Social drivers of rural forest dynamics: A multi-scale approach combining ethnography, geomatic and mental model analysis

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Highlights

- Rural forest dynamics over 150 years were assessed through photo-interpretation
- Farmers were interviewed regarding their management choices and perceptions
- Rural social organization contributed to rural forest continuity over time
- Socio-economic changes induced standardization of forest management practices
- Perceived ecosystem services and disservices influenced rural forest dynamics

Abstract

Farm forests and trees outside forests (i.e., ‘rural forests’) are key components for the sustainability of agricultural landscapes. Farmers are the main managers of rural forests and their practices vary according to a range of individual and collective factors. This diversity in management practices challenges the understanding of landscape patterns and dynamics, in particular at local and regional scales. In this study, we combined forest mapping over 150 years, ethnographic investigations and mental models to investigate the social drivers of rural forests in a French case study. Results showed a stability of woodlands and groves, favored by the social organization system, i.e., a self-reliance and house-centered system. Recent tree encroachment in abandoned lands – caused by rural exodus and the intensification of agriculture – resulted in a spread of woodlands. In addition, a shift from family-based to market-oriented woodland management was observed, contributing to the homogenization of forest management practices. Hedgerows declined but with contrasted trends according to their location and adjacent land uses: in-farm hedgerows that obstructed mechanization declined, whereas boundary hedgerows that assisted in the maintenance of farmers’ estates were reinforced. Scattered trees were considered of little interest by farmers and declined. This study achieved an understanding of rural forest patterns and underlying social drivers. Mental models provided a basis for exploring the tradeoffs between ecosystem services and disservices operated by farmers. They also revealed differences between scientific and farmer classifications of trees outside forests. Mental models constitute a promising tool for reinforcing bonds between the social and natural sciences.

Keywords

Non-industrial private forest; trees outside forests; ecosystem services; local ecological knowledge; agroforestry landscape; social representations.

1. Introduction

Trees are part of agricultural landscapes: almost half of the agricultural areas in the world have a tree cover of more than 10% (Zomer et al., 2014). This widespread presence of trees results in a diversity of agroforestry landscapes including, in temperate regions, *dehesa* parklands in the Mediterranean area, where trees are scattered within cropped or pastured fields (Plieninger, Pulido, & Schaich, 2004), and *bocage* landscapes in the Atlantic region, where trees form hedgerows around fields (Baudry, Bunce, & Burel, 2000). This spatial proximity between forested and agricultural areas generates a range of ecological interactions between these two components at landscape scale, and contributes to the production of multiple ecosystem services (Andrieu, Vialatte, & Sirami, 2015). In agroforestry landscapes, forests and 'trees outside forests' (i.e., scattered, linear, and groups of trees, FAO, 2010) simultaneously provide production (e.g., wood, fruits, mushrooms), environmental (e.g., biodiversity conservation, air purification) and agricultural services (e.g., pest control, erosion control, windbreaks) (Baudry et al., 2000), as well as cultural services (e.g., landscape identity, scenic value) (Oreszczyn, 2000).

In order to focus on the forests and trees outside forests that are parts of farm systems, the concept of 'rural forests' (or 'domestic forests') was proposed (Michon, de Foresta, Levang, & Verdeaux, 2007). Rural forests encompass all trees and forests that are (i) managed, shaped and transformed by rural societies, (ii) fully integrated within farming and pastoral systems, and (iii) significant components of rural landscapes and production systems (Genin, Aumeeruddy-Thomas, Balent, & Nasi, 2013). They are found in tropical and temperate regions, where they are shaped by a diversity of ecological and social factors (Genin et al., 2013). In France, rural forests encompass farm woodlands (i.e., woodlands and groves managed and used by farmers), hedgerows (and other rows of trees) and scattered trees. Each of these forest components is known to provide specific ecosystem functions and services and, together, they contribute to the quality of agricultural landscapes (Altieri, 1999; Decocq et al., 2016; Manning, Fischer, & Lindenmayer, 2006).

However, in France, farm woodlands (owned by farmers) have drastically declined over the last decades because of sales and inheritance processes that have progressively disconnected woodlands from farm systems (Cinotti & Normandin, 2002). In addition, the intensification of agriculture have caused the decline of hedgerows and scattered trees (Baudry, 1993). But beyond overall trends, the patterns of change in rural forests remain poorly understood at finer spatial and temporal scales (but see Andrieu, Sourdril, du Bus de Warnaffe, Deconchat, &

Balent, 2010). In particular, little is known of the temporal continuity of present day rural forests (i.e., their age and history), although it is a strong determinant of their role with regard to biodiversity and ecosystem functioning (Hermy & Verheyen, 2007; Herrera & García, 2009). Another gap in knowledge results from the lack of data on rural forest management. Similarly to most small private forests in western countries, most French rural forests have no formal management plan (Elyakime & Cabanettes, 2009), and are not necessarily managed on the basis of profitability (Sourdril, Andrieu, Cabanettes, Elyakime, & Ladet, 2012; Sourdril, Du Bus de Warnaffe, Deconchat, Balent, & de Garine, 2006). On the contrary, farmers' management decisions depends on individual factors – such as personal objectives, emotional ties and aesthetic values (Joshi & Arano, 2009; Tikkanen, Isokääntä, Pykäläinen, & Leskinen, 2006) – and social norms – for example when norms define what a well-managed hedgerow is (Notteghem, 1991). To better understand local landscape dynamics, that are known to be mainly driven by farmers (Baudry, 1993), it is therefore critical to be better informed with regard to this complex management system, the way it changes, and the way it influences rural forests. This objective raises methodological and theoretical issues for research, in particular because it requires simultaneously taking into account social and ecological drivers.

This study combines approaches from the natural and social sciences in order to comprehend (i) rural forest patterns and dynamics, and (ii) their social drivers in a landscape located in southwestern France. Firstly, a photo-interpretation method on the basis of four diachronic aerial photographs aimed to assess the dynamics of rural forests between 1962 and 2010. In addition, a historical map dating from around 1850 was used to assess the long-term continuity of woodlands. Secondly, long-term ethnographic investigations were used to explore the social drivers of the dynamics of rural forests. In addition, in order to explore farmers' perceptions and the rationale regarding rural forests, a mental model analysis was performed. This method originates in the cognitive sciences and aims at capturing the way people perceive their external environment and thereby at exploring the basis of their actions (Elsawah, Guillaume, Filatova, Rook, & Jakeman, 2015; Jones, Ross, Lynam, Perez, & Leitch, 2011). Finally, results obtained from these three methods were combined to analyze, in a cross-scale perspective, the links between the dynamics of rural forests and the patterns of change in rural society.

2. Materials & Methods

2.1 Study site

Research was conducted in the 440 km^2-large Long-Term Social-Ecological Research (LTSER) platform *Vallées et Coteaux de Gascogne* (43°13'02.63''; 0°52'53.76''), located in southwestern France in the Canton of Aurignac, about 80 km south-west of the city of Toulouse (Figure 1).

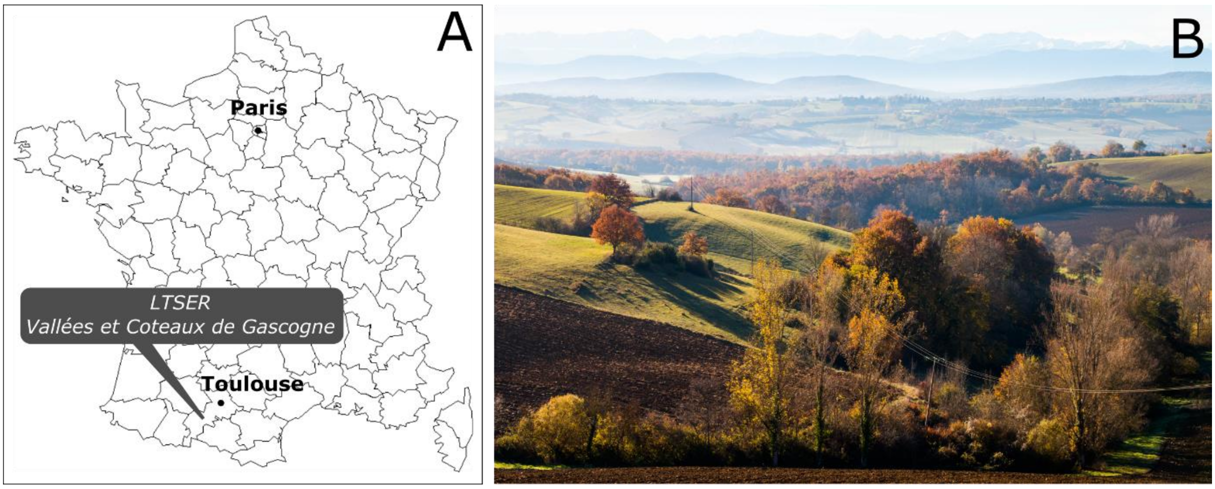

Figure 1: (A) Location of the LTSER platform Vallées et Coteaux de Gascogne and (B) photograph illustrating the landscape topography and rural forest components.

This hilly region (200-400m altitude) of the Pyrenean piedmont is temperate, with Atlantic and Mediterranean influences. The relief is characterized by an alternation of hills and valleys, crossed by a dense network of watercourses, with the Pyrenees mountain chain in the background (Figure 1). The landscape is a mosaic of cropped lands (maize, barley and wheat crops), meadows and small woodlands, interspersed with hedgerows and scattered trees (Sourdril, 2008). Mixed farming systems combining cereal cultivation and livestock dominate. According to the 2014 national census, the Canton of Aurignac is populated by 1,184 inhabitants (18 ind./km^2) and experiences a high level of rural exodus.

In this region, the house-centered system (or *système à maison*) (Augustins, 1989; Lévi-Strauss, 1979; Sourdril, 2008) is based on a social entity, 'the house', defined as a "moral person, keeper of a domain composed altogether of material and immaterial property, which perpetuates itself by the transmission of its name, of its fortune and of its titles in a real or fictive line held as legitimate on the sole condition that this continuity can express itself in the language of kinship or of alliance, and most often, of both together" (Lévi-Strauss 1979 translated by Gillespie, 2007, p. 33). In house societies, a single heir inherits the house and related farming activities and domain, which ensures the stability of real estate. As a consequence, three generations (the owner, the heir and his/her children) live together in the house/on the farm (for the sake of simplicity, we will use the terms 'houses' and 'farms' synonymously). The house-centered system is also characterized in southwestern France by a principle of self-reliance. Traditionally, each house owned different types of lands (cropped fields, meadows, gardens, and woodlands and groves) to make the farm self-supporting, which contributed to the diversity of lands owned by each house.

Together with geographical features, this social organization explains the patterns of distribution of farmers' woodlands and their management systems (Sourdril, 2008). Firstly, woodlands are typical of French small private forests (Cinotti & Normandin, 2002): most of them are divided into several small properties owned by active or retired farmers. 'Coppice with standards' is the dominant and traditional tree management system, providing firewood on a year-round basis and timber more occasionally. Secondly, forest work is processed by the owner, helped by his son or son-in-law. But occasional and labor-intensive tasks (such as wood extraction) can also rely on mutual aid networks with close neighbors (Sourdril, 2008). The dominant tree species are the sessile (*Quercus petraea* (Matt.) Liebl.) and pedunculate oaks (*Q. robur* L.), mixed with other deciduous species such as the European hornbeam (*Carpinus betulus* L.), the wild cherry (*Prunus avium* (L.) L.), the chestnut (*Castanea sativa* Mill.) and the wild service tree (*Sorbus torminalis* L.).

2.2 Long-term continuity of woodlands

On a territory of approximately 14,000 ha (Figure 2), the historical *Minutes d'Etat Major* map of France (1/40,000) was used to assess the forest cover in 1850. The map was produced between 1825 and 1866 (for the sake of simplicity, we use 1850 in the text) in the projection of Bonne by the National Institute of Geographic and Forest Information (abbreviated: IGN). It includes information on land uses, woodlands and large groves, but not on smaller or linear forest components (i.e., scattered trees, hedgerows and small groves). As a consequence, all forested areas identified from this map were considered as woodlands (including 25 large groves). A spatial comparative analysis between the *Minutes d'Etat Major* and the 2010 forest maps provided a basis for assessing the woodlands' continuity – i.e., to identify woodlands that have continuously existed from 1850 to 2010 (including woodlands that were subjected to silvicultural operations, such as logging, as long as they were not converted to another land use).

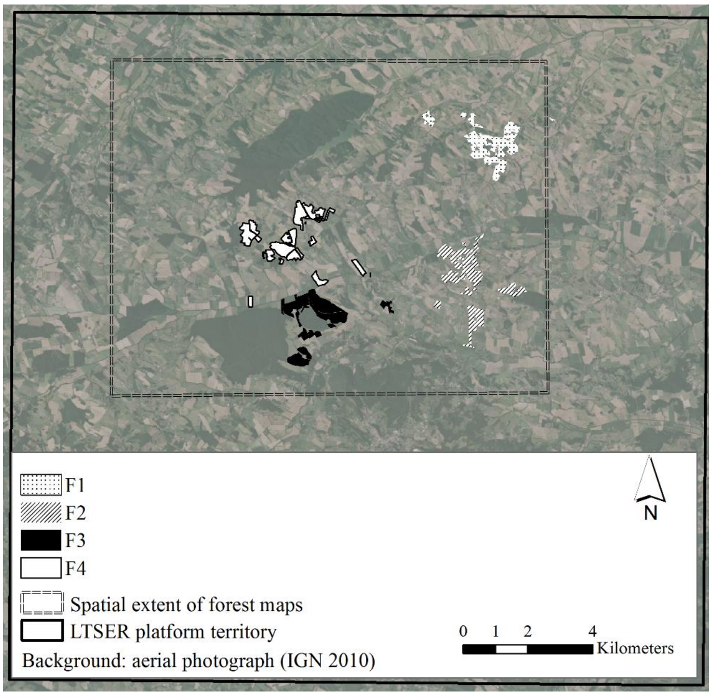

Figure 2: Map of the four case-study farms and spatial coverage of the forest maps used for the GIS analysis inside the LTSER Vallées et Coteaux de Gascogne.

2.3 Landscape-scale rural forest contemporary dynamics and management systems

In the same 14,000 ha territory, four rural forest maps were established from data from four successive surveys carried out by the IGN (1962, 1979, 1993 and 2010). A regressive photo-interpretation method was applied to digitize rural forests from these maps (Muraz *et al.*, 1999). According to the IGN classification, 4 types of rural forest components were distinguished: woodlands (area>0.5ha and width>25m), groves (area comprised between 0.05 and 0.5ha, width>20m), hedgerows (width<20m) and scattered trees (area<0.05ha, crown diameter>3m). The dynamics of these components (between 1962 and 2010) were assessed by means of three types of indicators: (i) woodland and grove total area, mean area and number, (ii) hedgerow total length and number, and (iii) scattered tree number. The fate of 1962 rural forest components (what had become of 1962 trees by 2010) and the origin of those of 2010 (which 2010 trees had existed in 1962) were determined on the basis of surface area.

In complement, ethnographic investigations have been conducted since 2003 in four townships (Sourdril, 2008). The aim of these investigations was to understand how (i) social organization (in particular the house-centered system), (ii) changing agriculture and (iii) changing land governance practices influenced the patterns and dynamics of rural forest and land uses. Ethnographers spent a total of 4 years in the investigated communities between

2003 and 2017, with a constant presence between 2003 and 2006. This long-term approach made it possible to gather in-depth information on the land and local community dynamics. Various investigation methods were used: (i) free-listings and semi-directive interviews were conducted on topics such as land use changes, family history and kinship patterns, perceived biodiversity dynamics, and local ecological knowledge, (ii) cognitive mapping and participative observation were used to identify farmers' practices and their use of the territory, and (iii) an analysis of land registries for 50 properties was performed to determine the transmission process for 107 forests (covering a total of 231 ha). Altogether, these investigations were conducted with about 70 forest owners and 210 forest users (Sourdril, 2008; Sourdril et al., 2012).

2.4 Farm-scale rural forest patterns of change and management systems

A survey focused on four farms (referred to as F1, F2, F3 and F4, Figure 2) was carried out to investigate (i) farm-scale forest patterns and dynamics and (ii) farmers' perceptions of rural forests. These four farms were chosen as being representative of the dominant type of farm in the study area: (i) they featured a conventional system mixing crop cultivation and livestock raising, (ii) they had a surface area between 100 and 150 ha, and (iii) the farmer was a relatively old male. Furthermore, the four farms were not adjoining, although the farmers knew each other. On several occasions between 2003 and 2017, the four farmers were interviewed for the purpose of ethnographic investigations. In addition, a mental model analysis was used to explore how they perceived and managed their rural forests. To elicit farmers' individual mental models (IMMs), a direct elicitation procedure was used during face-to-face interviews conducted between January and March 2017, and at farmers' homes to limit bias (Jones, Ross, Lynam, & Perez, 2014). In the first part of the interview, with the help of an aerial photograph of the farm, farmers were asked to explain how they managed their rural forests. This first phase enabled them to access their latent knowledge (Vuillot et al., 2016). In a second part, farmers were asked to summarize their perceptions and management of rural forests. This generic goal was guided by four questions, inspired by the ARDI method (Etienne, du Toit, & Pollard, 2011): (Q1) what kind of forested areas do you have on your farm? (Q2) who manages, works in or benefits from those forested areas? (Q3) what advantages, or benefits, are important to you regarding those forested areas? (Q4) what drawbacks, or constraints, are particularly important to you? Because farmers do not spontaneously remember everything during an exercise of this kind (Diniz, Kok, Hoogstra-

Klein, & Arts, 2015), the researcher suggested items on the basis of the information collected during the first part of the interview. Items were written on sticky notes that farmers could move and link to each other's notes by drawing arrows on a white board. To assist this process, only 4 types of links were asked for: (i) from stakeholder to stakeholder, (ii) from stakeholder to rural forest components, (iii) from forest components to advantages, and (iv) from forest components to drawbacks. Finally, to allow comparison between IMMs, a regrouping of synonyms was operated (e.g., the terms 'woods' and 'forests' were pooled together into 'woodlands') and the advantages and drawbacks were classified into ecosystem services (ES) and disservices (EDS). All interviews with farmers were conducted in French. The comments quoted in this article were translated into English by an English native speaker editor.

3. Results

3.1 Woodlands and groves

3.1.1 Patterns and dynamics at landscape scale

In 2010, woodlands covered approximately 1/5 of the 14,000 ha, while groves occupied less than 1% (Table 1). Between 1850 and 2010, woodland areas increased from 2,692 to 3,012 ha (+11.2%). More precisely, 66.1% of woodland areas in 2010 already existed in 1850 (referred to as 'ancient woodlands') whereas 33.9% did not. Of the 2,692 ha of woodlands in 1850, 702 ha (26.1%) were destroyed and converted into agricultural lands, mostly before 1962 and from parts of still existing woodlands (645 ha) rather than entire ones (57 ha). After 1962, woodland areas were relatively stable, with the maintenance of 93% of them (7% destroyed) and a slight increase between 1993 and 2010 (+3%, Figure 3). Ethnographic investigations established a link between woodland stability and the self-reliance principle, as each house owned at least a small piece of woodland. In addition, farmers explained the recent increase in woodland areas by agricultural and rural changes. Firstly, they observed a decrease in the number of farms over the last decades (from 390 farms in 1988 to 255 in 2010 in the Canton of Aurignac, according to the 2010 general agricultural census). Secondly, they also considered that mechanization and the abandonment of sheep farming contributed to the abandonment of the least fertile lands (especially sloping lands with a northern orientation) and to their natural encroachment.

Table 1: Patterns of change in rural forest components across the study site (around 14,000 ha) between 1962 and 2010.

	1962	**1979**	**1993**	**2010**
Woodland total area in ha (count)	2,911 (366)	2,907 (362)	2,923 (355)	3,012 (380)
Grove total area in ha (count)	119 (616)	125 (626)	124 (565)	128 (544)
Grove mean area (ha ± SD)	0.19 ± 0.12	0.19 ± 0.12	0.22 ± 0.11	0.23 ± 0.13
Hedgerow total length (km)	657	550	479	478
Total number of scattered trees	6,719	6,540	6,186	9,324

In contrast with woodland stability, only 43% of grove areas were conserved between 1962 and 2010, 34% of them were converted, 15% expanded and became woodlands and 9% were partially deforested and turned into hedgerows or scattered trees. Meanwhile, the overall dynamic of grove areas was positive (+7.6%), which was associated with a growth in grove mean area (+22%) rather than in number (-12%) (Figure 3).

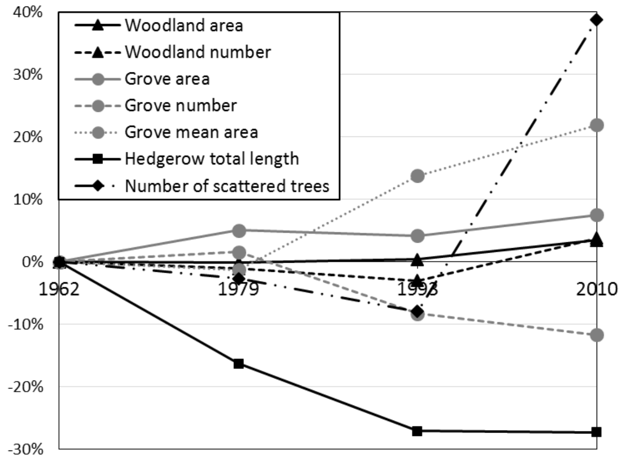

Figure 3: Patterns of change in rural forest components (in %) with 1962 as the baseline. Woodland dynamics are marked by black triangles, including woodland area (plain line) and number (dashed line). Grove dynamics are marked by grey circles, including grove area (plain line), number (dashed line) and mean area (pointed line). Hedgerow total lengths are marked by black squares. The number of scattered trees is marked by diamonds and double-dashed line.

3.1.2 Patterns and dynamics at farm scale

In the four case-study farms, woodlands and groves occupied 6.0%, 0.6%, 3.6% and 2.9% of, respectively, F1, F2, F3 and F4 farm areas (see Table 2 and Figure 4). The majority of woodlands (10 out of 13 in total) were conserved in these farms since 1962. In F2 and F3 farms, no deforestation was observed. In F1 and F4 farms, deforestation rates were 24.6% and

20.6%, respectively. One entire woodland was deforested in the F4 farm and partial clearings of 5 woodlands occurred in the F1 farm. Groves were less stable: in F1 and F3 farms, 4 of them were completely destroyed while 4 new groves appeared.

Table 2: Importance and trends between 1962 and 2010 of rural forest components in four case study farms.

		F1	**F2**	**F3**	**F4**
Descriptive variables in 2010	Farm area (ha)	137	154	156	155
	Woodland and grove area (ha)	8.2	0.9	5.8	4.5
	Woodlands and groves (count)	7	4	6	4
	Total Hedgerow length (km)	6.3	6.6	6.3	8.1
	% of bordering hedgerows	70.6	74.1	59.6	70.2
	Scattered trees (count)	78	127	121	133
Trends between 1962 and 2010	Evolution of hedgerow length (%)	-5.5	-35.6	-5.1	-17,9
	% of bordering hedgerows among all new ones	71.6	72.2	56.3	62.6
	% of preserved bordering hedgerows	70.3	76.6	61.9	73.1
	Evolution of scattered trees' count (%)	+2.6	-0.8	+44.0	+90.0
	% of remnant trees	19.2	26.0	16.5	16.5

3.2 Dynamics of hedgerows and scattered trees

3.2.1 Hedgerows at landscape and farm scales

Between 1962 and 1993, the total hedgerow length declined at landscape scale (-27%), but stabilized afterwards (Figure 3). In terms of area, 49% of hedgerow areas were conserved between 1962 and 2010, 42 % were removed and 7% grew into groves or woodlands. According to farmers, the main drivers of this decline were the intensification of agriculture and land consolidation:

> *"When plots were small and when they were worked with small tractors, or even, at the very beginning, with animals, the land plot system was adapted to… today, we've sort of adapted the land plots to the size of the tractors." (F1, 2017).*
>
> *"It is not that I am opposed to big plots, because it's handier for us to work big fields, so we've got rid of the hedgerows, I've got rid of some hedges because they got in the way." (F4, 2017).*

In the case-study farms, total hedgerow lengths ranged from 7.0 to 8.8 km (Table 2). Boundary hedgerows (i.e., located at the cadastral limit of the farms) represented from 61 to

77%, thus were longer than in-farm hedgerows (i.e., hedgerows located within the property). This result echoes the willingness of farmers to keep hedgerows as property markers:

> *"Hedgerows, we cut some down during the land consolidation but mainly inside the fields, the hedgerows around the boundary of the property, we try to keep them always, it marks the property" (F4, 2004).*

Figure 4: Digitalization output of rural forest components around F4 farm, with a differentiation between woodlands, groves, hedgerows and scattered trees.

3.2.2 Scattered trees at landscape and farm scales

Only 30% of scattered trees were conserved at landscape scale between 1962 and 2010, while 56% were removed (or died) and 14% were turned into hedgerows, groves or woodlands. The total number of scattered trees decreased by -7.9% from 1962 to 1993 (Figure 3). According to farmers, the trees conserved were mainly those that (i) did not hamper modern agricultural practices, (ii) marked specific limits (e.g., quince trees were generally planted at the corner of farm territories), (iii) provided for special needs and uses (e.g., fruit production), or (iv) exhibited owners' specific attachment to the land. Between 1993 and 2010, the number of scattered trees strongly increased (+50.8%, Figure 3): 57.9% of scattered trees in 2010 were already present in 1993, 4.9% were relicts of hedgerows present in 1993, 0.9% were relicts of groves and 34.3% appeared during the period. According to our observations, this recent appearance of scattered trees was due to bush encroachment in abandoned fields as it first leads to the growth of scattered trees that afterwards turn into groves and woodlands (through canopy closure). Farmers confirmed these observations:

> *"You can see more trees growing here and there in this field, but it's due to encroachment because, this field, we can't go in there anymore with the blue tractor" (F3, 2003).*

In contrast to scattered trees as a whole, more than half of remnant trees (i.e., trees present in 1962 and still alive in 2010) disappeared.

In the case-study farms, densities of scattered trees ranged from 0.57 to 0.86/ha and increased from 1962 to 2010 (Table 2), while the number of remnant trees remained low.

3.3 Farmers' perceptions and management

3.3.1 Farmers' perceptions of rural forests in general

Rural forests were positively valued by farmers who cited a total of 17 ecosystem services (ES) and 6 disservices (EDS) (Table 3, Figure 5). According to the common classification of ES (CICES 4.3), farmers listed 6 provisioning services (fuel wood, mushrooms, timber, fruits and nuts, habitat for game and additional CAP subsidies), 7 regulating services (erosion control, habitat for insects, windbreaks for crops, habitat for birds, oxygen production, shelter and shade for reared animals) and 4 cultural services (scenic value, biodiversity conservation, noble aspect and closure of visual gaps). Five EDS impacted agricultural activities (hindering work with machines, additional work load, damage to tractors caused by branches, damage to fences and obstruction of drains) and one affected social life (societal pressure). The balance between ES and EDS was variable between rural forest components: woodlands had the most positive balance while scattered trees had the most negative one (Table 3).

Farmers reported a total of 7 types of forested areas and, in particular, differentiated four types of linear trees (Figure 5). For instance, hedgerows were considered as physically impassable linear structures composed of shrubs and distinct from penetrable rows of trees (such as tree alignments or edge trees). For each type of forested area, farmers associated different types of management, ES and EDS (Figure 5), as for instance in the case of riverbank and ditch trees:

> *"Sometimes on the edge of a ditch, they [trees] can block the drains. As the roots go up… As most of the time we don't go and clean out the drains every year, sometimes the roots go to the end [of the drain], go inside it and it makes a stopper." (F3, 2017).*

3.3.2 Farmers' perceptions of woodlands and groves

Woodlands were associated with 12 ES and 2 EDS (Table 3). Among the main reasons for maintaining woodlands, farmers highlighted that woodlands were located in the most sloping areas and provided, among other services, firewood (Figure 5). However, slope was not the only reason why farmers maintained woodlands:

> *"Here are my woods, they are plots on slopes. One of them has a gentler slope, but I keep it for cows because there are places they go to shelter. Then, this other one, there's a bit they just pass through. There are also mushrooms here but you shouldn't record that. Ceps and chanterelles, very good spot." (F1, 2017).*

Mushrooms and timber were two ES specific to woodlands (i.e., not provided by other rural forest components, Figure 5). Woodland-related EDS were concentrated at the edges, where they interface with agriculture: edge trees damage fences, and their branches damage tractors. No EDS was specifically associated with the core of the woodlands. Finally, farmers explained that the traditional family-based management of woodlands has been impacted by changes in rural society, in particular by work force shortages that prevent family-based wood harvesting:

> *"We used to work with my father in the woods, but now he is too old and I do it by myself, but I have less and less time to do it with all the work on the farm and the woods are dying because we don't manage them as we should" (F4, 2011).*
>
> *"…collecting firewood, for a lot a farmers, it's dangerous if they are on their own. It is very dangerous work, so we don't go and get firewood on our own. If 2 or 3 of us go there together, that's all right." (F1, 2017).*

Groves were associated with 6 ES and no EDS (**Erreur ! Source du renvoi introuvable.**). However, only two farmers reported groves and the grove-related ES were not specific to groves (they were also woodland-related, Figure).

3.3.3 Farmers' perceptions of linear trees

Linear trees were associated with 14 ES and 6 EDS (Table 3). In particular, they were associated with firewood, services to agriculture, and environmental benefits:

> *"Then there's the landscape. That's why we don't do much clear cutting neither, because it's a bit ugly. Then there's the windbreak effect. I mean there's some plots with a good thick hedgerow or sheltered by the woods, we can go there for spraying when it's a bit windy. There's less dispersal." (F3, 2017).*

Table 3: Total number of ecosystem services (ES) and disservices (EDS) perceived by farmers in their mental models according to the National Institute of Geographic and Forest Information (IGN) classification of forested areas.

IGN classification	**Farmers' classification**	**F1**	**F2**	**F3**	**F4**	**Total**
Woodlands	Woodlands	6 ES 0 EDS Δ[¶]=+6	4 ES 2 EDS Δ=+2	7 ES 0 EDS Δ=+7	5 ES 2 EDS Δ=+3	12 ES 2 EDS Δ=+10
Groves	Groves Barrens & wastelands	-	-	6 ES 0 EDS Δ=+6	1 ES 0 EDS Δ=+1	6 ES 0 EDS Δ=+6
Hedgerows	Hedgerows Tree alignment Riverbank trees Edge trees	6 ES 2 EDS Δ=+4	7 ES 2 EDS Δ=+5	6 ES 4 EDS Δ=+2	6 ES 4 EDS Δ=+2	14 ES 6 EDS Δ=+8
Scattered trees	Scattered trees	-	2 ES 2 EDS Δ=0	4 ES 1 EDS Δ=+3	0 ES 0 EDS Δ=0	6 ES 2 EDS Δ=+4
All rural forest components		9 ES 2 EDS Δ=+7	7 ES 2 EDS Δ=+5	9 ES 4 EDS Δ=+5	8 ES 4 EDS Δ=+4	17 ES 6 EDS Δ=+11

[¶]Δ is the gap between the number of ES and of EDS reported by farmers (Δ= ES - EDS)

But farmers also insisted on the work required to reconcile linear trees and cropping activities:

> *"When there is a hedgerow, or some trees, around the border of a plot, it has to be pruned to around 3 meters to suit the machines used for the plot and the hedgerow […]. All the same, that means a week and a half's work to manage all the borders. Each year. You've got to believe in it!" (F1, 2017).*

In meadows, labor constraints were less of an issue, except in fenced areas:

> *"Rows of trees that are in the middle of the fields, we leave them alone. Here [shows on the map], these are just a couple of aligned trees, they're right in the middle, there's no fence, and there isn't necessarily a way through around there because they're in the middle of the undergrowth, on an embankment […]. So we leave those ones alone, and anyway they aren't ours. But here, there's a row of trees on the edge, and there's a fence there, so we pruned them a bit because there were branches that got in the way of the fence." (F3, 2017).*

3.3.4 *Farmers' perceptions of scattered trees*

Scattered trees were associated with 6 ES and 2 EDS (Table 3). Farmers appreciated scattered trees for their fruits (walnut and fig trees were particularly cited) and for their landscape scenic value (old oaks were generally preserved). Nevertheless, all these ES were not specific to scattered trees (Figure 5). For example, even if scattered trees were useful in pasture lands for sheltering animals, rows of trees were considered to be more effective:

"Because if during summer you put cows in a field where there are [scattered] trees, they will all crowd together under the trees. We should make tree corridors, with two rows of trees, you know, like the plane trees along the roads. Then they'll all have room to lie down in the middle." (F4, 2017).

In contrast, scattered trees represented real EDS, and were considered as a major obstacle in cropped fields:

"Because a scattered tree, we have to go around it. So instead of going straight, sometimes it means… we have to pull it up [the spreading ramp], go back, go the other way, do it again…Go round four ways instead of going straight" (F3, 2017).

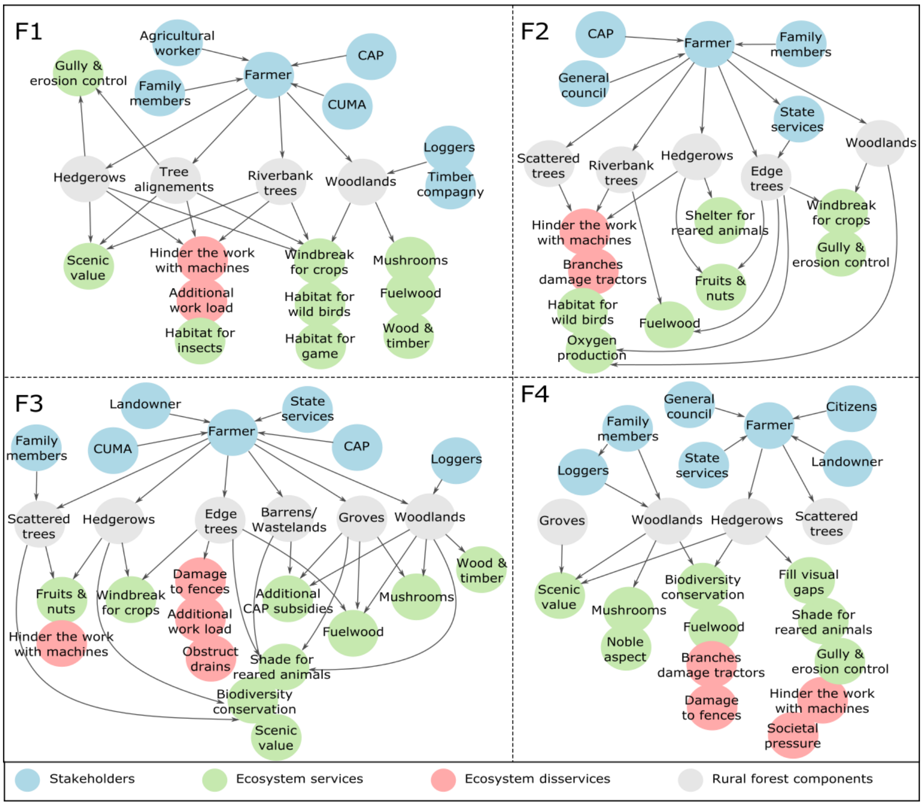

Figure 5: Individual mental models of F1, F2, F3 and F4 farmers regarding the management of rural forest components (grey circles) by stakeholders (blue circles) and associated ecosystem services (green circles) and disservices (pink circles). Arrows symbolize identified links between different stakeholders, between stakeholders and rural forest components, or between rural forest components and ecosystem services and disservices.

4. Discussion

4.1 The social-ecological evolution of rural forests in the study area

4.1.1 Dynamics of woodlands and groves: social factors and ecological consequences

The regressive photo-interpretation method used in this study revealed a maintenance of woodlands over the last decades, at both landscape and farm scales. At landscape scale, this maintenance was explained by the willingness of farmers to keep a piece of forest that (i) contributes to their self-sufficiency strategy, in particular for fuel wood provision, (ii) constitutes a family legacy, and (iii) is an additional source of income when harvested by a timber company. At farm scale, however, a period of deforestation was observed between 1962 and 1979. This period corresponds to the French 'Green Revolution' when farmers were encouraged to modernize and industrialize their farms.

Nevertheless, deforestation only affected parts of woodlands, not their entirety. This result could be explained by the ownership fragmentation of woodlands in the study area (Emilie Andrieu, Ladet, Heintz, & Deconchat, 2011), as the destruction of entire woodlands would require that every owner decide to deforest his/her plot. Overall, ownership fragmentation of private forests, which is often seen as a barrier for timber harvesting (Elyakime & Cabanettes, 2009), could have contributed to the maintenance of woodlands in our case. In addition, mental model analysis revealed that woodlands may have been maintained because they provide a diversity of specific ES and do not represent major constraints.

A recent expansion of groves and woodlands (in area but not in number, Figure 3) by natural encroachment was also observed, as a consequence of land abandonment and rural exodus. Because these newly forested areas were a symbol of rural decline, they were initially disapproved of by farmers. Nevertheless, they progressively became part of the farmsteads' forest patrimony and of farmers' self-reliance strategy, contributing to the emergence of a new social and territorial identity. From a conservation ecology viewpoint, however, recent woodlands have a lower value than ancient ones because they provide habitat for more common species. In particular, plant species associated with ancient forests have a low dispersal capacity and cannot colonize new forest fragments for several decades (Hermy & Verheyen, 2007). Conserving ancient forests in rural landscapes remains crucial for biodiversity conservation: they constitute refuges for less common species whence they can colonize more recent forests if they are maintained for a long enough period of time.

4.1.2 Changes in woodland management and functions

As interviews showed, woodlands and groves were, and still remain, a source of goods and services to farmers. They used to be considered as productive areas and as components of farms, just like the fields, pastures and meadows. But as elsewhere, this status altered with changes in farming systems and in patterns of social organization (Cinotti & Normandin, 2002). Firstly, with the intensification of agriculture, groves (as well as hedgerows and scattered trees) increasingly caused technical problems for farmers, especially when located in the middle of cropped lands. If this trend was less apparent for woodlands – except at the edges – they became less crucial for farmers' self-sufficiency because of the development of alternatives to firewood and local timber (Sourdril et al., 2012). Secondly, the intensification of agriculture and rural exodus have altered household composition, which has impacted woodland management. These changes have also undermined the traditional mutual-aid networks between houses and closest neighbors (around what is known as 'the neighborhood', Sourdril, 2008) that were the basis of an informal long-term management agreement between neighbors. This collective organization declined as children grew up and left the region. As a consequence, farmers were encouraged to outsource part of the forestry work to loggers and timber companies, as illustrated in the Figure 5. Every 20-30 years, they call upon timber or paper companies to harvest their woodlands, which has replaced the former management system and its associated diversity of practices (Andrieu et al., 2010; Du Bus de Warnaffe, Deconchat, Ladet, & Balent, 2006). This standardization is particularly pronounced for timber harvesting, which is undertaken by two or three local timber companies across the region. For firewood harvesting, the standardization of practices may therefore be less apparent because the practitioners are more diverse: some farmers are still harvesting their own firewood, while others outsource it to retired people or to teams of loggers. But this trend reveals the continuation of a reduction of woodland uses that has been occurring since the beginning of agricultural modernization (Sourdril et al., 2012). The decline of rural forest domesticity and of family-based management therefore appears as an ongoing process that may, in the future, further influence rural forest management systems and biodiversity. Monitoring this process could be useful to better qualify and quantify this influence.

4.1.3 The relative decline of hedgerows

Our results regarding the decline of hedgerows – mainly due to land consolidation and mechanization since the Second World War – give a similar picture to that of other regions in Europe, where between 40 and 80% of hedgerows have been removed (Bazin & Schmutz, 1994). This decline, along with the decline in the number of small groves (Figure 3), indicates an increasing separation between agricultural and forested areas. This dynamic may therefore have induced a decline of interface areas (i.e., forest edges) and, because interface areas are generally rich habitats (Terraube et al., 2016), of biodiversity. We may therefore suspect a negative trend for ecological flux between forest and agricultural habitats (Tscharntke, Rand, & Bianchi, 2005), and eventually for ecosystem services, such as erosion control and pest regulation.

In our study however, the decline in hedgerows was less pronounced than elsewhere. For instance, in Brittany, France, a 35.5% decline of hedgerows between 1952 and 1985 was reported (-1,08%/year, Burel & Baudry, 1990), while in our study we observed a slower pace (-0.82%/year) between 1962 and 1993. One explanation for this difference may lies in the lower initial hedgerow density in our study area than in Brittany. However, methodological differences between the two studies rule out straight comparisons. A second reason, as suggested by interviews and confirmed by map analyses, may be the willingness of farmers to maintain a visual marker of their property using boundary hedgerows, which could have reduced the decline of total hedgerow length at landscape scale.

Since the 2000s, the French government (through a local authority, the *Conseil Général*) has recognized the problems caused by the removal of hedgerows and has been promoting hedgerow replacement. Not all farmers have benefited from these measures and, for those who did, hedgerows were mainly replanted near and around modern agricultural buildings (especially modern cow and poultry sheds). These plantations did not replace former hedgerows, nor did they contribute to a significant increase in hedgerow total length or area, but they may have played a role, amongst other factors, in the observed stabilization (Figure 3).

Interviews confirmed a widespread result in the literature, that hedgerow management is influenced by land use (Baudry et al., 1998; Schmitz, Sánchez, & de Aranzabal, 2007). In addition, farmers highlighted that, due to the intensification of farm work and labor shortages, they spend less time than former generations managing hedgerows and controlling bush encroachment. This context may either contribute to the development of hedgerows if farmers stop controlling them – as is sometimes the case in meadows – but may also contribute to their decline if farmers decide to prune them more intensively or to destroy them – as is the case in cropped fields. Farmers' management practices therefore seem to be driven by the interaction between site-specific factors (such as land use and slope) and socio-economic constraints (such as labor availability and management costs). They determine their actions on the basis of a trade-off between site-specific services and disservices, which may be in favor of hedgerow maintenance (or reinforcement) or in favor of hedgerow removal (or control). Such fine spatial variations in hedgerow management remain poorly investigated (Baudry et al., 1998), although they could provide a clearer understanding of the links between farmers' practices and landscape patterns (Ango, Börjeson, Senbeta, & Hylander, 2014).

4.1.4 The ambiguous dynamics of scattered trees

If scattered trees declined until 1993, following the same trend as hedgerows, they have strongly increased since then (Figure 3), as a methodological artefact due to bush encroachment photo-interpretation. The decline of scattered trees was certainly associated with field mechanization, as they constitute a major obstacle for farmers. In addition, the absence of specific ES associated with scattered trees may have reinforced their decline. In addition, farmers showed little interest in renewing them or in planting new trees. As a result, remnant trees appeared to be rare on farms (Table 2), which could have a negative social-ecological impact. These mature trees play key roles in biological legacies and in spatial connectivity (Manning et al., 2006; Sebek et al., 2016), perform specific social functions, and provide intangible services (Hartel, Réti, & Craioveanu, 2017). In the absence of any interest in their renewing, a further decline of scattered trees, and associated ecosystem services and biodiversity (Herrera & García, 2009), might be expected.

4.2 Challenges and opportunities revealed by this interdisciplinary approach

4.2.1 Lessons learned on rural forest dynamics

The combination of the natural and social sciences is increasingly recognized as an appropriate approach to improve the understanding of the functioning and the patterns of change in social-ecological systems. This study illustrates the outcomes of such a combination in the case of French rural forests. It demonstrates an impact of agricultural modernization on rural forests, at both landscape and farm scales, but less pronounced than expected due to the local social organization and farmers' relationships with rural forests.

This study also illustrates the importance of cross-scale analyses, as in some cases, overall decline may hide local increases (as in the case of boundary hedgerows). Finally, the combination of different social methods constitutes a first step towards improving the understanding of how farmers are simultaneously influenced by changes in the rural society and site-specific factors.

This study also draws attention to limitations of the tools currently used in research on rural forest. The IGN classification of forested areas – based on size, shape and density criteria – offered an effective basis to distinguish woodlands, groves, hedgerows and scattered trees. Nevertheless, a more complex farmers' classification system was revealed by IMMs (Figure 5), associated with diversified management options. We therefore may have grounds to suspect contrasted dynamics within the formal "hedgerow" category. For instance, as riverbank trees are associated with different types of ES and EDS from other rows of trees, their patterns of change since 1962 may not be similar. A classification that is more closely related to farmers' actions may significantly improve the understanding of rural forest patterns of change. For instance, additional criteria could be taken into account to classify forested areas, such as topographical elements (e.g., watercourses, roads, slopes), cadastral limits and adjacent land uses (e.g., crops or pastures). In another perspective, a common classification between farmers on the one hand, and developers and decision makers on the other, may be of great help for landscape planning. Environmental management issues are often caused by ambiguity or differences of perception between stakeholders (Paletto, De Meo, Di Salvatore, & Ferretti, 2014). In the interests of problem solving and the design of consensual solutions, being aware of differences of perception and endeavoring to provide a basis for the convergence of perception systems (or at least coexistence based on mutual awareness) are crucial steps (Mathevet, Etienne, Lynam, & Calvet, 2011).

4.2.2 Limitations and methodological perspectives

Applying interdisciplinary frameworks to a real case study generally entails several shortcomings. In the present study, two main limitations were identified. Firstly, although we worked with superimposed spatial scales – as suggested in Deconchat et al. (2007) – and used relevant scales for each type of analysis, spatial and temporal mismatching persisted when coupling the three datasets. To limit such inconsistencies, collective and interdisciplinary protocols would need to be developed from the very beginning. However, this would require the emergence of well-founded and constructive dialogue between disciplines, and even so, it may not be possible to avoid differences of scale related to the requirements of each discipline.

The second main shortcoming of this study concerns the small number of farmers interviewed for the mental model analysis and of farms used to assess rural forest dynamics at farm scale. However, the mental model analysis offered reliable insights into farmers' perceptions and would appear to be a promising tool for future research with a larger number of informants. Firstly, IMMS provides a basis for semi-quantitative and network analyses (Vanwindekens, Stilmant, & Baret, 2013), which could be helpful to further explore the coupling between social and ecological processes. Secondly, several IMMs can be aggregated into collective mental models. This aggregation may help to better distinguish between shared and individual perceptions (Paletto et al., 2014), and thus to better address differences between individual and collectives scales. This work might contribute to the development of a better link between landscape patterns and dynamics and social drivers in a cross-scale perspective.

5. Conclusion

In our study, current rural forest patterns were shown to be a social-cultural heritage of past agro-pastoral systems, practices and traditions. But in parallel, several social drivers of change were identified, including (i) the intensification of agriculture, (ii) land abandonment and rural exodus, and (iii) the decline of mutual-aid networks. These drivers affected differently each rural forest component at landscape scale. In the meantime, contrasted patterns and dynamics were observed at farm scale, suggesting that individual farmers do not react homogeneously to social drivers. In terms of woodland management, social changes have contributed to the emergence of a market-oriented strategy that has replaced family-based management. However, the management of other rural forest components – i.e., trees outside forests – appeared to remain essentially family-based. Farmers tended to manage trees outside forests so as to balance ecosystem services and disservices, which vary according to site-specific factors. But in this area of management, farmers also took into account the general and intangible contributions of trees to human well-being – including landscape beauty and identity, and relational value. Finally, our study revealed a detailed farmers' classification of rural forest components that demonstrates the rich local ecological knowledge possessed by farmers. Furthermore, on-going trends in rural forest management, especially with regard to the maintenance of ancient woodlands and remnant trees, raised critical ecological concerns. As a consequence, we suggest that a better integration of farmers' perceptions and strategies into landscape analyses could help to achieve a better understanding of landscape dynamics and, eventually, more sustainable landscape management and planning. Refining official classifications of rural forest components to be more in phase with managers' practices may be a first step towards this goal.

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