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Forest management prolongates the CO₂ sink in ageing oak stands.

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INRAE

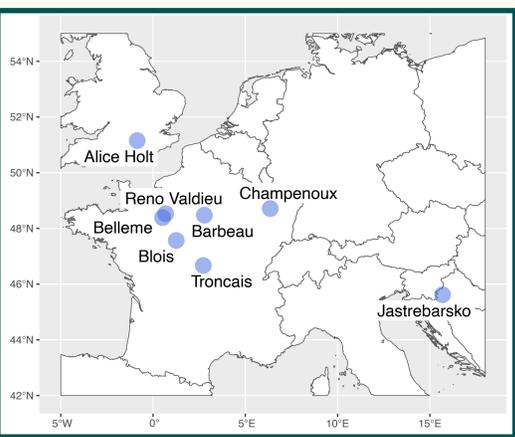


Key findings.

1. Ageing sessile and pedunculate oak stands can still accumulate carbon and positively respond to thinning.
2. Management maintains oak forests as net CO₂ sinks by reducing drought vulnerability and competition, while unmanaged are more prone to collapse under high water stress.
3. Adaptive management including “water-stress” thinnings is more efficient than other managements options.

Introduction.

Although it has been shown that old-growth forests can still act as carbon sinks, little is known about the permanence of these sinks under climate change [1-2]. It depends on the growth and mortality of trees which are controlled by the interplay between size effects [3-4], climate and pollution drivers [5-7], and management, including legacy effects [9]. In France, sessile and pedunculate oaks have reached their Southern and altitudinal margins and half of the oak production forests are over 80 years old and would need to be regenerated before 2100 [10]. In the meantime, an increasing number of oak forests are showing dieback signs due to extreme climate events [5-8]. This modelling experiment investigates how management would impact carbon sink permanence in ageing oak forests. We tested the model ability to reproduce the historical growth (15 stations) and carbon balance (3 stations) of oak forests in Europe and projected 11 old oak forests from 2015 to 2100 under three management and four climate scenarios.



Model evaluation.

The model GO+ [11] was evaluated using observations from fluxes measurements performed above oak forests (3 stations across Europe belonging to ICOS-RI and Fluxnet) and long-term inventories (15 stations across France). The latter are even-aged oak forests made of pedunculate and sessile oaks. The set of ecophysiological parameters values used is unique since the model is not site calibrated.

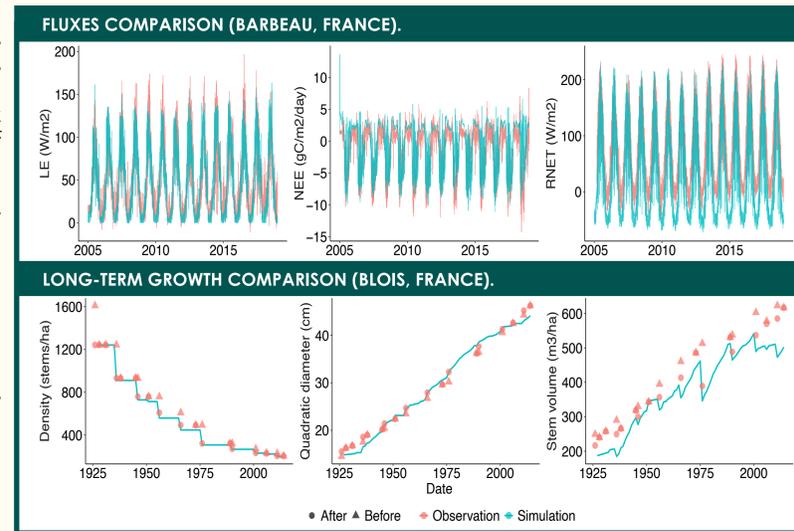
- At the flux sites, the site and soil parameters were provided by the station P.I.s and completed using different data sources.
- Historical tree growth from 1928 to 2015 was simulated using available management data for each site in terms of thinning (basal area and number of stems removed).
- Meteorological data was reconstituted using ERA-5 interim products.

The opposite figures present evaluation results. The top plots compare latent heat flux (LE), CO₂ flux (NEE) and net radiation (RNET) measured and simulated at the Barbeau station from 2005 to 2020. The plots below illustrate the comparison of model predictions with historical growth inventory at Blois (1928-2015), one of the 15 stations examined.

Acknowledgements.

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Soutenu par



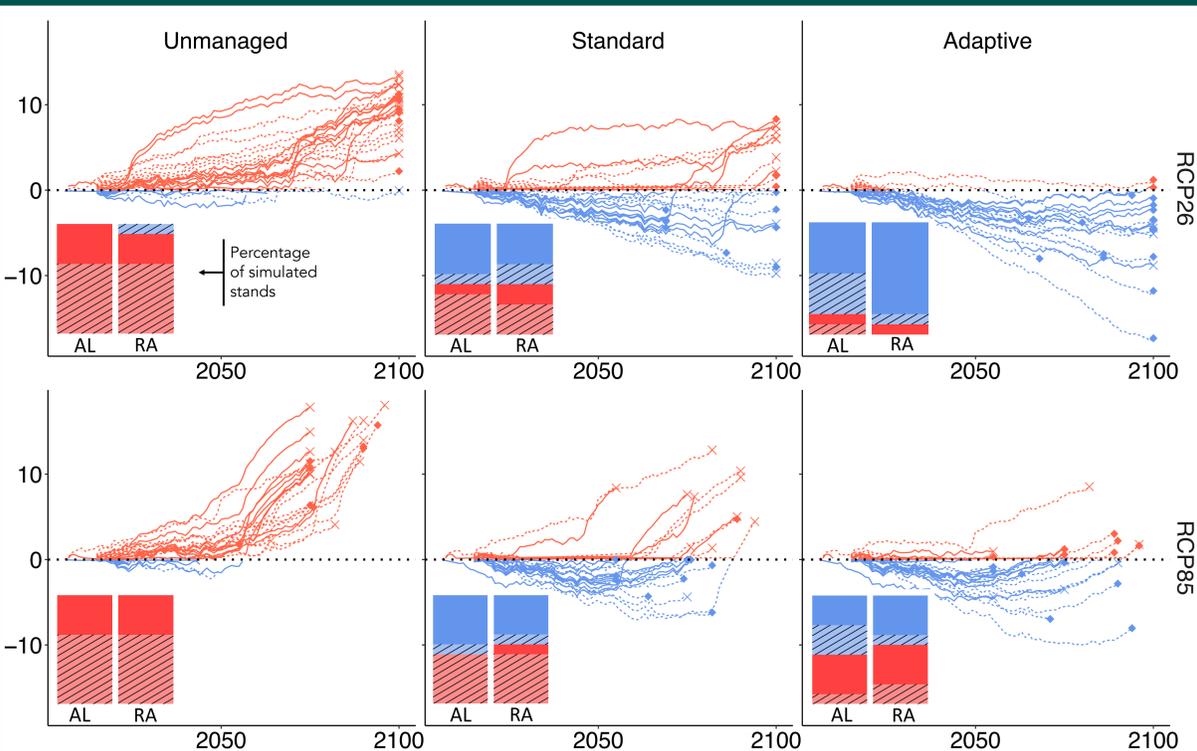
Projections experiment.

The eleven stands used for the model evaluation were projected from 2015 to 2100 according to the protocol detailed in the opposite table. Daily meteorological data were downloaded from the Météo-France Drias portal (2014 and 2020 releases) and recalculated at a hourly time step. Stands were initialized in 2015 using the last inventory data.

In this experiment, the reduction of tree density is provoked either by mortality (carbon starvation due to water stress or self thinning [12] due to competition) or regular thinning operations. The mortality due to hydraulic failure was not implemented in the model version used [13]. The results shown here are a subset of an extended experiment where 3 RCPs, 11 management options and a range of soil types were simulated for oaks, pines, beech and Douglas fir [14].

2 REGIONAL CLIMATE MODELS (RCMS)	2 CLIMATE SCENARIOS (RCPs)	3 MANAGERIES SCENARIOS	11 STANDS
<ul style="list-style-type: none"> • Aladin (Drias 2014) • Racmoe (Drias 2020) 	<ul style="list-style-type: none"> • RCP 2.6 • RCP 8.5 	<ul style="list-style-type: none"> • Unmanaged (self-thinning) • Standard (thinning triggered by competition) • Adaptive (thinning triggered by competition, cumulative water stress and diameter increment). 	Pure, even aged oak stands, aged from 100 to 200 years old in 2015. Standard management applied until 2015.

CO₂ BALANCE (NEE X 10³ gC m⁻² y⁻¹) PROJECTIONS FROM 2015 TO 2100 FOR 11 PURE OAK STANDS IN FRANCE.



STATUS
 Source (red), Sink (blue)

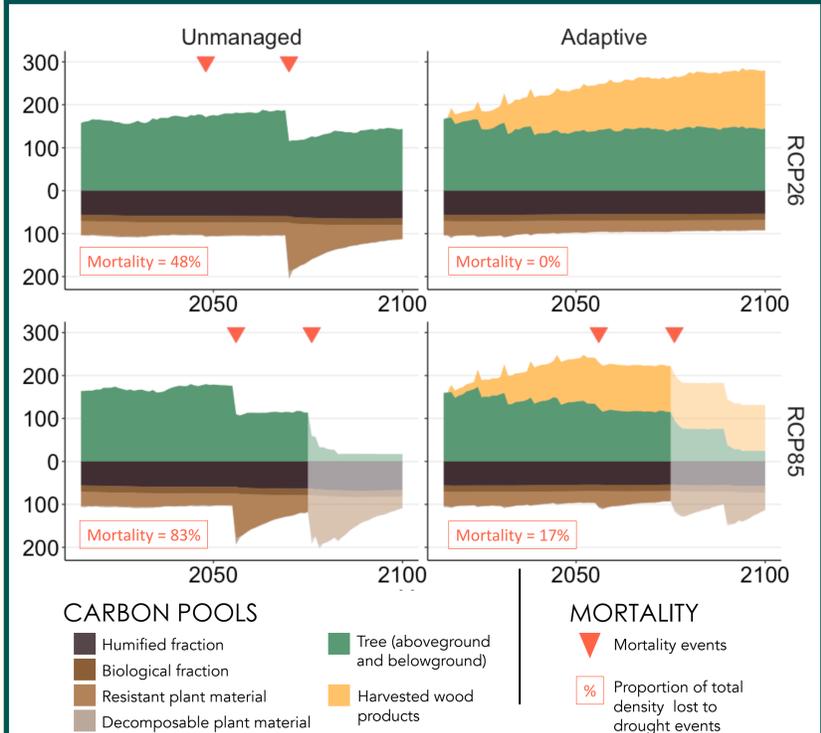
REGIONAL CLIMATE MODEL
 AL - Aladin, RA - Racmoe

REGENERATION STAGE
 X Not reached, Reached

According to French forest office guidelines, oak forests may start the regeneration phase when tree diameter exceeds 60cm.

Simulation are stopped when stand density < 50 stems ha⁻¹, basal area G < 15 m² ha⁻¹ or competition index RDI < 0.4. The box plots give the distribution of stands reaching regeneration stage (plain colors) or stopped before (hatched area). Management maintains at least 50% of the oak stands as net CO₂ sinks (blue) over the next century regardless of the climate scenario. Unmanaged stands are mostly net CO₂ sources (red) since the beginning of the simulation due to the higher tree density leading to a lower photosynthesis/respiration ratio. Various observations in central Europe confirm the negative impact of tree density on oaks survival [8, 12-13]. Forest management with frequent thinnings sustained tree growth allowing stands to reach the regeneration stage. At least 50% of the managed stands (against 36% of the unmanaged stands) reached a mean DBH>60 cm. Also, the triggering of thinnings by the criterion of cumulative stress proves to be more efficient than the standard regime based solely upon the competition index.

CARBON STOCKS PROJECTIONS UNTIL 2100 (tC.ha⁻¹). (PAUVERTS – BLOIS, 152 yo in 2015, RCM ALADIN).



Under RCP 2.6, adaptive management prevents natural mortality. By 2100, the total amount of carbon sequestered would overtake the unmanaged alternative by 31% including harvested products (7% lower without harvest). Under RCP 8.5, adaptive management remains more efficient in avoiding water stress mortality and sequestering carbon (total stock is 22% higher with harvest, and 15% lower without.) Forest management implemented in these simulations regulates the standing biomass and the leaf area index (LAI), which reduces rainfall interception and tree transpiration, and slows down soil water depletion, thereby delaying the occurrence and severity of water stress episodes. While dead trees are directly transferred to soil organic matter pools and decomposed in the unmanaged stand, harvesting stems by adaptive management builds up an ex-situ carbon stock, where timber is transformed into various products that contribute to the substitution of the emissions of fossil carbon [15]. Indeed, the role of management in forest carbon storage capacity strongly depends on the life span of harvested wood products.