The use of tree allometric equations into national forest inventories : French case study

Antoine Colin, Jean-Christophe Hervé, Laurent Saint-André

The use of tree allometric equations into National Forest Inventories: French case study

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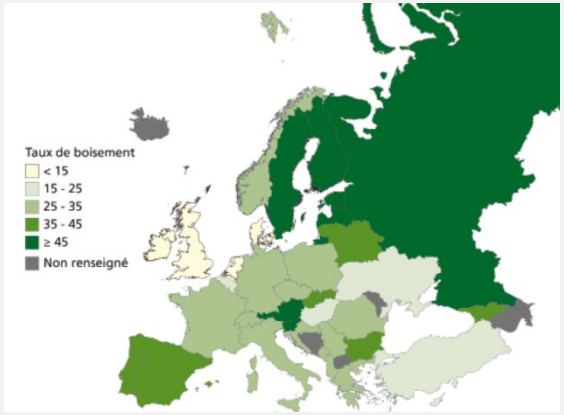
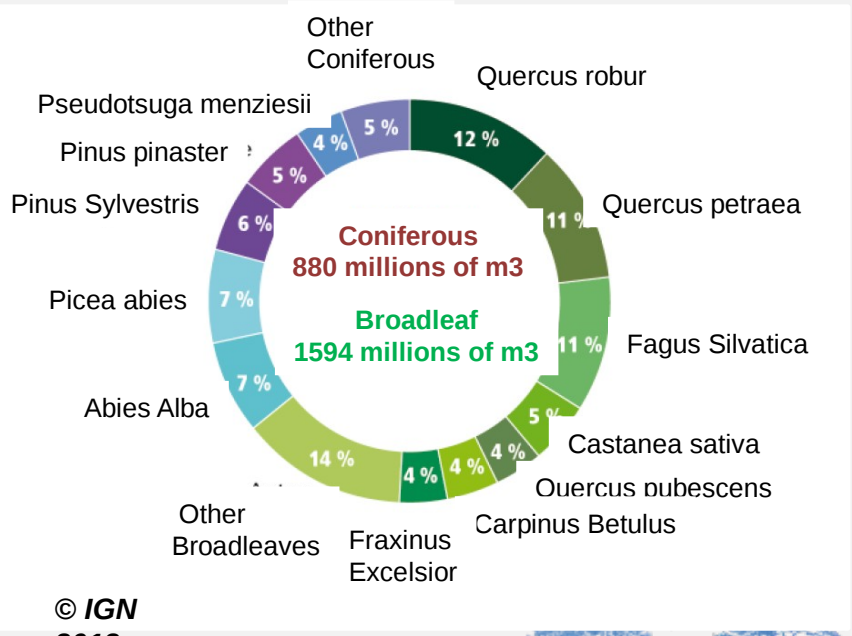
1. Introduction

Panorama of the French Forest



Forest land (% of land cover, source European State of Forests, 2011)



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Land cover area : 29.7% is Forests (Europe average, including Russia 32.2%)

Forest owners: 75% private, 25% public

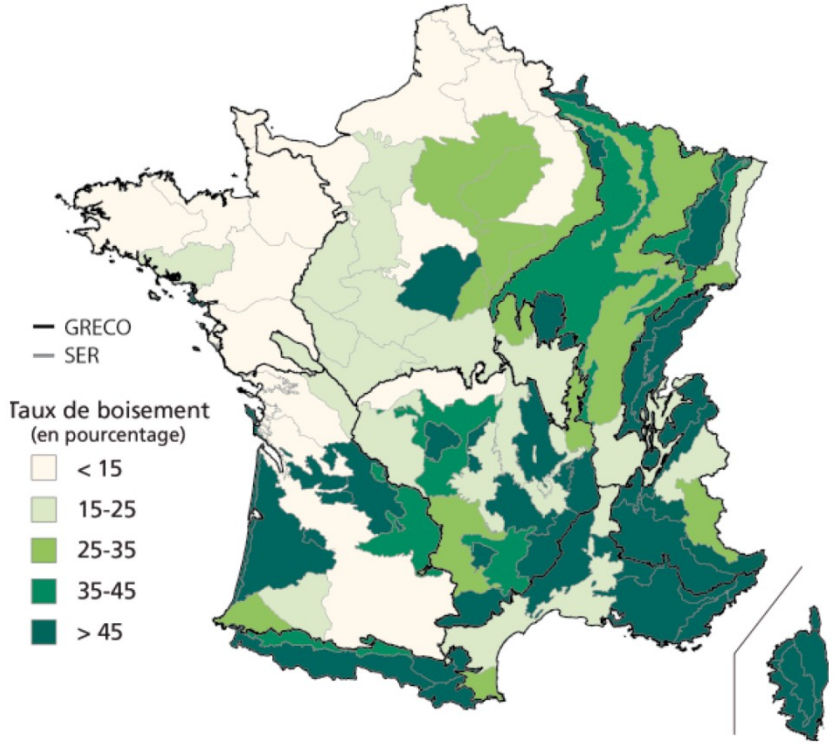
Total Volume (m3): 2.5 billion = 4th European country after Russia, Germany, Sweden.

Forest Composition : Broadleaves species (67%), Coniferous species (22%), Mixed stands (11%)

12 tree species contribute to 80% of the total volume of French Forests

1. Introduction

Panorama of the French Forest



Forest land (% of land cover) by SylvoEcoRegions

National Forest Inventory: The Institute (IFN) in charge of the national inventory has been embedded into the National Geographic Institute in 2012

Yearly assessment of forest inventory (it was every ten years before 2008)

Results provided by administrative departments and by SylvoEcological Regions : 91 SER and 12 GRECO

SER = SylvoEcologicalRegion (determinants of forest growth conditions and habitats)

GRECO = Ecological regions (one GRECO regrouping several SER)

2. Methodology

French National Carbon Stock assessment

IGN | **INRA, ONF, IRSTEA, FCBA**

Cartography

Forest Inventory

Permanent Plots

Temporary Plots

Forest Land area by SER/GRECO

Forest structure, etc…

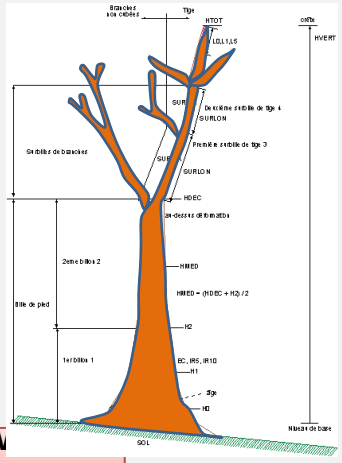
$AE_{vol\ tot\ G\ and\ sp}$

Total volumes by SER/GRECO

$AE_{vol\ G}$

$AE_{vol\ totSp}$

WD_{sp}



$ABG_{biomass}$= ABGb + DeadW Biomass

RSratio

$Total_{biomass}$= $Total_b$

C conc.

Total C stock

Total C

IGN

Tier 3 approach

2. Methodology

French National Carbon Stock assessment

Use of national volume functi

- Tree compartments : stem, bark, branches, twigs
- Measurements in 1920-1955 in France

$$Vtot = \frac{1}{4\pi}.C_{130}{}^{2}.Htot.f$$

$$f(C_{130}, Htot) = \left(\alpha + \beta \times C_{130} + \gamma \times \frac{\sqrt{C_{130}}}{Htot}\right)\left(1 + \frac{\delta}{C_{130}{}^{2}}\right) + \varepsilon$$

Cubage de bois abattu (hêtre, *Fagus sylvatica* L.).
Forêt domaniale d'Eawy (Seine-Inférieure).

tree species used to calibrate the equation	species for which the equation was used	Parameters of the equations			
		a	b	c	d
Quercus petraea	*Quercus petraea, Q. robur, Q.pubescens, Q. rubra*	0.471	-0.345	0.377	0
Fagus sylvatica	*Fagus sylvatica*	0.395	0.266	0.421	45.4
Quercus petraea & *Fagus sylvatica*	Other broadleafs	0.428	-0.191	0.456	0
Pseudotsuga menziesii	*Pseudotsuga menziesii*	0.534	-0.530	0	56.6
Pinus spp.	*Pinus spp.*	0.311	0.405	0.340	191
Larix spp.	*Larix spp.*	0.550	- 1.350	0.322	0
Abies alba	*Abies spp.*	0.550	- 0.749	0.277	0
Picea abies	*Picea abies* & other coniferous species	0.631	-0.946	0	0

Total volume: 8 equations, 7 species specific (for the main tree species in France)

2. Methodology

French National Carbon Stock assessment

	AGRIGES 1999		CITEPA 1999		IGD 2000		**CARBOFOR 2004**	
BRO. = BROADLEAFS, CON. = CONIFERS	BRO.	CON.	BRO.	CON.	BRO.	CON.	BRO.	CON.
Branch expansion factor aerial wood volume / merchantable volume	1.30	1.13	1.25	1.25	1.40	1.30	**1.61**	**1.34**
Root expansion factor total wood volume / aerial wood volume	1.19	1.24	1.28	1.28	1.14	1.15	1.28	1.30
Overall expansion factor total wood volume / merchantable volume	1.55	1.39	1.60	1.60	1.60	1.50	**2.06**	**1.74**
Wood specific gravity	0.56	0.41	0.54	0.43	0.53	0.40	0.55	0.44
Carbon concentration	0.5	0.5	0.5	0.5	0.5	0.5	0.475	0.475
Overall ratio (t C/m^3 IFN) carbon mass / merchantable volume	0.431	0.285	0.432	0.344	0.422	0.296	**0.535**	**0.361**
"Secondary" compartments (t C/ha) foliage, herbaceous and shrubby strata, non-recordable trees and dead wood	2.3	6.5	0	0	0	0	0	0

Sources: Dupouey et al. 1999, Dupouey 2002, Pignard et al. 2004

Litterature review

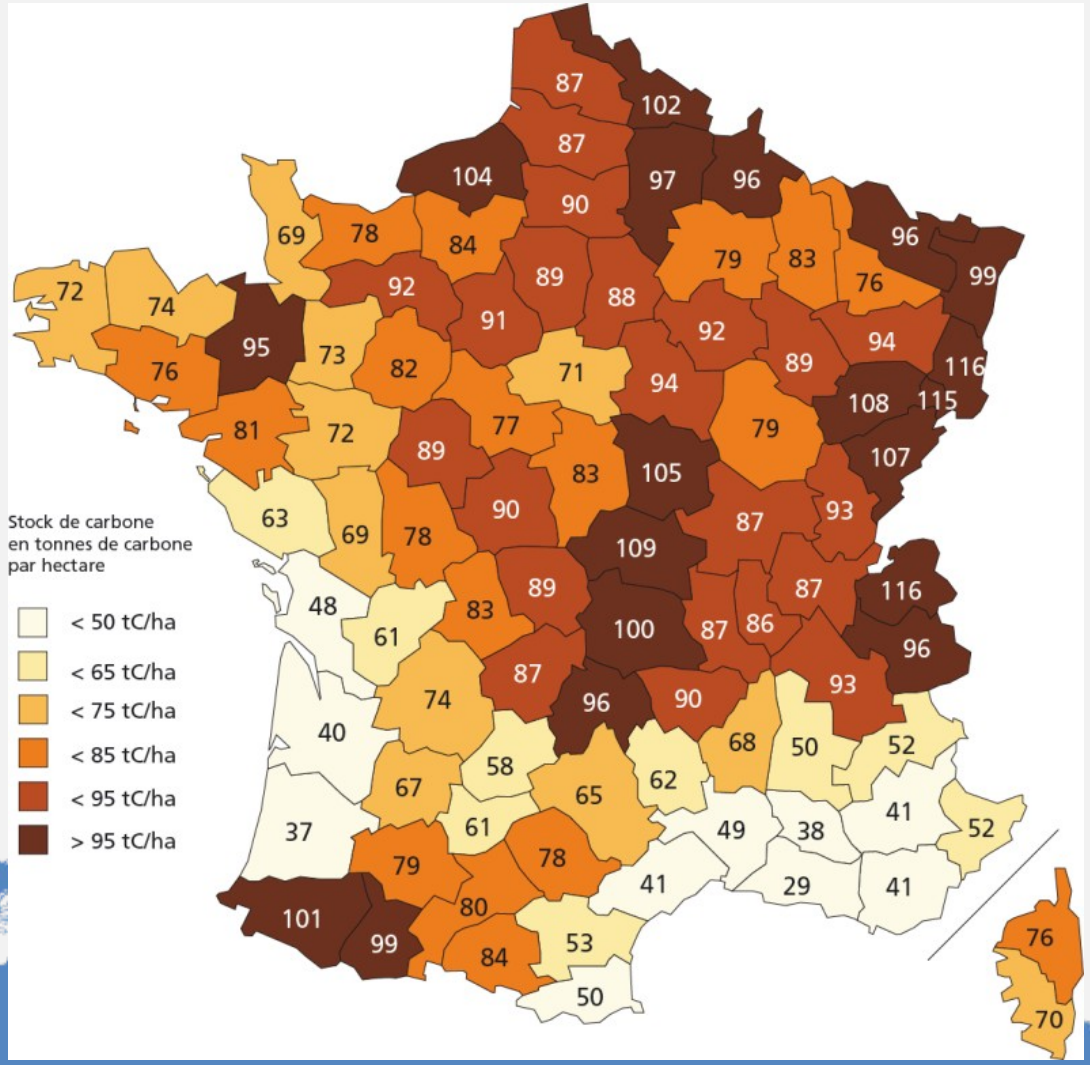
A posteriori calculation (Vtot /Vpartial) (consitency checking with the previous methodologies)

3. Results

French National Carbon Stock assessment

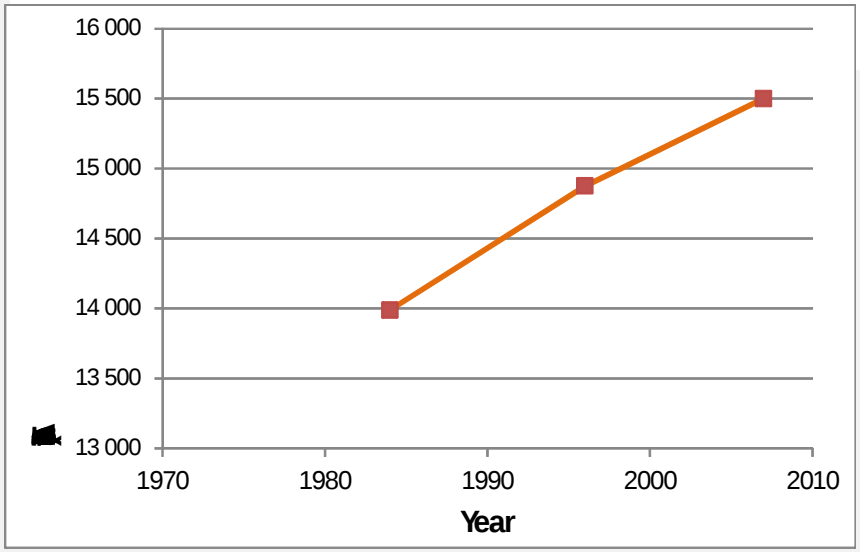
Carbon stock in woody biomass (2010)

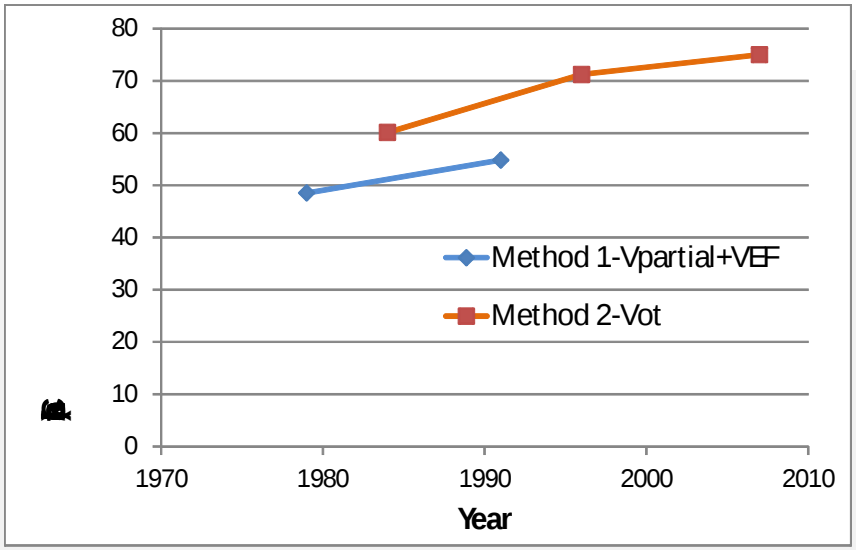
Consistent regional patterns (higher stocks in mountains area lower stocks in the mediterranean zone)



3. Results

French National Carbon Stock assessment





Sources: Dupouey et al. 1999, Pignard et al. 2004, 5th French National Reporting, 2009

Increase of forest areas, increase of carbon stock / ha, higher stocks for broadleaves spec

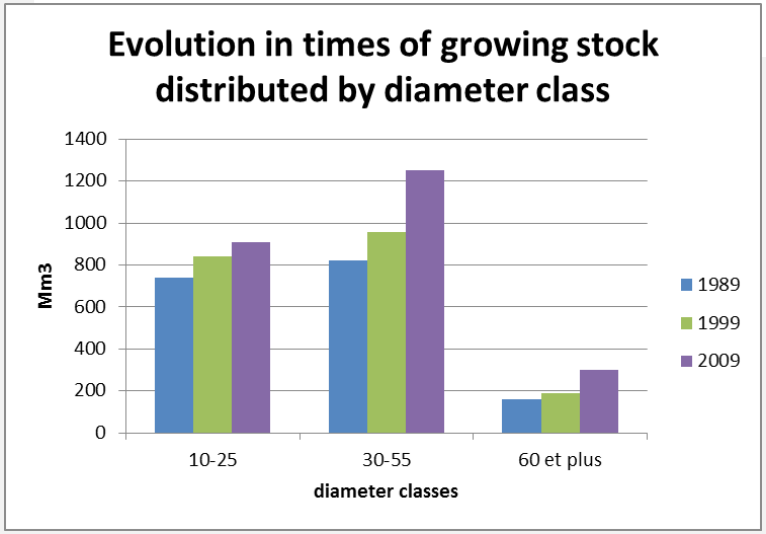
Recolonisation of abandonned agricultural lands + afforestation (coniferous)

Next slide !

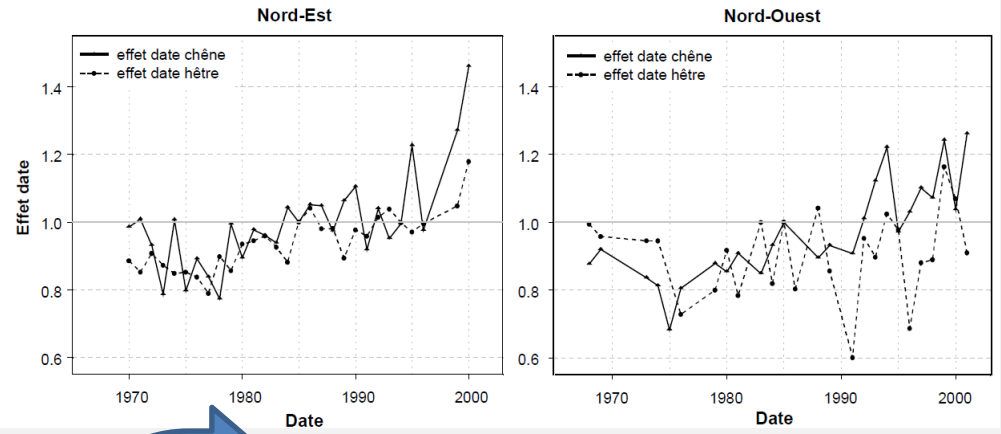
Higher wood density and higher branch proportion, less market opportunities

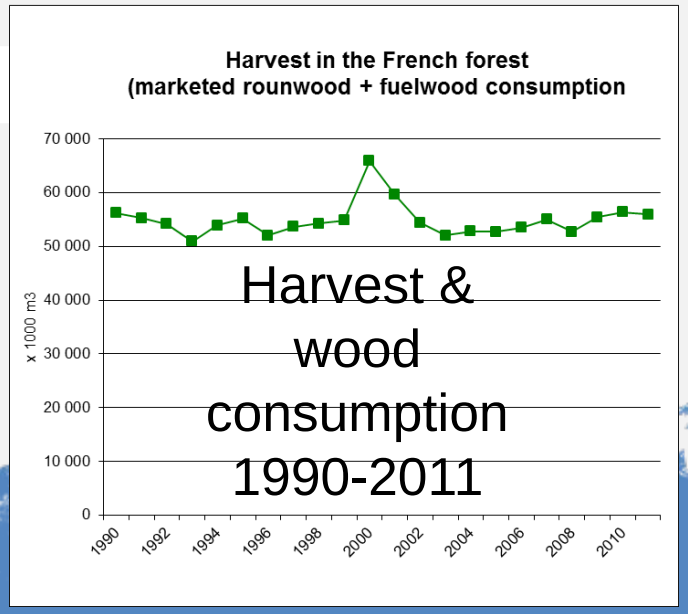
3. Results

French National Carbon Stock assessment

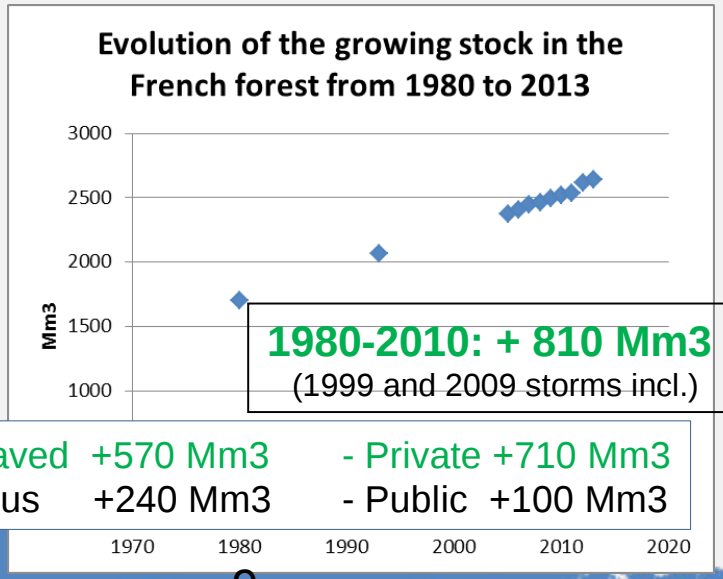


Increased wood productivity (Charru 2008)





Harvest & wood consumption 1990-2011



1980-2010: + 810 Mm3
(1999 and 2009 storms incl.)

Broadleaved	+570 Mm3	- Private	+710 Mm3
Coniferous	+240 Mm3	- Public	+100 Mm3

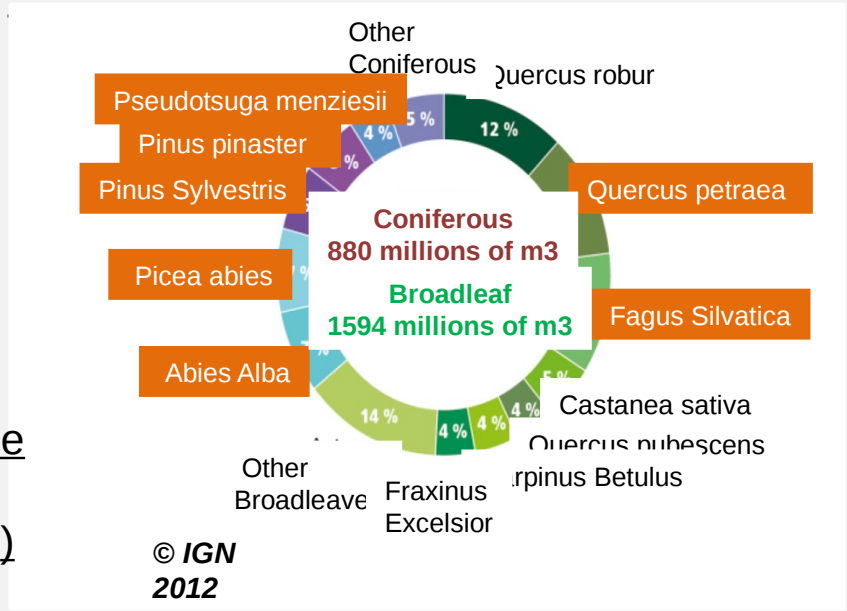
4. Discussion

French National Carbon Stock assessment

- Allometric equations

Although it comprised over 4000 trees, the sample used to build the Vtot allometric equations (Vallet et al. 2006) was probably not fully representative of the entire French

- many species are absent especially for broadleaves species
- Trees mainly collected in the northern part of France
- Data are old (1920-1955) while several factors may have modified the shape of the trees (*sylvicultural changes, genetic improvement, environmental changes, etc*)
- Data have mainly been collected in high forest (half of the forest structure)

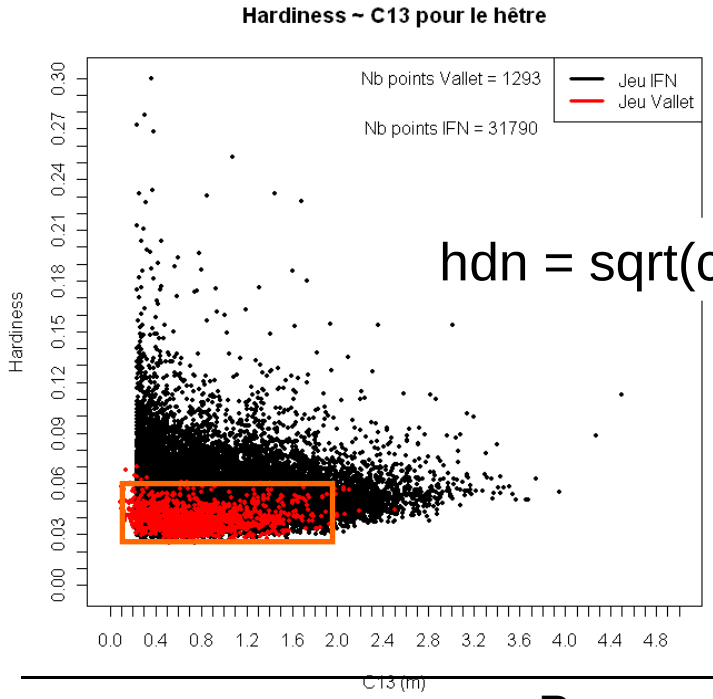


4. Discussion

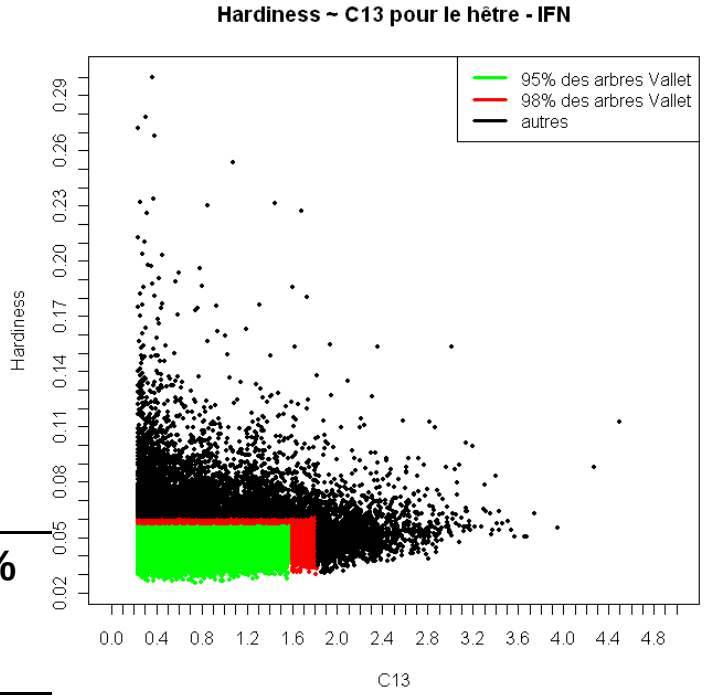
French National Carbon Stock assessment

- Sensitivity analysis (Beech forests, 11% to the French forest resource)

Source: Chevalier et al. 2013



hdn = sqrt(c130)/htot)



	Representativeness % of total volume of beech forests
95% samp. INRA	54%
98% samp. INRA	67%
Beyond 98% samp. INRA	33%

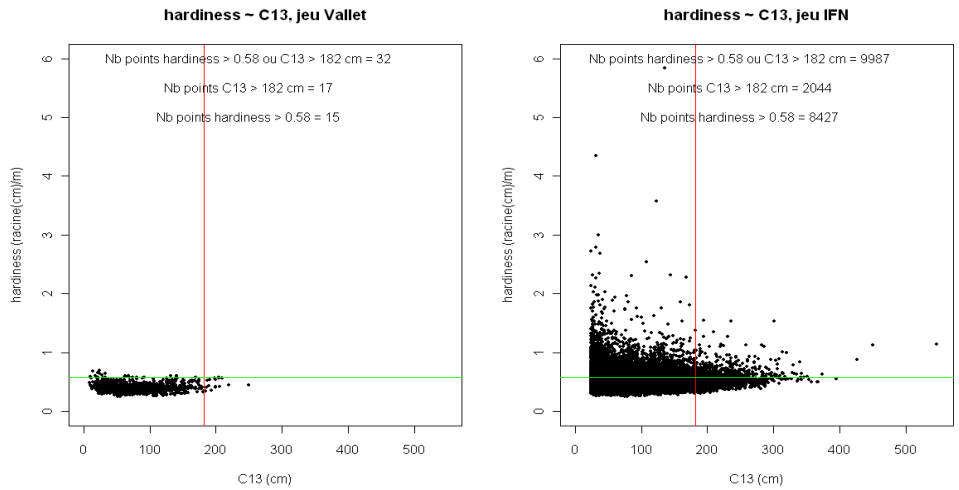
→ **Model used in extrapolation at national level .. Reliability of the estimates ?**

4. Discussion

French National Carbon Stock assessment

- Sensitivity analysis (Beech forests, 11% to the French forest resource)

Source: Chevalier et al. 2013



C130 > 182 cm
hdn > 0.58

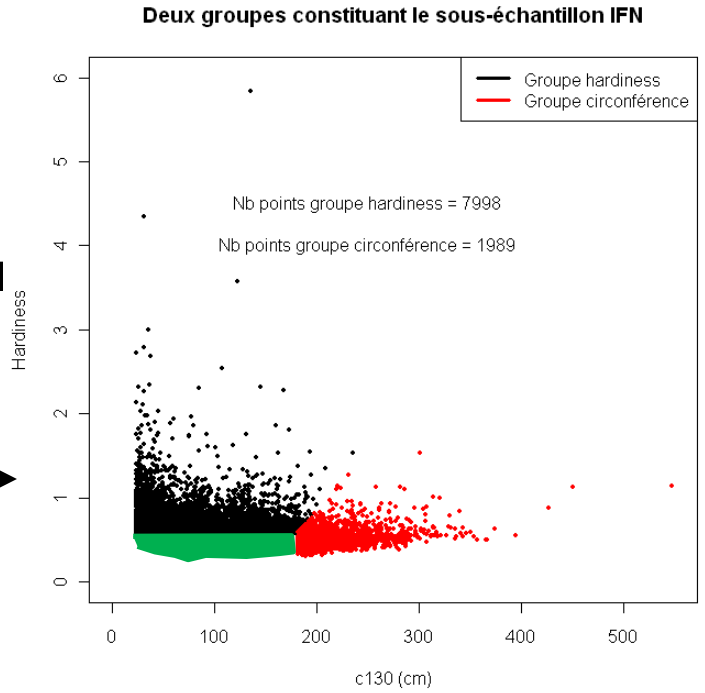
} Trees of the forest resource not represented by the calibration data set

Calibration of simplified models

Form_f = a + b * c130

Form_f = c + d * hardiness

With Form_f = Vtotal / V D2H



Application within the calibration range : **use of the full model**

Application outside the calibration range: use of the simplified models with ± 100% variation on the slopes (**b** and

4. Discussion

French National Carbon Stock assessment

- Sensitivity analysis (Beech forests, 11% to the French forest resource)

Source: Chevalier et al. 2013

Difference between Total V calculated and total V reference for the beech forest rersource (in %)		*Hardiness simplified model*				
		f : null slope	f : slope / 2	**f : fitted slope**	f : slope *1.5	f : slope *2
C130 simplified model	f : null slope	-11%	-7%	-3%	0%	4%
	f : slope /2	-9%	-5%	-2%	2%	6%
	f : slope	-7%	-4%	**0%**	4%	8%
	f : slope *1.5	-6%	-2%	2%	6%	10%
	f : slope *2	-4%	0%	4%	8%	12%

The differences ranged finally between -11% to 12% despite very high variations on the simplified model parameters (slope varying from -100 % to +100 %)

The same work will be done for the other main tree species in France

4. Discussion

French National Carbon Stock assessment

- Conversion factors

Representativeness of Wood density database ?

Set 1 compilation of European references, including a very old French reference (Mathieu, 1877)

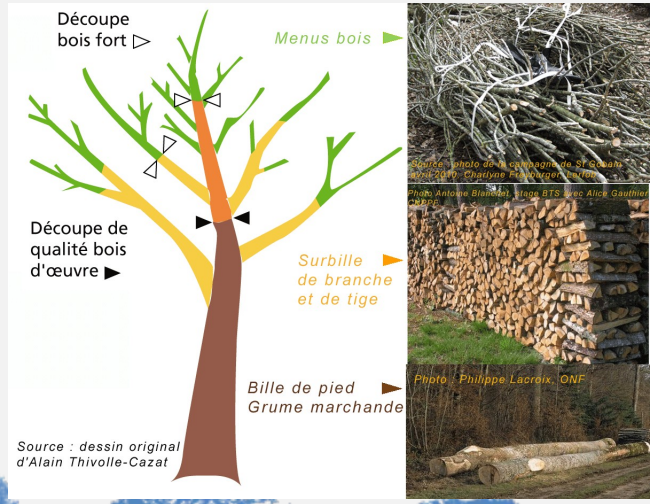
→ 71.2 tC/ha)

Set 2 old French reference only (Mathieu, 1877), woods from mountain regions or the Mediterranean zone, which are characterized by higher density, are more common in Mathieu's work than in the other sources

→ 77 tC/ha) (+8%)

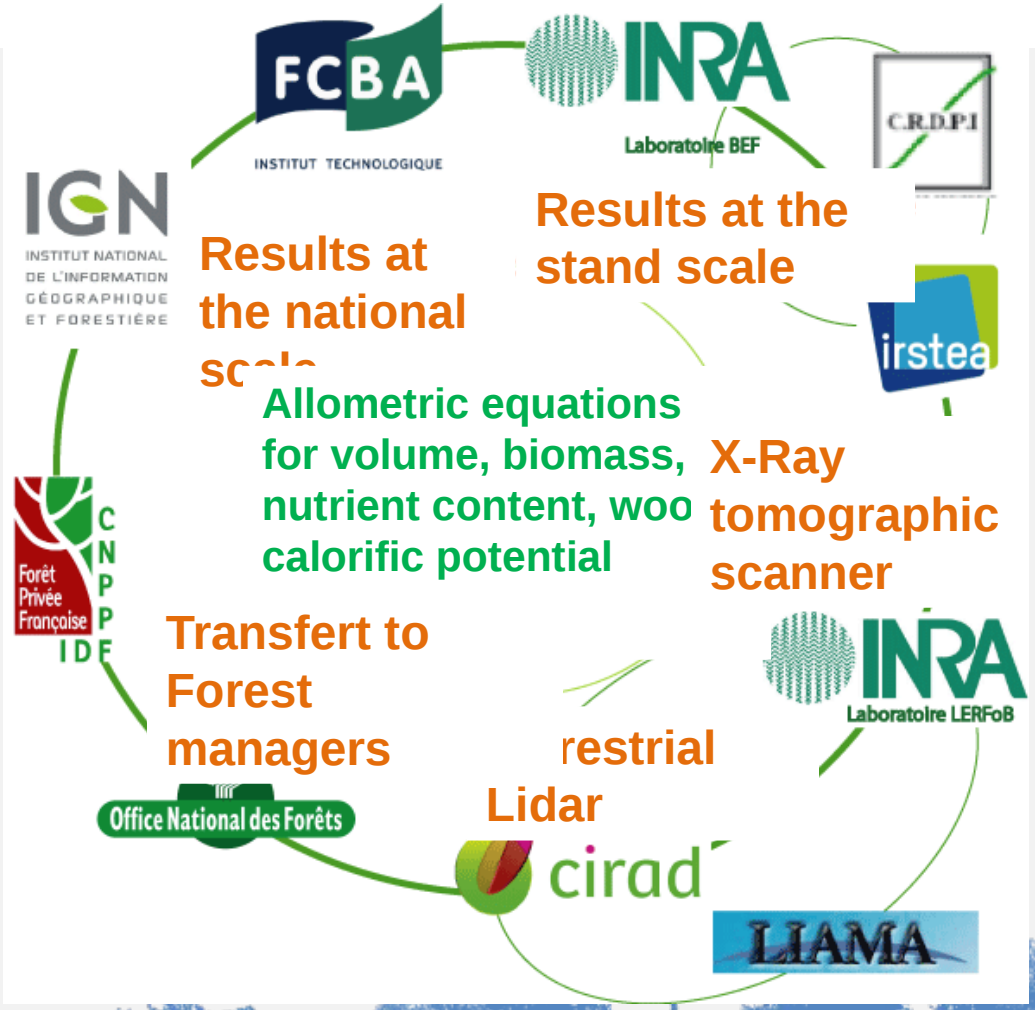
Estimation of carbon stocks by "end-products"?

Volume expansion factors ?



5. Current improvements

French National Carbon Stock assessment



ANR EMERGE project (funded by the French National Research Agency)

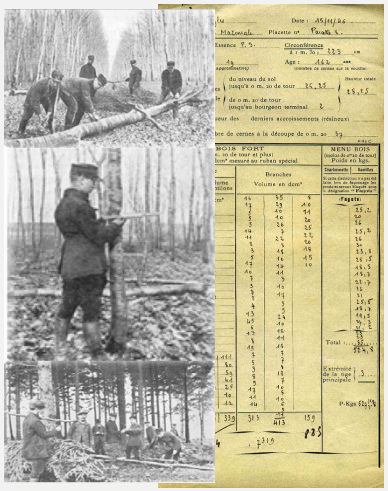
All R&D institutes working together

5. Current improvements

French National Carbon Stock assessment

1 106 099 trees from the NFI (standing trees)

118 505 stems from management and research



20 983 trees with small branches and 31 439 stem profiles from Research (old datasheets digitized)

6 037 trees sampled for biomass

1 797 trees sampled for nutrient content

220 trees sampled during the project 2009 et 2010

Data Shared among the 8 institutes through a common database, and a series of common works on this database

5. Current improvements

French National Carbon Stock assessment

Methodology : Vtot Models (number of considered tree species and model performance)

tree species used to calibrate the equation	species for which the equation was used	Parameters of the equations			
		a	b	c	d
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Picea abies	*Picea abies* & other coniferous species	0.631	-0.946	0	0

6 species specific equations
+ 2 general equations

Source: Vallet et al. (2006)

Stabilised models

	PV7 : a+b*hd+c*hdn			Mai 2 : a + b * hdn + d * hsurd			Mai3 : a * (1 + b * hdn) + c * (100 - 2 * h			Mai4 : a + b * hdn		Mai 5 : a
	a	**b (hd)**	**c (hdn)**	**a**	**b (hdn)**	**d (hsurd)**	**0.40306102**	**7.46884346**	**-0.00112855**	**a**	**b**	**a**
Broadleaves	0.4476243	0.3572339	1.1342901	0.5219646	0.66106715	-0.00165725	0.40306102	7.46884346	-0.00112855	0.449757	0.9214722	0.4960857
Acer campestre	0.4538029	0.31284332	1.23779862	0.53351841	0.66106715	-0.00163092	0.41924493	7.21838075	-0.00112855	0.45273687	1.1404647	0.50865834
Acer pseudoplatanus	0.42890067	0.25729382	1.20562231	0.50203569	0.66106715	-0.0015752	0.37541101	8.49444066	-0.00112855	0.44071505	0.9180001	0.48605376
Betula pendula	0.37817211	0.15540868	2.17569254	0.49335247	0.66106715	-0.00158541	0.3531563	9.94134965	-0.00112855	0.39973714	1.67049811	0.4721357
Carpinus betulus	0.45249097	1.39576771	0.31388382	0.53321079	0.66106715	-0.00149796	0.41754587	6.98091809	-0.00112855	0.47463101	0.71290368	0.50291802
Fagus sylvatica	0.41843709	1.59342339	1.16420024	0.54186507	0.66106715	-0.00150113	0.38323736	10.3059571	-0.00112855	0.42678324	2.19007513	0.51549119
Fraxinus excelsior	0.45712452	0.7367648	0.52330972	0.50863699	0.66106715	-0.00096579	0.44795617	4.39939701	-0.00112855	0.46916164	0.71363448	0.4969125
Prunus avium	0.44753819	0.40455728	1.04181481	0.52140633	0.66106715	-0.00166692	0.40008171	7.48956075	-0.00112855	0.44986434	0.91582454	0.49667711
Quercus palustris	0.44122083	1.07430536	0.10569853	0.51345508	0.66106715	-0.00213372	0.41649968	5.13438196	-0.00112855	0.4666736	0.2098591	0.47860844
Quercus robur_petraea	0.46137178	1.96933768	-0.33834823	0.56104231	0.66106715	-0.00235061	0.46523152	3.9610174	-0.00112855	0.50143684	0.24305729	0.51202918
Quercus rubra	0.36250181	0.44008373	2.4644662	0.51112289	0.66106715	-0.00166479	0.35224569	10.7630312	-0.00112855	0.37336363	2.48232629	0.47705214
Coniferous	0.4476243	-0.45415706	1.1342901	0.35638888	1.75592319	0.00173454	0.47685239	-0.13380765	0.00076101	0.449757	0.9214722	0.4960857
Abies alba	0.53589801	-0.96891556	0.51503548	0.39789783	1.75592319	0.00167846	0.52812701	-1.33359229	0.00076101	0.51591595	0.09823035	0.52022966
Abies nordmanniana	0.47736592	-0.87557306	1.57895197	0.37495833	1.75592319	0.00223205	0.45635944	1.71847397	0.00076101	0.45635512	1.3409089	0.53250582
Abies sp.	0.5682049	-1.2057074	0.01300548	0.35954963	1.75592319	0.00304478	0.51365573	-0.46865436	0.00076101	0.54836294	-0.46551452	0.52860662
Cedrus atlantica ou libani	0.52294547	-0.08235604	-0.88544817	0.3402012	1.75592319	0.0021991	0.55267317	-4.01112584	0.00076101	0.52318007	-0.95051925	0.48280466
Larix decidua	0.49151834	-0.52573625	0.307095	0.37657507	1.75592319	0.00107016	0.52346516	-2.70176635	0.00076101	0.49278497	-0.12208683	0.48763803
Picea abies	0.52567102	-3.05142633	1.78628221	0.30342317	1.75592319	0.00389663	0.52223825	-2.58158637	0.00076101	0.48521533	0.01829673	0.48602987
Picea sitchensis	0.45725296	-0.57155578	1.0654383	0.35056416	1.75592319	0.00172923	0.48849592	-1.0043041	0.00076101	0.45502188	0.80061079	0.49413069
Pinus halepensis	0.38507392	-0.23457564	2.53146735	0.40322491	1.75592319	0.00070391	0.40430197	3.45749057	0.00076101	0.39020763	2.27604473	0.52219565
Pinus laricio	0.45072018	-1.46337544	1.4432059	0.30566796	1.75592319	0.00278748	0.48498838	-2.51737616	0.00076101	0.43366775	0.5382834	0.45529814
Pinus mugo	0.40936184	-0.43451028	2.98217746	0.43241278	1.75592319	0.00115206	0.44252587	4.33852955	0.00076101	0.40149944	2.90823057	0.55033673
Pinus nigra	0.48494428	-1.57957613	1.35999511	0.30480604	1.75592319	0.0034877	0.49565647	-1.17098043	0.00076101	0.48420152	0.27948491	0.49804629
Pinus nigra ssp pallasiana	0.42493331	-0.75567384	1.44570231	0.33212982	1.75592319	0.00193102	0.52952831	-4.25127214	0.00076101	0.41726729	1.08462428	0.46775984
Pinus pinaster	0.30626526	0.90856388	1.83000357	0.39581474	1.75592319	-0.00186217	0.32190983	5.08881384	0.00076101	0.34198647	1.98135116	0.48861332
Pinus sp.	0.46359558	-0.69633341	0.72782366	0.33229573	1.75592319	0.00205861	0.52887501	-3.59907497	0.00076101	0.46651929	0.26977351	0.48359148
Pinus strobus	0.45300135	0.26832227	0.35662562	0.35628305	1.75592319	0.00109325	0.49742201	-1.74349237	0.00076101	0.46682445	0.319512	0.48542189
Pinus sylvestris	0.27851372	-0.88683163	4.90048763	0.37160635	1.75592319	0.00063504	0.29058003	11.7832043	0.00076101	0.26783132	4.49954938	0.47263871
Pinus uncinata	0.48113729	1.07182825	0.07919527	0.44257463	1.75592319	-0.00050919	0.493487	0.27268291	0.00076101	0.49782486	0.70102238	0.54135549
Pseudotsuga menziesii	0.51551572	-1.85884158	-0.17106132	0.23501441	1.75592319	0.00389353	0.50905349	-3.68450751	0.00076101	0.49342509	-0.97322548	0.44666169

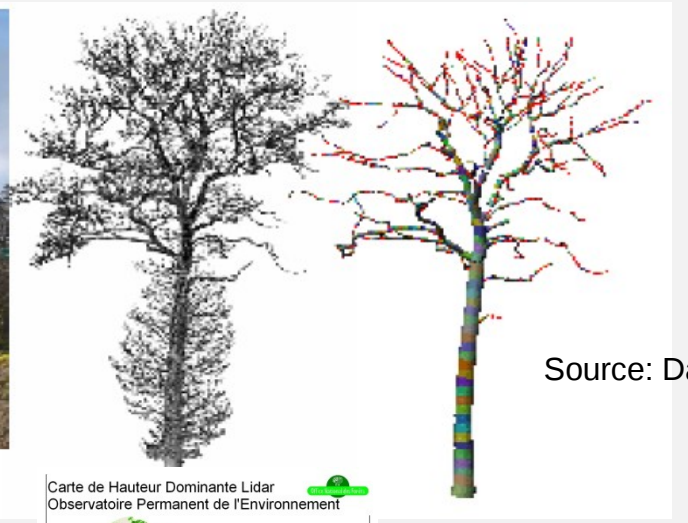
28 species specific equations
+ 2 general equations
(including recent field campaigns)

Source: Deleuze et al. (2013)

5. Current improvements

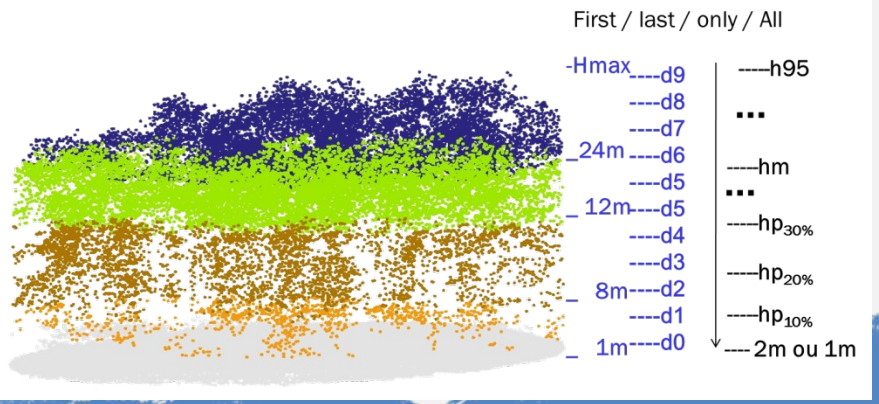
French National Carbon Stock assessment

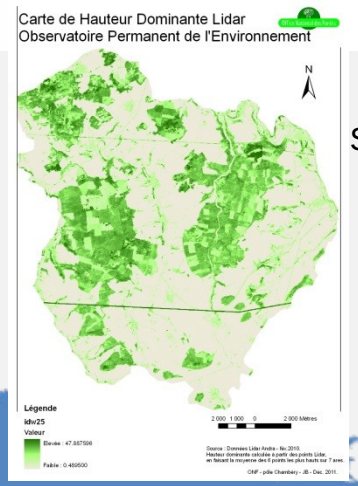
Technics : Lidar (both terrestrials and airborne) and Photogrammetry



Source: Dassot et al. (2011)

Indicateurs de densité





Source: Bock et al. (2012)

ANR FORESEE (end 2014) and EU funded DIABOLO (2015-2018)

6. Main messages

French National Carbon Stock assessment

- Take advantage of the NFI field campaigns to take additional in situ measurements (ex: standing stem volume, wood density cores, ..)
- Random sampling if of outmost importance to ensure the largest coverage of the forest resource
- The same variables should be used for the models building and their application to prevent methodological biases (ex if DBH is used in the equation, DBH should be measured on the field… not the circumference)
- The methodology for wood production oriented forests (like in France and in most of European countries) is probably not the same for natural forests

Thanks for your attention!

(www.ign.fr)