipd.it/promoth/



Source: Hervé Jactel

Aim: Compute the optimal rotation age and land expectation value (LEV) under PPM disturbance

Theoretical model

$$\max_R \left(-C_P P(0) + \sum_{\varepsilon=1}^{E} I_{\{a_\varepsilon < R\}} \frac{\pi(R-a_\varepsilon)}{(1+r)^{R-a_\varepsilon}} + \frac{\pi(R)+\pi_b(R)}{(1+r)^R} \right) \frac{(1+r)^R}{(1+r)^R - 1}$$

Planting costs; Net revenues from thinning; Net revenues from final harvest of pine and/or birch; "Infinite rotations term"

s.t.:

- $\pi(t) = p(dbh) \cdot h(t)$ where $h(t) = \begin{cases} v_P & \text{If Final Cut} \\ e_i & \text{If Thinning} \\ 0 & \text{Elsewhere} \end{cases}$

- $V(t) = \theta v_P(t) + (1-\theta) v_B(t), \quad 0 < \theta \leq 1$

  $V(t)$: Standing volume in time t; $v_P(t)$: Pine volume in t; $v_B(t)$: Birch volume in t

- $V(t+1) = \underbrace{\theta \left[v_P(t) + \hat{X}_k(t) g_P(t) \delta(t) + \left(1 - \hat{X}_k(t)\right) g(t) \right]}_{v_P(t+1)} + (1-\theta) \underbrace{\left[v_B(t) + g_B(t) \right]}_{v_B(t+1)}, \quad 0 < \delta(t) < 1$

  $\hat{X}_k(t) g_P(t) \delta(t)$: Growth of attacked pines; $\left(1 - \hat{X}_k(t)\right) g(t)$: Growth of healthy pines; $g_B(t)$: Growth of birches; $\delta(t)$: Annual growth loss

- $\hat{X}_k(t) = X_k(t) - \sum_{i=1}^{4} b_i \, \vartheta$

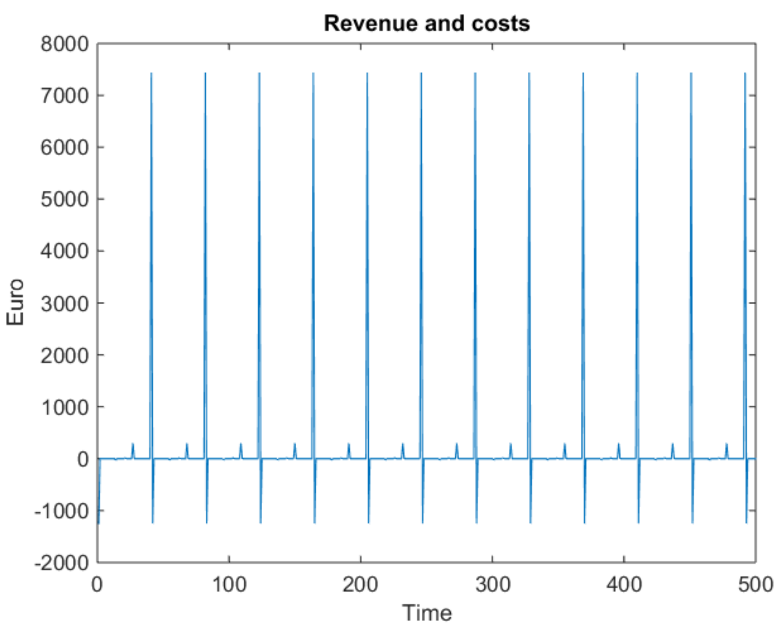
  $\hat{X}_k(t)$: % attacked trees in the stand; $\sum_{i=1}^{4} b_i \, \vartheta$: Birch "protection" effect

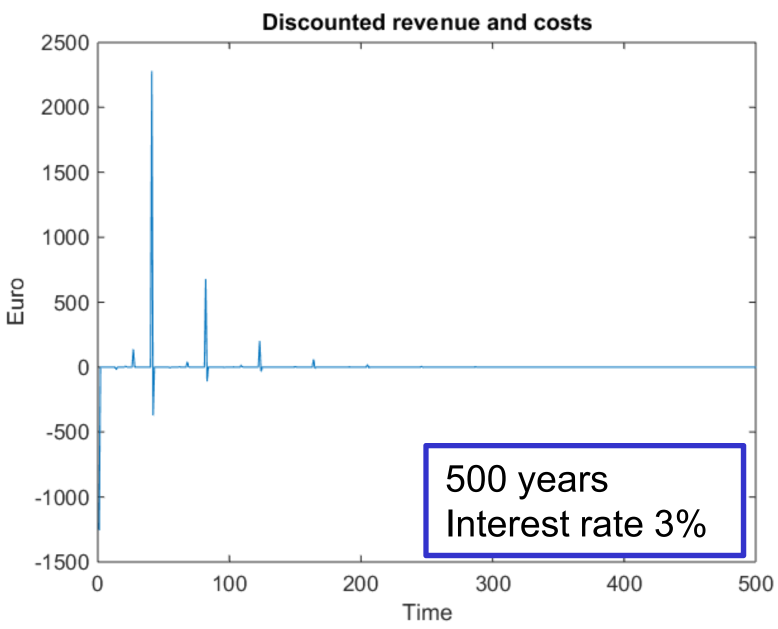
  $b_i = \begin{cases} 1, & \text{if the hedgerow } i \text{ is planted with birch} \\ 0, & \text{if the hedgerow } i \text{ is planted with pine} \end{cases}$

A non-linear problem

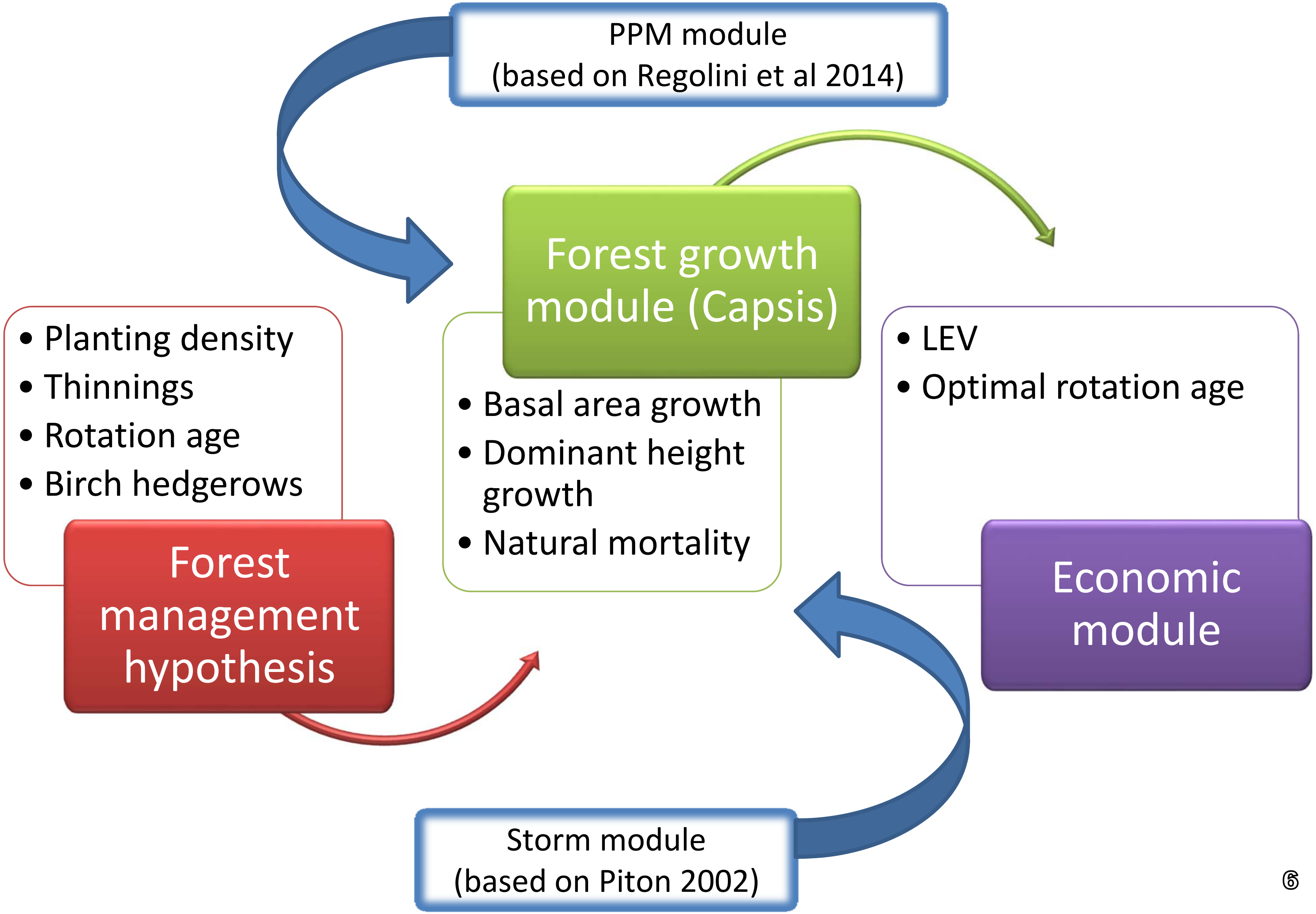
- The forest dynamics as well the PPM dynamics are not linear
- An analytical solution is not possible

NUMERICAL METHOD





The model structure



The code structure

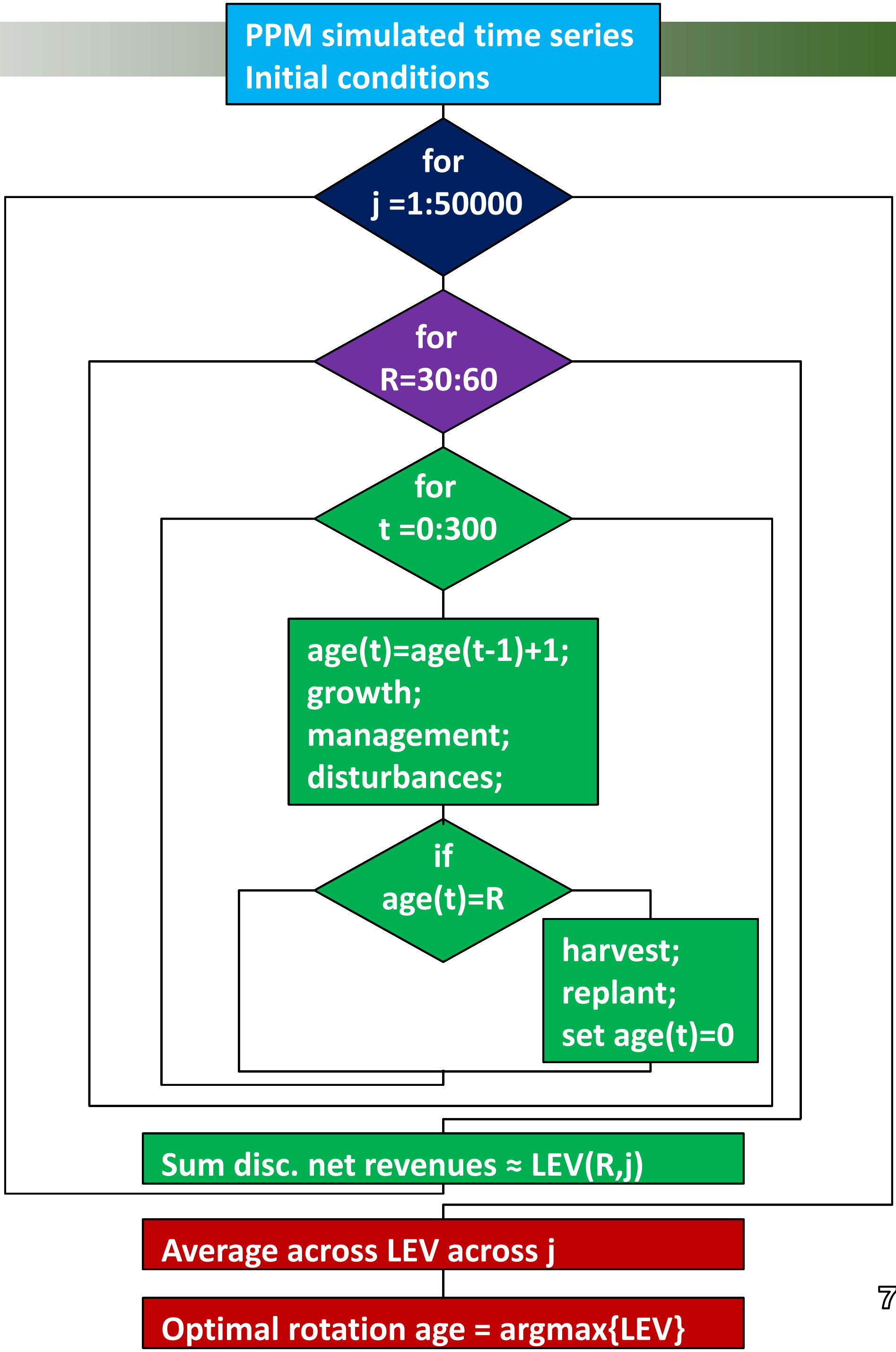
1) Initialisation of the stand, forest management hypothesis, PPM time series generation

2) <u>For a given rotation age R</u>: Simulate the evolution of the forest stand for 300 years compute the discounted sum of net revenues ≈ LEV

3) Test all rotation ages

4) Repeat point 2 and 3 for 50000 times and take the average LEV per each R

5) Optimal rotation age



Forest management hypothesis

The stand (Modis Pinaster)

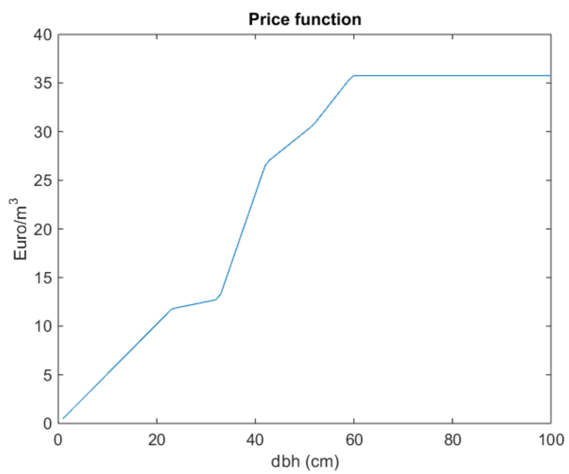
Characteristics	Value
Stand age	12
Dom height	9.4 m
Planting density	1250 stem/ha
Basal area	14.63 m^2/ha
Dom diameter	14.95 cm

Thinning scheme (CRPF)

Age	Before	After
13	1250	815
20	815	575
26	575	350

Economic parameters

Plantation costs	1 euro/seedling
Harvesting costs	8 euro/m^3
Interest rate	3%



Simulated PPM dynamics

- The data generation process was created using (Jactel et al, unpublished):
  - a = 0.4, b = 0.4,
  - d = 0.1
  - T = 7

$$X_t = a \sin\frac{2\pi t}{T} + b \cos\frac{2\pi t}{T} + d + \epsilon_t$$

To this model we added:

- a normally distributed shock in each peak year
  - mean= 0.1, sd= 0.06 for the present intensity
  - mean= 0.4, sd= 0.1 for the increased intensity

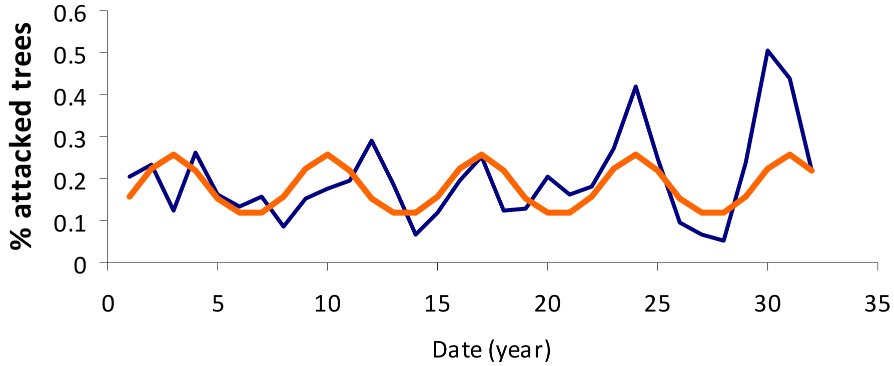
} mimicing the varying amplitude of the observed data

- an autoregressive component in each year after a peak

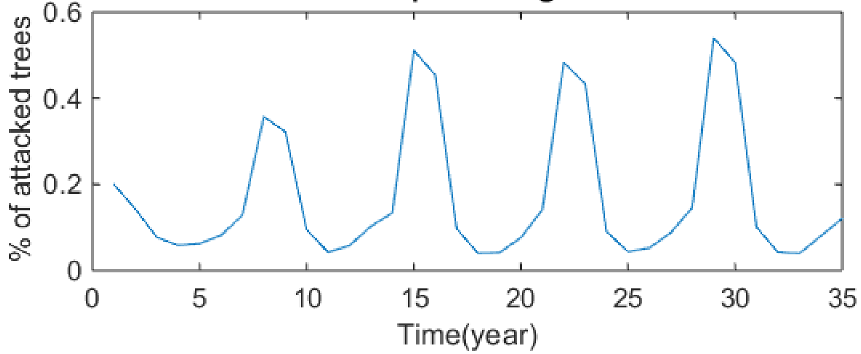
} capturing the persistence in the % of attacked trees

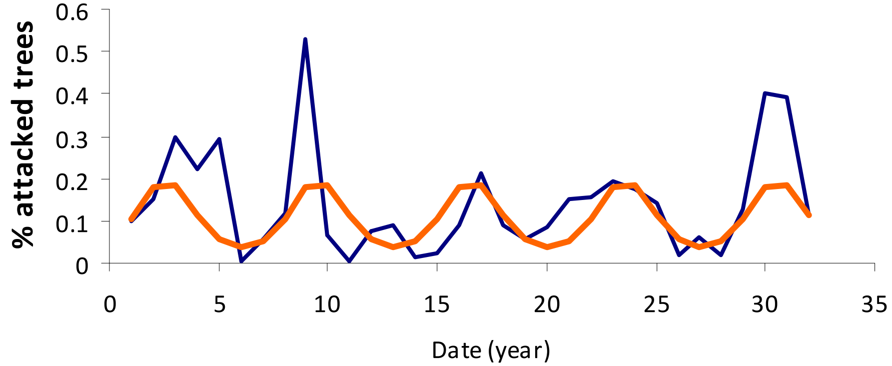
- a normal distributed white-noise
  - with zero mean and sd=0.01

PPM regional dynamics – observed vs simulated

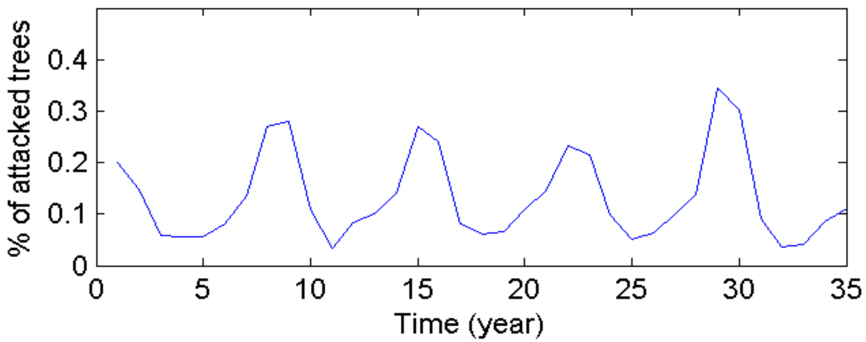


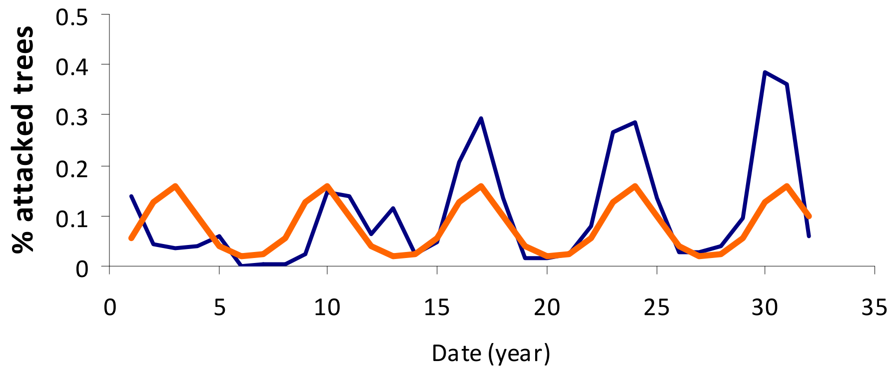
Simulated PPM impacts - high level scenario



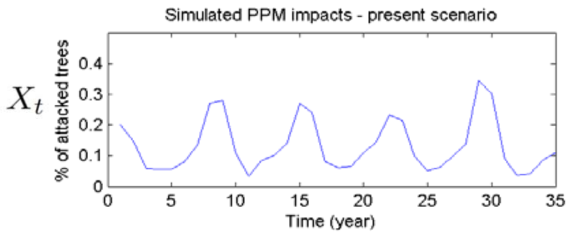


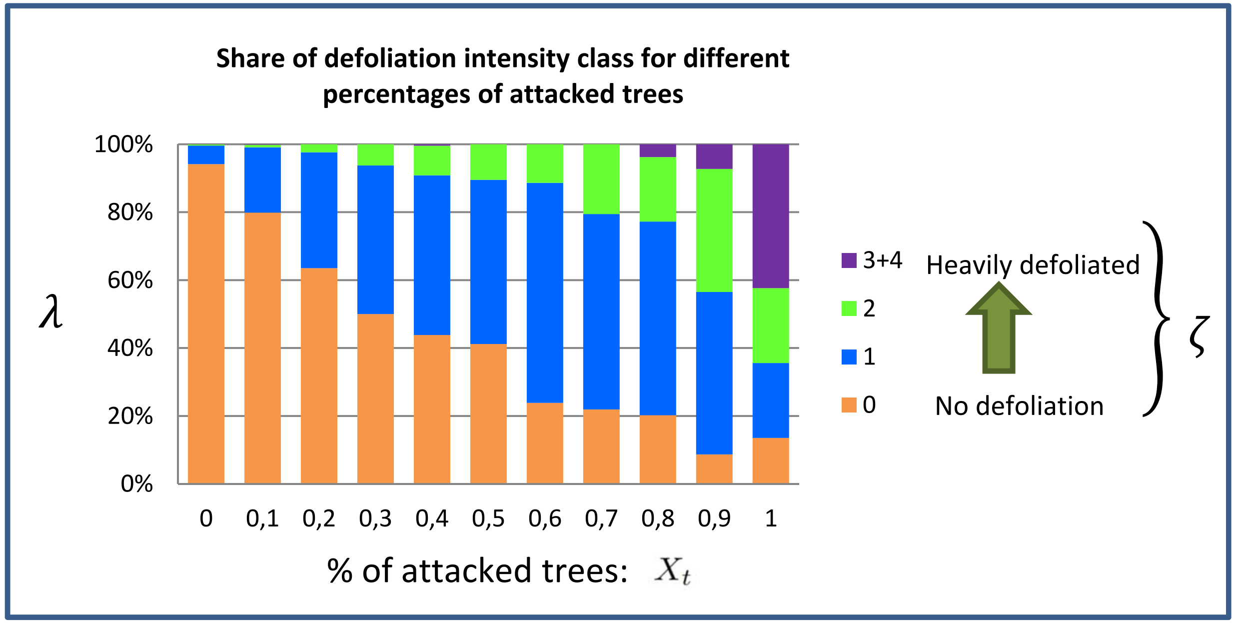
Simulated PPM impacts - present scenario





From regional to stand dynamics





Annual growth loss per defoliation class: $\delta_\zeta(age) = a(\zeta)age^2 + b(\zeta)age + c(\zeta)$

Total annual growth loss in the stand: $\Delta = \sum_\zeta \lambda_\zeta \, \delta_\zeta$

Source: Regolini et al. 2014 (unpublished)

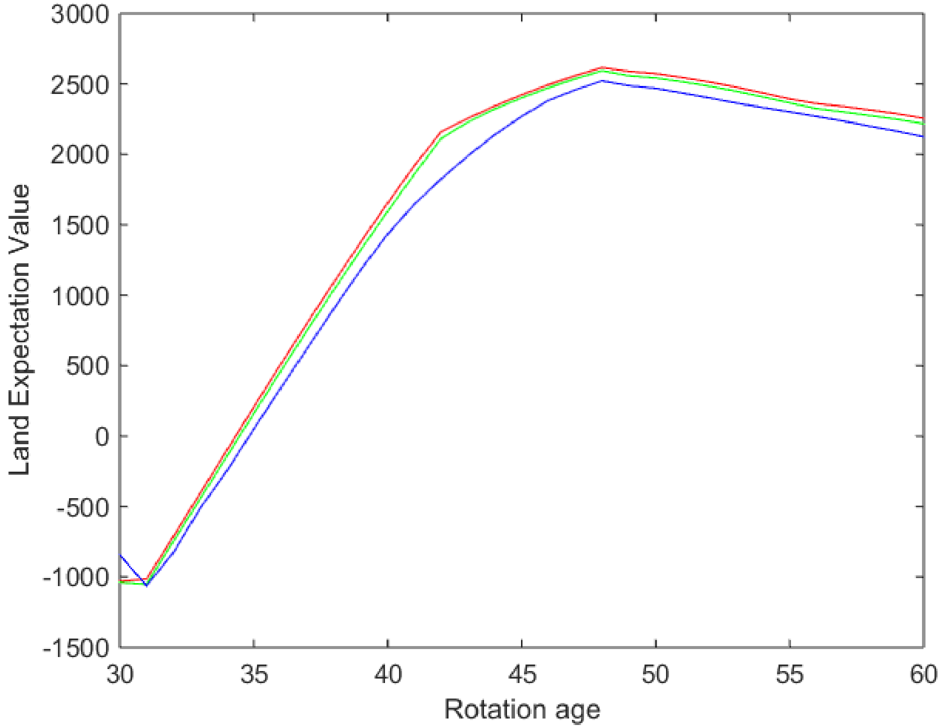
Storm module hypothesis

- Wind speed = 180 km/ha
- Rate or return: 1 over 400 years
- Damage function: the damage function depends on the wind speed and the stand height
- After a storm, two options:
  - keep the standing trees to the end of the rotation
  - clear the stand and replant:
    - 30% of the wind-thrown wood cannot be salvaged
    - 70% of the salvaged timber can be sold

Decision rule for clearing and replanting:

$$\pi_{salvage} + LEV > (1 - Damage)\frac{\pi(R)}{(1+i)^{R-a}} + \frac{LEV}{(1+i)^{R-a}}$$

Simulation results

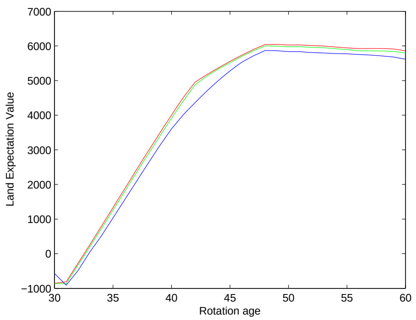


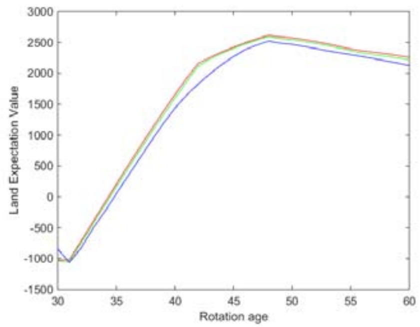
Scenarios		Optimal rotation age	LEV (euro/ha)
No PPM	red	48	2616
Present level	green	48	2594
High level	blue	48	2322

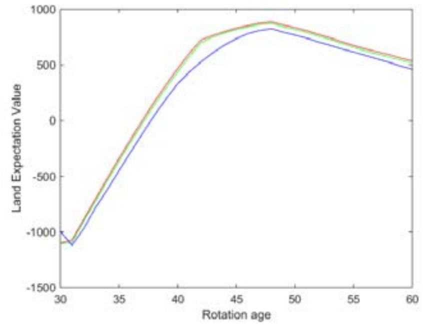
50000 simulations
300 years
Interest rate 3%

Sensitivity to the discount rate

	Optimal rotation age (years)			LEV (euro/ha)		
	2%	3%	4%	2%	3%	4%
No PPM	49	48	48	6046	2616	890
Present level	48	48	48	5999 (-1%)	2594 (-1%)	877 (-1.5%)
High Level	48	48	48	5866 (-3%)	2322 (-11%)	827 (-7%)

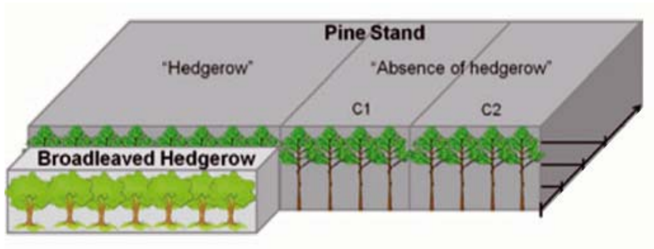


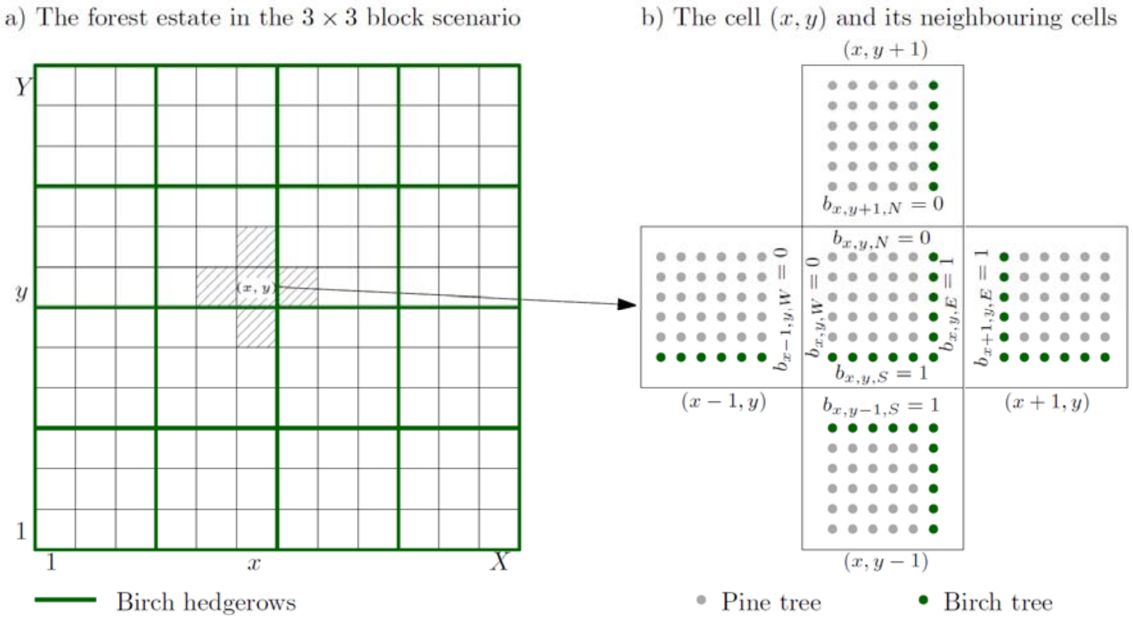




Next steps

New control method: inclusion of a second tree species (Castagneyrol et al. 2014)





Concluding remarks

According to our simulations (still preliminary results):

- The presence of PPM does not affect the optimal rotation age
- In the present level scenario, the LEV is reduced by a minor share (about 1%)
- In the high level scenario, the impact is about 11% for a 3% discount rate
- The results highly depend on the discount rate

Thank you!

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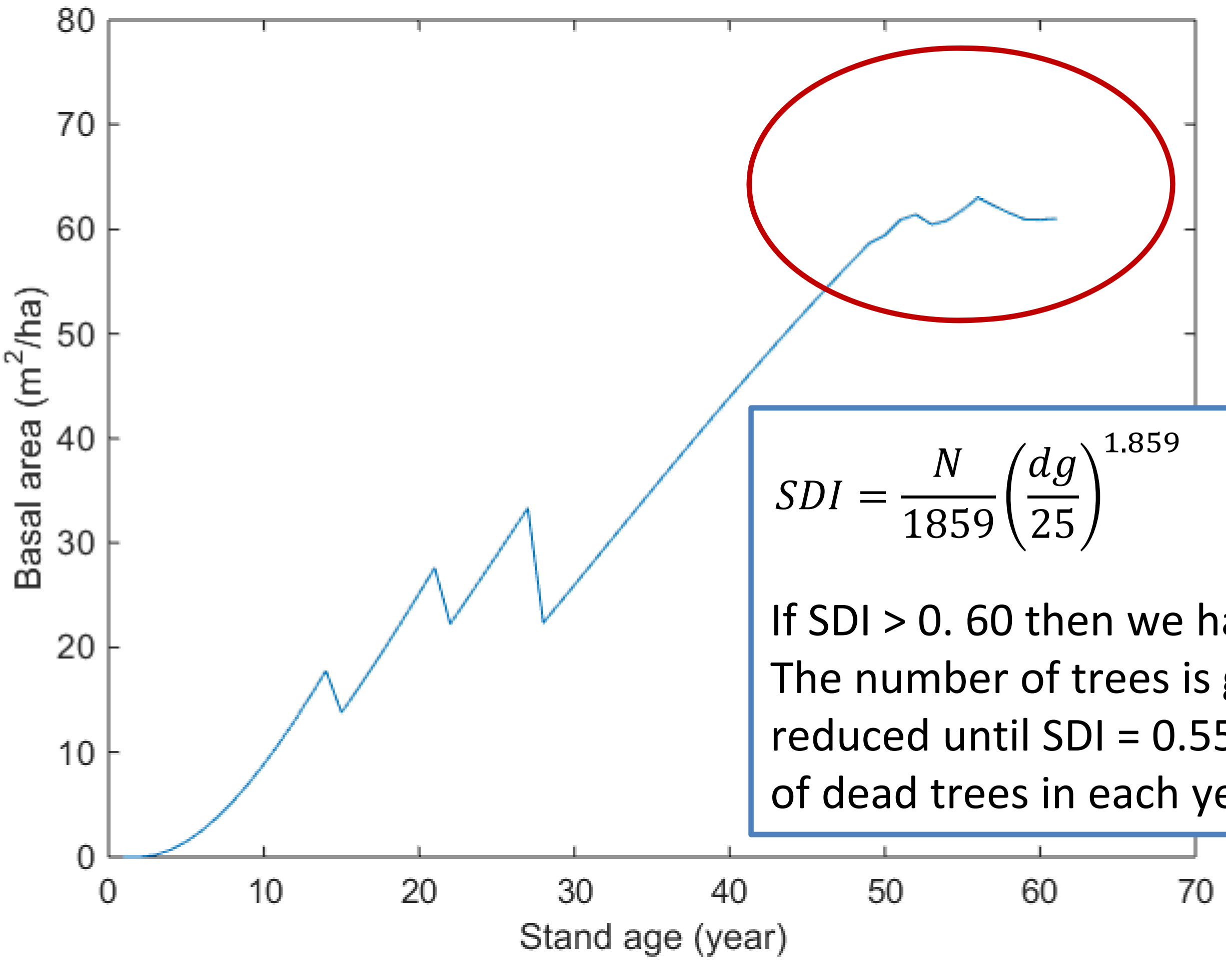
The scenarios

Scenario	PPM	PPM intensity	Birch market	Storms
no PPM	✗	✗	✗	✗
no PPM	✗	✗	✗	✓
PPM present	✓	**present level**	✗	✓
PPM high intensity	✓	**high level**	✗	✓
PPM present-BM	✓	**present level**	✓	✓
PPM high intensity-BM	✓	**high level**	✓	✓
Spraying	✓	**present level**	✗	✓

Équation de la forme a*AGE^2+b*AGE+c avec les coefficients ci-dessous suivant le taux de défoliation																			
DSF	**DEF**	a	b	c	**DSF**	**DEF**	a	b	c	**DSF**	**DEF**	a	b	c	**DSF**	**DEF**	a	b	c
	0.01	0.00051	0.02174	0.0055		**0.26**	0.00071	0.03274	0.0605		**0.51**	0.00091	0.04374	0.1155		**0.76**	0.001108	0.05474	0.1705
0-	**0.02**	0.00052	0.02218	0.0077		**0.27**	0.00072	0.03318	0.0627		**0.52**	0.00092	0.04418	0.1177		**0.77**	0.001116	0.05518	0.1727
Pour la classe de défoliation 0 (=>0 à 5%) on considère qu'il n'y a pas de perte de croissance	**0.03**	0.00052	0.02262	0.0099		**0.28**	0.00072	0.03362	0.0649		**0.53**	0.00092	0.04462	0.1199		**0.78**	0.001124	0.05562	0.1749
	0.04	0.00053	0.02306	0.0121		**0.29**	0.00073	0.03406	0.0671		**0.54**	0.00093	0.04506	0.1221		**0.79**	0.001132	0.05606	0.1771
	0.05	0.00054	0.0235	0.0143		**0.3**	0.00074	0.0345	0.0693	**2**	**0.55**	0.00094	0.0455	0.1243		**0.8**	0.00114	0.0565	0.1793
	0.06	0.00055	0.02394	0.0165		**0.31**	0.00075	0.03494	0.0715		**0.56**	0.00095	0.04594	0.1265		**0.81**	0.001148	0.05694	0.1815
	0.07	0.00056	0.02438	0.0187		**0.32**	0.00076	0.03538	0.0737		**0.57**	0.00096	0.04638	0.1287		**0.82**	0.001156	0.05738	0.1837
	0.08	0.00056	0.02482	0.0209		**0.33**	0.00076	0.03582	0.0759		**0.58**	0.00096	0.04682	0.1309		**0.83**	0.001164	0.05782	0.1859
	0.09	0.00057	0.02526	0.0231		**0.34**	0.00077	0.03626	0.0781		**0.59**	0.00097	0.04726	0.1331		**0.84**	0.001172	0.05826	0.1881
	0.1	0.00058	0.0257	0.0253		**0.35**	0.00078	0.0367	0.0803		**0.6**	0.00098	0.0477	0.1353		**0.85**	0.00118	0.0587	0.1903
	0.11	0.00059	0.02614	0.0275		**0.36**	0.00079	0.03714	0.0825		**0.61**	0.00099	0.04814	0.1375		**0.86**	0.001188	0.05914	0.1925
	0.12	0.0006	0.02658	0.0297		**0.37**	0.0008	0.03758	0.0847		**0.62**	0.001	0.04858	0.1397	3-4	**0.87**	0.001196	0.05958	0.1947
	0.13	0.0006	0.02702	0.0319	**2**	**0.38**	0.0008	0.03802	0.0869		**0.63**	0.001	0.04902	0.1419		**0.88**	0.001204	0.06002	0.1969
	0.14	0.00061	0.02746	0.0341		**0.39**	0.00081	0.03846	0.0891		**0.64**	0.00101	0.04946	0.1441		**0.89**	0.001212	0.06046	0.1991
1	**0.15**	0.00062	0.0279	0.0363		**0.4**	0.00082	0.0389	0.0913		**0.65**	0.00102	0.0499	0.1463		**0.9**	0.00122	0.0609	0.2013
	0.16	0.00063	0.02834	0.0385		**0.41**	0.00083	0.03934	0.0935		**0.66**	0.00103	0.05034	0.1485		**0.91**	0.001228	0.06134	0.2035
	0.17	0.00064	0.02878	0.0407		**0.42**	0.00084	0.03978	0.0957		**0.67**	0.00104	0.05078	0.1507		**0.92**	0.001236	0.06178	0.2057
	0.18	0.00064	0.02922	0.0429		**0.43**	0.00084	0.04022	0.0979	**3-4**	**0.68**	0.00104	0.05122	0.1529		**0.93**	0.001244	0.06222	0.2079
	0.19	0.00065	0.02966	0.0451		**0.44**	0.00085	0.04066	0.1001		**0.69**	0.00105	0.05166	0.1551		**0.94**	0.001252	0.06266	0.2101
	0.2	0.00066	0.0301	0.0473		**0.45**	0.00086	0.0411	0.1023		**0.7**	0.00106	0.0521	0.1573		**0.95**	0.00126	0.0631	0.2123
	0.21	0.00067	0.03054	0.0495		**0.46**	0.00087	0.04154	0.1045		**0.71**	0.00107	0.05254	0.1595		**0.96**	0.001268	0.06354	0.2145
	0.22	0.00068	0.03098	0.0517		**0.47**	0.00088	0.04198	0.1067		**0.72**	0.00108	0.05298	0.1617		**0.97**	0.001276	0.06398	0.2167
	0.23	0.00068	0.03142	0.0539		**0.48**	0.00088	0.04242	0.1089		**0.73**	0.00108	0.05342	0.1639		**0.98**	0.001284	0.06442	0.2189
	0.24	0.00069	0.03186	0.0561		**0.49**	0.00089	0.04286	0.1111		**0.74**	0.00109	0.05386	0.1661		**0.99**	0.001292	0.06486	0.2211
	0.25	0.0007	0.0323	0.0583		**0.5**	0.0009	0.0433	0.1133		**0.75**	0.0011	0.0543	0.1683		**1**	0.0013	0.0653	0.2233

Natural mortality



$$SDI = \frac{N}{1859}\left(\frac{dg}{25}\right)^{1.859}$$

If SDI > 0. 60 then we have mortality. The number of trees is gradually reduced until SDI = 0.55. The number of dead trees in each year is random