REPRESENTATIONS SOCIALES ET INTERETS ECOLOGIQUES DE LA NECROMASSE (RESINE)

ANNEXES

Programme « Biodiversité et gestion forestière »
Rapport Scientifique Final
N° de contrat : CV05000150 (janvier 2006)
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20 février 2009

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Annexe 3 : Copie de publication : BRIN, A., BRUSTEL, H., JACTEL, H., 2009. Species variables or environmental variables as indicators of forest biodiversity: a case study with saproxylic beetles in maritime pine plantations. Annals of Forest Science sous presse

Annexe 4 : Copie de publication : DEUFFIC P. (2007) Deadwood for biodiversity or energy savings ? An environmental dilemma for foresters. In: 8th conference of European Sociological Association (ESA), Research network 12 : Environment and Society, University of Glasgow, 3-6 septembre 2007, p. 13.

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ANNEXE 1

Publications scientifiques parues

Participation à des colloques nationaux ou internationaux (communication orale et poster)

- **Bouget, C.** 2006. Limites du protocole 'Réserves' dans la cadre de projets de recherches. Séminaire "Réserves", Paris, 23 novembre 2006
- **Brin A., Brustel H., Samalens J.C., Piou D., Jactel H.,** 2006. Dead wood attributes as biodiversity indicators in plantation forests. IUFRO Conference - FORSEE project final meeting : Indicators for sustainable forest management in cultivated forests, 11-13 décembre 2006 à Porto.
- **Deuffic P.** (2007) Deadwood for biodiversity or energy savings? An environmental dilemma for foresters. In: 8th conference of European Sociological Association (ESA), Research network 12 : Environment and Society, University of Glasgow, 3-6 septembre 2007, 13 p.
- **Bouget, C., Ricou, C., Nusillard, B., Moreau, P.A.,** 2008. Dead wood and saproxylic biodiversity. Dead wood volume and quality in a French managed oakwood context. 5th Symposium and Workshop on the conservation of saproxylic beetles, Lüneburg, DEU, 14 juin 2008.
- **Jactel, H., Brin A., Brustel H., Meredieu C., Labbé T., Piou D.,** 2008. Managing dead wood to conserve biodiversity in plantation forests. IUFRO Conference "Biodiversity in forest ecosystems and landscapes", 5-8 août 2008, Kamloops, Canada.

Rapports de fin d'étude (mémoires de maîtrise, de DEA, thèses...)

- **Duchemin, L.,** 2006. *Caractérisation du bois mort à l'échelle du peuplement et analyse préliminaire des relations entre bois mort et diversité des coléoptères saproxyliques*. Rapport de stage de Master Pro 2^e année ''Contrôle et Conservation des Populations d'Insectes'', Université de Tours.
- **Pineau, X.,** 2007. Analyse des relations entre la diversité des coléoptères saproxyliques et les propriétés qualitatives des pièces de bois mort (chêne). Rapport de stage de Master Pro 2^e année ''Contrôle et Conservation des Populations d'Insectes'', Université de Tours.
- **Ricou, C.,** 2008. Influence de différents types qualitatifs de pièces de bois mort sur la biodiversité saproxylique, entomologique (chêne Rambouillet ; Pin Landes) et fongique (chêne Rambouillet). Rapport de stage de Master Recherche 2^e année ETAH, Université d'Orléans
- **Fleury, J.,** 2008. Analyse des relations entre la biodiversité saproxylique et les descripteurs de nécromasse à l'échelle du peuplement (Rambouillet, 78). Rapport de stage de Master 1^e année ETAH, Université d'Orléans
- **Deuffic, P.,** 2008. La production sociale de normes environnementales. Le cas de la biodiversité forestière. Mémoire pour l'obtention du Master 2 Recherche en Sociologie, « Education et problèmes sociaux », Université de Bordeaux 2, 65 p.

Articles techniques

Bouget, C., Pineau, X., Duchemin, L., Arnaboldi, F., 2007. Des nouvelles de *Mycetophagus ater* Reitter et *Mycetophagus populi* Fabricius en Ile-de-France (Coleoptera Mycetophagidae). *L'Entomologiste*, 63 (3) : 107-110
Bouget, C., 2007. Enjeux du bois mort pour la conservation de la biodiversité et la gestion des forêts. *Rendez-vous techniques*, 16 : 55-59

Articles scientifiques : écologie

Brin A. ; Meredieu C. ; Piou D. ; Brustel H. ; Jactel H. (2008) Changes in quantitative patterns of dead wood in maritime pine plantations over time. Forest Ecology and Management (256), 5: 913-921.

Publications scientifiques à paraître

Brin, A., Brustel, H., Jactel, H., 2009. *Species variables or environmental variables as indicators of forest biodiversity: a case study with saproxylic beetles in maritime pine plantations*
Annals of Forest Science *sous presse*
Etat : accepté

Publications scientifiques prévues

Articles techniques en préparation

Cordonnier, Th. & Gosselin, F. La gestion adaptative : intégrer l'acquisition des connaissances parmi les objectifs de gestion. Manuscrit soumis à la *Revue Forestière Française*

Dossier collectif programmé dans *Rendez-Vous Techniques* – 2009 : « Bois mort, biodiversité et gestion forestière » avec 4 articles autour du projet RESINE:

- **Deuffic, P. Quelles représentations du bois mort pour les acteurs forestiers ?**
- **Granet, A.M.. Les risques liés au bois mort dans le domaine de la sécurité du public.**
- **Bouget, C., Brin, A. & Moreau, PA. Bois morts et biodiversité à différentes échelles**
- **Gosselin, F. & Cordonnier, T. Pour une gestion adaptative du bois mort**

Etat : en préparation

Articles scientifiques en préparation

Article : sociologie

Deuffic, P. *(in prep).* Biodiversity Burning. Deadwood, an Environmental issue for Foresters? (revue : Human Ecology ?)
Etat : en préparation

Article pluri-disciplinaire

Deuffic, P., Bouget, C. et al. (in prep). Regards croisés sur un habitat forestier, le bois mort (revue : Ingénieries ?)
Objectif : stigmatiser les enjeux actuels et les interrogations des acteurs forestiers, en apportant quelques éléments d'information et de réponse socio-économiques et écologiques, quand ils existent
Etat : en préparation

Articles: écologie

Brin et al. (in prep.) Oak and pine dead wood in lowland French forests: type, stratum, decay class and size from a saproxylic beetle's perspective. Part I and Part II *(revue : ?)*
Objectif : analyse comparative de l'effet du type de bois mort sur les assemblages de coléoptères saproxyliques, pour 2 essences dominantes dans deux régions forestières françaises contrastées (pin des Landes et chêne de Rambouillet)
Etat : en préparation

Bouget et al. (in prep.) Effects of stratum, decay class and size of oak dead wood on saproxylic beetle and fungus assemblages in a French lowland forest *(revue : ?)*
Objectif : analyse comparative de l'effet du type de bois mort sur les assemblages de coléoptères et de mycètes saproxyliques (chêne de Rambouillet)
Etat : en préparation

Bouget et al. (in prep.) Dead wood and saproxylic beetle diversity in temperate deciduous forests: is the local volume a relevant surrogate? *(revue : ?)*
Etat : en préparation

Bouget et al. (in prep.) Response of different taxonomical saproxylic groups to dead wood descriptors at a local scale. A co-analysis in a temperate deciduous forest (*revue* : ?)
Etat : en préparation

ANNEXE 2

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Changes in quantitative patterns of dead wood in maritime pine plantations over time

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ABSTRACT

Although the volume of dead wood is commonly acknowledged as an indicator of biodiversity in sustainable forest management schemes, only few data are available for plantation forests. To evaluate the volume and qualify the diversity of woody debris along a chronosequence of maritime pine plantations, we sampled downed woody debris, snags and stumps in 143 stands of different ages. To test the hypothesis that the pattern of dead wood accumulation mainly results from silvicultural operations, we developed a predictive model. It combined an empirical growth model evaluating the amount of dead wood produced by successive thinnings with a decay function that estimated the loss of dead wood with time.

The volume of dead wood averaged 15 m^3/ha. Downed woody debris, stumps and snags represented 81%, 11% and 8% of this volume, respectively. Pieces of downed woody debris were equally distributed between fine and coarse woody debris however large pieces (diameter ≥20 cm) were scarce. The dead wood was mainly from anthropogenic origin (77%) and its volume significantly increased with stand productivity. The pattern of dead wood accumulation along the forestry cycle showed a convex shape with a peak in stands of ca. 30-year-old, after the third thinning. The dynamics was successfully predicted for downed woody debris ($r = 0.47$, $P < 0.001$) and for stumps ($r = 0.45$, $P < 0.001$) by the model combining inputs from thinnings and loss with time. This model may help to predict the effect of alternative forestry practices on dead wood accumulation by forest managers or nature conservationists in similar pine forest plantations.

1. Introduction

Dead wood is an important component of forest ecosystems with several crucial ecological functions, like carbon sequestration or contribution to energy flow and nutrient cycles (Harmon et al., 1986). Moreover, perhaps the most important role of dead wood is to provide habitat for a large proportion of forest species (Elton, 1966). Stokland et al. (2004) consider that 25% of Scandinavian forest species depend on dead wood and that many of them are threatened. As the importance of dead wood for biodiversity has become widely acknowledged (Speight, 1989; Grove, 2002; Stokland et al., 2004) several international schemes for Sustainable Forest Management (MCPFE in Europe, CIFOR in tropical forests) have included "dead wood" in their list of biodiversity indicators. For example, the MCPFE (2003) proposed the "volume of standing and lying dead wood by different forest types" as an indicator for the conservation, maintenance and improvement of biodiversity in European forests.

Surprisingly, knowledge on quantitative and qualitative patterns of dead wood in planted forests is still scarce whereas the area of these forests, which include both forest plantations and the planted component of semi-natural forests, continue to expand worldwide with an increment of ca. 25% in the last 15 years and their contribution to global wood production is approaching 50% (FAO, 2007). References exist for plantation forests from some northern European countries (Green and Peterken, 1997; Kirby et al., 1998; Humphrey et al., 2003; Travaglini et al., 2007), Australia (Woldendorp and Keenan, 2005; Guo et al., 2006) or from the USA (Harmon et al., 1986; Duvall and Grigal, 1999). However, to our knowledge, there are no published data concerning dead wood abundance in plantation forests in southern Europe. A large-scale assessment of planted forests biodiversity in Britain showed that plantations should not be considered as "biodiversity deserts" (Humphrey et al., 2003). Dead wood quantity and quality was an

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important driving factor for lichens, bryophytes and fungi diversity (Humphrey et al., 2002). Beetles community of *Pinus radiata* exotic plantations in New Zealand was largely dependent on the abundance of debris resource (Hutcheson and Jones, 1999). Humphrey (2005) compiled several studies suggesting that some species can benefit from the presence of decaying wood in plantations and are capable of dispersing between considerably distant suitable habitats. Lindenmayer and Hobbs (2004) pointed out the importance of maintaining some elements of dead wood within plantations, because they may have benefits for ecological key processes such as pest control. Some predators and parasitoids of early successional beetles appeared to be more sensitive to habitat change than their hosts (Hilszczanski et al., 2005; Johansson et al., 2007). According to these authors, the conservation of this helpful group of insects is related to both substrate (logs and snags) and stand quality and diversity. Humphrey et al. (2000) also highlighted the positive contribution of plantations of both native and exotic conifers to the conservation of native fungi. Some of these species were wood saprotrophs. Furthermore, at the landscape scale, plantation forests can play a role for biodiversity conservation by providing complementary forest habitat, buffering edge effects, and increasing connectivity between patches of remnant forests (Lindenmayer and Hobbs, 2004; Brockerhoff et al., in press). All this speaks in favour of dead wood management in planted forests. Even though very demanding species, the old-growth forests specialists, may be unable to colonise plantation forests, these results show that woody debris management should not be neglected in such intensively managed forests.

In primary or secondary forests, dead wood mainly comprises broken branches or dead trees resulting from natural disturbances (storms, fire, sanitary damage) but also natural ageing of trees (Siitonen, 2001). By contrast in plantation forests, intensive management activities such as thinning, pruning and harvesting, mainly contribute to woody debris input (Carlyle, 1995; Green and Peterken, 1997). Forestry operations may also reduce the volume or the quality of dead wood through the removal or fragmentation of the debris, especially during the final harvesting (Duvall and Grigal, 1999; Fridman and Walheim, 2000; Ehnström, 2001; Ranius et al., 2003; Hautala et al., 2004). Other detrimental effects of silviculture on dead wood in plantations may be due to changes in tree size distribution and tree species composition (Duvall and Grigal, 1999; Fridman and Walheim, 2000; Siitonen et al., 2000; Siitonen, 2001). Large pieces of dead wood, such as snags or logs, are often replaced by small-diameter logging or thinning wastes that may be less suitable for threatened dead wood dwelling species (Siitonen, 2001; Simila et al., 2003; Montes and Cañellas, 2006).

In previous studies that aimed at sampling downed woody debris (DWD), the minimum diameter size varied considerably from 1 to 25 cm (Woldendorp and Keenan, 2005). A recommended size breakpoint between fine woody debris (FWD) and coarse woody debris (CWD) is 10 cm at the large end of a piece of dead wood (Harmon and Sexton, 1996). These authors also suggested that pieces less than 1 cm diameter should be treated as "fine litter". Snags and logs are the most common dead wood types that have been inventoried whereas only few studies have also sampled small dead branches and stumps (Sippola et al., 1998; Norden et al., 2004b; Guo et al., 2006; Montes and Cañellas, 2006). However, some authors (Kruys and Jonsson, 1999; Schiegg, 2001; Heilmann-Clausen and Christensen, 2004; Kuffer and Senn-Irlet, 2005) pointed out the importance of small woody debris for the diversity of saproxylic fungi and insects indicating that this dead wood component should not be overlooked in ecological studies.

Alternative management practices to improve the quantity and the amount of dead wood within commercial forests have been suggested by several authors (Hartley, 2002; Lindenmayer and Franklin, 2002; Humphrey, 2005). But standards and recommendations proposed in Scandinavia, UK or North America may not be appropriate in other countries, especially for stands growing in different soil or climatic conditions and submitted to different silvicultural regimes. Furthermore, the growing interest in harvesting logging residues for energy production may represent a new threat for some saproxylic species associated with this substrate (Jonsell et al., 2007). Another threat lies in the reduction of the rotation cycle in order to produce biomass which might reduce both the size and the diversity of woody debris (Wright, 2006; Sochacki et al., 2007).

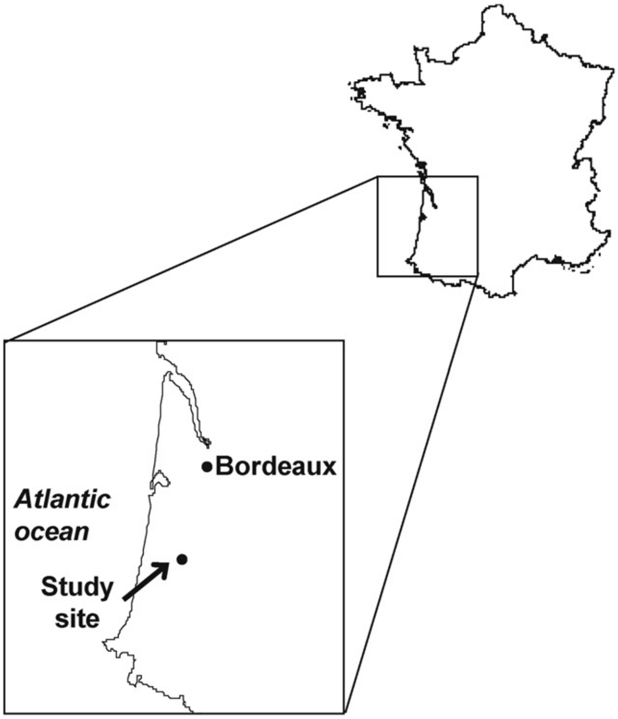

Fig. 1. Location of the study area in south-western France.

The first objective of our study was therefore to test the hypothesis that dead woody debris in plantation forests have specific attributes such as a preponderant anthropogenic origin, a higher proportion of downed woody material and stumps, a lower proportion of snags, with a dominance of small-diameter pieces. The second objective was to check the hypothesis that because most of the woody debris originate from silvicultural practices like thinning and pruning, the volume of dead wood is correlated with the volume of standing wood and varies with site fertility. The third objective was then to develop a model to predict the dynamics of dead wood accumulation along the forestry cycle according to thinning options in maritime pine plantation forests. For this purpose we combined an empirical growth model that evaluates the amount of dead volume produced by successive thinnings with a decay function that estimates the loss of dead wood with time.

2. Material and methods

2.1. Study area and sample design

The Landes de Gascogne forest is located in south-western France and represents the largest artificial forest in Europe (ca. 1 million ha) (Fig. 1). It is an intensively managed forest plantation

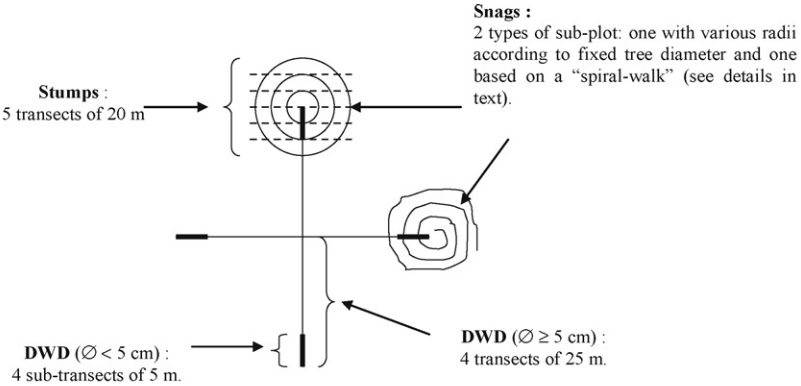

Fig. 2. Sampling design of dead wood at the stand level (DWD: downed woody debris).

of maritime pine (*Pinus pinaster* Ait.), a native species in this region. Current silvicultural practices are characterised by a medium-term rotation cycle (ca. 40–50 years) with clear-cut harvesting, mechanical soil preparation and fertilising, frequent thinning (ca. every 5–7 years) and mechanical removal of the understorey vegetation commonly prior to each thinning.

A total of 145 maritime pine stands were sampled within an area of 256 km^2 (16 km × 16 km) along a systematic grid with sampled stands arranged in staggered rows. Sampled stands were separated by 2 km along grid lines and by 1.4 km with regards to the diagonal of the staggered row design. We could not collect data in two stands that had just been clear-cut.

2.2. Sampling of woody debris

We sampled snags, stumps and DWD from 1 cm diameter in order to provide a more complete overview of dead wood quality and quantity in maritime pine plantation and also make comparisons with other forest types. Fieldwork was conducted during autumn 2005. DWD were inventoried using the line intersect sampling (LIS) method (De Vries, 1973; Marshall et al., 2000) (Fig. 2). On 4 transects of 25 m long, starting at the centre of each plot, we measured the intersected diameter of all woody debris with a diameter equal to or greater than 5 cm. As sampling smaller pieces (diameter between 1 and 5 cm) was more time-consuming, we only surveyed this fraction of DWD on 4 sub-transects of 5 m long each, located at the end of the 25 m transects (Fig. 2). We did not measure the exact diameter of these pieces but classified them into classes A (1–2.4 cm) or B (2.5–4.9 cm) by using a gauge. For further calculations of the volume, we used the quadratic mean diameter of each class, respectively, 1.90 and 3.95 cm. For each piece of DWD, we recorded its origin (natural or anthropogenic) based on visual appearance. If the piece showed sharp edges, we considered that it originated from forestry operations such as thinning or pruning (anthropogenic origin); otherwise it was considered of natural origin.

This LIS method is widely used (Stokland et al., 2004) but three sources of error have been acknowledged (Waddell, 2002). They concern basic assumptions about log shape, log orientation and log position (i.e. lying entirely or partially on the ground). In our study, only the first one may be considered as we only measured the diameter at the point of intersection assuming that it was the midpoint of a cylinder. However, due to the small diameter of most of the sampled DWD we can suppose that their shape was more similar to cylinders than to cones. In order to reduce the "piece orientation bias", we sampled DWD along 4 crossed-transects 25 m long, starting from a common point in four different cardinal directions (Fig. 2). Concerning the last assumption, we can consider that no bias occurred as the great majority of pieces encountered were lying entirely on the ground.

Data from the 4 transects were pooled for statistical analysis so as to obtain within each sampled stand a 100-m long sample for pieces with a diameter greater than 5 cm and a 20-m long sample for smaller pieces.

The volume (m^3/ha) of DWD per hectare was calculated for each stand using the following formula from De Vries (1973):

$$\text{volume} = \pi^2 \times \sum \frac{d_i^2}{8L} \tag{1}$$

where L is the length of transect and d_i the diameter of the piece i at the intercept point.

In each stand, stumps were inventoried on five lines of 20 m along tree rows (ca. 360 m^2) or in a circular sub-plot of ca. 710 m^2 (15 m radius) if tree rows were not apparent (old stands) (Fig. 2). As pine stumps were quite straight and cut roughly at the same height (20 cm), we only recorded the diameter at the top height, by cross-measurements.

The height and diameter at breast height were measured on all snags in two circular sub-plots in each stand. These sub-plots were delimited according to two different methods. The first sub-plot was based on the French National Forest Inventory protocol. It had a variable radius depending on the mean diameter of trees: 6 m (giving a 113-m^2 area) for trees with diameter less than 17.5 cm, 9 m (giving a 254-m^2 area) for trees with diameter between 18 and 27.5 cm and 15 m (giving a 706-m^2 area) for trees with diameter

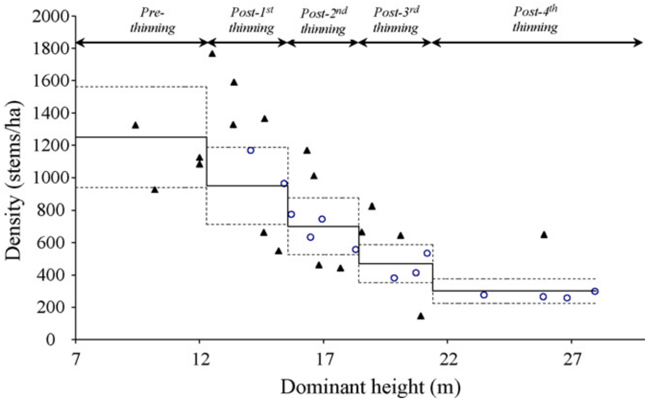

Fig. 3. Illustration of plot allocation to successional stages for the modelling purpose (example with stands belonging to site index 27 m). All stands with a tree density comprised within the interval of recommended density ±25% and that have been thinned at least once (open circles) where selected for the modelling process (see text for further details) (solid line: recommended density, dash lines: upper and lower limits for plot selection).

Table 1
Stand characteristics in the five successional stages (mean ± S.E.)

	Age (years)	Density (stem/ha)	Diameter (cm)	Dominant height (m)
Pre-thinning ($n = 36$)	9 ± 0.5	1512 ± 40	9.6 ± 0.6	6.8 ± 0.5
Post-first thinning ($n = 13$)	16 ± 0.5	1102 ± 97	17.0 ± 0.7	13.6 ± 0.3
Post-second thinning ($n = 25$)	23 ± 0.7	645 ± 37	23.4 ± 0.4	17.0 ± 0.2
Post-third thinning ($n = 34$)	31 ± 1.0	421 ± 28	29.8 ± 0.7	20.4 ± 0.2
Post-fourth thinning ($n = 35$)	44 ± 1.5	321 ± 21	38.2 ± 0.9	24.8 ± 0.4

greater than 28 cm. The second sub-plot consisted of a fixed number of 20 living trees encountered in a spiral-walk from the centre of the sub-plot. Distance between the centre and the most remote tree was considered as the radius of the sub-plot. The total volume of stumps and snags per ha were calculated from respective measurements and using the Huber's formula for a cylinder (2):

$$\text{volume} = \left(\sum_i \frac{\pi}{4} \times D_i^2 \times H_i\right) \times \frac{10000}{S} \qquad (2)$$

where H_i is the snag total height (m) or $H_i = 0.2$ m for stumps, D_i is its diameter at breast height (m) for snags and at top height for stumps and S is the area of the sub-plot (m^2). In the analysis we used the mean value of snag volumes calculated from the two types of sub-plots in each stand.

We used three classes to describe the stage of decomposition of any type of dead wood: (I) freshly dead, at most 1-year-old, wood hard and bark completely stuck to the wood; (II) wood hard, bark partly loose but >50% remaining; (III) wood hard or soft in the surface, but inner part soft and <50% of the bark remaining.

In order to analyse the effects of forest management on dead wood accumulation, diameter classes were pooled into two diameter groups following recommendations of Harmon and Sexton (1996): FWD with diameter at intersect point less than 10 cm and CWD for larger diameters.

2.3. Successional stages

The forestry cycle was divided into five stages according to the four thinning operations that lead successively the stand from an initial tree density of about 1250 stems/ha to a final recommended tree density of ca. 300 stems/ha (Fig. 3 and Table 1). Annual growth of trees was simulated with a forest growth model of maritime pine entitled "Pp3" (derived from Lemoine, 1991 and Salas-Gonzalez et al., 2001) using different silvicultural scenario according to site index.

2.4. Dead wood inputs

Accumulation of dead woody debris from natural origin is likely to depend on natural pruning and wind effects. Because wind speed and spatial occurrence is highly stochastic in forests, we found it too difficult to predict the accumulation of natural dead wood and rather focussed on anthropogenic dead wood.

We first hypothesized that woody debris from anthropogenic origin corresponded to the wood left over of thinning operations. Integrated in a simulation platform CAPSIS (de Coligny et al., 2003), the empirical tree growth model Pp3 coupled with a stem profile model and a virtual logging tool (described in Bouffier et al., in press) gives the volume of logs with no commercial value that is left in thinned stands (i.e. the upper part of the stem above a fixed girth of 20 cm), as well as the diameter of stumps. It gives also the biomass of cut branches (allometric biomass equation developed by Porte et al., 2002). All these data are provided for each trees of a theoretical stand of 1 ha. Mass of cut branches was converted into volume using a density of 400 kg/m^3 (Porte, pers. comm.). We added the volume of trees below the merchantable dimension and the volume of branches so as to obtain the volume of DWD from anthropogenic origin, whatever the class of diameter.

We simulated four silvicultural scenarios according to four forest site indices (Table 2). The site index is a measure of site productivity described as the stand dominant height at an age of 40 years in maritime pine plantations (ONF, 2003). The simulated scenarios also differed by the intensity of thinning (number of trees per ha left after thinning) and by the time lag between two thinning operations as recommended in the south-western part of France (ONF, 2003).

2.5. Decay process

As no available data exist on the decay process of maritime pine dead wood, we tried to predict the decay of total DWD without considering diameter or decay class. A Logistic function (3) was used to describe the percentage of DWD volume loss L_{DWD_i} since

Table 2
Stand characteristics for the four simulated scenarios according to four forest site indices

Site index	Stands characteristics	Pre-thinning	Post-1st thinning	Post-2nd thinning	Post-3rd thinning	Post-4th thinning	Final harvest
27 m ($n = 33$)	Age (year)	<14	14–18	18–22	22–27	27–35	>35
	Stems/ha (mean)	1250	950	700	470	300	300
	Dominant height (m)	<12.3	12.3–15.6	15.6–18.4	18.4–21.4	21.4–25.3	>25.3
25 m ($n = 32$)	Age (year)	<14	14–18	18–26	26–30	30–40	>40
	Stems/ha (mean)	1250	850	650	480	320	320
	Dominant height (m)	<11.4	11.4–14.4	14.4–19.4	19.4–21.4	21.4–25.3	>25.3
23 m ($n = 33$)	Age (year)	<15	15–20	20–25	25–36	36–49	>49
	Stems/ha (mean)	1250	900	560	450	300	300
	Dominant height (m)	<11.3	11.3–14.6	14.6–17.4	17.4–22.2	22.2–26.1	>26.1
20–22 m ($n = 27$)	Age (year)	<15	15–21	21–29	29–41	41–52	>52
	Stems/ha (mean)	1250	950	600	400	300	300
	Dominant height (m)	<10.3	10.3–13.9	13.9–17.8	17.8–22.2	22.2–25	>25

Two site indices (i.e. 20 and 22 m) were pooled to balance the sampling design. Site index was impossible to determine for young stands (<10-year-old).

the thinning i as follows:

$$L_{\mathrm{DWD}_i} = \frac{1}{1 + a\exp^{-b(t-t_i)}} \tag{3}$$

with $(t - t_i)$ the period of time between the time t and the date of the last thinning t_i.

Then the model considered that the volume of DWD, V_{DWD}, observed at the time t was the sum of the volumes of DWD produced by each of the previous thinnings (P_{DWD_i}) minus the volume loss during the period of time between these thinnings and the time t:

$$V_{\mathrm{DWD}} = \sum_i P_{\mathrm{DWD_i}} \times (1 - L_{\mathrm{DWD_i}}) \tag{4}$$

The same method was used to predict changes in volume of stumps.

2.6. Fitting the model parameters

The parameters a and b were determined by an iterative procedure that aimed at optimizing the Pearson's correlation coefficient between the simulated values and the observed ones. We selected plots that had undergone at least one thinning, discarding those younger than 10-year-old. We only considered plots that could be allocated to one of the four specific site indices according to their tree density and dominant height. For a given dominant height, we excluded stands with a tree density below or above the target density ±25% as they might result from other types of silvicultural regimes (anticipated or delayed thinning) or because of eventual problems of measurement (Fig. 3). A total of 57 plots were used in the analysis.

2.7. Data analysis

As data did not match the assumptions of the ANOVA, even after the transformation of raw data, we used the Kruskal–Wallis method to test the significant ($P < 0.05$) difference of volume between types (DWD, stump, snag), diameter classes, decay stages and origins (natural *vs.* anthropogenic). Multiple comparisons after a Bonferroni's correction (test Z, $P < 0.05$) were then conducted to compare means between each factor classes.

Effect of successional stages and site index on volume of all woody debris and on volume of woody debris according to their origin (natural *vs.* anthropogenic) was tested using ANOVA (after a log transformation of data) coupled with a Tukey's post hoc test ($P < 0.05$). For the volume of natural origin that did not fit the assumptions of ANOVA (even after the log transformation) we used a Kruskal–Wallis analysis of variance coupled with multiple comparisons of means after a Bonferroni's correction (test Z, $P < 0.05$). In order to ensure a relatively balanced sample design we had to pool two site indices so as to get only three categories: dominant height of 20–22, 23–25 and 27 m, respectively.

The effect of site productivity (site index) on the amount of dead wood was also investigated by exploring the relationship between total volume of dead wood and volume of living trees. We computed the Pearson product moment correlation after a normalisation of data. We used Statistica 7.1 as statistical software (StatSoft®).

Table 3
Volume of woody debris (mean ± S.E.) in m^3/ha, according to several categories (i.e. type, diameter class, decay stage, origin or site index)

Categories	Classes	Volume (mean ± S.E.) (m/ha)
All		14.9 ± 1.16
Type	Downed woody debris	12.1 ± 1.03a (81)
	Snags	1.21 ± 0.33b (8)
	Stumps	1.63 ± 0.11c (11)
Diameter class	$1 \le x < 2.5$ cm	3.75 ± 0.24a (25)
	$2.5 \le x < 5$ cm	3.79 ± 0.36a (25)
	$5 \le x < 10$ cm	1.27 ± 0.13b (9)
	$10 \le x < 15$ cm	1.64 ± 0.24b (11)
	$15 \le x < 20$ cm	1.68 ± 0.30b (11)
	$x \ge 20$ cm	2.78 ± 0.47b (19)
Decay stage	Fresh	1.69 ± 0.30a (11)
	Initial decay	7.26 ± 0.80b (49)
	Advanced decay	5.93 ± 0.46b (40)
Origin	Natural	3.48 ± 0.59a (23)
	Anthropogenic	11.41 ± 0.84b (77)
Site index[a]	27 m	21.53 ± 2.75a
	23–25 m	17.30 ± 1.77a
	20–22 m	9.39 ± 1.21b

Within each category, percentage of each class is displayed in parenthesis and values indicated with different letters are significantly different at the $P < 0.05$ level after a Tukey's post hoc test. Site indices 23 and 25 m were pooled to balance the sampling design for the factorial ANOVA (see text for details).

[a] Dominant height (in meters) at a reference age of 40 years.

3. Results

3.1. Average dead wood volume and quality

In our sample of 143 maritime pine plantations that varied from 4 to 61 years old, dead wood consisted mainly of DWD (81%) whereas stumps and snags represented, respectively, 11% and 8% (Table 3). Differences between these three types were significant ($K = 234.4$, $P < 0.001$).

Small-diameter size pieces were predominant and corresponded mainly to branch sections. The volume of woody debris was significantly higher in the two smallest diameter classes compared to others ($K = 124.2$, $P < 0.001$) (Table 3). The overall volume of dead wood was slightly dominated by FWD with 8.8 m^3/ha on average (±0.6 S.E.) whereas the volume of CWD averaged 6.1 m^3/ha (±0.8 S.E.). The mean volume of the largest woody debris (diameter larger than 20 cm and greater) was equally distributed between the three types (stumps, DWD and snags). The largest diameter encountered for a woody debris was 32 cm (it was a log). Fresh woody debris were by far and significantly ($K = 114.8$, $P < 0.001$) less abundant than the two other decay stages (Table 3). There was no significant difference between volumes of initial and advanced decay stages.

As expected, the dead wood was mainly from anthropogenic origin (77% of the total). The observed difference with natural dead wood was significant ($K = 100$, $P < 0.001$) (Table 3). The proportion of anthropogenic dead wood varied with the decay stage: from 99% in fresh dead wood to 73% and 87% in early and advanced decay stage, respectively.

3.2. Effect of site productivity

The effects of successional stage ($F = 8.28$, $P < 0.001$) and site indices ($F = 5.46$, $P = 0.001$) on volume of all woody debris were significant. There was no significant interaction between the two factors ($F = 1.01$, $P = 0.43$). The mean volume of all woody debris was higher in more productive sites (Table 3). The difference was significant only between the poorest sites (i.e. site index 20–22 m) and other sites. This clear pattern was observed both for natural and anthropogenic woody debris. The total volume of woody debris was significantly correlated with the volume of living trees ($N = 143$, $r = 0.60$, $P < 0.0001$).

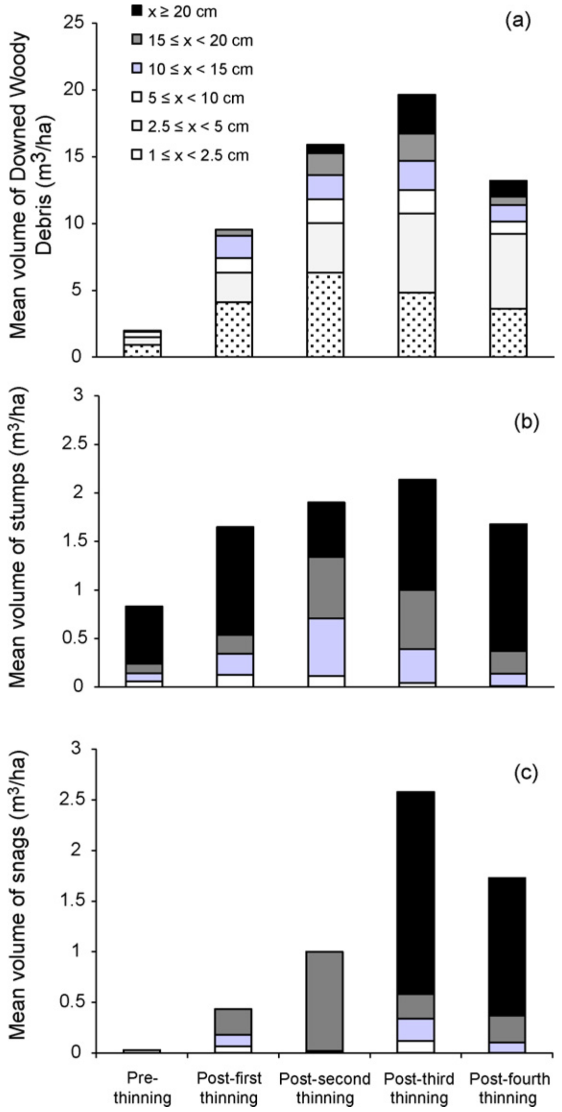

Fig. 4. Mean volume of dead wood (a: downed woody debris (DWD), b: stumps and c: snags) per diameter class according to five successional stages.

3.3. Pattern of dead wood accumulation over time (observation and simulation)

For all types of woody debris (i.e. DWD, stumps or snags), there was a clear pattern of accumulation along the forestry cycle (Fig. 4) with a peak after the third thinning when the total volume of dead wood reached 24 m^3/ha (±3.2 S.E.) on average. Pre-thinning stands were the poorest ones, for all types of woody debris, with only 2.9 m^3/ha (±0.5 S.E.). Whereas large stumps (diameter ≥20 cm) were present all along the forest cycle, large logs or snags were mainly observed during the second part of the forestry cycle, after the third thinning (Fig. 4).

The prediction of anthropogenic dead wood accumulation over time that resulted from the combination of input (from thinning) and decay (with time) processes appeared to perform well (Fig. 5). We managed to fit prediction curves for both DWD ($r = 0.47$, $P < 0.001$) and stumps ($r = 0.45$, $P < 0.001$) with the same model type. The parameters' values of the logistic function (3) were, respectively, $a = 5000$ and $b = 0.65$ for DWD and $a = 9000$ and $b = 0.5$ for stumps. This confirmed our hypothesis of silvicultural prevalence in dead wood production in plantation forest. According to the numerical optimization, it takes about 22 and 28 years to decompose 99% of the volume of DWD and stumps, respectively (Fig. 6).

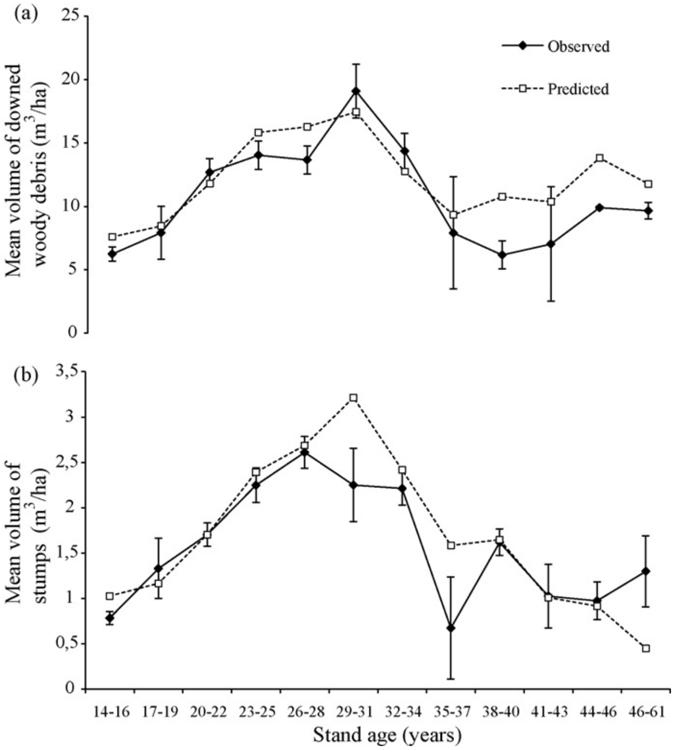

Fig. 5. Comparison between observed ($n = 57$ stands) and predicted mean volume of downed woody debris (a) and stumps (b) per class of stand age (see text for the model Eq. (4)). Vertical bars indicate standard error.

4. Discussion

4.1. General patterns

Our results are consistent with previous estimates of dead wood volume in managed European forests. The mean volume of CWD in maritime pine managed stands (ca. 5 m^3/ha excluding stumps) is comparable to that estimated in UK Scots pine plantations (5 m^3/ha in Kirby et al., 1998) or in managed pine forests of the temperate zone of Sweden (4.9 m^3/ha in Fridman and Walheim, 2000). Ekbom et al. (2006) found twice as much CWD (excluding stumps) in managed centro-boreal forest of Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* L.) where the total amount of CWD was 14 m^3/ha on average. However, these volumes remain much lower than those observed in natural or

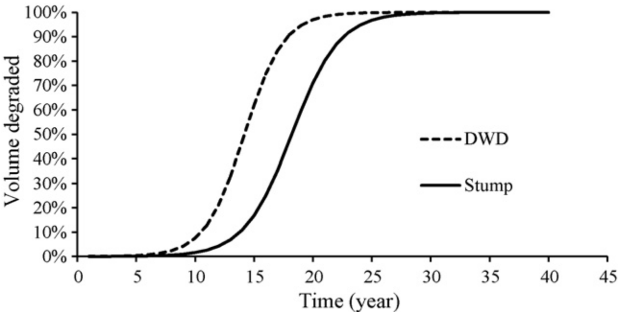

Fig. 6. Decay process of downed woody debris and stumps.

unmanaged forest of North America, Fennoscandia and continental Europe where they vary from 50 to 150 m^3/ha (Kirby et al., 1998; Duvall and Grigal, 1999; Siitonen, 2001; Rouvinen et al., 2002; Ekbom et al., 2006). A more relevant comparison should be made for a given tree species at similar stand age and productivity, since these factors greatly influence the total amount of dead wood (Sturtevant et al., 1997; Sippola et al., 1998; Ranius et al., 2003).

Dead branches and logs were the prevalent type of woody debris in maritime pine stands, with about 80% of the total volume of dead wood. This is consistent with other inventories made in British or Scandinavian managed forests (Green and Peterken, 1997; Sippola et al., 1998; Rouvinen et al., 2002; Norden et al., 2004a). As also observed in these studies, standing dead wood represented less than 10% of the total volume of dead wood and it was virtually absent in young stands. The scarcity of snags is one of the most striking differences between dead wood resource in managed and unmanaged forests (Rouvinen et al., 2002; Ekbom et al., 2006). Another consistent result is the low volume of large DWD (Green and Peterken, 1997; Siitonen, 2001). They were almost absent from youngest stands (<25-year-old) and no woody debris larger than 32 cm diameter were recorded in the present study. The volume of dead wood at decay stage I (fresh) was consistently low, probably because it represents a fleeting stage as noticed by Rouvinen et al. (2002). The dead wood from anthropogenic was highly predominant (averaging 77%). This proportion may be even underestimated since a higher proportion (99%) was observed in the fresh decay class. A fraction of the observed woody debris qualified as from natural origin may actually have originated from fragmentation of woody debris from anthropogenic origin.

Our study therefore tends to confirm that a typical profile of dead wood abundance and composition is prevalent in plantation forests, combining a volume of 5–15 m^3/ha, a rarity of snags and a majority of branches and logs of small diameter, as well as a predominant anthropogenic origin.

4.2. Dynamics of dead wood accumulation in plantation forests

As observed in previous studies carried out in managed forests there is a clear trend of increasing volume of deadwood with increasing stand age (Duvall and Grigal, 1999; Fridman and Walheim, 2000; Rouvinen et al., 2002). However, in maritime pine plantations, the temporal accumulation of CWD depicts a unimodal convex pattern rather than the general U-shaped pattern observed in previous studies (Sturtevant et al., 1997; Ranius et al., 2003) since the volume of dead wood in very young maritime pine plantations was at a minimum. This is likely the result of the intensive site preparation that precedes afforestation. To prevent seedlings attacks by the pine weevil *Hylobius abietis*, the plantation is often postponed for 2–3 years after final harvesting. During this period woody debris, resulting from the previous final clear-cut, start decaying. Later they are often entirely destroyed by ploughing operations. The destruction of late decay CWD by harvesting machinery has already been reported (Ehnström, 2001). Hautala et al. (2004) showed that following tree cutting and soil scarification, ca. 70% of the pre-treatment volume of CWD was destroyed. In the red pine forests of the Great Lakes states, the volume of CWD at stand initiation is 80% lower in managed than in unmanaged forests (Duvall and Grigal, 1999). In maritime pine plantations, the final cutting disturbance is therefore more similar to a re-set than to a major pulse of dead wood.

We observed dead wood from natural origin in the sampled stands but we did not try to develop a model to predict its accumulation over time. This type of dead wood may originate from natural pruning, competition between neighbouring trees but more likely from windstorm impacts. The importance of one-tree windthrow has already been stressed in other coniferous plantations (Green and Peterken, 1997; Kirby et al., 1998). However such events remain very difficult to include in a predictive model as they are stochastic in essence. Some authors attempted to do it through a Weibull function (Montes and Cañellas, 2006) or by carrying out stochastic simulations (Ranius et al., 2003). However it probably is not worth the effort in maritime pine plantation forest as the dead wood from natural origin represents less then 25% of the total volume. Lastly, sanitary measures are often taken after big storms in order to reduce breeding substrate for bark beetles, thus reducing the main source of dead wood from natural origin.

Thinning operations are often acknowledged to contribute the most to deadwood recruitment in managed forests (Spies and Franklin, 1988; McCarthy and Bailey, 1994; Montes and Cañellas, 2006). It is obviously the case in maritime pine plantations. The peak of deadwood abundance observed after the third thinning is well predicted by our model. During the first part of the rotation cycle, the time duration between two successive thinnings is probably too short (5–7 years) to let most of the residues decompose, leading to an accumulation of woody debris. After the fourth thinning and until the final clear-cut, there is a long period of time, ca. 15–20 years, with no more anthropogenic inputs of deadwood while decay processes can last longer. The total amount of woody debris therefore logically decreased during the final part of the forestry cycle. Both the observed pattern and our simulating data therefore confirmed the prevalence of silvicultural operations as a key factor in deadwood dynamics.

The logistic function, or similar growth functions like the Gompertz and the Chapman–Richard's functions, performed well in describing the decay process as already showed in other studies (Makinen et al., 2006; Montes and Cañellas, 2006; Vanderwel et al., 2006). They consistently show a slow initial decomposition, followed by a period of rapid decay and finally again by a period of slow decomposition. According to Brown et al. (1996), the average lifetime for *P. pinaster* deadwood in Western Australia, where a Mediterranean climate occurs, is 60 years for pieces ranging from 3 to 15 cm in diameter. With 99% of the volume degraded within 22 and 28 years for DWD and for stumps, respectively, the decomposition appeared to be faster in the south-western part of France. This may be due to warmer and more humid conditions in south-west France as climate seems to influence the decay rate (Harmon et al., 1986). It also may be due to difference in the size distribution of woody debris since most pieces of dead wood observed in our study had a diameter smaller than 15 cm, and half of the total volume of dead wood was produced by pieces with a diameter ranging from 1 to 5 cm. Small pieces are usually degraded faster than large ones (Brown et al., 1996; Montes and Cañellas, 2006; Vanderwel et al., 2006). The results of our modelling seem to corroborate these assumptions as stumps, which are both larger and better protected in the soil than DWD lying on the ground, take more time (6 years on average) to decompose. Anyway, the duration of the decomposition process suggests that final clear-cut should not occur before 30 years after the last thinning operation. Otherwise the entire wood decomposition process would not be achieved, resulting in a lack of suitable breeding habitat for late-successional saproxylic species (i.e. species occurring in very advanced decay stages).

Some models predict the volume of dead wood according to the size and the decay stage (Ranius et al., 2003; Montes and Cañellas, 2006; Vanderwel et al., 2006). They are probably more informative but also more difficult to develop. They require reliable information on the residence time for each decay stage and each class of diameter that needs long-term surveys (Ranius et al., 2003). Our model is thus a first encouraging step toward a modelling of dead wood in pine maritime plantations. It proved to be a promising predictive tool for the volume of downed dead wood and stumps. However, we should acknowledge that its validity domain is restricted to the part of the forest cycle ranging from ca. 15 to 60 years, i.e. from the first thinning operation to just before the final clear-cut.

In the present study, the mean volume of anthropogenic dead wood increased with the site index. To disentangle the respective effect of site fertility and stand management it would have been informative to test the correlation between the volume of dead wood and the volume of standing trees in natural stands of maritime pine. Unfortunately natural or old-growth *P. pinaster* forests are not anymore available in the study area. Nevertheless, because the main objective of plantation forest is to maximize biomass production, whatever the cause of productivity (site conditions or intensive management), our study indicates that it will eventually result in increased production of dead wood, as a by-product. Intensification of forest management may then paradoxically benefit to saproxylic organisms as long as logging residues are left within the stand and are not exported for further use such as biofuel. Taking into consideration the main effects of silvicultural itineraries, i.e. thinning regimes according to site indices, our model may help predict the effects of alternative forestry practices on dead wood accumulation in pine plantation forests.

Overall the abundance of dead wood is low in the pine plantations of the Landes de Gascogne. The lack of woody material lying on the ground may help limit the risk of fire in warm climate conditions. In contrast the small volume (ca. 5 m^3/ha) and the scarcity of snags and large logs may be problematic for saproxylic species. It has been suggested that they would need at least 20 to 30 m^3/ha of CWD (Okland et al., 1996; Martikainen et al., 2000; Angelstam et al., 2003), and even 70 m^3/ha for some demanding species (Siitonen and Saaristo, 2000) to survive. A better knowledge of local saproxylic assemblages and species conservation values is therefore needed to balance the risks and benefits from dead wood accumulation in plantation forests. Once the ecological requirements of deadwood dwelling species are known, such as the volume and the diversity of woody debris, our model may be used as a simulation tool to adapt forestry practices in order to enable wood production while maintaining biodiversity, two of the main objectives of sustainable forest management.

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ANNEXE 3

Species variables or environmental variables as indicators of forest biodiversity: a case study with saproxylic beetles in maritime pine plantations

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Abstract

For the assessment of sustainable management in plantation forests we aimed at developing biodiversity indicators. We used the species richness of saproxylic beetles as an example to test the "species" and "environmental" approaches. We compared single species abundance or occurrence and deadwood volume or diversity as predictor variables.

Beetles were sampled with flight interception traps in 40 maritime pine plantation stands. The volume and diversity of deadwood was estimated with line intersect and plot sampling in the same stands. Predictive models were built with simple linear or Partial Least Square regressions.

Deadwood variables appeared to be good predictors of saproxylic beetle richness at the stand-scale with at least 75% of variance explained. Deadwood diversity variables consistently provided better predictive models than volume variables. The best environmental indicator was the diversity of deadwood elements larger than 15cm in diameter.

By contrast, the use of "species variables" appeared to be less relevant. To reach the quality of prediction obtained with "environmental variables", the abundance or occurrence of 6 to 7 species – some of which are difficult to identify – had to be used to build the indicator.

Keywords : Indicator / biodiversity / saproxylic beetles / maritime pine

Approche directe ou indirecte pour les indicateurs de biodiversité en forêt: l'exemple des Coléoptères saproxyliques dans les plantations de pin maritime

Résumé

Pour améliorer le suivi de la gestion durable des forêts de plantation, nous avons cherché à développer des indicateurs de biodiversité en prenant pour exemple la richesse en Coléoptères saproxyliques. Nous avons comparé l'approche directe, basée sur l'abondance ou l'occurrence de certaines espèces de Coléoptères saproxyliques, et l'approche indirecte, basée sur les caractéristiques du bois mort comme variables prédictives.

Les Coléoptères ont été inventoriés à l’aide de pièges à interception dans 40 peuplements de pin maritime. Le volume et la diversité des pièces de bois mort ont été estimés à l'aide d'un échantillonnage par transects ou par placettes dans les mêmes plantations. Les modèles prédictifs ont été construits à l'aide de régressions linéaires simples ou PLS.

Les variables locales de bois mort apparaissent comme de bons prédicteurs de la richesse spécifique en Coléoptères saproxyliques, avec jusqu'à 75% de la variance expliquée. Les variables de diversité du bois mort semblent de meilleurs prédicteurs que les variables volumiques. Le meilleur indicateur "indirect" pourrait être la diversité des pièces de bois mort de diamètre supérieur à 15cm.

En revanche, le recours à des indicateurs "directs" semble moins prometteur. Pour obtenir une qualité de prédiction équivalente à l’approche indirecte, il faudrait prendre en compte l'abondance ou l’occurrence d'au moins 6 ou 7 espèces dont certaines sont difficilement identifiables.

Mots-clés : Indicateur / biodiversité / Coléoptères saproxyliques / Pin maritime

Introduction

Policy makers, forest managers and stakeholders require instruments to evaluate progress towards implementing sustainable forest management. Nine major inter-governmental processes or initiatives, involving more than 150 countries, have so far developed sets of criteria and indicators for assessing the sustainability of forest management. In Europe, the Ministerial Conferences for the Protection of Forests have proposed six criteria that relate to key elements of sustainability (MCPFE, 2003). In particular the fourth criterion deals with the "maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems".

However, biodiversity is extremely difficult to quantify and repeatedly monitor, thus to meet the fourth criteria for biodiversity, relevant indicators have to be developed (Duelli and Obrist, 2003). Ideally a biodiversity indicator should be correlated or a surrogate of biodiversity that is able to provide a continuous assessment, sufficiently sensitive to detect changes early on, widely applicable, easy and cost-effective to measure, collect or calculate (Noss, 1990). Usually no single indicator possesses all these qualities and a set of complementary indicators are required to help assess biodiversity changes (Hansson, 2001).

Usually two main ways are proposed to develop forest biodiversity indicators (Larsson et al., 2001) qualifying “species” (or “direct”) indicators and “environmental” (or “indirect”) indicators. The “species” indicator is a descriptor of a particular component of the biodiversity and it derives from direct measures of biodiversity per se. For example, species richness of a taxonomic group, diversity indices, abundance or occurrence of single or a group of species can be significantly correlated with the total species richness (Lindenmayer et al., 2000).

The second type of indicators relies on the assumption that there are key driving factors of biodiversity in forest ecosystems. For example structural factors such as canopy openness can control for microclimatic stand conditions which ultimately influence the diversity of understorey vegetation. Measures of these driving factors can be used as “environmental” indicators of biodiversity.

Nine “environmental” indicators of forest biodiversity have been adopted by the MCPFE scheme, among which is the "volume of standing and lying deadwood" (MCPFE 2003). The latter also belongs to the Streamlining European 2010 Biodiversity Indicators or SEBI 2010 (EEA, 2007). The main rationale behind the selection of this particular indicator is that 20 to 25% of forest-dwelling species depend on deadwood (Elton, 1966; Stokland and Meyeke, 2008). Species which, during some part of their life cycle, depend on deadwood, wood-rotting fungi or on other saproxylic species are termed saproxylic (Speight, 1989). Several studies have demonstrated a significant positive correlation between the amount of deadwood and the species richness of saproxylic beetles (Økland et al., 1996; Martikainen et al., 2000; Grove, 2002; Sippola et al., 2002; Similä et al., 2003; Jacobs et al., 2007; McGeoch et al., 2007), wood-inhabiting fungi (Bader et al., 1995; Pentillä et al., 2004; Stokland et al., 2004; Similä et al., 2006), mammals or birds (Mac Nally et al., 2001). Nevertheless, some authors pointed out that the diversity of deadwood (type, dimension and decay stage) are equally important for species diversity, particularly for saproxylic beetles, as it represents the variety of possible microhabitats (Siitonen, 2001; Similä et al., 2003; Ranius and Jonsson, 2007). Therefore, the “volume of deadwood” indicator might be improved by also taking into account the quality of deadwood as suggested by Schlaepfer and Bütler (2004). Stokland et al. (2004) have validated the ability of several deadwood descriptors to predict species richness of threatened fungi species in Norwegian forests. They call for similar studies to be carried out on other saproxylic organisms across a wide range of forests types. To our knowledge, such investigations have never been conducted in southern European forests.

However, the relevance of deadwood as biodiversity indicator in any kind of forest ecosystems has been criticized by several authors (Noss, 1990; Failing and Gregory, 2003). They questioned its interest in forests that are subject to frequent fires and where deadwood is generally not a naturally occurring structural element such as. One may also argue that few saproxylic species can live in planted forests since the intensive management of plantations, including ploughing and understorey tending, can considerably reduce the amount and persistence of deadwood. However a large-scale assessment of planted forests biodiversity in Britain showed that many deadwood quantity and quality is still an important driving factor for many species of lichens, bryophytes and fungi (Humphrey et al., 2002). Smith et al. (2008) also found strong relationships between the volume of coarse woody debris and saproxylic hoverflies diversity in plantation forests. Recently we also found that deadwood averaged 15 m^3/ha and was present throughout a cultivated forestry cycle in maritime pine plantations of south-western France (Brin et al., 2008). But to our knowledge, there are no references about saproxylic beetle biodiversity in such forest plantations.

Saproxylic species use a large range of microhabitats some of which are not easy to inventory such as fungus fruiting bodies, bark loss, dead branches on standing trees etc. The presence or abundance of some single saproxylic species may then provide interesting information on assemblages associated with such microhabitats. However, so far the “species” indicator approach for the assessment of saproxylic beetle species richness in forest has led to contrasting results. The presence of *Osmoderma eremita* has been successfully tested by Ranius (2002) as an indicator of beetles species richness in oak hollows. The presence of another saproxylic beetle, *Cerambyx cerdo* may be also considered as an indicator of species-rich assemblages of beetles in oak forests (Buse et al., 2008). But according to Sætersdal et al. (2005) who investigated the nestedness of assemblages and Similä et al. (2006) who used the richness of indicator groups (i.e. rare or threatened species) there would be no clear evidence for suitable species indicators of saproxylic beetle diversity.

Thus, for saproxylic species diversity, the question remains whether it is better to use deadwood or some key species as an indicator. To help answer this question, we developped a study on saproxylic beetles, which represent about 20% of saproxylic species (Stokland and Meyeke, 2008). Our investigations concerned intensively managed forest plantations of maritime pine. The main objectives were:

1. To relate saproxylic beetles richness to deadwood descriptors in order to test “environmental” indicators.
2. To identify saproxylic beetle species, the abundance or occurrence of which is correlated to species richness, in order to test “species” indicators.
3. To compare “species” and “environmental” indicators on the basis of their prediction ability and cost-effectiveness.

Material and methods

Study area and sample design

The Landes de Gascogne forest is located in south-western France and represents the largest artificial forest of Europe (1 million ha) (Fig.1). It is an intensively managed plantation of maritime pine (*Pinus pinaster* Ait.), a native species in this region. Current silvicultural practices are characterized by pure, even-aged stands with clear-cut harvesting at ca 40-50 years, mechanical soil preparation and fertilising, frequent thinning, pruning and mechanical removal of the understorey vegetation.

A total of 40 maritime pine stands were sampled within an area of 64 km^2 (8 x 8 km) along a systematic grid with sampled stands arranged in staggered rows. Sampled stands were separated by 2 km along grid lines and by 1.4 km with regards to the diagonal of the staggered row design. In our study the stand surface averaged 17 ha (± 9 ha) and stand age ranged from 5 to 61 years-old.

Sampling of woody debris

Dead wood with a diameter 1cm at least was measured during autumn 2005. downed woody debris were inventoried using the Line Intersect Sampling (LIS) method (De Vries, 1973; Marshall et al., 2000). Downed woody debris larger than 5 cm in diameter were sampled on four 25m long transects, whereas smaller pieces assessed on four 5m long sub-transects. Data from all transects per stand were pooled for statistical analysis. Stumps were inventoried on 5 lines of 20 meters along tree rows (ca. 360 m²) or in a circular sub-plot of ca. 710 m² (15 m radius) if tree rows were not apparent (old stands). On all snags the height and diameter at breast height were measured in two circular sub-plots in each stand, one based on the French National Forest Inventory protocol, the second sub-plot consisting of a fixed number of 20 living trees encountered in a spiral-walk. The stage of decomposition of any type of deadwood was qualified according to three classes: (I) fresh, (II) initial decay, (III) advanced decay. We also recorded to which tree species belonged the pieces of deadwood. Further details on deadwood sampling and volume computations are provided in Brin et al. (2008).

Beetles sampling

Beetles were sampled with Polytrap™ which is a manufactured window trap. Each trap consisted of two transparent plastic panes (40 x 60 cm) placed crosswise, with a funnel and a container below the panes. The containers were filled with salt water and some detergent to ensure insect preservation. Two traps were place about 30 m apart, in each sampled stand, for a total number of 80. The trapping period was 10 May – 30 August 2005. Traps were assessed four times during that period. For Coleoptera families comprising saproxylic species, we identified all individuals to the species level, except for the Corylophidae. Families and species were classified as saproxylic or not according to a life history traits database

(FRISBEE) developed by Bouget et al. (2008). As dead wood was mainly of maritime pine (99%, unpublished), we excluded species that cannot develop on dead pine wood from our further analyses (16% of saproxylic species).

Data analysis

The two traps in each location were pooled together to be considered one sample. The number of species caught per plot was used as a measure of species diversity. We chose not to standardize species richness according to the sample size (by using rarefaction techniques). Since the samples were collected with a standard trapping effort we considered that differences in the numbers of individuals caught between sample plots reflect real differences in the abundance of flying beetles.

First the volume of deadwood was calculated for each combination of type (downed, stumps, snags), decay stage (I, II, III) and diameter classes (1-2.5 cm, 2.6-5 cm, 5.1-10 cm, 10.1-15 cm, 15.1-20 cm, >20 cm), thus providing 54 independent volume descriptors (Tab. 1).

An index of deadwood diversity (D_{tot1}) was calculated as the number of observed combinations formed by the three types (downed, stumps, snags), the three decay stages (I, II, III) and the six diameter classes from 1cm (1-2.5 cm, 2.6-5 cm, 5.1-10 cm, 10.1-15 cm, 15.1-20 cm, >20 cm), as suggested by Siitonen et al (2000). Theoretically, D_{tot1} values ranged from 0 to 54. In practice, D_{tot1} equaled 54 in one stand if at least one piece of deadwood was observed in each of the 54 categories. We computed 3 other diversity indices: D_{ddw1}, D_{sng1} and D_{stp1} for the diversity of downed woody debris, snags and stumps, respectively. Their values ranged from 0 to 18. We calculated the same four indices for diameter classes above 10, 15 and 20 cm, respectively. In total we produced sixteen deadwood diversity descriptors (Tab. 1).

Partial Least Square (PLS) regressions were used to relate saproxylic beetle richness to predictor variables such as dead wood descriptors (Tab. 1), abundance or occurrence of single species. PLS computes latent variables similar to principal components, but in a way that ensure a good representation of predictor variables and a high correlation with the response variable (Tenenhaus, 1998). This method is a suitable substitute for multiple linear regressions in applications that deal with numerous and correlated predictor variables. Another advantage of the PLS regression is to provide information about the relative influence of each predictor, the variable importance in the projection (VIP). Predictors with a VIP-value > 1 are considered the most relevant to explain variation in the response variable (Tenenhaus, 1998). A more parsimonious model can then be computed by using only these "important" variables. To assess how many components are optimal for the model, we plot the root mean squared error of prediction (RMSEP) against the number of components so as to identify the number of components corresponding to the first local minimum of the RMSEP (Mevik and Wehrens, 2007). The PLS-regression is increasingly used in ecological studies both for dealing with multicollinearity and identifying important variables (Johansson and Nilsson, 2002; Schmidtlein and Sassin, 2004; Ekblad et al., 2005; Sarthou et al., 2005).

Concerning the "environmental" indicator approach, the search for predictive models was conducted in several steps. We first considered different subsets of all possible deadwood volume and diversity variables for four minimum diameter thresholds (i.e. 1, 10, 15 and 20 cm). For each subset a first PLS-regression was computed to give a "complete" model and to identify the most relevant predictors (VIP>1). Those variables were then used to build two parsimonious models for each of the four diameter thresholds. The first one was constituted by all relevant predictors, and the second one, called "diversity model", only used the diversity variables. As the "diversity model" based on the 15 cm diameter threshold appeared to be the most promising, we went further into the simplification by progressively excluding types (stumps, downed woody debris or snags) or decomposition stages in the set of diversity variables.

We also performed four simple linear regressions with the four most relevant single variables (i.e. volume or diversity of deadwood larger than 1 cm in diameter and volume or diversity of deadwood larger than 15 cm in diameter).

The root mean squared error of prediction (RMSEP) and the coefficient of determination (R^2) were used as performance criteria to compare models. We aimed at reducing the RMSEP and increasing R^2. Our dataset was not large enough to allow an estimation of the RMSEP with an independent test set. We therefore used an internal estimation method, the leave-one-out cross-validation. This method is widely used and recommended for the estimation of the RMSEP (Mevik and Cederkvist, 2004).

For the "species" indicators approach, analyses were carried out considering two steps for both abundance and occurrence (i.e. presence / absence) data. First, we performed a PLS-regression to relate saproxylic species richness to the abundance (or occurrence) of the 93 species that occurred in at least 3 stands (Appendix). The complete model with the 93 independent variables was used to select variables with VIP-value equal or greater than 1. Then, we computed several parsimonious models with groups of a decreasing number of explanatory variables; groups were separated according to dramatic decreases visually noticeable in the histogram of VIP-values.

All analyses were performed with R software (R Development Core Team, 2008) using the pls package (Wehrens and Mevik, 2007).

Results

Beetle sample overview

A total of 12 669 individual beetles were caught. Of these, 7244 individuals were saproxylic beetles belonging to 240 species and 46 families. Half of the species were represented per one or two individuals. Our analyses focused on the 201 saproxylic species that can develop in dead wood of pine. The average number of species per plot was 32.5 (CV=26.6%), ranging from 19 to 63.

Relationships between deadwood attributes and species richness of saproxylic beetles

Among the 18 PLS models computed, the one constructed with all deadwood descriptors for wood above 15 cm in diameter appeared to explain the largest fraction of variance of saproxylic beetle species richness (R^2=0.75) (Tab.2). We therefore focused on this set of independent variables to look for more parsimonious models. Two models were of interest: one with the 10 variables that showed a VIP value higher than 1 and the second, with only the four "diversity" variables (Tab.2). The same value of RMSEP (5.4) was observed for these two models. Both of them explained an important fraction of the species richness deviance with an R^2 of 0.68. Further reduction in the number of variables entered in the model resulted in higher RMSEP and lower R^2.

Among the linear regression models with single predictor variables (Fig.3 and Fig.4), the one based on the diversity index of all pieces of deadwood above 15 cm in diameter had the lowest RMSEP (5.8) with also the best R^2 (0.63) (Fig.4b).

Relationships between single species abundance or occurrence and species richness of saproxylic beetles

The complete model with 93 single species abundance variables allowed to identify 26 variables with VIP higher than 1. The model built with these selected species had good predicting performances (RMSEP = 4.6, R^2 = 0.82, Tab.3). A model including the abundance of 6 different species (Tab.3) reached a slightly better explanatory level than those obtained with “environmental” variables (i.e. R^2=0.71) for similar RMSEP (ca. 5.3).

The complete model with 93 species occurrence variables allowed to identify 31 variables with VIP higher than 1. The model built with these selected species had good predicting performances (RMSEP = 4.3, R^2 = 0.82, Tab.4). A model including the occurrence of 7 different species (Tab.4) reached an explanatory level similar to those obtained with "environmental variables" indicators (i.e. $R^2=0.67$) for similar RMSEP (ca. 5.5).

Sampling cost

The time required for sampling deadwood in maritime pine plantations ranged from 20 to 135 min per sampling unit and averaged 52 min for two people involved, giving ca. 100 min for one person. It took almost 200 min for one person to assess the two window traps in each sampled stand and an additional time of ca. 200 min was needed to sort out and identify saproxylic beetle species. All in all the time spent to get the list and abundance of saproxylic beetle species captured in one stand reached ca. 400 min for one person.

Discussion

"Species" indicators

Single species variables (abundance or occurrence) may be of interest to provide an indicator of saproxylic beetle species richness as only 6 to 7 species suffice to get a predictive ability similar to those obtained with environmental variables (Tab.2, Tab.3 and Tab.4). However, even though some of these species are easy to recognize (e.g. large species such as *Prionus coriarius, Hylobius abietis, Arhopalus rusticus, Spondylis buprestoides*) most of them can only be identified by trained entomologists (e.g. *Hylis olexai, Crypturgus cinereus, Anisotoma humeralis*). This technical difficulty is a critical drawback of the "species" indicator approach. As a matter of fact, the two saproxylic beetle species that have been proposed so far for indicating species rich assemblages in oak forests (*Osmoderma eremita* and *Cerambyx cerdo*) were easy to catch and identify (Ranius, 2002; Buse et al., 2008). The list of saproxylic beetles suggested by Nilsson et al. (2001) as potential indicators of biodiversity in northern European forests focused on species that were easy to identify.

Furthermore, the time spent trapping, identifying and counting individual species of saproxylic beetle was four times higher than the time spent sampling deadwood at the stand level. Even if one just wants to focus on some particular single species in the samples, all individual specimens will have to be sorted out to find the smallest species such as *Crypturgus cinereus* (2 mm length) or *Anisotoma humeralis* (4 to 5 mm length). Decreasing the number of individual species in predictive models would therefore not result in a proportional time reduction.

"Environmental" indicators

In the sampled pine plantations, deadwood attributes at the stand-scale appeared to be good predictors of the saproxylic beetle richness with at most 75% of variance explained (Tab.2). There are contrasting results on the relevance of physical variables to saproxylic species richness. Whereas positive correlation between the volume of deadwood and saproxylic beetle richness at the plot level have been often observed (Grove, 2002, Martikainen et al., 2000; Sippola et al., 2002; Similä et al., 2003; McGeoch et al., 2007); several authors found no relationships between the local amount of deadwood and the richness of saproxylic beetle assemblages (Siitonen, 1994; Økland, et al., 1996; Similä, et al., 2006; Franc et al., 2007). Likewise, a part of species richness variance remained unexplained by the predictive models in this study. As shown by the intercept value of the linear regressions (Fig. 3a and Fig.4a) a minimum of 20 to 28 saproxylic beetle species were observed irrespective to the local abundance of deadwood. Several reasons may account for these discrepancies. In the cited studies, what is considered as local scale referred to a broad range of sampled surfaces, from 0.01ha to 2 ha. Interestingly, all positive and significant effects of the local amount of deadwood on saproxylic beetle richness were observed at a scale comprised between 0.5 ha and 1 ha (Grove, 2002; Martikainen et al., 2000; Sippola et al., 2002). By contrast no or weak effects were detected at smaller scale (i.e. 0.01 ha and 0.16 ha) or at larger scale (i.e. 2 ha) (Siitonen, 1994; Økland et al. 1996; Similä et al., 2006; Franc et al., 2007). This sampling scale effect may reflect the dispersal capacities of flying saproxylic beetles. Saproxylic beetle communities encompass species with different dispersal abilities and traps can catch long distance flying beetles that did not originate from the sampled stand. The predominance of highly mobile species in the assemblage of sampled beetles may then result in poor correlation with local deadwood measurement (Nilsson and Baranowski, 1997; Jonsson et al., 2005). Moreover, in maritime pine forest, it has been shown that stand but also landscape variables had to be taken into account to interpret local species assemblages of birds, carabids, spiders (Barbaro et al., 2005) and butterflies (Van Halder et al., 2008). On the other hand, deadwood sampling methods may not be appropriate. If the sampled area is too small, the range in deadwood volume or diversity may be too narrow to allow identifying significant correlation with species richness (Similä et al., 2006). Some elements are also often overlooked, such as dead branches in tree crown, polypores or fallen cones that are also habitats for some saproxylic beetles (Winter and Möller, 2008). We therefore suggest combining local abundance of several deadwood compartments to variables measured at broader-scale, such as landscape heterogeneity or fragmentation, in order to develop relevant set of indicators for saproxylic beetle diversity.

One of the main advantages of the "environmental variables" approach is that it saves time in data collection. Furthermore, the best and most parsimonious models that we obtained were constructed by entering variables of volume or diversity of pieces of deadwood larger than 15cm in diameter. This finding may allow further reduction in the time spent on deadwood inventory since only large pieces would have to be considered.

The relationship between total volume or diversity of dead wood and beetle species richness appeared to be linear (Fig.3 and Fig.4). However the number of species cannot increase indefinitely with increasing amount or diversity of deadwood. Asymptotic models such as proposed by Martikainen et al. (2000) or Norden and Appelqvist (2001) are more ecologically sound. They are analogous to the species – area relationship (MacArthur and Wilson, 1967). Our linear model may then only account for the initial part of an asymptotic relationship. To test this hypothesis, investigations would have to be undertaken in stands with higher amount or diversity of dead wood.

An important outcome of this study is that deadwood diversity variables consistently provided similar, or even better, predictive models than volume variables. This is consistent with previous findings about the importance of deadwood quality for saproxylic assemblages (Similä et al., 2003, McGeoch et al., 2007). Diversity variables are probably more informative than abundance variables (i.e. volume per ha) as they may reflect the diversity of available habitats. Saproxylic species communities depend on a wide spectrum of different habitat requirements and the ability of saproxylic species to exploit deadwood as breeding substrate is often restricted to certain size, type or stages of decay (Jonsell et al., 1998; Siitonen, 2001; Schuck et al., 2004; Stokland, et al., 2004). The other interest of using diversity variables is that it can help reduce the time spent to sample deadwood since only the presence of deadwood pieces within each sub-category will have to be recorded instead of sampling them all and measuring all their diameters.

Implications for forestry and biodiversity monitoring

Stand-level indicators are useful because they correspond to the operational scale for forest managers (Failing and Gregory, 2003). An interesting feature of structure-based indicators such as deadwood volume is that they can be related to silvicultural operations. A model for predicting the volume of downed deadwood and stumps in pine maritime plantation was developed by combining inputs from thinning operations and loss with time (Brin et al., 2008). Now that significant correlation between volume of deadwood and saproxylic beetle species richness were found, deadwood accumulation can be used in a model to help predict the effect of alternative forestry practices on saproxylic beetles diversity. By doing so, one of the main expectations for sustainable forest management indicators, which is to allow for detecting changes in response to new management options will be met (Noss, 1990). For example, the model could be used for testing whether shortening the forestry cycle would result in a lower volume and diversity of deadwood through reduced number of thinning operations and interruption of the decay process.

It is important to acknowledge that one should not deduce from our datasets and analyses what the most important deadwood variables for the preservation of saproxylic beetle species richness are. As emphasized by Mac Nally (2000), predictive models should not be considered as explanatory models. PLS regressions are not appropriate to assess variables that are not important (Vancolen, 2004). In our dataset, some variables were excluded from parsimonious models due to lack of variance. Again further investigations are needed to sample deadwood and saproxylic beetles across a wider gradient of forestry conditions, for example in more ancient or less intensively managed maritime pine stands, in order to better identify significant explanatory variables.

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Table 1 Deadwood variables used for prediction of the species richness of saproxylic beetles (DWD: Downed Woody Debris).

Variable	Explanation	Theoritical range	Observed range
Volume descriptors			
Vddw_ij	Volume of DWD of diameter class “i” and decomposition stage “j” (m^3/ha)	-	0-16.2
Vstp_ij	Volume of stumps of diameter class “i” and decomposition stage “j” (m^3/ha)	-	0-6.85
Vsng_ij	Volume of snags of diameter class “i” and decomposition stage “j” (m^3/ha)	-	0-17.25
Diversity descriptors			
D_{tot1}	Diversity of all deadwood pieces with a minimum diameter of 1 cm	0-54	2-25
D_{ddw1}	Diversity of downed deadwood pieces with a minimum diameter of 1 cm	0-18	0-13
D_{stp1}	Diversity of stumps with a minimum diameter of 1 cm	0-18	0-10
D_{sng1}	Diversity of snags with a minimum diameter of 1 cm	0-18	0-2
D_{tot10}	Diversity of all deadwood pieces with a minimum diameter of 10 cm	0-27	0-16
D_{ddw10}	Diversity of downed deadwood pieces with a minimum diameter of 10 cm	0-9	0-6
D_{stp10}	Diversity of stumps with a minimum diameter of 10 cm	0-9	0-9
D_{sng10}	Diversity of snags with a minimum diameter of 10 cm	0-9	0-2
D_{tot15}	Diversity of all deadwood pieces with a minimum diameter of 15 cm	0-18	0-11
D_{ddw15}	Diversity of downed deadwood pieces with a minimum diameter of 15 cm	0-6	0-4
D_{stp15}	Diversity of stumps with a minimum diameter of 15 cm	0-6	0-6
D_{sng15}	Diversity of snags with a minimum diameter of 15 cm	0-6	0-2
D_{tot20}	Diversity of all deadwood pieces with a minimum diameter of 20 cm	0-9	0-5
D_{ddw20}	Diversity of downed deadwood pieces with a minimum diameter of 20 cm	0-3	0-2
D_{stp20}	Diversity of stumps with a minimum diameter of 20 cm	0-3	0-3
D_{sng20}	Diversity of snags with a minimum diameter of 20 cm	0-3	0-2

Table 2 Results of PLS regressions with deadwood volume and diversity variables as predictors of the species richness of saproxylic beetles (RMSEP: root mean squared error of prediction).

Minimum diameter	Models	Nb of variables	RMSEP	R^2	*P*
1 cm	All independent variables	34	6.2	0.74	0.941
	Important variables (VIP>1)	14	5.2	0.72	<0.001
	Diversity variables	4	6.2	0.57	<0.001
10 cm	All independent variables	23	5.8	0.74	0.080
	Important variables (VIP>1)	12	5.4	0.69	<0.001
	Diversity variables	4	5.8	0.62	<0.001
15 cm	All independent variables	23	5.7	0.75	0.013
	Important variables (VIP>1)	10	5.4	0.68	<0.001
	Diversity variables	4	5.4	0.68	<0.001
	Diversity variables without decomposition class n°1	4	5.7	0.63	<0.001
	Diversity variables without decomposition class n°2	4	6.5	0.54	<0.001
	Diversity variables without decomposition class n°3	4	5.9	0.63	<0.001
	Diversity variables without snags	2	5.8	0.64	<0.001
	Diversity variables without stumps	2	6	0.57	<0.001
	Diversity variables without downed dead wood	2	6.4	0.56	<0.001
20 cm	All independent variables	13	6.6	0.56	0.021
	Important variables (VIP>1)	8	6.3	0.59	<0.001
	Diversity variables	4	6.4	0.55	<0.001

Table 3: Results of PLS regressions with species abundance as predictors of the species richness of saproxylic beetles (RMSEP: root mean squared error of prediction). The number of independent variables (predictors) entered in the model is indicated in brackets.

Species	VIP	Model 1 (p=26)	Model 2 (p=23)	Model 3 (p=14)	Model 4 (p=11)	Model 5 (p=6)
Hylastes attenuatus	2.36	x	x	x	x	x
Hylis olexai	2.15	x	x	x	x	x
Prionus coriarius	2.13	x	x	x	x	x
Dacne sp.	2.11	x	x	x	x	x
Crypturgus cinereus	2.09	x	x	x	x	x
Hylobius abietis	2.08	x	x	x	x	x
Anisotoma humeralis	1.96	x	x	x	x	
Wanachia triguttata	1.96	x	x	x	x	
Arhopalus rusticus	1.92	x	x	x	x	
Rhagium inquisitor	1.89	x	x	x	x	
Stenagostus rhombeus	1.88	x	x	x	x	
Brachytemnus porcatus	1.77	x	x	x		
Aulonothroscus brevicollis	1.66	x	x	x		
Thanasimus formicarius	1.66	x	x	x		
Mesocoelopus niger	1.51	x	x			
Enicmus rugosus	1.50	x	x			
Hylurgus ligniperda	1.44	x	x			
Cetonia aurata	1.37	x	x			
Hylastes angustatus	1.36	x	x			
Magdalis memnonia	1.28	x	x			
Diaperis boleti	1.27	x	x			
Ptinus dubius	1.27	x	x			
Anaspis maculata	1.25	x	x			
Xyleborus saxesenii	1.06	x				
Spondylis buprestoides	1.05	x				
Berginus tamarisci	1.04	x				
	RMSEP	4.6	4.7	5.9	5.6	5.3
	R^2	0.82	0.79	0.71	0.73	0.71
	P	0.061	0.026	0.001	<0.001	<0.001

Table 4: Results of PLS regressions with species occurrence (presence/absence) as predictors of the species richness of saproxylic beetles (RMSEP: root mean squared error of prediction). The number of independent variables (predictors) entered in the model is indicated in brackets.

Species	VIP	Model 1 (p=31)	Model 2 (p=18)	Model 3 (p=7)	Model 4 (p=5)
Prionus corarius	2.55	x	x	x	x
Hylobius abietis	2.35	x	x	x	x
Arhopalus rusticus	2.28	x	x	x	x
Mycetophagus quadripustulatus	2.18	x	x	x	x
Spondylis buprestoides	2.16	x	x	x	x
Anisotoma humeralis	1.84	x	x	x	
Hylis olexai	1.81	x	x	x	
Dacne sp.	1.65	x	x		
Xyleborus saxesenii	1.65	x	x		
Stenagostus rhombeus	1.64	x	x		
Wanachia triguttata	1.63	x	x		
Hylastes attenuatus	1.57	x	x		
Mesocoelopus niger	1.54	x	x		
Thanasimus formicarius	1.51	x	x		
Cetonia aurata	1.50	x	x		
Crypturgus cinereus	1.47	x	x		
Hylastes angustatus	1.45	x	x		
Stagetus pilula	1.42	x	x		
Dasytes virens	1.29	x			
Dryophthorus corticalis	1.26	x			
Anidorus nigrinus	1.19	x			
Rhagium inquisitor	1.17	x			
Corymbia rubra	1.15	x			
Hemicrepidius hirtus	1.15	x			
Ampedus nigerrimus	1.13	x			
Hylurgus ligniperda	1.12	x			
Diaperis boleti	1.11	x			
Anastrangalia sanguinolenta	1.09	x			
Magdalis memnonia	1.04	x			
Aulonothroscus brevicollis	1.03	x			
Parabaptistes filicornis	1.00	x			
	RMSEP	4.3	4.4	5.5	6.0
	R^2	0.82	0.8	0.67	0.59
	P	0.433	<0.001	<0.001	<0.001

Appendix : Saproxylic beetle taxa used in PLS regression for "species" indicator.

Family	Species	No individuals
Aderidae	*Anidorus nigrinus* (Germar, 1842)	138
	Phytobaenus amabilis Sahlberg, 1834	16
Anobiidae	*Mesocoelopus niger* (P.W.J. Müller, 1821)	26
	Stagetus pilula (Aubé, 1861)	50
	Ptinus dubius Sturm, 1795	63
	Ptinus sexpunctata Panzer, 1795	21
Cerambycidae	*Anastrangalia sanguinolenta* (Linné, 1761)	8
	Arhopalus rusticus (Linné, 1758)	17
	Corymbia rubra (Linné, 1758)	83
	Prionus coriarius (Linné, 1758)	37
	Rhagium inquisitor (Linné, 1758)	7
	Spondylis buprestoides (Linné, 1758)	19
	Stenurella melanura (Linné, 1758)	18
Cerylonidae	*Cerylon ferrugineum* Stephens, 1830	7
	Cerylon histeroides (Fabricius, 1792)	15
Cleridae	*Allonyx quadrimaculatus* (Schaller, 1783)	9
	Thanasimus formicarius (Linné, 1758)	19
Colydiidae	*Endophloeus markovichianus* (Piller & Mitterpacher, 1783)	5
Cryptophagidae	*Atomaria testacea* Stephens, 1830	7
	Micrambe perrisi Brisout de Barneville, 1882	5
	Micrambe vini (Panzer, 1797)	12
Cucujidae	*Pediacus dermestoides* (Fabricius, 1792)	3
Curculionidae	*Brachytemnus porcatus* (Germar, 1824)	1801
	Hylobius abietis (Linné, 1758)	13
	Magdalis memnonia Gyllenhal, 1837	7
	Dryophthorus corticalis (Paykull, 1790)	142
	Crypturgus cinereus (Herbst, 1793)	14
	Hylastes angustatus (Herbst, 1793)	5
	Hylastes ater (Paykull, 1800)	3
	Hylastes attenuatus Erichson, 1836	49
	Hylurgus ligniperda (Fabricius, 1787)	12
	Orthotomicus erosus (Wollaston, 1857)	2
	Pityogenes bidentatus (Herbst, 1784)	4
	Pityophthorus pubescens (Marsham, 1802)	5
	Xyleborus saxesenii (Ratzeburg, 1837)	10
Elateridae	*Ampedus aurilegulus* (Schaufuss, 1862)	37
	Ampedus balteatus (Linné, 1758)	343
	Ampedus glycereus (Herbst, 1784)	24
	Ampedus nigerrimus (Lacordaire, 1835)	70
	Ampedus praeustus (Fabricius, 1792)	7
	Ampedus sanguineus (Linné, 1758)	3
	Brachygonus ruficeps (Mulsant & Guillebeau, 1855)	13

Family	Species	No individuals
Elateridae	*Cardiophorus goezei* Sanchez-Ruiz, 1996	356
	Hemicrepidus hirtus (Herbst, 1784)	218
	Melanotus crassicollis (Erichson, 1841)	382
	Melanotus villosus (Geoffroy in Fourcroy, 1783)	72
	Stenagostus rhombeus (Olivier, 1790)	10
Eucnemidae	*Hylis olexai* (Palm, 1955)	13
Latridiidae	*Cartodere nodifer* (Westwood, 1839)	5
	Corticarina fuscula (Gyllenhal, 1827)	3
	Corticarina similata (Gyllenhal, 1827)	9
	Cortinicara gibbosa (Herbst, 1793)	60
	Enicmus histrio Joy & Tomlin, 1910	9
	Enicmus rugosus (Herbst, 1793)	117
	Melanophthalma distinguenda (Comolli, 1837)	16
	Melanophthalma fuscipennis (Mannerheim, 1844)	6
Leiodidae	*Agathidium rotundatum* (Gyllenhal, 1827)	10
	Anisotoma castanea (Herbst, 1792)	104
	Anisotoma humeralis (Fabricius, 1792)	13
Melandryidae	*Dircaea australis* Fairmaire, 1856	4
	Wanachia triguttata (Gyllenhal, 1810)	5
Melyridae	*Aplocnemus impressus* (Marsham, 1802)	26
	Dasystes pauperculus Laporte de Castelnau, 1840	3
	Dasytes virens (Marsham, 1802)	14
	Attalus analis (Panzer, 1796)	17
	Axinotarsus marginalis (Laporte de Castelnau, 1840)	42
Monotomidae	*Rhizophagus bipustulatus* (Fabricius, 1792)	3
Mordellidae	*Tolida artemisae* Mulsant & Rey, 1859	27
Mycetophagidae	*Berginus tamarisci* Wollaston, 1854	87
	Mycetophagus quadripustulatus (Linné, 1761)	98
	Parabaptistes filicornis (Reitter, 1887)	38
Oedemeridae	*Chrysanthia geniculata* (W. Schmidt, 1846)	9
	Chrysanthia viridissima (Linné, 1758)	637
	Nacerdes carniolica atlantica Allemand, 1993	5
	Oedemera flavipes (Fabricius, 1792)	50
Scarabaeidae	*Cetonia aurata* (Linné, 1761)	8
Scraptiidae	*Anaspis frontalis* (Linné, 1758)	36
	Anaspis maculata (Fourcroy, 1785)	332
Silvanidae	*Uleiota planata* (Linné, 1761)	7
Sphindidae	*Aspidiphorus lareyiniei* Jacquelin du Val, 1859	540

Family	Species	No individuals
Staphylinidae	*Atheta crassicornis* (Fabricius, 1792)	50
	Platydracus fulvipes (Scopoli, 1763)	3
	Scaphisoma agaricinum (Linne, 1758)	8
	Sepedophilus testaceus (Fabricius, 1793)	3
	Stichoglossa semirufa (Erichson,1839)	3
Tenebrionidae	*Clamoris crenata* (Mulsant, 1854)	45
	Diaperis boleti (Linné, 1758)	4
	Hymenalia rufipes (Fabricius, 1792)	25
	Nalassus laevioctostriatus (Goeze, 1777)	38
	Prionychus fairmairei (Reiche, 1860)	17
	Uloma rufa (Piller & Mitterpacher, 1783)	3
Throscidae	*Aulonothroscus brevicollis* (de Bonvouloir, 1859)	5
Trogossitidae	*Nemozoma elongatum* (Linné, 1761)	4

Figure 1: Location of the study area in south-western France.

Figure 2: Sampling design of deadwood at the stand level (DWD: downed woody debris) and position of the two window traps.

Figure 3: Simple linear regressions of saproxylic beetle species richness against the volume (a) and the diversity (b) of deadwood (diameter above 1 cm) (RMSEP: root mean squared error of prediction).

Figure 4: Simple linear regressions of saproxylic beetle species richness against the volume (a) and the diversity (b) of deadwood (diameter above 15 cm) (RMSEP: root mean squared error of prediction).

Figure 1

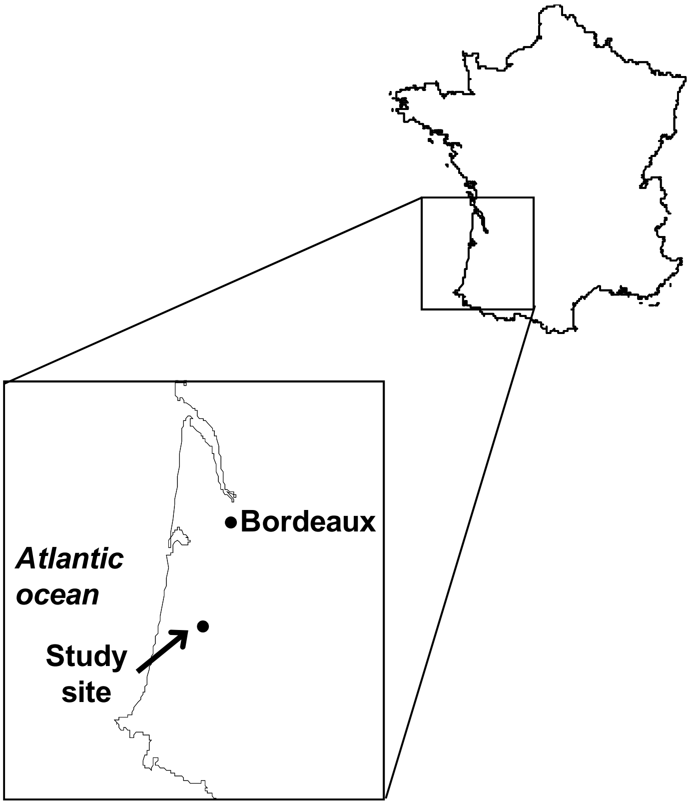


Figure 2

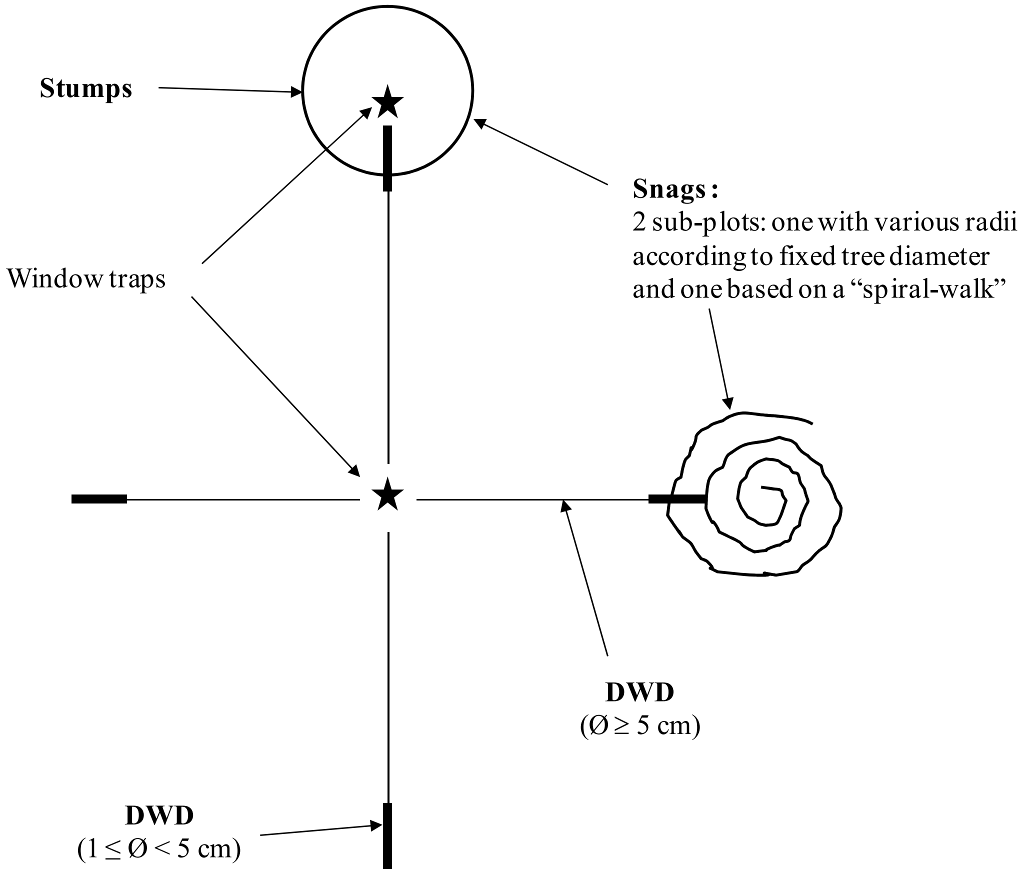

Stumps
Window traps
Snags:
2 sub-plots: one with various radii according to fixed tree diameter and one based on a "spiral-walk"
DWD
(Ø ≥ 5 cm)
DWD
(1 ≤ Ø < 5 cm)

Figure 3

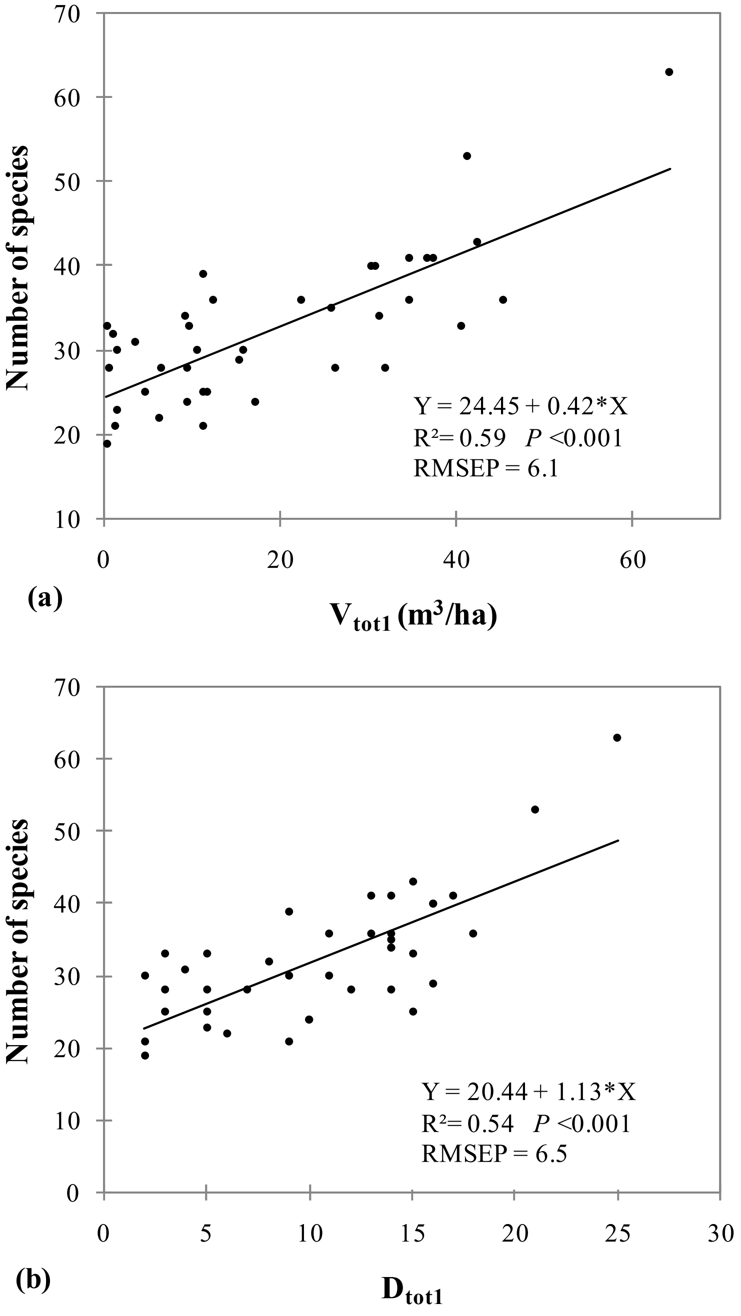
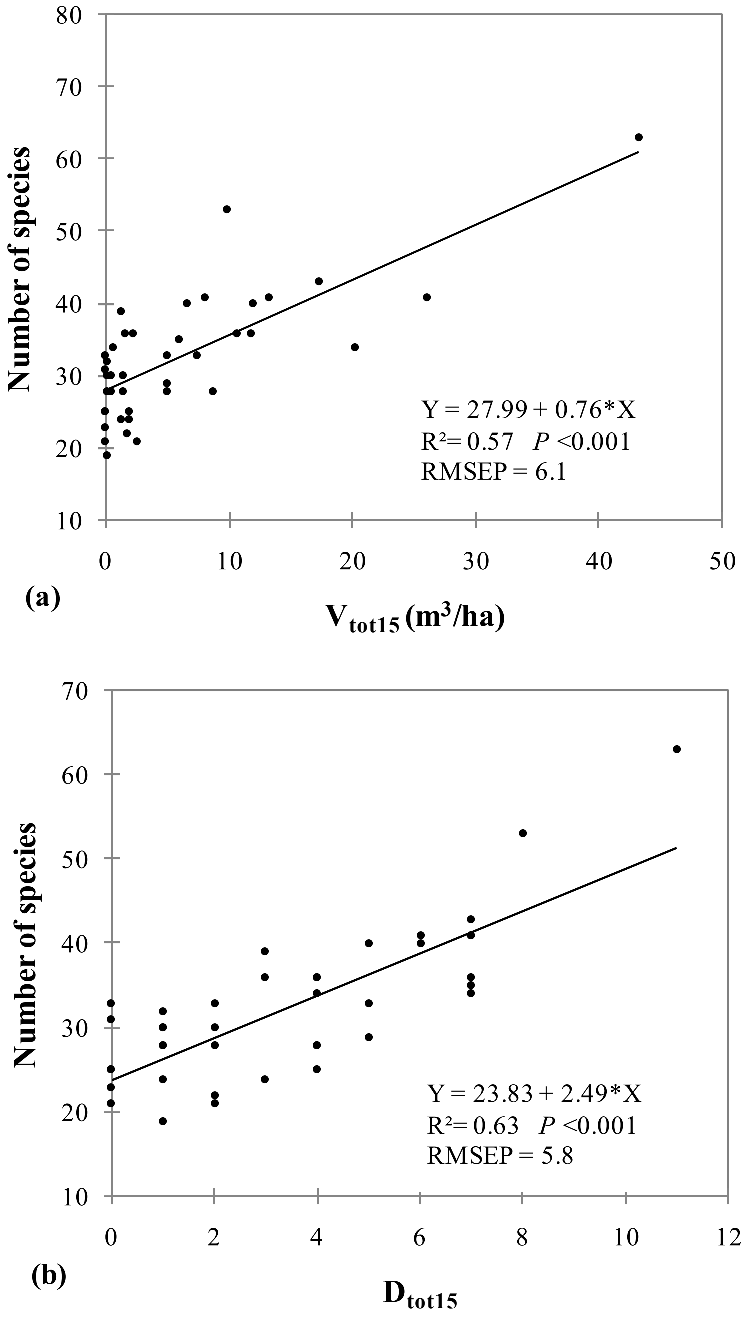

70
60
50
40
30
20
10
Number of species
Y = 24.45 + 0.42*X
R² = 0.59 P <0.001
RMSEP = 6.1
0
20
40
60
(a)
V_{tot1} (m³/ha)
70
60
50
40
30
20
10
0
Number of species
Y = 20.44 + 1.13*X
R² = 0.54 P <0.001
RMSEP = 6.5
0
5
10
15
20
25
30
(b)
D_{tot1}

Figure 4


80
70
60
50
40
30
20
10
Number of species
Y = 27.99 + 0.76*X
R²= 0.57 P <0.001
RMSEP = 6.1
0
10
20
30
40
50
(a)
V_tot15 (m³/ha)
70
60
50
40
30
20
10
Number of species
Y = 23.83 + 2.49*X
R²= 0.63 P <0.001
RMSEP = 5.8
0
2
4
6
8
10
12
(b)
D_tot15

ANNEXE 4

8th ESA conference, Research network 12 : Environment and Society, University of Glasgow, 3-6 september 2007, Deadwood for biodiversity or energy savings ? An environmental dilemma for foresters, Philippe DEUFFIC[1]

(Work in progress)

Biodiversity, a public environmental problem ?

In France, social surveys regularly show that environmental concerns are coming eighth or ninth, position far behind unemployment, insecurity or health.

But the public continue to pay attention to it as it reveals the contradictions of our socio economic model of development (Dobré, 2002; Moscovici, 1977). A new common-sense elevates environment to the status of a central problem so that discourses and social actions often must be reformulated around this question to be legitimated (Kalaora, 2001).

To take into considerations environmental problems seems so obvious that their relevance are rarely discussed (Micoud *et al.*, 2006; Migot *et al.*, 2006).

BIODIVERSITY : MITIGATE COMMITMENT BEYOND THE FINE WORDS

Global warming, greenhouse gas emissions and their effects on the daily weather or industrial hazards are frequently quoted by public as potential environmental threatens for human beings.

But other environmental issues – for example biodiversity – spread slower into the public and comes to light with difficulty and still in very general terms as the “safeguarding of animals and plants” (IFEN, 2002)

Conversely, when the biodiversity topic is discussed inside the scientific community or in the environmental NGOs, the terms used for the diagnosis are often negative and denounce the massive extinction of species due to human activity, the disappearing of emblematic animals (whales, elephant, bear, wolf), the tropical forest deforestation, the intensive forestry, etc.

On the opposite, the foreseen solutions are positively connoted, politically correct ; they advocate moral responsibility towards nature and biodiversity conservation, the sustainable management of all the species of the ecosystem, the diversification of forest species…

But, behind the fine words, when we carefully look at the action programmes in favour of biodiversity, we observe that actions are very selective. The conservation or preservation of <u>some</u> ecosystems or species are exemplified by scientist or environmental institutions with the secret hope that the public will join and consolidate their actions. This strategy may transform a confidential question into a public problem but, in return, it also could orientated the scientific programmes (Machlis, 1992).

On the opposite, entire compartment of the ecosystem like insects, fungi, soil microfauna, bacteria are completely ignored by the public and research programmes on these species are scarcely financed by the policy makers (Dunn, 2005; Kellert, 1993).

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Biodiversity also raises questions to the foresters and their relation to nature. For them nature is often reduced to its commercial value and elements which are not compatible with this seem to be ignored (Görg, 2004).

Foresters still keep in mind the utilitarian conception of fauna and flora so that they often classify some animal and plants as noxious for forestry even if they are useful for the ecosystem (Compagnon, 2001).

DEADWOOD, THE REPULSIVE FORGOTTEN ISSUE

Since 2000, several scientific meetings deals with the role of deadwood and coarse woody debris (CWD) as an habitat for an important proportion of forest insects and fungi and as a factor of soil fertility thanks to humus production.

The number of scientific article published per year on this topics have doubled since 2001. Deadwood has been integrated as an indicator of forest biodiversity defined at the ministerial conference on the protection of forest in Europe in Vienna in 2003.

But this step of the forest cycle is ignored by the public and the archetype of the cultivated, clean, controlled forest still largely dominates among the public (BVA, 1991; OPRESE, 1998).

By the foresters, the situation is contrasted and controversial (Blandin, 1995). The law about forest multifunctionality encourage foresters to respect 3 mains objectives for forest : Wood production, amenities, and environment conservation. Concerning this last objectives, French Public Forest Office (ONF), have edicted norms in response to environmentalist NGO criticisms ; at least one deadwood per hectare is assigned to fauna and flora if it does not hamper economic profitability (Buttoud, 2003).

But some scientists and environmentalists claim for a significant increase of this volume, from 2 to 10 cubic meter per hectare according to the type of forest ecosystem.

Concerning private forest owners, we have very few elements about their practices and perceptions of biodiversity and deadwood conservation. Organisations as forest owners associations have been harsh opponents to biodiversity policies in general and to the implementation of Natura 2000 policy in particular (Alphandéry *et al.*, 2007). First surveys show a great distrust and sometimes a psychological block by foresters towards deadwood conservation.

A pluridisciplinary resarch programme on CWD

Within the framework of a French national interdiciplinary research programme on biodiversity, we study the forest actors' attitude and beliefs that explain the foresters' approval or rejection of CWD conservation programmes.

The assumption we test is that deadwood is a sign of the ambiguous relations of forest owners towards nature and close-to-nature forestry and an indicator of their environmental commitment. Our research questions are the following :

- how French foresters are integrating – or not– biodiversity and deadwood in their forest management practices?
- how do they chose between two opposite national environmental policies: on one hand forest owners are encouraged to preserve deadwoods as habitats for insects but, on the other hand, to save fossils energies, industrial companies propose them to export their CWD to transform them as fuelwood?

- What are the social consequence of the strengthening of the environmental norms for the forest owner community?

To understand in-deep the practices and the opinions of forest owners towards biodiversity and deadwood management, we have adopted the theoretical frame of the common-sense knowledge sociology proposed by Berger and Luckmann (1986) which they developed from the phenomenological perspective of Alfred Schütz (1987). *These authors argue that knowledge is socially constructed and oriented towards particular practical problems so that facts can never be considered as neutral but reflective of why they are required.*

We therefore make the assumption that foresters elaborate the sense of their activity, collectively, in various places of social integration by discussing with selected peers or interlocutors, such as other foresters, forestry consultants, local councillors.

By content and cross-analysis, we have segmented the interviewees into three groups. Usual social variables as age, gender, job, part of the income coming from forest products are not really discriminating. More complex variables seem to distinguish attitudes of foresters towards the integration of rejection of environmental practices :

- The social networks of discussion : three main networks are more important to distinguish foresters .
    - The first one is the official professional and corporative network of South-west forest owners association (SSSO) which is politically very influent and is a lobbyist at a regional and national level. A large majority of forest owners are members of this network but few are active.
    - The second one is the network of neighbouring which is often very local, not official and essentially composed of members of the family or neighbouring foresters and forest users (hunters, walkers). This network is very important as official advices coming from the first two networks are often discussed and sometimes refuted inside this local and private sphere.
    - The third network is a nebula of owners who are member or sympathizer of a pro-environmental association of close-to-nature foresters (Pro silva).
- their forest values we also differentiate sub-groups by their forest management models and the associated values. Despite the hegemony of the Maritime Pine intensive model, different paradigms of forest management are discussed and applied within each social networks forest management practices goes from soft-managing forestry to close-to-nature forestry model with intermediary situations
- Their faith in science or nature : If the scientific community has largely abandoned the idea of a complete control of nature (Görg, 2004), foresters' community still has faith in science to prevent and eliminate risk even if some foresters count more and more on nature to restore ecosystem balance.

Our investigation material consists of semi-structured, tape-recorded and face-to-face interviews conducted with 18 forest owners, 8 industrials and regional forest policy makers and 2 NGOs' members. In this presentation, we analyse the discourse of the first group of stakeholders, the forest owners.

The interviews were carried out in Gascony region in the south of France. The forest cover rate rages from 60% at a departemental level to 74% locally. The Landes Forest is the largest private-owned forest of Europe with 1 million ha of pine forest (Pinus pinaster). 90% of the forest is private. Economically, the primary and industrial forest sector is very important as it employs 20 000 people and contributes to 2 billions euros of total sales per year.

Forest owners attitude: From industrial to close-to-nature forestry

Their first problem forest owners are dealing with, is not deadwood but the lethargy of wood market and the stagnation of the price.

Then, when we asked them about environmental concerns in the study-case area, they never talk about loss of biodiversity or deadwood conservation but about the consequence of climate change in terms of drought and lack of water that directly threaten tree life span and about the impact of the mechanization on soil compaction.

*Most of the time, it is because the interviewer introduce the word "biodiversity" that foresters react on this terms. The definition are often succinct : "*biodiversity is it the variety of tree species that can be grown for forestry*" ; this anthropentric point of view also prevails for fauna, their definition are limited to the animals which damage forest trees, to the game as roe deer and wild boar and to birds.*

That does not mean that they perceive no other forms of diversity but they focus on fauna and flora directly connected to their forest practices. Biodiversity sounds for them as a buzzword, used by politics and scientists but as the relevant term to describe fauna and flora they observe in their forest.

Opposite to the notion of biodiversity, the interviewees' discourse about deadwood is more spontaneous and more precise because this aspect of the forestry cycle directly interferes with their everyday forest management practices and even more with lack of management.

Most of the interviewees need to explicit what they mean by deadwood as this term sounds very clear for them but also very polysemous. If scientists often use the terms necromass or CWD, foresters prefer to use the common-sense word "deadwood".

But this term refers to very different things as old trees with cavity, trees struck by lightning, logging residues, unutilised logs, uprooted stumps, broken or uprooted stems, branches (heavy slash), twigs, needles, bark and chips... According to the interviewee profile, it goes from 1 to 9 categories.

According to their social network belonging, their forestry model and their relation to science, the forest actors can be divided into three main groups.

GROUP 1, THE « INTENSIVE PRODUCERS » OR DEADWOOD AS A WASTE

These forest owners often are board members of the professional and corporative regional network of forest owners association. Still on the leading edge of the forest technology, they mobilize most of the new technological development as genetically selected plants, fertilization, systematic thinning, mechanized harvesting, plot inventory by GIS etc.

In return of these investments, they wait for a substantial financial compensation as timber is an important source of their incomes. For them, the economic performance is the standard to measure the progress in forestry sector and they draw their legitimacy from the profitability of the commercial exchanges with the industrial sector.

To satisfy the demand of the forest industries, they also have adopted the PEFC[2]. For them, this “ecolabel” testifies of their environmental commitment. In the contrary, they are strongly opposed to the Natura 2000 policy and limit the notion of biodiversity to the tree species that are useful and highly profitable for forestry as Pinus pinaster and Pinus taeda.

They sometimes introduce broadleaves on marginal forest stands not to appear as only obsess by productivity.

For these defenders of the intensive productive model, deadwood is considered not only as a waste but also as the sign of a lack of management, a lack of rigor and efficiency. Economically, the presence of deadwood on the forest stands slows down the mechanised forest operations and increase the cost of thinning or felling coupes.

It also induces two major risks : accident for the forester or the visitor and pest invasion as deadwood is perceived as a privilege habitat for the insects, noxious or not. Concerning the role of deadwood for the soil fertility cycle, this group partly relies on chemical fertilisation to solve the problem.

Moreover, from a symbolic and cultural point of view, deadwood is seen as a stain whose presence damages the beauty of forest landscape.

All those arguments lead those foresters to evacuate as quick as possible deadwoods from the forest stands ; they traditionally propose to the non-forest owners, who are members of the village community, to cut themselves the dying trees to use them as they want, generally as fuelwood for the domestic fireplace. It operates as a system of gift and counter-gift : non-owners received deadwood from forest owners in exchange for forest fires surveillance.

GROUP 2 THE « WISE PRODUCERS » OR DEADWOOD AS A NON-PROFIT SUB PRODUCT

In opposition to the group 1 and 3, most of them are part-time forester. As the group 1, they are members of the forest organizations (producer cooperatives, forest owner associations...) but without assuming elective responsibilities. They are more oriented towards local neighbouring network or familial network.

They adhere to PEFC under the strong incitation of industrial wood buyers but they are not convinced by the environmental efficiency of this label.

They try to follow the technical advises promoted by the professional structures but they often fail to apply all of them by lack of financial resources. They rarely take time to calculate the return on investment – the economic profit is weaker than for the other group and sometimes even negative – and the economic performance is not their main preoccupation. They manage the forest wisely and cautiously.

They are sometimes sceptical towards the real progress of forest science and technologies. By the past, they get their fingers burnt by natural disasters as frost and windstorm or hazardous technics (systematic thinning, introduction of eucalyptus…).

. Concerning biodiversity, they often let grow broadleaves as oak (Quercus sp.) and alder (Alnus sp.) on marginal sites but also in the periphery and even inside the forest stand.

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[2] Programme for the Endorsement of Forest Certification. It provides a framework for the development of and mutual recognition of national or sub-national forest certification schemes that have been developed locally according to internationally recognised requirements for sustainable forest managements.

But as the first group, they are doubtful about deadwood conservation ; they do not analyse it as a economic problem or a risk for visitors but they fear pest invasion and they do not imagine and understand the environmental role of deadwood as an habitat for fauna and flora. For them, the unique positive benefit of deadwood is to bring humus to the soil. As a result, they act as the first group and even if they do not hunt the smaller piece of deadwood, they prefer to give it to non-forest owner than to take the risks associated to its presence

GROUP 3, THE « ALTERNATIVE PRODUCERS » OR DEADWOOD AS A PART OF THE ECOSYSTEM

Most of the time, they are active members or sympathizers of alternative forest network as Pro Silva after having broken off relations with the regional professional network.

They adhere to PEFC as it is an obligation to market their timber products but they are very critical towards this so-called "certificate of environmental quality" even if they don not adhere either to the FSC label. For them, close-to-nature forestry is not reducible to norms but it is a question of relation to nature, of values and practices

. If they search for economic profitability as the first group , they do not adopt the intensive forestry model but choose technologies with the lowest impacts on environment (as no-ploughing, mechanical mowing instead of herbicides, selective thinning...).

In their idea of a "close-to-nature forestry », the productive conditions are optimized by the cohabitation of all the components of the forest. It is the reason why they promote elements of biodiversity as broadleaves or deadwood not only to catalyse forest productivity but also to preserve the ecosystem.

In this « close-to-nature » model, deadwood is not seen as a waste but as an important element for the sustainability of the ecosystem in terms of habitats and for the recycling of the nutrient and the soil fertility.

But they share in common with the two others groups the same fear of the risks of pest invasion. They rely on the presence and the antagonism of the different insects (pine pests eaten by carnivorous predator) to restore a natural balance but they demand for scientific confirmation of this potential phenomena.

If biodiversity and deadwood conservation make sense for them, they wish more knowledge to be sure of the validity, sustainability and innocuousness of their model. If this "close-to-nature forestry" is strongly supported by ecologist NGOs and some biologist, it seems to concerns a handful of forest owners.

Deadwood : green energy or habitat

As the primary question of the research focused on foresters' attitude towards CWD, a secondary question has emerged during the survey as most of the interviewees massively preferred to eliminate deadwood than to keep it and with pro-environmental arguments : to save fossils energies.

DEADWOOD AS A « GREEN » ENERGY

If industrial outlets for firewood have existed for 20 years in France, it still remains a sub-product of the forestry sector.

In the Gascony forest, woods coming from thinning are too small to be used in carpentry or furniture and they currently are sold bought at a low price by paper mills.

Bringing into disrepute for ages and considered as a sub-product and even as a waste, CWD progressively becomes a co-product of the forestry management and a renewable source of energy that participate to the environment conservation and fossil energy saving .

The objectives is to supply paper mills and collective building with electricity produced by boiler rooms, water being heated by would.

Since 1994, this idea has been particularly promotes by the French Environment and Energy Management Agency (ADEME)[3] which depends on the Ministry of Environment. the ADEME's objective is to multiply by three the energy power produced by firewood (from 320 MW to 1000 MW) between 2000-2006.

Industrial companies, as paper mills and forest cooperatives, have also understood the benefits gained from using fuelwood : they can produce cheap electricity from firewood by co-generation and they can integrate the use of firewood in their environmental management system (EMS, ISO 14001 norm).

Since the last two years, several investigations have been carried out by industrial and professional actors of the forestry sector to assess the resource of firewood that could be used locally by the local paper industries.

First results show that 50 to 80% of the CWD as logging residues, stumps, trees with cavity could be used as fuelwood. And the Landes forest is at the first place in terms of volume of firewood that could be easily mobilised for biomass production.

But do foresters share this opinion which looks like a marketing slogan promoted by industrial companies?

A NEW PROFITABLE MARKET MINUS A RISK OF PEST

Forest owners of the first group begin to make themselves acquainted with the terms of the debate by participating to the discussion in their professional network. They subscribe to the industrial companies' idea that the use of CWD has positive environmental impacts on in terms of fossils energy saving and climate change.

They also see the direct benefits that they could derive from the exploitation of CWD. Ideologically, to harvest CWD reinforces their ideal of forest management : it optimises their intensive forestry model at an ultimate point as it remains almost nothing but needles and twigs on the ground.

Technically, it also simplifies future operations as tree planting and it decreases the amount of pest. Concerning the potential loss of fertility on a long-term, they rely on chemical fertilizers to restore it.

Finally, they minimize the environmental consequence of CWD harvest as study shows that 20 to 50% of CWD would remains on soil.

But ecologist claims that only needles and twigs remains and that it is not the most interesting part of the CWD for the biodiversity : as industrial companies, insects also needs large piece of woods.

Another point of harsh discussion remains between companies and forest owners : how do CWD cost ? forest owners consider that CWD is a raw material as wood thinning and that it must be bought at a fair price. On the opposite, companies think that they do forest owners a

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[3] ADEME is an industrial and commercial public agency, under the joint supervision of French Ministries for Ecology, Sustainable Development and Spatial Planning (MEDAD) and for Higher Education and Research. It aims at encouraging, supervising, coordinating, facilitating and undertaking operations with the aim of protecting the environment and managing energy.

favour by relieving them of a waste and that this operation is cost effective as they need to mobilizes new forest machines.

We can expect that is part of the game in the negotiation and that they will rapidly find an agreement except if forest owners prefer other intensive forestry models dedicated to firewood production as short rotation coppice

WAITING FOR THE CONCLUSION OF THE EXPERTS

Lot of members of this group ignore the debates about the possibility of using CWD as firewood.

Passive members of the professional network, they claim for more information before taking a decision.

At first glance, they are dubious and very cautious. The first reaction is "*Wait and see*", "*listen to the expert*", "*discuss with the neighbours and decide inside the family*". After asking for a short presentation of the argument of the ecologist on one hand and of the industrial companies on the other hand, they were sceptical and they feared the soil fertility loss not only for environmental reason but also because they think they have no more money to spend in chemical fertilisation.

But most of them are also seduced by the possibility to reduce the amount of pest by evacuating CWD from their forest stands.

But none of them mention larger benefits for climate change or global warming or consequence about biodiversity.

DEADWOOD IS NOT FUELWOOD

This position is discussed by the members of the third group in their regional or neighbouring networks. For them, the use of CWD will directly affect negatively the soil fertility. CWD evacuation sounds like a loss of humus but they also fear that the harvesting will seriously affect the soil structure, particularly if stumps are dug out. As a forester mentioned it: "*I don't want a nuclear war on my forest stands just to dig out stumps and make money with them* ".

For them, as in organic farming, to preserve the soil quality is an important criterion to manage their forest.

If they are aware of the secondary effect of CWD harvesting on habitats, they do not succeed to express it very clearly : for them the forest ecosystem just needs every compartment of living beings, noxious or not, and they are mitigate towards a systematic evacuation of deadwood and others logging residues, even to decrease the risk of pest invasion: "*If the forest ecosystem is balanced, it could sort it out by itself*".

Conclusion

If the future of CWD will depend on individual foresters' attitude, it will also be driven by two different policies : one coming from the Ministry of environment which promotes the biodiversity conservation and the maintenance of CWD and the other one driven by ADEME, the regional forest owners association, the industrial companies and the regional council which promotes the use of CWD for fuelwood.

In this competitive arena, policy in favour of deadwood conservation does not attract lot of forest owners : the biological benefits of deadwood for the ecosystem are still not well established as scientist proved it for broadleaves maintenance. There is no tangible financial spin-off and risks of pest invasion are more visible than problem linked to fertility loss.

Moreover, the political influence of the promoters of biodiversity are weak and limited to the sphere of biologist and some NGOs whose message on this topics is inaudible. It will be also difficult to count on the public as he feebly adheres to the idea of biodiversity conservation and he really does not care about deadwood and its associated fauna and flora.

This debate about deadwood as fuelwood or habitat shows the ambiguous relations of forest owners towards nature and the integration of environmental concerns in their forest management model. As we assume it, the acceptance of CWD partly contributes to reveal the degree of foresters's ecologisation.

If debates on CWD conservation contribute to set up environmental issue, it also reveals the internal tension and the ideological oppositions that exist inside the forest owners community. It also contributes to recombine forest owners social networks. The traditional forest-owners network is locally still dominant but its monopolist vision of what forestry model should, be is more and more discussed.

Some forest owners have even left this network to join new groups of discussion that promote alternative forestry. The environment issues contribute to question dogmas and to shake up instituted authority. It is the reason why it is so strategic for the first and the third group to show the legitimacy of their own system of ecocertification.

Even if group 1 and 3 are engaged in two different models of forest management, both of them use those models to stand apart from the mass of the forest owners.

The implementation of those models, their argument of legitimacy based on economic <u>or</u> <u>environmental </u>performance act as a criterion of distinction. Their cultural and economic capital distinguish them from the majority of the forest owners – the second group – who just apply « stereotyped models » and who never « venture off the beaten track ».

If their forest practices contributes to reinforce their position and their social status inside their network and community, they have diametrically opposed views concerning the role and place of nature in their forest management. With the economic criterion, it is one of the reason why foresters of the first group prefer to transform CWD into fuelwood than to keep it for biodiversity.

And even with subsidies coming from the Natura 2000 policy or the European Agricultural Fund for Rural Development (EAFRD), we can bet that those forest owners would refuse this financial support because subsidies are against their system of value based on economic performance of the forest itself and independently from external aid.

For the third group, the criterion of performance associates both the environmental outlets and the economic profitability. But, to respect both objectives, they sometimes have to sell CWD to avoid a debit balance. In this case, <u>dedicated subsidies could be interesting to circumvent this transitory difficulty.</u>

Concerning the attitude to adopt towards biodiversity and deadwood conservation, the second group – who adopts a wait-and-see attitude for the moment – will be very interesting to follow during the next years.

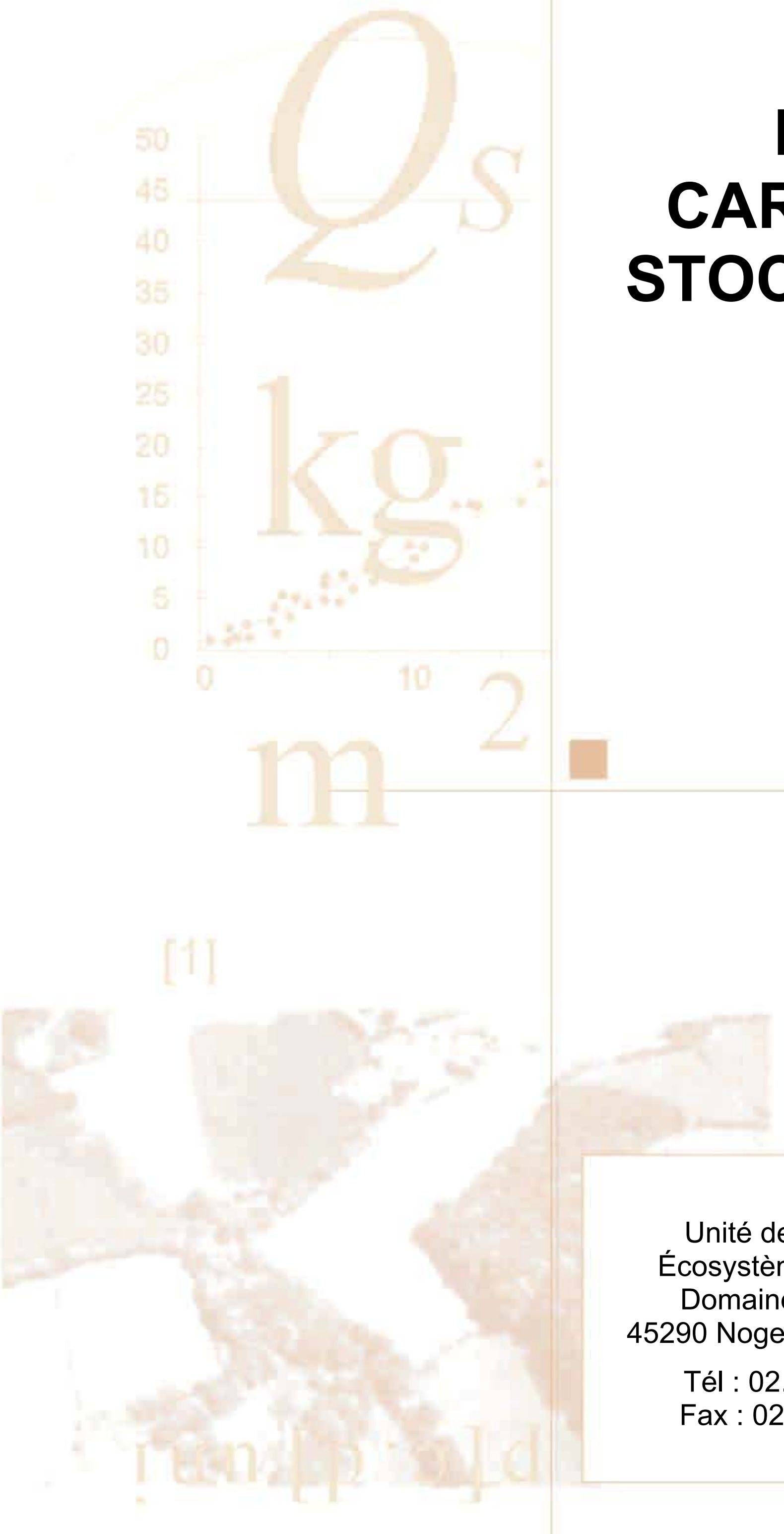
Many options can occur :

- on one hand, we can imagine a large rallying of the second group to the views of the first group as his model is historically, economically and culturally very anchored, dominant and influent.

- But, on the other hand, more and more forest owners have adapted their forest management model and are not opposed – as in the past – to the integration of environmental practices on their property.
- But the question is : will it be only marginal, small, out-of-touch forest owners or will it be pro-active, socially influent forest owners, able to reinforce the position of the third group ?
- Another hypothesis could be the reintegration of the absentee forest owners or those who are tempted to give up their property : they could be seduced again by the current evolution of the forest management model that integrate more environmental practices.

ANNEXE 7

Cemagref



PROTOCOLE DE CARACTERISATION DU STOCK DE BOIS MORT ET VIVANT D’UN PEUPLEMENT

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Ce protocole est inspiré et adapté des procédures rédigées par Brucciamacchie (2005), Chirici (2003), Koehl et al. (2001).

Il s'inscrit dans le cadre du projet de recherches RESINE (REprésentations Sociales et Intérêts écologiques de la NEcromasse), programme du GIP Ecofor – BGF 2005-2008.

***Objectifs** : Variables synthétiques à estimer sur 60 placettes en FD de Rambouillet (78) :*

- ratio volume ligneux mort / volume ligneux vivant
- volumes de bois mort : total, par essence, par classe de diamètre, par classe de décomposition, au sol ou sur pied
- diversité des pièces de bois mort
- surface terrière des ligneux vivants (indice de clarté du peuplement)

OPERATEURS

2 personnes :

- 1 notateur plutôt au centre (avec fiches, boussole, jalons), qui vérifie à distance de visu que l'opérateur n'oublie rien
- 1 opérateur mobile (avec télémètre, compas et couteau) qui dicte ce qu'il mesure

Temps de travail

Compter :

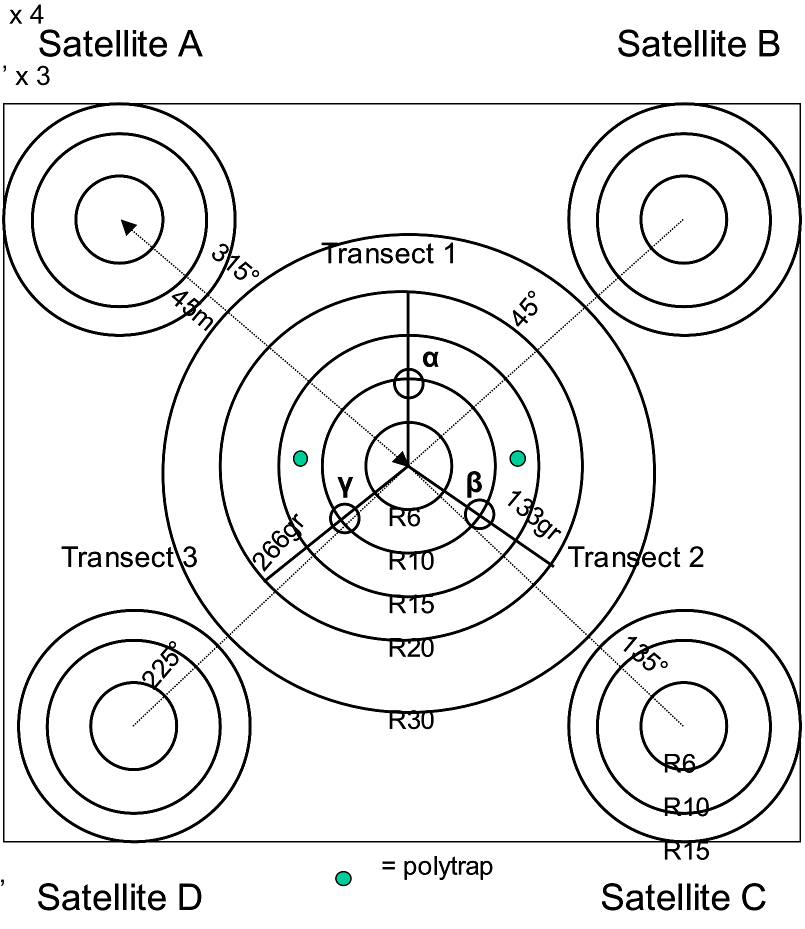
- zone ''riche'' en bois mort (>15-20 m3/ha)
    - point central : 60 min (selon les conditions locales [fougères, chablis…]
    - point périphérique : 25 min x 4
    - placettes linéaires : 5' x 3
    - placettes circulaires 2.5 : 1' x 3
- zone pauvre en bois mort (<5 m3/ha)
    - point central : 30 min
    - point périphérique : 10 min x 4
    - placettes linéaires : 5' x 3
    - placettes circulaires 2.5 : 1' x 3

soit de 1h30 à 3h par placette

1. CONFIGURATION DU DISPOSITIF (CF SCHEMA)

Piquetage bois (120cm, tête rouge) du centre de la placette

- 1 placette centrale à mesures renforcées :
    - 5 sous-placettes circulaires de rayon 6,10, 15, 20, 30 (avec des seuils de diamètre différents pour BM ou BV, car la probabilité de ces deux évènements est différente)
    - 3 sous-placettes linéaires de 20m pour le bois mort au sol de petit diamètre
    - 3 sous-placettes circulaires de 2.5m à 10 m,



pour le petit bois debout

- 4 placettes satellites périphériques, situées à 45m du point central dans les 4 directions suivantes (A=45°, B=135°, C=225°, D=315°), avec mesures allégées (pour chaque point : 3 placettes circulaires concentriques de 6, 10, 15m)

Cette configuration permettra de connaître

- la représentativité de la zone centrale (zone des pièges) dans le paysage proche (zone homogène, zone hétérogène ?)
- l'influence du bois mort à des échelles moins locales qu'à celle de la zone centrale seulement

*Un peu plus d'un demi hectare sera ainsi caractérisé autour des pièges (4 * 7a + 28a), avec peu de chevauchement*[4].

1 seul passage de mesures en mars 2006
Positionnement des sous-placettes ou des placettes satellites. En cas de chevauchement de mardelle ou de chemin ou d'autre singularité majeure, décaler le centre par rapport à l'azimut prévu.

Informations générales placette : coordonnées GPS ; pente ; altitude

2. MESURES

- Diamètres : diamètre compensé en classes de 5 cm, 2 mesures en croix à partir de la classe 20, au compas 1m sous la classe 80, au ruban au delà de la classe 80
    - Pas de correction de pente
- Arbres vivants et dépérissants (essence, D_{130})
- Bois mort debout (selon les cas : essence, écorce, pénétration, D_{casse}, $D_{H/2}$, H, D_{130})
    - arbres morts (essence, écorce, pénétration, D_{130})
    - chandelles hautes
    - chandelles basses
- Bois mort au sol
    - enregistré si Longueur inscrite dans le cercle dépasse 1m
    - en billons de 2 m (L>1m), mesurés au mètre compensé, au diamètre mesuré à 1m à partir du gros bout
    - billon terminal enregistré si diamètre à 1 m du gros bout supérieur au seuil de découpe du rayon exploré

3. TYPES DE PLACETTES UTILISEES

CAS DES ARBRES SUR PIED (VIVANT, DEPERISSANT OU MORT) ET CHANDELLES DE DIAMETRE >7,5 CM (> CLASSE 5)

Placettes concentriques avec seuils de diamètre différents
Les arbres seront échantillonnés sur 5 cercles de 6, 10, 15, 20, 30m de rayon.
Ces arbres ne seront pas localisés.

☐ Série de placettes concentriques d'inventaire des individus vivants et morts sur pied :

- 5 placettes de rayons 6 (classe 10), 10 (classe 10 pour BMort, classe 20 pour BVivant), 15 (classe 20 pour BMort, classe 30 pour BVivant) et 20 (classe 30 pour BMort, classe 50 pour BVivant) , et 30m (classe 50 pour BMort, classe 70 pour BVivant)
    - dans le point central, il faut alourdir le relevé des bois morts par rapport aux bois vivants, pour pouvoir mettre en évidence de faibles différences de volume
- 30 m à partir de la classe 70 cm (très gros bois)
- 20 m à partir de la classe 50 cm (gros bois)
- 15 m à partir de la classe 30 (bois moyens)
- 10 m à partir de la classe 20
- 6 m à partir de la classe 10

Chaque individu doit impérativement être affecté à un cercle d'inventaire pour pouvoir exploiter les données à différentes échelles d'expression locale du peuplement et permettre un emboîtement avec d'autres protocoles de mesure.

Placettes	Surface	BM au sol	BM sur	Arbres

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[4] soit davantage que le seuil de 0.2ha proposé par Stokland et al. (2004)

	cumulée		**pied**	**vivants**
6m	113 m²	> classe 10 (D>7.5)	> classe 10 (D>7.5)	> classe 10 (D>7.5)
10m	314 m²	> classe 10 (D>7.5)	> classe 10 (D>7.5)	> classe 20 (D>17.5)
15m	706 m²	> classe 20 (D>17.5)	> classe 20 (D>17.5)	> classe 30 (D>27.5)
20m	1256 m²	> classe 30 (D>27.5)	> classe 30 (D>27.5)	> classe 50 (D>47.5)
30m	2826 m²	> classe 50 (D>47.5)	> classe 50 (D>47.5)	> classe 70 (D>67.5)

	Cercles	Seuil Bois vivant	Seuil Bois mort	Bois mort du houppier (sur chênes de D_{130}>40)
Point central	6 10 15 20 30	classe 10 classe 20 classe 30 classe 50 classe 70	classe 10 classe 10 classe 20 classe 30 classe 50	+
Point périphérique	6 10 15	classe 10 classe 20 classe 30	classe 10 classe 20 classe 30	-

Arbres vivant et dépérissant

Noter par individu :

- essence
- diamètre D130
- ''statut'' = arbre vivant (pas de symbole), arbre dépérissant (D)

Pour ajuster le tarif de cubage selon la forme de l'arbre, noter si arbre réserve de TSF (R) si D>CL40
Ou plutôt noter si peuplement de TSF pour tous les chênes

Branches mortes du houppier d'arbres vivants sur pied (dont charpentières), à partir de classe 10, sur les chênes de diamètre supérieur à 40
Estimer par classe de diamètre (cl10, cl15, cl20…), le nombre de billons de 2m par individu-chêne

Arbre mort, chandelle basse (<4m), chandelle haute (>4m)

Les chandelles basses sont assimilées à des billons debout, et mesurées non en billons de 2m, mais en 1 billon de 4m maxi pour simplifier le protocole.
Mesurer toujours le D_{130} pour évaluer la distribution en classes de diamètre des chandelles

Noter par individu :

- essence
- ''statut'' = chandelle Basse, chandelle haute, arbre mort
- stade de décomposition à D_{130}(1 variable en 4 classes, 1 variable en 3 classes)
- diamètre et hauteur (en cm au m compensé) :
  - Pour les moins de 4m, on note la $D_{130,}$ la hauteur H et le diamètre à H/2 (volume calculé avec la formule de Huber : V=(π/4)d²H).
  - Pour les plus de 4m, volume par tarifs de cubage: V=f(H, D_{130}, essence)
    - si diamètre à hauteur de la casse est > 17.5, on note H, D_{130}, Dcasse
    - si diamètre à hauteur de la casse est < 17.5, on note H, D_{130}
    - si diamètre D_{130} < 17.5 (dans les cercles R6 et R10), on note H, D_{130}

Eviter le double comptage systématique (chandelle cubée en arbre entier et volis au sol)
Bien cuber le bois d'œuvre (>CL20), dominant dans le volume,

Statut	Rayon	Essence	D_{130}	H	D_{casse}	$D_{H/2}$	Ecorce	Pénétration
Arbre mort	X	X	X	X			X	X

Chandelle haute (H>4m, D_{casse} > 17.5)	X	X	X	X	X		X	X
Chandelle haute (H>4m, D_{casse} < 17.5)	X	X	X	X			X	X
Chandelle basse	X	X	X	X		X	X	X

Pour éviter les approximations abusives, la hauteur des arbres de D_{130}<40 a été mesurée à la découpe 10, celle des arbres de D_{130}>40 à la découpe 20 bois d'œuvre.

Point central

		Mesures			
rayons	Classe de découpe seuil	H<4m	H>4m, D_{casse} < 17.5	H>4m, D_{casse} > 17.5	
6	10	$D_{H/2}$, H, D_{130}, Ecorce, Pénétration	H, D_{130}, Ecorce, Pénétration	H, D_{130}, D_{casse}, Ecorce, Pénétration	Diamètre à hauteur d'homme > 7.5cm
10	10				Diamètre à hauteur d'homme > 7.5cm
15	20				Diamètre à hauteur d'homme > 17.5cm
20	30				Diamètre à hauteur d'homme > 27.5cm
30	50				Diamètre à hauteur d'homme > 47.5cm

Point satellite

		Mesures			
rayons	Classe de découpe seuil	H<4m	H>4m, D_{casse} < 17.5	H>4m, D_{casse} > 17.5	
6	10	$D_{H/2}$, H, D_{130}, Ecorce, Pénétration	H, D_{130}, Ecorce, Pénétration	H, D_{130}, D_{casse}, Ecorce, Pénétration	Diamètre à hauteur d'homme > 7.5cm
10	20				Diamètre à hauteur d'homme > 7.5cm
15	30				Diamètre à hauteur d'homme > 17.5cm

CAS DU BOIS MORT AU SOL

Plusieurs statuts :

- *dressé (en compte les tiges perchées, ou cassées et dressées en l'air sans contact avec le sol)*
- *au sol (y compris chablis à billonner)*

CAS DU BOIS MORT AU SOL (A PARTIR D'UN DIAMETRE DE 7,5 CM)

Pour les pièces dont le diamètre est supérieur à 7,5 cm, en utilisant plusieurs placettes circulaires concentriques de rayon 6, 10, 15, 20,30 m

Mesures dans les placettes circulaires (à partir d'un diamètre de 7,5 cm) :
La pièce de bois est découpée virtuellement en billons réguliers de 2m. Pour les bois morts au sol, décomposer en billons permet d'enregistrer la présence de gros diamètres de base de tige, mieux qu'un diamètre moyen ou le D130, évidemment plus faible)[5]*.*

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[5] Un des objectifs du protocole est de porter l'accent sur les gros bois (notamment morts), ressource rare dans les forêts gérées (cf Sippola et al. (1998) en Finlande).

La décomposition systématique en billons de 2m semble plus opérationnelle qu'une décomposition aux redants éventuels.
Règle d'inclusion et de troncature : Lorsque la pièce de bois est limite, seule la partie inscrite à l'intérieur de la placette est mesurée.
Si une pièce intersecte plusieurs rayons d'étude, mesurer tous les billons en même temps quel que soit le cercle.
En cas de chablis nombreux et encroués, noter l'arrêt de mesure à la peinture pour faire les mesures exactes par rayon.
En cas de billon de moins d'un mètre en limite de rayon, recommencer les mesures à partir de la limite de rayon dans le rayon supérieur (et non à partir du dernier billon mesuré dans le rayon précédent)

Inventorier les billons de 2m inscrits dans le cercle de rayon en cours d'inventaire, en cm au m compensé, et de diamètre supérieur au seuil de cette placette (seuil de découpe à 1 m du gros bout du billon) :
Enregistrement des billons :

- **Diamètre à 1 m du gros bout > seuil de découpe du rayon concerné,**
- **L > 1m**

Notation par billon :

- numéro d'arbre ou regroupement des lignes billons d'un même arbre avec accolade
- le stade de décomposition (1 variables en 4 classes, 1 en 3 classes)
- diamètre mesuré à 1m du gros bout du billon (classes de 5 cm, ex : 20 = [17,5 ; 22,5 cm[ ),
- l'essence avec un code à 2 ou 3 lettres
- le contact avec le sol (1 variable à 3 classes)
- le statut : sol ou dressé (bois encroué suspendu), ou chablis, ou souche

PAS DE MESURE DE LONGUEUR DE BILLONS, MAIS INVENTAIRE DE BILLONS DE 2M

SOUCHES

A partir de la classe20, noter le diamètre supérieur, l'essence, la pourriture et la dégradation d'écorce (noter creux en cas de souches creuses)
Mêmes seuils et même fiche que le bois mort au sol (Statut = souche)

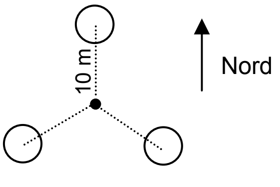
☐ **3 sous-placettes circulaires pour les petits bois (mort ou vivant) sur pied**

Placettes	**Surface cumulée**	**BM au sol**	**BM sur pied**	**Arbres vivants**
3 sous-placettes 2.5m à 10m	60 m²	-	classe 5 (2.5<D<7.5)	classe 5 (2.5<D<7.5)

CAS DES ARBRES SUR PIED (VIVANT OU MORT) ET CHANDELLES DE DIAMETRE 2,5<D<7,5 CM (CLASSE 5)

Association de placettes circulaires fixes concentriques et de sous-placettes circulaires arbre mort encroué, arbre mort sur pied, chandelle
Ils seront comptabilisés sur 3 sous-placettes de rayon 2,5m (environ 3 fois 20m²) disposées en étoile à 10 m du centre de la placette. La première est installée au nord, la deuxième à 133gr, la troisième à 266gr.
Centrées sur les jalons des demi transects 1.1, 2.1, 3.1.
1 seule classe de diamètre (classe 5)
Indiquer les mesures suivantes :

- essence
- statut = vivant ou mort



☐ **3 sous-placettes linéaires pour les petits bois mort au sol**

Placettes	Surface	BM au sol	BM sur pied	Arbres vivants
2 transects 20m	40 m	classe 5 (2.5<D<7.5)	-	-
1 transect 20m	20 m	classe 5 + 1<D<2.5		

PLACETTES LINEAIRES (PIECES DE BOIS MORT AU SOL DE CLASSE 5)

D'après Brucciamacchie (2005)

La méthode d'échantillonnage linéaire est une méthode ancienne proposée par Warren et Olsen (1964) pour estimer des résidus d'exploitation ou bien par Van Wagner (1968) pour estimer une biomasse combustible, donc pour estimer des volumes d'objets de faible dimension, dont le coût de mesure est élevé avec des placettes à surface fixe.

Principe

Le domaine d'inventaire est échantillonné en utilisant une ou plusieurs lignes d'inventaires - de longueur L - dont le point de départ est disposé de manière systématique. Des placettes linéaires sous forme de croix ou d'étoile (la première direction étant tirée au hasard) permettent également de ne pas privilégier une direction donnée.

Avantage

L'intérêt principal de cette méthode réside dans le fait que le volume à l'hectare ne dépend plus de la longueur de la pièce de bois, mais uniquement du diamètre intercepté.

Inconvénient

Cette méthode accorde à chaque pièce de bois, un poids généralement très élevé (inversement proportionnel à sa longueur et à la longueur de la placette). Pour une pièce de bois de 10 m de long et une longueur de placette de 50 m, le poids est comparable à une placette circulaire de 10 m de rayon.

Pour les pièces dont le diamètre est compris entre 2,5 et 7,5 cm (**classe 5**) dans 2 placettes linéaires de 20 m de longueur, et pour les pièces dont le diamètre est compris entre 1 et 7,5 cm dans 1 placette linéaire de 20 m, toutes trois disposées en étoile au départ du centre de placette (cf schéma), soit une distance totale échantillonnées de 60m par placette
Diamètre mini au point d'intersection : 2.5cm (sauf transect 3 : 1cm)
l'axe longitudinal central de la pièce doit intersecter le transect
en cas de double intersection (fourches, pièces courbes) : double comptage (si >2.5 cm)
Mesures dans les placettes linéaires (pièces de classe 5) :

- numéro de transect
- Essence
- Stade de décomposition (2 variables en 3 classes)
- contact avec le sol (1 variable en 3 classes)
- diamètre
  - transects 1 et 2 : pas de diamètre au niveau de l'intersection puisque toutes les pièces considérées sont de classe
  - transects 3 : classe de diamètre 1 ou 5 au niveau de l'intersection

Subdiviser chaque transect en 2 parties égales, afin d'estimer la perte d'information due à l'utilisation de transects de 10m (1.1, 1.2., 2.1., 2.2., 3.1., 3.2.)
ex. transect 12 = partie située entre 10 et 20m du transect n°1
En cas de passage du transect dans un houppier ou un andain ou un tas de rémanents, estimer un nombre de tiges de classe 5.

4. VARIABLES COMMUNES

4.1. CONTACT AVEC LE SOL

Le contact avec le sol influence le déroulement de la saproxylation, de même que l'exposition au soleil, la station…Mais plutôt que le % de longueur en contact avec le sol, nous suggérons deux variables binaires :

- longueur de contact avec le sol
  - nulle (0%)
  - <50%
  - > 50%

4.2. STADE DE DECOMPOSITION

A partir du protocole européen CostE4 (4 classes pour nécromasse aérienne et au sol, utilisant le degré de pourriture et la dégradation de l'écorce), nous suggérons de séparer ces deux critères pour décrire le stade de décomposition en 2 variables complémentaires. Nous supposons que la déhiscence de l'écorce est négativement corrélée au recouvrement résiduel de l'écorce.
Le 'test du couteau' donne des résultats différents selon l'essence et le climat. L'enfoncement est mesuré en rapport avec le diamètre de la pièce (cf Cost E4), plutôt qu'avec un seuil fixe de 1 ou n cm.

Dans les placettes circulaires à partir de la classe 10 :
écorce :
[1] présente sur tout le billon,
[2] partiellement présente
[3] totalement absente du billon

pourriture du bois 'test du couteau' :
[1] dur, ou non altéré (cf bois tendres : tremble, saules, bouleau)
[2] pénétration < 1/3 du diamètre,
[3] pénétration > 1/3 du diamètre
[4] pourriture généralisée

Dans les placettes linéaires pour la classe 5 :
écorce :
[4] présente sur tout le billon,
[5] partiellement présente
[6] totalement absente du billon

pourriture du bois 'test du couteau' :
[5] dur
[6] pénétration partielle
[7] pourri

4.3. CODES ESSENCE

2 premières lettres du genre + 2 premières lettres de l'espèce : Potr, Cabe, Casa, Fasy…

REFERENCES CITEES

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5. TABLEAU RECAPITULATIF DES MESURES

Placettes	Statut	N° transect	Rayon	Essence	H	D	D_{130} ou DBH	D_{casse}	$D_{L/2}$	Nb	$D_{H/2}$	Inventaire billons 2m	Ecorce	Pourriture	Contact sol
Placettes circulaires (centrales et satellites)	**Arbres vivants et dépérissants**														
	Arbres vivants - Réserve		x	x			x								
	Arbres dépérissants		x	x			x								
	Bois mort sur pied														
	Branches mortes et charpentières (uniquement pour Quercus)		x			x						x			
	Arbres morts		x	x	x		x				x		x	x	
	Chandelles hautes (H>4m, D_{casse} > 17.5cm)		x	x	x		x	x			x		x	x	
	Chandelles hautes (H>4m, D_{casse} < 17.5cm)		x	x	x		x	x			x		x	x	
	Chandelles hautes (H>4m,D130 <17,5cm)		x	x	x		x				x		x	x	
	Chandelles basses (H<4m)		x	x	x		x				x		x	x	
	Bois mort au sol														
	Billons (au sol, chablis ou dressé)		x	x					x			x	x	x	x
	Souches (à partir de la classe 20)		x	x					x				x	x	
Sous-placettes circulaires	**Arbres vivants (classe 5)**			x						x					
	Bois mort sur pied (classe 5)			x						x					
Sous-placettes linéaires	**Bois mort au sol (classe 5)**	x		x										x	x

ANNEXE 8

Protocole d'inventaire du bois mort dans le site des Landes de Gascogne

Dispositif

L'inventaire a été conduit dans 143 placettes disposées selon une grille d'échantillonnage systématique couvrant 256 km² (16 km x 16 km).

Trois types de bois mort ont été mesurés : le bois mort au sol (branches et grumes), les souches et les chandelles.

Le diamètre minimum pour la prise en compte d'une pièce de bois mort a été fixé à 1 cm.

La caractérisation du stade de décomposition s'est appuyée sur une typologie à 3 classes :

	Consistance
Classe 1	Bois de cœur dur ou non altéré, cassant, Ecorce adhérente
Classe 2	Bois de cœur encore rigide, cassant, écorce déhiscente
Classe 3	Bois de cœur altéré (la pièce se brise par simple torsion) à complètement pourri , écorce non adhérente ou absente

Pour le bois mort au sol, la méthode d'échantillonnage linéaire (LIS : Line Intercect Sampling, DeVries, 1973, Marshall et al., 2000) a été adaptée en fonction du diamètre des pièces (Fig.1). Pour les pièces de diamètre égale ou supérieur à 5 cm, le diamètre exacte au point d'intersection du transect a été relevé alors que pour les plus petites pièces (diamètre<5cm), deux classes de diamètre ont été considérées (A : 1-2,4 cm, B : 2,5-4,9cm) pour réduire le temps de mesure.

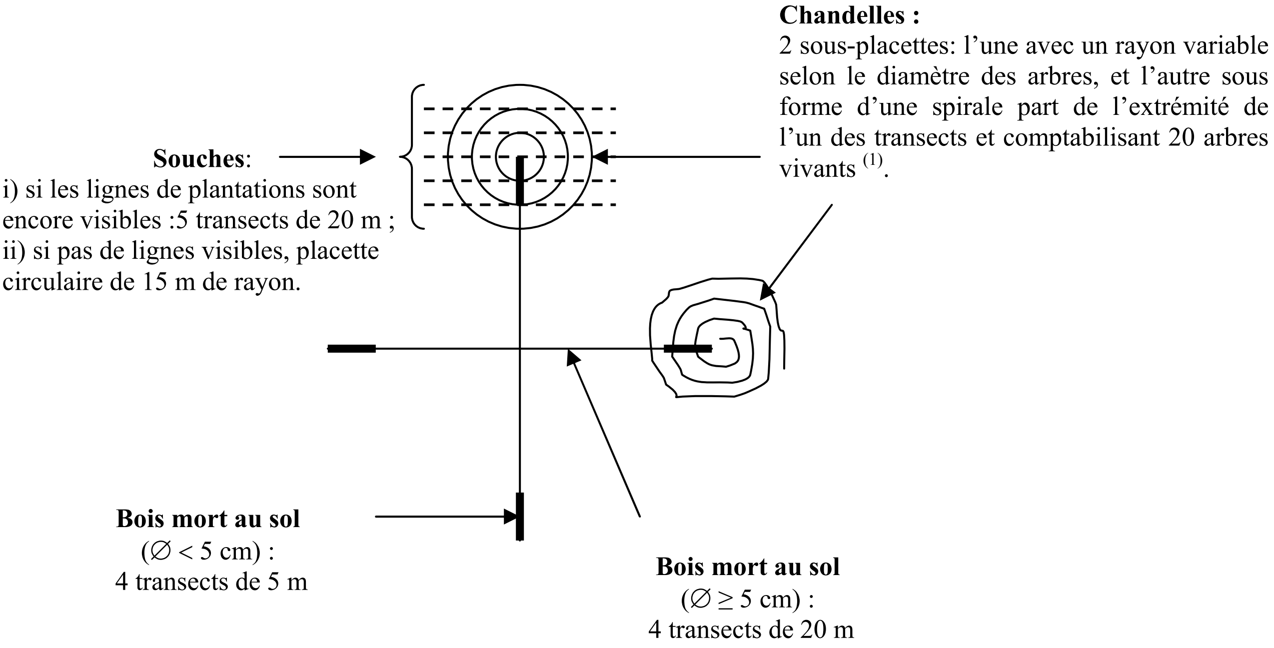

Figure 1 : Détail du dispositif dans une placette.

Calculs

Pour le bois mort au sol, les données des 4 transects sont regroupées pour constituer une longueur d'échantillon de 100 ou 20 m selon le diamètre des pièces considérées (voir précisions plus haut).

Le volume de bois mort au sol (m3/ha) a été estimé en utilisant la formule de De Vries (1973) :

$$Volume = \pi^2 \times \sum \frac{d_i^2}{8L}$$

où L est la longueur du transect et d_i le diamètre de la pièce au point d'intersection. Pour les pièces de diamètre inférieur à 5 cm, nous avons considéré la moyenne quadratique des deux classes utilisées (soit respectivement 1.9 et 3.95 cm pour les classes A et B). Pour les souches et les chandelles, le volume a été estimé en utilisant la formule de Huber pour les cylindres :

$$Volume = (\sum_i \frac{\pi}{4} \times D_i{}^2 \times H_i) \times \frac{10000}{S}$$

où H_i est la hauteur de la chandelle ou $H_i = 0.2$ m pour les souches, D_i est le diamètre à hauteur de poitrine (1,3m) pour les chandelles ou le diamètre de coupe pour les souches, et S la surface de la placette. Pour les chandelles, la valeur affectée à chaque site correspond à la moyenne obtenue avec les deux placettes (circulaire et spirale).

ANNEXE 9

Variables dendrométriques mesurées dans les Landes

Ech.	Code	Description de la variable	Min.	Max.	Moy.	Ec-type
Peuplement	*Descripteurs volumiques du bois mort*					
	Vtot	Volume total de bois mort	0,29	62,95	17,75	15,00
	Vddw_a1	Volume de bois mort au sol de la classe de diamètre "a" au stade D1	0,00	2,08	0,14	0,36
	Vddw_a2	Volume de bois mort au sol de la classe de diamètre "a" au stade D2	0,00	9,07	1,77	1,83
	Vddw_a3	Volume de bois mort au sol de la classe de diamètre "a" au stade D3	0,00	8,31	1,98	1,84
	Vddw_b1	Volume de bois mort au sol de la classe de diamètre "b" au stade D1	0,00	4,34	0,22	0,79
	Vddw_b2	Volume de bois mort au sol de la classe de diamètre "b" au stade D2	0,00	13,88	2,32	3,49
	Vddw_b3	Volume de bois mort au sol de la classe de diamètre "b" au stade D3	0,00	10,41	1,80	2,17
	Vddw_c1	Volume de bois mort au sol de la classe de diamètre "c" au stade D1	0,00	2,33	0,13	0,41
	Vddw_c2	Volume de bois mort au sol de la classe de diamètre "c" au stade D2	0,00	4,16	0,79	1,20
	Vddw_c3	Volume de bois mort au sol de la classe de diamètre "c" au stade D3	0,00	2,02	0,39	0,54
	Vddw_d1	Volume de bois mort au sol de la classe de diamètre "d" au stade D1	0,00	0,00	0,00	0,00
	Vddw_d2	Volume de bois mort au sol de la classe de diamètre "d" au stade D2	0,00	12,99	1,29	2,46
	Vddw_d3	Volume de bois mort au sol de la classe de diamètre "d" au stade D3	0,00	10,22	0,58	1,76
	Vddw_e1	Volume de bois mort au sol de la classe de diamètre "e" au stade D1	0,00	0,00	0,00	0,00
	Vddw_e2	Volume de bois mort au sol de la classe de diamètre "e" au stade D2	0,00	11,15	0,57	1,90
	Vddw_e3	Volume de bois mort au sol de la classe de diamètre "e" au stade D3	0,00	7,56	0,57	1,61
	Vddw_f1	Volume de bois mort au sol de la classe de diamètre "f" au stade D1	0,00	0,00	0,00	0,00
	Vddw_f2	Volume de bois mort au sol de la classe de diamètre "f" au stade D2	0,00	10,38	1,24	2,84
	Vddw_f3	Volume de bois mort au sol de la classe de diamètre "f" au stade D3	0,00	16,20	0,53	2,62
	Vstp_a1	Volume de souches de la classe de diamètre "a" au stade D1	0,00	0,00	0,00	0,00
	Vstp_a2	Volume de souches de la classe de diamètre "a" au stade D2	0,00	0,00	0,00	0,00
	Vstp_a3	Volume de souches de la classe de diamètre "a" au stade D3	0,00	0,00	0,00	0,00
	Vstp_b1	Volume de souches de la classe de diamètre "b" au stade D1	0,00	0,01	0,00	0,00
	Vstp_b2	Volume de souches de la classe de diamètre "b" au stade D2	0,00	0,01	0,00	0,00
	Vstp_b3	Volume de souches de la classe de diamètre "b" au stade D3	0,00	0,04	0,00	0,01
	Vstp_c1	Volume de souches de la classe de diamètre "c" au stade D1	0,00	0,05	0,00	0,01
	Vstp_c2	Volume de souches de la classe de diamètre "c" au stade D2	0,00	0,05	0,01	0,01
	Vstp_c3	Volume de souches de la classe de diamètre "c" au stade D3	0,00	0,21	0,02	0,05
	Vstp_d1	Volume de souches de la classe de diamètre "d" au stade D1	0,00	0,35	0,04	0,08
	Vstp_d2	Volume de souches de la classe de diamètre "d" au stade D2	0,00	0,47	0,06	0,10
	Vstp_d3	Volume de souches de la classe de diamètre "d" au stade D3	0,00	1,31	0,16	0,25

Vstp_e1	Volume de souches de la classe de diamètre "e" au stade D1	0,00	0,93	0,14	0,26
Vstp_e2	Volume de souches de la classe de diamètre "e" au stade D2	0,00	0,83	0,12	0,19
Vstp_e3	Volume de souches de la classe de diamètre "e" au stade D3	0,00	0,95	0,19	0,27
Vstp_f1	Volume de souches de la classe de diamètre "f" au stade D1	0,00	2,20	0,25	0,47
Vstp_f2	Volume de souches de la classe de diamètre "f" au stade D2	0,00	1,25	0,20	0,30
Vstp_f3	Volume de souches de la classe de diamètre "f" au stade D3	0,00	6,85	0,61	1,20

Vsng_a1	Volume de chandelles de la classe de diamètre "a" au stade D1	0,00	0,00	0,00	0,00
Vsng_a2	Volume de chandelles de la classe de diamètre "a" au stade D2	0,00	0,00	0,00	0,00
Vsng_a3	Volume de chandelles de la classe de diamètre "a" au stade D3	0,00	0,00	0,00	0,00
Vsng_b1	Volume de chandelles de la classe de diamètre "b" au stade D1	0,00	0,00	0,00	0,00
Vsng_b2	Volume de chandelles de la classe de diamètre "b" au stade D2	0,00	0,00	0,00	0,00
Vsng_b3	Volume de chandelles de la classe de diamètre "b" au stade D3	0,00	0,00	0,00	0,00
Vsng_c1	Volume de chandelles de la classe de diamètre "c" au stade D1	0,00	0,00	0,00	0,00
Vsng_c2	Volume de chandelles de la classe de diamètre "c" au stade D2	0,00	1,46	0,04	0,23
Vsng_c3	Volume de chandelles de la classe de diamètre "c" au stade D3	0,00	0,00	0,00	0,00
Vsng_d1	Volume de chandelles de la classe de diamètre "d" au stade D1	0,00	1,07	0,03	0,17
Vsng_d2	Volume de chandelles de la classe de diamètre "d" au stade D2	0,00	2,08	0,12	0,45
Vsng_d3	Volume de chandelles de la classe de diamètre "d" au stade D3	0,00	0,00	0,00	0,00
Vsng_e1	Volume de chandelles de la classe de diamètre "e" au stade D1	0,00	0,00	0,00	0,00
Vsng_e2	Volume de chandelles de la classe de diamètre "e" au stade D2	0,00	6,67	0,29	1,17
Vsng_e3	Volume de chandelles de la classe de diamètre "e" au stade D3	0,00	1,93	0,09	0,39
Vsng_f1	Volume de chandelles de la classe de diamètre "f" au stade D1	0,00	17,25	0,43	2,69
Vsng_f2	Volume de chandelles de la classe de diamètre "f" au stade D2	0,00	11,29	0,41	1,91
Vsng_f3	Volume de chandelles de la classe de diamètre "f" au stade D3	0,00	4,41	0,24	0,95

Descripteurs de diversité de bois mort

D_{tot1}	Diversité de tout le bois mort d'un diamètre minimum de 1cm	2	25	10,63	5,60
D_{ddw1}	Diversité du bois mort au sol d'un diamètre minimum de 1cm	0	13	5,40	2,96
D_{stp1}	Diversité des souches d'un diamètre minimum de 1cm	0	10	4,83	3,08
D_{sng1}	Diversité des chandelles d'un diamètre minimum de 1cm	0	2	0,40	0,70

D_{tot10}	Diversité de tout le bois mort d'un diamètre minimum de 10cm	0	16	5,30	3,83
D_{ddw10}	Diversité du bois mort au sol d'un diamètre minimum de 10cm	0	6	3,93	2,85
D_{stp10}	Diversité des souches d'un diamètre minimum de 10cm	0	9	0,38	0,66
D_{sng10}	Diversité des chandelles d'un diamètre minimum de 10cm	0	2	1,00	1,34

D_{tot15}	Diversité de tout le bois mort d'un diamètre minimum de 15cm	0	11	3,45	2,74

	D_{ddw15}	Diversité du bois mort au sol d'un diamètre minimum de 15cm	0	4	2,70	1,96
	D_{stp15}	Diversité des souches d'un diamètre minimum de 15cm	0	6	0,48	0,84
	D_{sng15}	Diversité des chandelles d'un diamètre minimum de 15cm	0	2	0,28	0,59
	D_{tot20}	Diversité de tout le bois mort d'un diamètre minimum de 20cm	0	5	1,73	1,43
	D_{ddw20}	Diversité du bois mort au sol d'un diamètre minimum de 20cm	0	2	1,35	0,99
	D_{stp20}	Diversité des souches d'un diamètre minimum de 20cm	0	3	0,23	0,52
	D_{sng20}	Diversité des chandelles d'un diamètre minimum de 20cm	0	2	0,15	0,42
	Densité	Nombre de tiges par hectare	146,19	1768,68	753,20	457,73
	Age	Age du peulement (en années)	5,00	61,00	25,43	13,59
	Feuil	Nombre de feuillus d'une hauteur supérieur à 7 m dans les 4 sous-placettes	0,00	9,00	0,53	1,69
	Couvert	Recouvrement au sol de la strate arborescente (1)	0,30	0,90	0,62	0,17
Paysage	dDW400	densité de bois mort dans un rayon de 400 m	3,13	16,05	9,09	2,85
	dCR_400	densité de coupes rase dans un rayon de 400 m	0,00	0,34	0,04	0,08
	dFeuil_400	densité de peuplements feuillus dans un rayon de 400 m	0,00	0,47	0,12	0,14
	dPM400	densité de peuplements de pin maritime dans un rayon de 400 m	0,39	1,00	0,78	0,17
	dDW300	densité de bois mort dans un rayon de 300 m	2,93	17,17	9,50	3,36
	dCR_300	densité de coupes rase dans un rayon de 300 m	0,00	0,43	0,03	0,08
	dFeuil_300	densité de peuplements feuillus dans un rayon de 300 m	0,00	0,45	0,10	0,13
	dPM300	densité de peuplements de pin maritime dans un rayon de 300 m	0,42	1,00	0,81	0,16
	dDW200	densité de bois mort dans un rayon de 200 m	3,02	18,66	10,13	3,86
	dCR_200	densité de coupes rase dans un rayon de 200 m	0,00	0,49	0,03	0,09
	dFeuil_200	densité de peuplements feuillus dans un rayon de 200 m	0,00	0,46	0,08	0,11
	dPM200	densité de peuplements de pin maritime dans un rayon de 200 m	0,49	0,99	0,85	0,14

ANNEXE 10

Variables dendrométriques mesurées à Rambouillet

				stations A et B				stationA	station B
libellé	variable		Ech. (ha)	Moy.	SD	Min	Max	Moy.	Moy.
BMT.glob.BESP	BMT.BESP	Volume total de BM de bouleau	0,9	6,43	6,95	0	38,01	7,74	5,13
BMT.X.BESP	BMT.BESP	Volume total de BM de bouleau	0,3	7,52	10,31	0	36,69	8,76	6,29
BMT.XR.BESP	BMT.BESP	Volume total de BM de bouleau	0,07	7,13	9,95	0	36,01	8,09	6,16
BMT.glob.CABE	BMT.CABE	Volume total de BM de charme	0,9	0,51	1,17	0	5,65	0,28	0,75
BMT.X.CABE	BMT.CABE	Volume total de BM de charme	0,3	0,84	2,84	0	15,56	0,23	1,44
BMT.XR.CABE	BMT.CABE	Volume total de BM de charme	0,07	0,77	2,76	0	15,39	0,21	1,32
BMT.glob.FASY	BMT.FASY	Volume total de BM de hêtre	0,9	0,13	0,65	0	4,92	0,00	0,26
BMT.X.FASY	BMT.FASY	Volume total de BM de hêtre	0,3	0,02	0,11	0	0,68	0,00	0,04
BMT.XR.FASY	BMT.FASY	Volume total de BM de hêtre	0,07	0	0	0	0	0,00	0,00
BMT.glob.P1	BMT.P1	Volume total de BM de classe de dégradation 1	0,9	8,95	9,53	0	45,9	12,30	5,60
BMT.X.P1	BMT.P1	Volume total de BM de classe de dégradation 1	0,3	19,23	20,98	0	104,74	24,79	13,66
BMT.XR.P1	BMT.P1	Volume total de BM de classe de dégradation 1	0,07	13,84	14,17	0	60,92	15,92	11,76
BMT.glob.P2	BMT.P2	Volume total de BM de classe de dégradation 2	0,9	1,65	1,66	0	7,38	1,90	1,40
BMT.X.P2	BMT.P2	Volume total de BM de classe de dégradation 2	0,3	2,53	2,95	0	12,78	3,29	1,78
BMT.XR.P2	BMT.P2	Volume total de BM de classe de dégradation 2	0,07	2,44	2,95	0	12,78	3,20	1,68
BMT.glob.P3	BMT.P3	Volume total de BM de classe de dégradation 3	0,9	9,52	6,45	0,69	37,11	9,07	9,97
BMT.X.P3	BMT.P3	Volume total de BM de classe de dégradation 3	0,3	21,16	15,73	0,5	67,83	21,19	21,12
BMT.XR.P3	BMT.P3	Volume total de BM de classe de dégradation 3	0,07	18,43	15,16	0,3	64,2	17,79	19,06
BMT.glob.P4	BMT.P4	Volume total de BM de classe de dégradation 4	0,9	2,73	1,97	0	8,69	2,40	3,06
BMT.X.P4	BMT.P4	Volume total de BM de classe de dégradation 4	0,3	4,72	4,04	0	17,3	4,95	4,48
BMT.XR.P4	BMT.P4	Volume total de BM de classe de dégradation 4	0,07	4,25	3,93	0	17,3	4,45	4,05
BMT.glob.PISP	BMT.PISP	Volume total de BM de pin	0,9	0,05	0,33	0	2,46	0,11	0,00
BMT.XR.PISP	BMT.PISP	Volume total de BM de pin	0,07	0	0	0	0	0,00	0,00
BMT.glob.POTR	BMT.POTR	Volume total de BM de tremble	0,9	3,7	6,83	0	40,35	3,62	3,77
BMT.X.POTR	BMT.POTR	Volume total de BM de tremble	0,3	6,46	16,82	0	89,35	5,60	7,31
BMT.XR.POTR	BMT.POTR	Volume total de BM de tremble	0,07	5,98	15,41	0	85,16	4,95	7,00
BMT.glob.QUSP	BMT.QUSP	Volume total de BM de chêne	0,9	10,72	8,7	0,28	42,73	12,98	8,46
BMT.X.QUSP	BMT.QUSP	Volume total de BM de chêne	0,3	32,46	27,56	0,3	99,64	39,57	25,35
BMT.XR.QUSP	BMT.QUSP	Volume total de BM de chêne	0,07	24,74	23,45	0	87,67	28,04	21,45
DBH.3TGBV.glob	DBH.3TGBV	D_{130} moyen des 3 plus gros arbres	0,9	82,54	8,86	68,33	113,33	80,47	84,61
DBH.3TGBV.X	DBH.3TGBV	D_{130} moyen des 3 plus gros arbres	0,3	75,89	9,4	57,5	101,67	72,58	79,19
DBH.3TGBV.XR	DBH.3TGBV	D_{130} moyen des 3 plus gros arbres	0,07	56,42	14,92	20	80	53,08	59,76
GBMD.glob.BESP	GBMD.BESP	Volume de bois mort debout de bouleau (>7.5cm)	0,9	1,09	1,36	0	5,02	0,89	1,28
GBMD.X.BESP	GBMD.BESP	Volume de bois mort debout de bouleau (>7.5cm)	0,3	0,76	1,58	0	6,08	0,57	0,95
GBMD.XR.BESP	GBMD.BESP	Volume de bois mort debout de bouleau (>7.5cm)	0,07	0,75	1,55	0	6,08	0,57	0,93
GBMD.glob.CABE	GBMD.CABE	Volume de bois mort debout de charme (>7.5cm)	0,9	0,09	0,43	0	3,17	0,05	0,14
GBMD.X.CABE	GBMD.CABE	Volume de bois mort debout de charme (>7.5cm)	0,3	0,03	0,26	0	2	0,00	0,07
GBMD.XR.CABE	GBMD.CABE	Volume de bois mort debout de charme (>7.5cm)	0,07	0,03	0,26	0	2	0,00	0,07
GBMD.glob.POTR	GBMD.POTR	Volume de bois mort debout de tremble (>7.5cm)	0,9	0,51	1,29	0	8,42	0,44	0,58
GBMD.X.POTR	GBMD.POTR	Volume de bois mort debout de tremble (>7.5cm)	0,3	0,84	2,8	0	15,47	0,69	0,99
GBMD.XR.POTR	GBMD.POTR	Volume de bois mort debout de tremble (>7.5cm)	0,07	0,64	2,07	0	11,88	0,28	0,99

GBMD.glob.QUSP	GBMD.QUSP	Volume de bois mort debout de chêne (>7.5cm)	0,9	1,72	3,04	0	14,54	2,60	0,84
GBMD.X.QUSP	GBMD.QUSP	Volume de bois mort debout de chêne (>7.5cm)	0,3	4,16	8,27	0	43,78	7,58	0,73
GBMD.XR.QUSP	GBMD.QUSP	Volume de bois mort debout de chêne (>7.5cm)	0,07	1,82	3,97	0	20,1	3,25	0,38
GBMD.sup30.glob	GBMDsup30	Volume de bois mort debout de diamètre supérieur à 30cm	0,9	1,93	3,43	0	17,68	2,66	1,21
GBMD.sup30.X	GBMDsup30	Volume de bois mort debout de diamètre supérieur à 30cm	0,3	4,78	8,45	0	43,78	8,28	1,27
GBMD.sup30.XR	GBMDsup30	Volume de bois mort debout de diamètre supérieur à 30cm	0,07	2,22	4,17	0	20,1	3,54	0,90
GBMS.glob.BESP	GBMS.BESP	Volume de bois mort au sol de bouleau (>7.5cm)	0,9	5,2	6,43	0	37,53	6,70	3,69
GBMS.X.BESP	GBMS.BESP	Volume de bois mort au sol de bouleau (>7.5cm)	0,3	6,63	9,49	0	35,57	8,04	5,22
GBMS.XR.BESP	GBMS.BESP	Volume de bois mort au sol de bouleau (>7.5cm)	0,07	6,26	9,17	0	35,57	7,38	5,15
GBMS.glob.CABE	GBMS.CABE	Volume de bois mort au sol de charme (>7.5cm)	0,9	0,38	0,94	0	4,65	0,22	0,53
GBMS.X.CABE	GBMS.CABE	Volume de bois mort au sol de charme (>7.5cm)	0,3	0,75	2,78	0	15,26	0,20	1,31
GBMS.XR.CABE	GBMS.CABE	Volume de bois mort au sol de charme (>7.5cm)	0,07	0,7	2,73	0	15,26	0,20	1,19
GBMS.glob.FASY	GBMS.FASY	Volume de bois mort au sol de hêtre (>7.5cm)	0,9	0,1	0,57	0	4,31	0,00	0,20
GBMS.XR.FASY	GBMS.FASY	Volume de bois mort au sol de hêtre (>7.5cm)	0,07	0	0	0	0	0,00	0,00
GBMS.glob.PISP	GBMS.PISP	Volume de bois mort au sol de pin (>7.5cm)	0,9	0,05	0,33	0	2,46	0,11	0,00
GBMS.XR.PISP	GBMS.PISP	Volume de bois mort au sol de pin (>7.5cm)	0,07	0	0	0	0	0,00	0,00
GBMS.glob.POTR	GBMS.POTR	Volume de bois mort au sol de tremble (>7.5cm)	0,9	3,15	5,7	0	31,8	3,15	3,16
GBMS.X.POTR	GBMS.POTR	Volume de bois mort au sol de tremble (>7.5cm)	0,3	5,58	14,57	0	77,47	4,88	6,27
GBMS.XR.POTR	GBMS.POTR	Volume de bois mort au sol de tremble (>7.5cm)	0,07	5,32	13,96	0	73,28	4,66	5,98
GBMS.glob.QUSP	GBMS.QUSP	Volume de bois mort au sol de chêne (>7.5cm)	0,9	8,99	8,02	0,28	40,88	10,35	7,63
GBMS.X.QUSP	GBMS.QUSP	Volume de bois mort au sol de chêne (>7.5cm)	0,3	27,18	24,04	0	88,65	30,98	23,39
GBMS.XR.QUSP	GBMS.QUSP	Volume de bois mort au sol de chêne (>7.5cm)	0,07	22,49	21,67	0	80,21	24,32	20,66
GBMS.30.glob	GBMSsup30	Volume de bois mort au sol de diamètre supérieur à 30cm	0,9	4,23	6,26	0	34,67	5,77	2,69
GBMS.30.X	GBMSsup30	Volume de bois mort au sol de diamètre supérieur à 30cm	0,3	11,87	13,26	0	44,54	14,90	8,85
GBMS.30.XR	GBMSsup30	Volume de bois mort au sol de diamètre supérieur à 30cm	0,07	6,5	8,19	0	37,74	7,36	5,64
GBVT.glob.mean	GBVT	Surface terrière des arbres vivants (DBH<7.5cm)	0,9	1,34	0,29	0,65	2	1,22	1,46
GBVT.X	GBVT	Surface terrière des arbres vivants (DBH<7.5cm)	0,3	2,96	1,05	0,99	6,01	2,67	3,26
GBVT.XR	GBVT	Surface terrière des arbres vivants (DBH<7.5cm)	0,07	1,3	0,5	0,24	2,34	1,14	1,45
GGBD.glob.mean	GGBD	Surface terrière des arbres dépérissants (DBH<7.5cm)	0,9	0,02	0,04	0	0,2	0,01	0,02
GGBD.X	GGBD	Surface terrière des arbres dépérissants (DBH<7.5cm)	0,3	0,04	0,15	0	0,88	0,04	0,04
GGBD.XR	GGBD	Surface terrière des arbres dépérissants (DBH<7.5cm)	0,07	0,03	0,11	0	0,66	0,02	0,04
GPBV	GPBV	Surface terrière des petits arbres vivants (2.5<DBH<7.5cm)		0,08	0,11	0	0,6	0,07	0,09
GTGBV.XR	GTGBV	Surface terrière des gros arbres vivants (DBH>40cm)	0,07	5,56	3,72	0	15,06	5,24	5,88
GTGBV.X	GTGBV	Surface terrière des gros arbres vivants (DBH>40cm)	0,3	13,5	6,1	3,61	29,63	12,72	14,27
GTGBV.glob	GTGBV	Surface terrière des gros arbres vivants (DBH>40cm)	0,9	5,49	2,13	1,21	9,7	5,10	5,88
nb.cldec.BMT.glob	nb.cldec	Nombre de classes de décomposition du bois mort	0,9	9	0	9	9	9,00	9,00
nb.cldec.BMT.X	nb.cldec	Nombre de classes de décomposition du bois mort	0,3	7,17	1,61	2	9	7,07	7,27
nb.cldec.BMT.XR	nb.cldec	Nombre de classes de décomposition du bois mort	0,07	6,75	1,75	2	9	6,67	6,83
nb.cldia.BMT.glob	nb.cldia	Nombre de classes de diamètre du bois mort	0,9	4,62	0,52	3	5	4,63	4,60
nb.cldia.BMT.X	nb.cldia	Nombre de classes de diamètre du bois mort	0,3	4,43	0,67	3	5	4,57	4,30
nb.cldia.BMT.XR	nb.cldia	Nombre de classes de diamètre du bois mort	0,07	3,7	0,87	2	5	3,93	3,47
Nb.of.DW.types	nb.DW.types	Nombre de types du bois mort	0,3	32,02	13,18	8	75	31,53	32,50
nb.ess.BMT.glob	nb.ess	Nombre d’essences de bois mort	0,9	3,23	1,06	1	5	2,77	3,70
nb.ess.BMT.X	nb.ess	Nombre d’essences de bois mort	0,3	2,42	0,83	1	4	2,23	2,60
nb.ess.BMT.XR	nb.ess	Nombre d’essences de bois mort	0,07	2,2	0,88	1	4	1,97	2,43
PBMS.CL2	PBMS.CL2	Volume de petit bois mort au sol (D<2.5cm)	0,3	2,68	1,7	0,45	8,41	2,75	2,62

PBMS.CL5	PBMS.CL5	Volume de petit bois mort au sol (2.5<D<7.5cm)	0,3	8,08	3,8	1,77	19,96	8,47	7,68
VPBMS.X	VPBMS	Volume total de petit bois mort au sol (D<7.5cm)	0,3	10,76	4,76	2,68	23,79	11,23	10,30
Rglob	R	Ratio [volume total de bois mort] / [volume total des arbres vivants]	0,9	9,14	7,69	1,02	45,7	11,35	6,92
RX	R	Ratio [volume total de bois mort] / [volume total des arbres vivants]	0,3	13,2	13,63	0,43	61,07	17,21	9,20
RXR	R	Ratio [volume total de bois mort] / [volume total des arbres vivants]	0,07	19,34	18,15	0,37	73,38	23,17	15,51
S.sup30.glob	Ssup30	Volume de souches de diamètre > 30cm	0,9	1,06	0,69	0	2,89	0,72	1,39
S.sup30.X	Ssup30	Volume de souches de diamètre > 30cm	0,3	1,14	0,86	0	4,53	0,99	1,29
S.sup30.XR	Ssup30	Volume de souches de diamètre > 30cm	0,07	0,39	0,41	0	1,62	0,40	0,38
VBMH.X	VBMH	Volume de bois mort (D>7.5cm) dans les houppiers de chêne vivants (DBH>40cm)	0,3	4,31	2,51	0,51	12,47	3,19	5,43
VBMTglobmean	VBMT	Volume total de bois mort	0,9	23	16,01	2,97	98,31	25,79	20,22
VBMTXR	VBMT	Volume total de bois mort	0,07	38,95	28,3	0,89	106,11	41,36	36,54
VBMTX	VBMT	Volume total de bois mort	0,3	47,63	33,63	1,4	138,36	54,22	41,05
VBVT.glob.mean	VBVT	Volume total de bois vivant	0,9	269,84	59,07	158,61	369,82	246,63	293,05
VGBD.glob.mean	VGBD	Volume total des arbres dépérissants (DBH>7.5cm)	0,9	2,81	5,12	0	21,55	1,64	3,98
VGBMDglobmean	VGBMD	Volume total du bois mort debout (DBH>7.5cm)	0,9	3,56	4,05	0	22,62	4,09	3,03
VGBMDXR	VGBMD	Volume total du bois mort debout (DBH>7.5cm)	0,07	3,3	4,54	0	20,41	4,11	2,49
VGBMDX	VGBMD	Volume total du bois mort debout (DBH>7.5cm)	0,3	5,86	8,52	0	44,22	8,85	2,86
VGBMSglobmean	VGBMS	Volume total du bois mort au sol (DBH>7.5cm)	0,9	18,02	14,23	1,02	88,23	20,67	15,37
VGBMSXR	VGBMS	Volume total du bois mort au sol (DBH>7.5cm)	0,07	35,03	26,62	0	96,8	36,61	33,46
VGBMSX	VGBMS	Volume total du bois mort au sol (DBH>7.5cm)	0,3	40,41	29,39	0	106,98	44,15	36,67
VGBV.glob.mean	VGBV	Volume de bois vivant (DBH>7.5cm)	0,9	255,73	55,02	142,33	349,3	234,23	277,22
VPBMD.X	VPBMD	Volume total de petit bois mort debout (DBH<7.5cm)	0,3	0,19	0,51	0	2,67	0,19	0,19
VPBV	VPBV	Volume des petits arbres vivants (2.5<DBH<7.5cm)		14,11	17,75	0	100,06	12,40	15,82
VSXR	VS	Volume total de souches (D>7.5cm)	0,07	0,61	0,56	0	2,39	0,63	0,59
VSglobmean	VS	Volume total de souches (D>7.5cm)	0,9	1,42	0,8	0,09	3,25	1,02	1,82
VSX	VS	Volume total de souches (D>7.5cm)	0,3	1,37	0,94	0	4,61	1,22	1,52