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DATA PAPER **Open Access**

Dendrometric data from the silvicultural scenarios developed by Office National des Forêts (ONF) in France: a tool for applied research and carbon storage estimates

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Abstract

Key message: We provide a database of 52 silvicultural scenarios recommended in French public forests including relevant dendrometric variables and metrics for carbon accounting. The dataset is available at https://doi.org/10.57745/QARRFS. Associated metadata are available at https://metadata-afs.nancy.inra.fr/geonetwork/srv/fre/catalog.search#/metadata/f76ed27f-325d-493b-8731-0995dcaa7805. Special attention was paid to offer carbon metrics required for the French *Label Bas Carbone* offset projects.

Keywords: Forest management, Silviculture, Simulation, Forest dynamics, Carbon, Mitigation

1 Background

Forests are a source of multiple ecosystem services that benefit society (e.g. wood production, global climate regulation, habitat for biodiversity, landscape amenities, etc.; Brockerhoff et al. 2017), most of which are influenced by forest management. In this regard, European forests are characterised by their wide variety of forest types (Barbati et al. 2007), therefore maintaining the important range of associated forest ecosystem services in a changing climate might require to explore a range of alternative forest management and assess their impact to adapt European forests (Mina et al. 2017; Biber et al. 2020).

Some of the issues at stake are easily and directly linked to usual dendrometric variables manipulated by foresters to assess their actions. Accordingly, simulations of silvicultural scenarios, which are common management tools to plan silvicultural interventions, offer a realistic basis for applied studies that aim at researching the impact of forest management on forest ecosystem features or services.

Office National des Forêts (ONF) is a French government agency responsible for the sustainable management of publicly owned forests, representing 4.6 million hectares (25% of the forest area of metropolitan France). The core of its activity lies in timber production, and it marketed 11.4 million m^3 of timber (40% of national production) in 2020 (ONF 2021). The agency is also responsible for preserving the biodiversity and landscapes of public forests, welcoming public and raising awareness among forest users on environmental issues.

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The agency being active since 1964, the historical technical expertise of its agents has been compiled throughout the years in silvicultural guides i.e. sets of possible silvicultural scenarios relevant for a homogenous silvicultural context (a set of environmental and economic conditions), including both planned programs of silvicultural interventions and growth dynamics associated with them (Sardin and Deleuze 2020).

Each guide covers a large regional and contextual domain, providing a basis on which technical recommendations can be made. They describe in figures, the possible interventions, the rates and intensities of harvesting as well as the regeneration processes to produce an adequate quality of roundwood specific for a primary wood product (lumber, plywood, pulp, fuel). ONF experts in charge of writing silvicultural guides, in partnership with academic researchers, have adopted growth and yield models and acquired simulation skills through intensive use, providing more accurate information on stand growth for their management decisions. However, even if a guide illustrates a silvicultural scenario with a large number of usual dendrometric variables, the level of details provided in the different guides can be heterogeneous, making it impossible to extract all figures from the written document and compare them objectively. Furthermore, the few officially published silvicultural guides are no longer available for external purchase from the publisher, while new guides or revisions have now been limited to internal use altogether. Although they can be made available upon request for educational and research purposes, this represents a massive obstacle to their distribution outside of ONF both in France and abroad.

The evolution of silvicultural guides along with the development of growth and yield models offer opportunities for applied forestry research. For instance, quantifying forest carbon stocks and fluxes is mandatory to assess the impact of forest mitigation measures at a forest stand level. Therefore, the collection of ONF silvicultural guides have increasingly been used to calculate carbon sequestration with the development of carbon offset certifications like the *Label Bas Carbone* in France (i.e. government-run carbon offset program created in 2018 and involving forest activities among other sectors : Ministère de la transition écologique et solidaire, I4CE 2020; Grimault and Gleizes 2019).

On the one hand, ONF silvicultural recommendations can be carefully expanded outside of French borders to shared European ecoregions, making them relevant for a wider use. On the other hand, the development of generic and comparative modelling approaches at European scale (Mahnken et al. 2022) offers additional purpose to ONF silvicultural simulations to provide realistic reference scenarios as a baseline for comparison in a constant climate.

Consequently, our objective was to provide a consolidated database of standard ONF silvicultural scenarios for major tree species and silvicultural contexts throughout the French metropolitan territory, including relevant dendrometric variables and carbon storage as an example of valorisation. The database will be completed with new silvicultural developments (for mixed and uneven stands for example) and wider range of species and silvicultural contexts in the future. Moreover, silvicultural scenarios will be updated in the wake of potential future improvements in growth and yield models' predictions, specifically to account for changes in forest productivity related to climate change.

2 Methods

2.1 Description of the silvicultural guides provided in the database

Ten silvicultural guides were used to build the current version of the database provided here, which represent silvicultural scenarios for 12 French major species in pure even-aged systems (Fournier et al. 2022). They are listed in Table 1 and their domains of applicability are shown in Fig. 1.

2.2 Growth and yield models used to simulate silvicultural scenarios

All the growth and yield models used here to build silvicultural scenarios simulate the evolution of individual trees without taking into account their spatial position (distance-independent tree-based models). They are listed in Table 1. These growth and yield models have been designed to build and simulate silvicultural scenarios and partly rely on similar construction principles originating from the *Fagacées* model (Le Moguédec and Dhôte 2012).

2.3 Construction of silvicultural scenarios on the Capsis platform

All growth and yield models used to simulate silvicultural scenarios in the database are hosted on the *Capsis* platform (Dreyfus and Bonnet 1995; Dufour-Kowalski et al. 2012). A large amount of the original simulations used for the guides developments using the *Capsis* platform are not available anymore, related to the successive updates of the original growth and yield models. Therefore, most of the silvicultural scenarios in the database are from new simulations following the references of the guides.

New silvicultural alternatives have also been added and flagged in the database such as silvicultural scenarios for planting densities (e.g. for sessile oak in the Loire Basin), while others have been updated to better take into account recent silvicultural recommendations such as modification of the minimum exploitable diameter

Table 1 List of silvicultural guides provided in the database for each species, silvicultural context, and growth and yield models used for simulating stand dynamics

Original ONF guide	Current guide revision	Geographical area	Estimated forest area ($\times 10^3$ha)	Studied species	Used growth and yield model	Model developer	Model reference
(Sardin 2008)	(Sardin et al. 2018)	North-east of France	659	*Quercus petraea* (Sessile Oak)	Fagacées	J-F. Dhôte, P. Vallet, G. Le Moguédec, F. Mothe	(Le Moguédec and Dhôte 2012)
				Quercus robur (Pedonculate Oak)	Fagacées	J-F. Dhôte, P. Vallet, G. Le Moguédec, F. Mothe	(Le Moguédec and Dhôte 2012)
(Jarret 2004)	(Delord and Mandret 2018)	Loire basin	217	*Quercus petraea* (Sessile Oak)	Fagacées	J-F. Dhôte, P. Vallet, G. Le Moguédec, F. Mothe	(Le Moguédec and Dhôte 2012)
(Ladier et al. 2012)		Southern Alps mountains	129[a]	*Abies alba* (Silver fir)	Sydy	P. Dreyfus	https://sydycapsis.blogspot.com/
				Pinus nigra ssp *nigra* (Austrian black pine)	Sydy	P. Dreyfus	https://sydycapsis.blogspot.com/
				Pinus sylvestris (Scots pine)	Sydy	P. Dreyfus	https://sydycapsis.blogspot.com/
(ONF 1997)	(Sardin 2013b)	Pyrenees mountains	107	*Fagus sylvatica* (European beech)	Fagacées	J-F. Dhôte, P. Vallet, G. Le Moguédec, F. Mothe	(Le Moguédec and Dhôte 2012)
(Abt 2014)		Jura mountains	103	*Abies alba* (Silver fir)	Abial	J-D. Bontemps, F. Longuetaud, F. Mothe, V. Pérez, D. Rittié, L. Saint-André, I. Seynave	(Bontemps et al. 2009)
				Picea abies (Norway spruce)	FCBA Picea abies	P. Cailly, S. Cavaignac	(Pain and Boyer 1996)
(Chabaud and Nicolas 2009)		Plains of central and northern France	69	*Pinus nigra* ssp *laricio* var *corsicana*, *Pinus nigra* ssp *laricio* var *calabrica* (Laricio pine)	Laricio	C. Meredieu	(Meredieu 1998)
				Pinus pinaster (Maritime pine)	PP3	B. Lemoine, P. Dreyfus, C.Meredieu	(Meredieu 2002)
				Pinus sylvestris (Scots pine)	Silvestris	T. Perot, S. Perret, C. Meredieu	(Pérot et al. 2007)
(Angelier 2007)	(Sardin 2013a) (ONF 2017)	France	65	*Pseudotsuga menziesii* (Douglas fir)	FCBA Pseudotsuga menziesii	P. Cailly, S. Cavaignac	(Bailly and Bigot 1997)
					Gymnos	G. Ligot, J. Perin, A. de Pierpont, S. Quevauviller	(Perin et al, 2016)
(Tresmontant and Quesney 2015)		Mediterranean coast	50	*Pinus halepensis* (Aleppo pine)	NRG-Sydy	P. Dreyfus	(Chomel et al. 2016)
(ONF 2003)		Forest of Landes de Gascogne	45	*Pinus pinaster* (Maritime pine)	PP3	B. Lemoine, P. Dreyfus, C.Meredieu	(Meredieu 2002)
(Sardin et al. 2022)		France	n/a	*Cedrus atlantica* (Atlas cedar)	CA1 - Sydy	F. Courbet, P. Dreyfus	(Courbet 2002)

Forest area was estimated for 2019 using the free access OCRE online platform which computes data from French NFI plots (https://ocre-gp.ign.fr/ocre, [a] the studied species could not be isolated from other non-relevant species, *n/a* no data was found on the species); the *Sydy* interface offer features to simplify silvicultural simulations in Capsis with existing growth and yield models as well as offering original models designed by P. Dreyfus

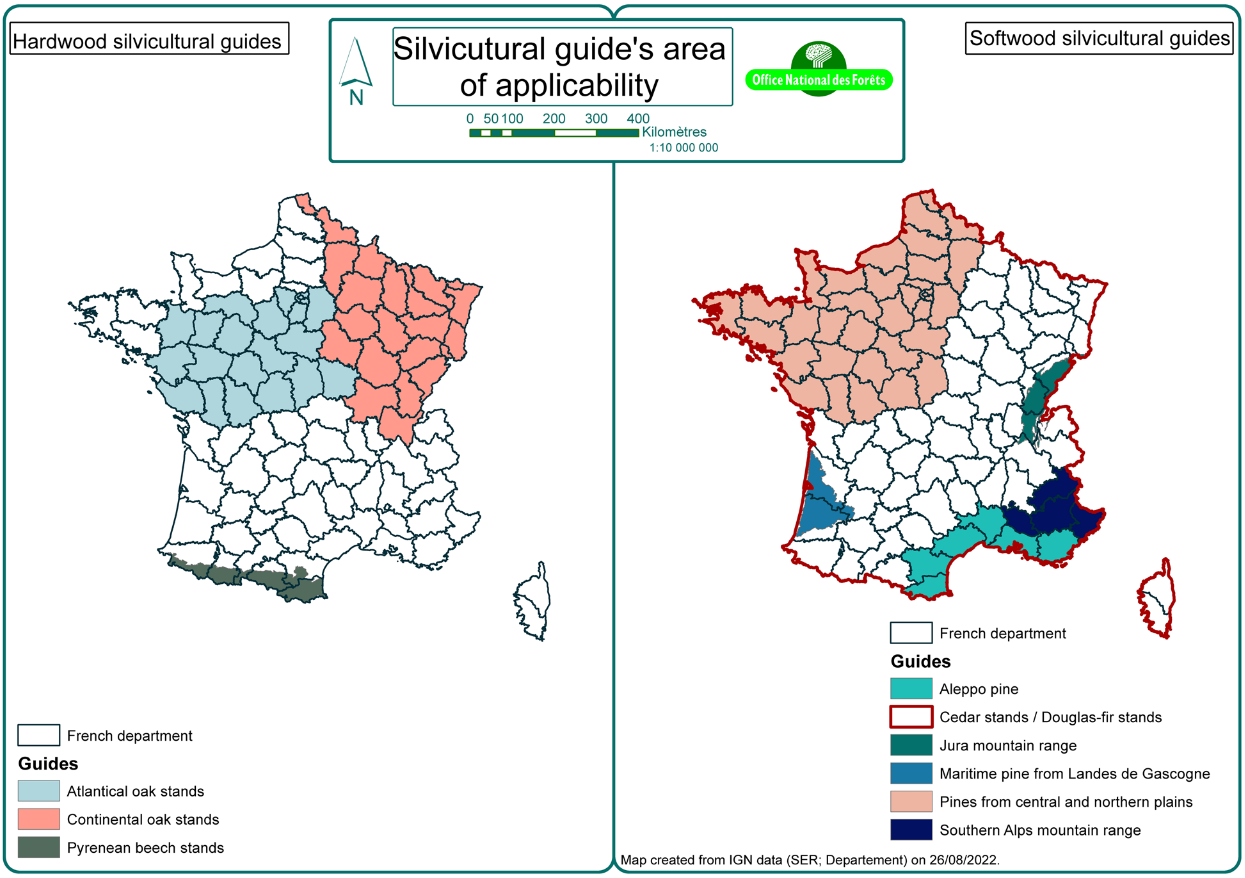

Fig. 1 Areas of applicability for each silvicultural guide represented in the database

to adapt to new market constraints (e.g. for Douglas-fir stands in 2007, exploitable diameter were 55 to 65 cm depending on site fertility and was fixed to 55 cm after 2017, regardless of site fertility; ONF 2017).

2.4 Simulation outputs from Capsis and volume calculations

Dendrometric data at stand-level was extracted and stored directly in the database from *Capsis* outputs: age, density, basal area (BA), dominant height, quadratic mean diameter at breast height (DBH), and dominant DBH. The minimum DBH threshold for inventory was set to 7.5 cm. Moreover, for each simulation tree-level data was used for volume calculation but was not available as an output for each simulated age depending on the growth and yield model. Therefore, tree-level data was extracted when available: DBH, total height and tree status (i.e. alive, cut, dead). As a result, some volume data is not available for given ages in the database.

Tree-level data was then treated using the R software version 4.0.2 (2020-06-22).

Even though each growth and yield model supplies their own stand volume outputs based on different volume tables, in the database, we computed every volume at tree-level based on volume tables from Deleuze et al. (2014) for standardisation purposes. During this process, two merchantable volumes following Gschwantner et al. (2019) definitions and a whole stem volume were calculated:

- Merchantable stem volume (over-bark volume of the bole, diameter > 7 cm)
- Merchantable stem and branches volume (over-bark volume of the bole and big branches, diameter > 7 cm)
- Whole stem volume (over-bark volume of every aerial biomass compartment of the tree)

Input variables were: tree species, DBH, total height and the height at which stem diameter decreases of more than 10% (Hdec). In the database, Hdec was fitted as a linear function of individual total height using the data from the National Forest Inventory (NFI) plots freely available (https://inventaire-forestier.ign.fr/dataIFN/).

Volumes of each individual were then aggregated at stand-level and stored in the database.

Mean annual increment and current annual increment (for BA, merchantable stem volume, and whole stem volume) at stand-level were also calculated for each available date (time intervals depend on the models). For the computation of total production, living, cut and dead individuals were considered, except for the *Sylvestris* and *Laricio* models for which dead tree's diameters and heights were not individually available, so it may be marginally underestimated for these particular silvicultural scenarios.

2.5 Methodology to calculate carbon storage for each silvicultural scenario

The steps to calculate carbon variables for the database are as follows:

For most growth and yield model, simulations could not start from seed but only from a somewhat later stand age after the juvenile phase. Thus, in order to compute the mean carbon storage on the revolution length volume data was completed before the initial date of the simulation, an exponential model was fitted and defined as

$$\mathrm{stand\_vtot\_c0}(\mathrm{stand\_age}) = \mathrm{ini\_juv\_alpha} \times (\exp(\mathrm{ini\_juv\_beta} \times \mathrm{stand\_age}) - 1) \tag{1}$$

Where ini_juv_alpha and ini_juv_beta are constraint with the initial growth dynamics (ensuring continuity and continuity of derivative) and provided in the database for each silvicultural scenario.

Next, aboveground carbon storage is calculated as

$$\mathrm{carb\_aer}(\mathrm{stand\_age}) = \mathrm{stand\_vtot\_c0}(\mathrm{stand\_age}) \times \mathrm{biom\_dens\_Dupouey_i} \times \mathrm{t_C} \times \frac{44}{12} \tag{2}$$

Then, root carbon storage is estimated as a function of aerial biomass for temperate forests based on (Cairns et al. 1997):

$$\mathrm{carb\_root}(\mathrm{stand\_age}) = \exp(-1.0587 + 0.8836 \times \ln(\mathrm{stand\_vtot\_c0}(\mathrm{stand\_age}) \times \mathrm{biom\_dens\_dupouey_i}) + 0.2840) \times t_C \times \frac{44}{12} \tag{3}$$

Thereby, total carbon storage is calculated as

$$\mathrm{carb\_stor}(\mathrm{stand\_age}) = \mathrm{carb\_aer}(\mathrm{stand\_age}) + \mathrm{carb\_root}(\mathrm{stand\_age}) \tag{4}$$

Finally, mean carbon storage on the rotation length is calculated as

$$\mathrm{carb\_stor\_mean} = \frac{1}{N} \cdot \int_0^N \mathrm{carb\_stor}(\mathrm{stand\_age}) . d\mathrm{stand\_age} \tag{5}$$

Where N the rotation length, $\mathrm{biom\_dens\_dupouey_i}$ the basic specific gravity of the species' wood i according to Dupouey's database (*unpublished but used in* Loustau 2004) and t_C the carbon fraction in dry biomass components based on the work of Longuetaud et al. (2013).

3 Access to the data and metadata description

The dataset is available at Recherche Data Gouv repository: https://doi.org/10.57745/QARRFS. Associated metadata are available at https://metadata-afs.nancy.inra.fr/geonetwork/srv/fre/catalog.search#/metadata/f76ed27f-325d-493b-8731-0995dcaa7805. The database contains two tables. The first table contains the dendrometric and carbon variables over the years of a silvicultural scenario:

- An identity card of the silvicultural scenario : tree species, original ONF silvicultural guide, current or newer version of a guide, description of the given alternative silvicultural scenario, fertility, dominant height at 50 years old, minimum exploitable diameter, origin of the stand (plantation, natural regeneration);
- Temporal evolution of dendrometric variables (density, BA, dominant height, mean DBH, dominant DBH, volumes, total productions, mean and current annual increments);
- Thinning characteristics (harvested density, BA, mean DBH, volumes, thinning qualifier coefficient (i.e. preferential thinning in dominated or dominant individuals, calculated with the ratio: $K_g = \left(\frac{\mathrm{harvestedDBH}}{\mathrm{initialDBH}}\right)^2$));
- Carbon storage: basic specific gravity of the species, aerial carbon storage, root carbon storage, total carbon storage in the forest stand, harvested carbon

content, mean carbon storage during the silvicultural scenario, carbon capture flow.

The second table records the information needed to replicate the simulations for a database user:

- General information on the model used for simulation : name of the model, version, option of initialisation, ONF agents involved in the simulation and processing chain;
- A characterisation of the initial stand: type of stand (real or virtual), origin, possible modification of the original variables, dendrometric characteristics (age, dominant height, N, BA, diameter class distribution), model parameters to calculate whole stem volume for juvenile stands prior to simulation.

Dendrometric variables are described in Table 2 and each variable definition is available in the metadata file of the database as well. Each row of the database represents the age of a forest stand within a silvicultural scenario.

4 Technical validation

A technical validation of the results was performed. Field experts were asked to evaluate simulations in the database to ensure their technical feasibility on field. Table 3 sums up the pairs of simulation model author and silvicultural expert for each silvicultural context provided in the database.

Dendrometric data available in the database are given for fully stocked stands and do not account for usual gaps found in real forest stands (e.g. due to the heterogeneous nature of the ecosystem). Furthermore, growth and yield models are highly sensitive to initial stands and thinning algorithms. That is why, even though we tried to follow as closely as possible the silvicultural scenarios, changing simulation tools from the ones originally used can create some dissimilarities between the new simulations and data of a silvicultural guide. However, using homogeneous simulation tools for the silvicultural scenarios of the database was part of our goal of standardising them. Therefore, to make sure the new simulations represented correctly the original work behind the silvicultural scenarios, experts were also asked to validate the acceptability of those changes.

Moreover, silvicultural scenarios in the database are tightly related to each specific model's weaknesses linked to their construction principles and domain of validity, and models were calibrated with data collected in past climatic conditions. We recommend that the creation of alternative silvicultural scenarios based on ONF ones from the database should be restricted to

- The geographic areas where the growth and yield model's calibration or validation data was collected;
- The growth and yield model's range of validated age or DBH;
- The growth and yield model's range of validated density or BA.

Nonetheless, some ONF silvicultural guides are made using growth and yield models used in extrapolated conditions after validation by experts of the silvicultural context. For example, the *PP3* model has never been calibrated on maritime pines from northwestern and central France but was used by the experts to simulate the silvicultural scenarios in this geographic area. Therefore, it leaves the possibility for other database users to extrapolate, with caution, the results of silvicultural scenarios to areas outside of France with similar environmental conditions (e.g. Swiss Jura Mountains, Western Germany).

5 Reuse potential and limits

5.1 Potential use

Based on the richness of silvicultural contexts, the diversity of species and types of silvicultural scenarios provided in the present database, comparisons of several metrics are easily done to guide forest managers and provide educational elements. Figure 2 shows the mean annual increment (MAI) in whole stem volume for each simulated silvicultural scenario and illustrates how management decisions coupled with environmental characteristics affect stand growth for a given species. Indeed, these silvicultural scenarios are relevant for several types of studies that assess the impact of forest management on the forest ecosystem features or services (Sing et al. 2018; Lundholm et al. 2020). Another illustrated example of potential use can be the differential between harvested whole stem (variable *stand_vtot_c0*) and merchantable stem and branches volumes (variable *stand_vtot_c7*), which can be interesting to simulate the impact of harvest scenarios for small branches under a 7-cm-diameter threshold like in the RESPIRE project (Saint-André et al. 2019).

Furthermore, the description of initial stand characteristics and detailed temporal dendrometric data provided here should allow new users to simulate ONF silvicultural scenarios to the closest, freely calculate unavailable dendrometric variables in the database (e.g. mean total height, relative density index) or access available *Capsis* extensions to offer additional features.

Besides, to face global environmental changes, the diversification of silvicultural scenarios is a key component of future forest management. Therefore, potential model users may experiment, through model simulation, new silvicultural scenarios to address various issues and

Table 2 Overview of the variables from the dendrometric, thinning and carbon segments of the database with the definition of the variable

Type	Variable	Description of the variable	Unit
Dendrometric variables	stand_age	Age from seed	Year
	stand_cut	Stand before or after thinning	
	stand_hdom	Dominant height of the stand	m
	stand_n	Density of the stand	N.ha^{-1}
	stand_ba	Basal area of the stand	m^2. ha^{-1}
	stand_dbh_mean	Mean quadratic diameter of the stand	cm
	stand_dbh_dom	Mean dominant diameter of the stand	cm
	stand_vstem_c7	Merchantable stem volume of the stand (overbark volume of the bole with a stem top diameter > 7 cm)	m^3. ha^{-1}
	stand_vtot_c7	Merchantable stem and branches volume of the stand (overbark volume of the bole with a stem top diameter > 7 cm and large branches of a diameter > 7 cm)	m^3. ha^{-1}
	stand_vtot_c0	Whole stem volume of the stand (overbark volume of the stump, bole and branches without conditions of minimum diameter)	m^3. ha^{-1}
	stand_prod_ba	Total basal area production of the stand	m^2. ha^{-1}
	stand_mai_ba	Mean annual basal area increment of the stand	m^2. ha^{-1}.an^{-1}
	stand_cai_ba	Current annual basal area increment of the stand	m^2. ha^{-1}.an^{-1}
	stand_prod_vstem_c7	Total merchantable stem volume production of the stand	m^3. ha^{-1}
	stand_mai_vstem_c7	Mean annual merchantable stem volume increment	m^3. ha^{-1}.an^{-1}
	stand_cai_vstem_c7	Current annual merchantable stem volume increment of the stand	m3. ha^{-1}.an^{-1}
	stand_prod_vtot_c0	Total whole stem volume production of the stand	m3. ha^{-1}
	stand_mai_vtot_c0	Mean annual whole stem volume increment of the stand	m3. ha^{-1}.an^{-1}
	stand_cai_vtot_c0	Current annual whole stem volume increment of the stand	m3. ha^{-1}.an^{-1}
Thinning variables	harv_n	Harvested density in the stand	N. ha^{-1}
	harv_ba	Harvested basal area in the stand	m2. ha^{-1}
	harv_dbh	Mean quadratic diameter of the harvested stems	cm
	harv_vstem_c7	Harvested merchantable stem volume in the stand	m3. ha^{-1}
	harv_vtot_c0	Harvested whole stem volume in the stand	m3. ha^{-1}
	harv_vstem_c7_unit	Mean harvested merchantable stem volume per tree	m3. stem^{-1}
	harv_kg	Thinning qualifier coefficient	
Carbon accounting variables	biom_dens_Dupouey	Basic specific gravity of the species according to the Dupouey database	
	carb_aer	Carbon storage in aerial biomass of the stand	tCO_2. ha^{-1}
	carb_root	Carbon storage in root biomass of the stand	tCO_2. ha^{-1}
	carb_stor	Carbon storage in total biomass of the stand	tCO_2. ha^{-1}
	harv_carb_aer	Exported carbon content from harvested biomass	tCO_2. ha^{-1}
	carb_stor_mean	Mean carbon storage on a rotation length	tCO_2. ha^{-1}
	carb_cai	Annual flow of carbon converted in biomass (current annual carbon increment)	tCO_2. ha^{-1}.an^{-1}

unexplored silvicultural contexts. ONF silvicultural scenarios of the present database can serve as references in comparison to these newly simulated alternatives. Furthermore, potentially improved growth and yield models are expected to appear in *Capsis,* which is continuously updated. Therefore, following these new developments, the present database could be used to facilitate the publication of new and updated silvicultural scenarios both in and out of ONF. A new release of *Capsis-ONF* (for ONF internal use) is compiled every year, and past versions of it are now saved to facilitate the transmission of simulations through the years.

5.2 Carbon accounting: an example of further valorisation

The French carbon offset certifications program called *Label Bas Carbone* (LBC) has devoted 3 methodologies designed for forest activities at the moment (i.e. afforestation activities, reconstitutions of degraded forest stands by plantation, coppice conversion into high forests). The first two methodologies require an assessment of

Table 3 Synthesis of people involved in performing models for simulation on the one hand and in expertise for validation of simulation on the other hand, for each studied species. Authors of simulation models contributed to add silvicultural scenarios (SSCs) of the ONF guides in the database

Species	Geographical area	Original ONF guide	Simulation authors	ONF Experts
Abies alba (Silver fir)	Jura mountains	(Abt 2014)	T. Sardin [a]	
	Southern Alps mountains	(Ladier et al. 2012)	P. Dreyfus [a]	
Cedrus atlantica (Atlas cedar)	France	(Sardin et al. 2022)	T. Sardin[a]	
Fagus sylvatica (European beech)	Pyrenees mountains	(Sardin 2013b)	S. Fournier	T. Sardin
Picea abies (Norway spruce)	Jura mountains	(Abt 2014)	S. Fournier	T. Sardin
Pinus halepensis (Aleppo pine)	Mediterranean coast	(Tresmontant and Quesney 2015)	M. Simeoni S. Fournier	P. Dreyfus
Pinus nigra ssp *laricio var corsicana*, *Pinus nigra* ssp *laricio var calabrica* (Laricio pine)	Plains of central and northern France	(Chabaud and Nicolas 2009)	S. Fournier	X. Mandret
Pinus nigra ssp *nigra* (Austrian black pine)	Southern Alps mountains	(Ladier et al. 2012)	P. Dreyfus [a]	
Pinus pinaster (Maritime pine)	Plains of central and northern France	(Chabaud and Nicolas 2009)	S. Fournier	T. Sardin
	Forest of Landes de Gascogne	(ONF 2003)	S. Fournier	T. Sardin
Pinus sylvestris (Scots pine)	Plains of central and northern France	(Chabaud and Nicolas 2009)	S. Fournier	X. Mandret
	Southern Alps mountains	(Ladier et al. 2012)	P. Dreyfus [a]	
Pseudotsuga menziesii (Douglas fir)	France	(Angelier 2007)	S. Fournier	T. Sardin
Quercus petraea (Sessile Oak)	North-east of France	(Sardin 2008)	S. Fournier	D. François
	Loire basin	(Jarret 2004)	S. Fournier	X. Mandret
Quercus robur (Pedonculate Oak)	North-east of France	(Sardin 2008)	S. Fournier	D. François

[a] Corresponds to the original author of simulations, so no additional experts were involved

biomass carbon storage at 30 years old and the mean carbon storage on the complete revolution length. These two values have been added in the database to answer these two LBC's specific requirements. If the simulation data did not provide any value at 30 years old, a linear approximation was made between the values of the two closest ages available. Furthermore, because the volumes of the database are all calculated based on the same equations, they ensure consistency and comparability in calculation. On the other hand, because one of the provided volumes of the database is the whole stem volume, biomass calculations do not need a volume expansion factor (Loustau 2004; Longuetaud et al. 2013) to convert merchantable stem volumes to whole stem volumes like it is presently done in the LBC.

As described in the potential uses of the database, graphical comparisons (Fig. 3) for different species or silvicultural contexts are valuable illustrations for forest managers to understand temporal dynamics of forest carbon storage.

The present version of the database does not yet provide any data for storage in harvested wood products nor for the carbon emissions avoided by their use. Some of the silvicultural scenarios from the database have been used in the *Carbon Accounting Tool* (CAT: Pichancourt et al. 2018) to assess these two carbon pools in *Capsis*. However, the generalisation of this method to every silvicultural scenarios of the database is currently impossible; as CAT operates with volume equations specific to each growth and yield model, carbon outputs do not match the ones provided in our database using standardized volume equations. Moreover, only a few species-specific processing chains and harvested wood products greenhouse gas emissions assessments were formalised in research projects for the French territory (Cornillier et al. 2017; Vallet et al. 2019) and with different degrees of precision. Thus, further work would be required for being able to complete the database in this respect.

5.3 Limits of silvicultural simulations in a changing climate

One of the most important weaknesses of current growth and yield models is their limited ability to predict stand dynamics in the face of global productivity changes. Current forest management may thus experience difficulties to respond to climate-related disturbances that are actually not represented in silvicultural scenarios like those presented in the database (postponement of thinnings, troubles of regeneration). Nevertheless, forest managers will continue to rely, at least in part, on current silvicultural scenarios (among other management tools) to adapt their decisions to a changing environment. These scenarios are indeed solid enough to be applied in low

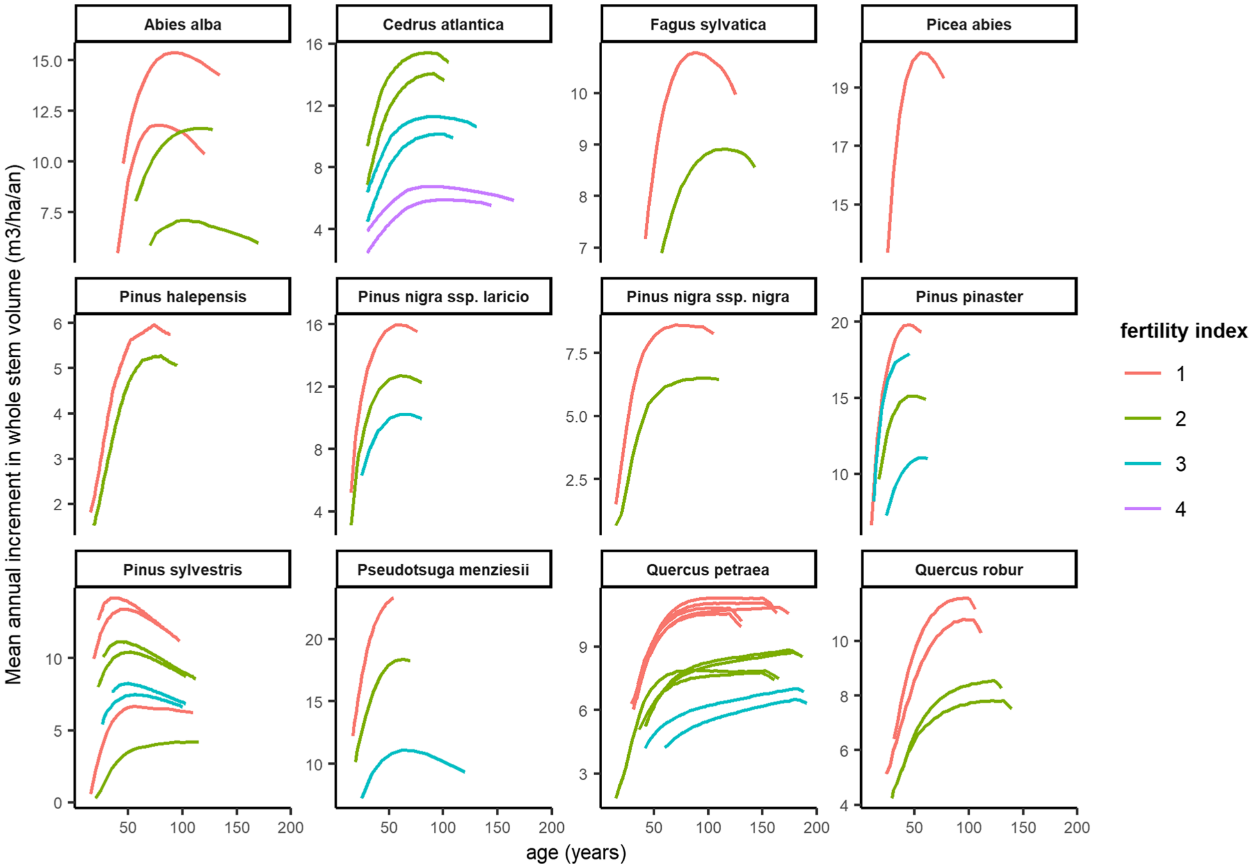

Fig. 2 Temporal evolution of simulated MAI in whole stem volume for each silvicultural scenario of the database. Silvicultural scenarios are discriminated by fertility index (specific for a species and silvicultural context, a same index does not correspond to equivalent environmental conditions for two different silvicultural guides), the different silvicultural guides and alternatives, or stand origins are not discriminated

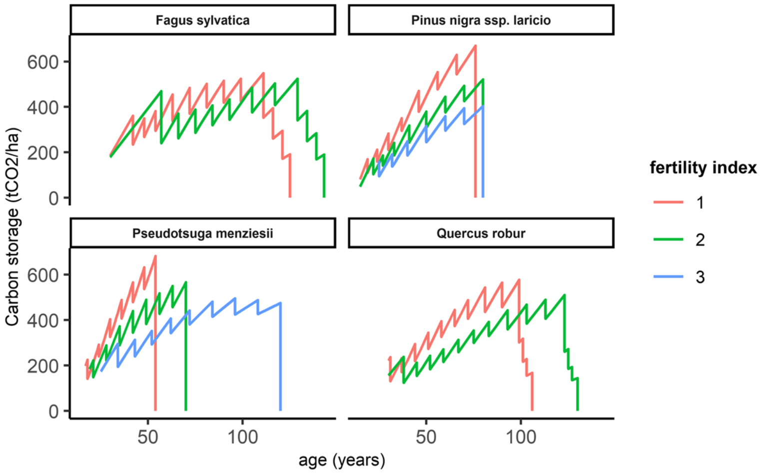

Fig. 3 Temporal evolution of total carbon storage (above and underground carbon) for silvicultural scenarios in stands of contrasted fertility indexes for four common French species

vulnerable stands to guarantee the production of quality roundwood in the future, and flexible enough to allow building alternatives pathways in case of significant changes.

Moreover, these silvicultural scenarios still represent good references for the evaluation of climate-sensitive growth and yield models to assess their consistency with usual dendrometric relationships in a constant climate. For instance, comparisons of different variables (density, basal area, DBH) have been made for oak stands between simulations from the GO+ model (Moreaux et al. 2020) and two scenarios from the database using the Fagacées model under RCP 2.6 scenario as baseline silvicultural scenarios in the Forets21 project (https://forets21.inra.fr/pelican3.1/itk-quercus.html).

Finally, species distributions in Europe may go through significant changes in future years (Buras and Menzel 2019). That is why the European forest managers and researchers community may benefit from sharing years of technical knowledge and past silvicultural experiments to anticipate management of migrating species for which silvicultural guidelines are lacking in their new projected areas.

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Code availability
Code is not available.

Authors' contributions
Salomé Fournier, Thierry Sardin, Philippe Dreyfus, Marion Simeoni contributed to the dataset with simulations of silvicultural scenarios. Philippe Dreyfus and François de Coligny added growth and yield models to the *Capsis* platform. Thierry Sardin, Philippe Dreyfus, Didier François, Xavier Mandret reviewed the realism of silvicultural scenarios as silvicultural experts. Alain Bouvet and Alain Berthelot provided dendrometric data. Salomé Fournier computed additional dendrometric data and wrote the datapaper, all co-authors reviewed it. Christine Deleuze supervised the work. All authors read and approved the final manuscript.

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Availability of data and materials
Dataset access is at https://doi.org/10.57745/QARRFS. Associated metadata are available at https://metadata-afs.nancy.inra.fr/geonetwork/srv/fre/catalog.search#/metadata/f76ed27f-325d-493b-8731-0995dcaa7805.

Declarations

Ethics approval and consent to participate
Not applicable.

Competing interests
The authors declare that they have no conflict of interest.

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