ACTAFORSE : Interactions des acteurs pour la gestion des arbres hors-forêt et la production de services écosystémiques

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RAPPORT FINAL (2019)

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Résumé pour décideurs

Reboiser les campagnes françaises en y réintroduisant des petites forêts et des haies de diverses sortes, et en promouvant l'agroforesterie, est crucial pour une agriculture plus vertueuse pour l'environnement et plus en phase avec les attentes de la société. Néanmoins, cet objectif se heurte à de nombreuses difficultés, dont notamment celles des contraintes que représentent les arbres pour les agriculteurs, contraintes qui les incitent à déboiser plutôt que l'inverse. Dans le cadre du projet ACTAFORSE, nous avons étudié plus précisément le point de vue des agriculteurs vis-à-vis des arbres, en faisant une focale sur une région de polyculture-élevage située dans le Sud-Ouest de la France, à 60 km environ de Toulouse. Selon les agriculteurs rencontrés, les arbres produisent de nombreux services : le bois, dont l'utilisation et la vente participe à l'économie des fermes ; le maintien des sols, qui bénéficie à la production agricole ; l'esthétique du paysage, qui est associée à une identité locale. En regard de ces nombreux bénéfices (nous en avons identifié un total de 29), les agriculteurs ont fait remonter 18 sortes de nuisances dont les principales était liée à la difficulté de maintenir des arbres dans des parcelles mécanisées, ainsi qu'à la charge de travail nécessaire à leur entretien, notamment pour les haies. Bien que les arbres ont un grand potentiel pour aider l'agriculture française à répondre aux enjeux écologiques actuels, il sera nécessaire dans le futur de mieux valoriser les ressources qu'ils produisent tout en permettant aux agriculteurs de mieux se prémunir contre les nuisances associées. Une première piste envisageable serait de promouvoir la mobilisation et la commercialisation du bois issu des haies et autres types de formations boisées. En effet, si les arbres deviennent une source de revenu, les agriculteurs seront davantage enclins à les conserver. Une seconde piste serait de mieux prendre en compte les nuisances liées aux arbres dans les politiques publiques et d'adapter les pratiques et machines agricoles à leur présence. Une prise en compte plus spécifique des arbres dans les directives de la Politique Agricole Commune apparaît notamment comme un levier puissant de promotion de l'arbre champêtre et de pratiques agroforestières au sens large.

1. Introduction

Le maintien et la promotion des arbres dans les paysages ruraux représentent une piste prometteuse pour l'agriculture de demain, une agriculture moins nuisible à l'environnement, plus productive et plus qualitative (Guillerme 2010, Torralba et al. 2016). En effet, les forêts paysannes (forêts privées qui appartiennent ou sont gérés par les agriculteurs) et les arbres hors-forêt (arbres isolés, haies, ripisylves et bosquets) fournissent des services écosystémiques indispensables à la qualité écologique des paysages agricoles et à la durabilité économique des exploitations agricoles. En particulier, ces forêts rurales (i.e. concept qui regroupe forêts paysannes et arbres hors forêt) contribuent à la connectivité entre les habitats forestiers, ce qui constitue un atout pour la conservation de nombreux espèces animales et végétales (López-Barrera et al. 2006, Fischer et Lindenmayer 2007). Elle fournissent aussi de nombreuses ressources d'intérêt économique ou patrimonial, comme notamment du bois de chauffe et d'œuvre, des fruits, des champignons, ou encore des plantes médicinales (Ouin et al. 2015).

Malgré cette importance, les paysages européens connaissent un déclin de la forêt rurale en lien avec une réduction de pratiques traditionnelles qui parvenaient à concilier arbres et agriculture (Bergmeier et al. 2010, Guillerme 2010, Pfund et al. 2011, Nerlich et al. 2013). En outre, les pratiques d'agroforesterie « moderne » connaissent un essor encore limité en France et en Europe (den Herder et al. 2017). Ce constat témoigne de la difficulté, pour les agriculteurs à l'échelle collective et individuelle de concilier arbres et agriculture dans leurs systèmes actuels. Mieux comprendre cette difficulté peut aider à trouver des leviers d'action pour promouvoir effectivement les forêts rurales dans les paysages agricoles européens dans la perspective d'une agriculture moins nocive pour les écosystèmes et davantage conforme aux attentes d'une société civile toujours plus consciente des enjeux écologiques actuels.

L'ambition du projet ACTAFORSE était d'améliorer nos connaissances des difficultés que les agriculteurs ont à maintenir et développer des arbres dans leurs systèmes agricoles, tout en mettant ces difficultés en perspective des avantages associés aux arbres et du contexte sociotechnique et institutionnel. Le présent rapport synthétise les principaux résultats de ce projet après un bref rappel des enjeux scientifiques et sociétaux, ainsi que des objectifs spécifiques. A travers un cas d'étude situé dans le Sud-Ouest de la France, il présente notamment une synthèse des avantages et contraintes perçus par les agriculteurs en lien avec les forêts rurales, ainsi que le potentiel de ces forêts à fournir des services écosystémiques pour la production de ressources et pour la conservation des écosystèmes. Enfin, il tire les principaux enseignements du projet ACTAFORSE et identifie quelques perspectives de recherche.

2. Enjeux scientifiques et sociétaux

2.1. Les forets rurales : des piliers menaces dans les paysages agricoles

La présence d'espaces arborés dans les paysages agricoles, sous forme de petits bois et bosquets, de haies et autres formations linéaires (en bordure des cours d'eau, en alignement le long des chemin), ou encore d'arbres isolés, aboutit à des paysages hétérogènes à forte valeur socio-économique et écologique. Nous utiliserons ci-après le concept de 'forêt rurale' pour désigner ces espaces dont la gestion repose essentiellement sur les agriculteurs et qui est fortement influencée par la gestion et l'évolution des espaces agricoles avoisinants (Michon et al. 2007). Ce concept inclut ainsi les bois paysans (qui appartiennent aux agriculteurs) ainsi que les espaces arborés de type haie, ripisylves, alignements, et arbres isolés (i.e. l'ensemble des arbres se trouvant dans des paysages à vocation principalement agricole).

La diversité d'habitats qui résulte de la coexistence de forêts rurales et d'espaces arborés est propice au maintien d'une diversité de communautés animales et végétales. En outre, les forêts rurales fournissent des services variés pour l'agriculture, ainsi que pour les agriculteurs. En Bretagne par exemple, les paysages de bocage se caractérisent par des réseaux de haies qui participent au maintien d'une biodiversité utile à la lutte contre les ravageurs, au bon fonctionnement des écosystèmes via notamment le maintien de la structure et fertilité des sols, ainsi qu'à la durabilité économique des systèmes agricoles à travers la production de bois de chauffe (Burel et Baudry 1990, Baudry et al. 2000, Petit et al. 2003). Culturellement, les paysages de bocage ont également une valeur non négligeable, s'érigeant au titre de patrimoine naturel pour les agriculteurs, les visiteurs et les touristes (Oreszczyn et Lane 2000). Un autre exemple de tels paysages en Europe est représenté par les pâturages boisés dont le maintien est étroitement lié à celui des cultures et pratiques locales (Plieninger et al. 2015, Garrido et al. 2017, Jakobsson et Lindborg 2017). En d'autres termes, les forêts rurales participent à des paysages agricoles riches en biodiversité ainsi qu'à la production d'une diversité de ressources et services pour une diversité d'acteurs (Plieninger et al. 2015).

Malgré ce rôle crucial, les forêts rurales tendent à disparaître des paysages agricoles français dans un processus de séparation croissante des milieux forestiers et agricoles (Cinotti et Normandin 2002). Cette dynamique a commencé il y a plusieurs décennie, avec la révolution verte qui a transformé les systèmes agricoles, et continue aujourd'hui avec l'intensification croissante de ces systèmes (Baudry 1993). Néanmoins, au-delà des dynamiques régionales et nationales, de fortes disparités existent à des échelles plus locales selon la dynamique propre des différents systèmes agricoles, mais aussi selon les rapports qu'entretiennent les sociétés locales aux forêts rurales (Sourdril 2008, Andrieu et al. 2010, Genin et al. 2013). A l'heure actuelle, nous manquons d'études locales qui nous permettraient de comprendre finement ces rapports hommes-nature particuliers, et ce faisant de mieux identifier les causes du déclin des forêts rurales dans les paysages agricoles et d'y apporter des solutions qui aient du sens localement.

Ce fût l'ambition générale du projet ACTAFORSE, qui s'ancrait dans deux grands défis d'ordre scientifique et sociétal. Le premier, le scientifique, est lié à la difficulté d'étudier les rapports hommes-nature en les liant à des dynamiques écologiques mesurées ou observées. En particulier, les relations entre représentations, savoirs et pratiques des sociétés rurales vis-à-vis de leur environnement sont complexes à révéler, et il est souvent encore plus périlleux de les mettre en relation avec des dynamiques écologiques telles que l'évolution des paysages ou des niveaux de biodiversité. Le second défi, d'ordre sociétal, est lié à la non-durabilité des systèmes agricoles actuels, qui nous impose aujourd'hui de les « reverdir », en s'appuyant davantage sur les services fournis par la biodiversité plutôt qu'en luttant contre (Altieri 2002). Dans cette perspective, la réintroduction (et la préservation) des arbres dans les paysages et parcelles agricoles apparaît comme une piste prometteuse, mais qui peine à prendre de l'ampleur en Europe (Torralba et al. 2016, Fagerholm et al. 2016).

2.2. Vers une approche socio-ecosystemique des forets rurales

A l'intersection entre milieux forestiers et milieux agricoles, évoluant sous l'influence de facteurs biophysiques (climat, topographie, nature des sols, etc.), socio-économiques (changements dans les pratiques agricoles, évolution du prix du bois, etc.) et culturels (visions de l'arbre par les agriculteurs, savoirs locaux liées aux plantes forestières, etc.), les forêts rurales sont les composantes d'un socio-écosystème complexe qui défie les approches disciplinaires (Berkes et Folke 1992). Il s'agit en effet, pour comprendre ces forêts, de naviguer entre composantes sociales et écologiques afin d'en identifier les principaux éléments qui les affectent. Pour ce faire, le projet ACTAFORSE s'est doté d'un cadre conceptuel permettant de faire le pont entre les forêts rurales, les acteurs impliqués de manière directe ou indirecte dans leur gestion, et les services rendus par ces forêts (Figure 1).

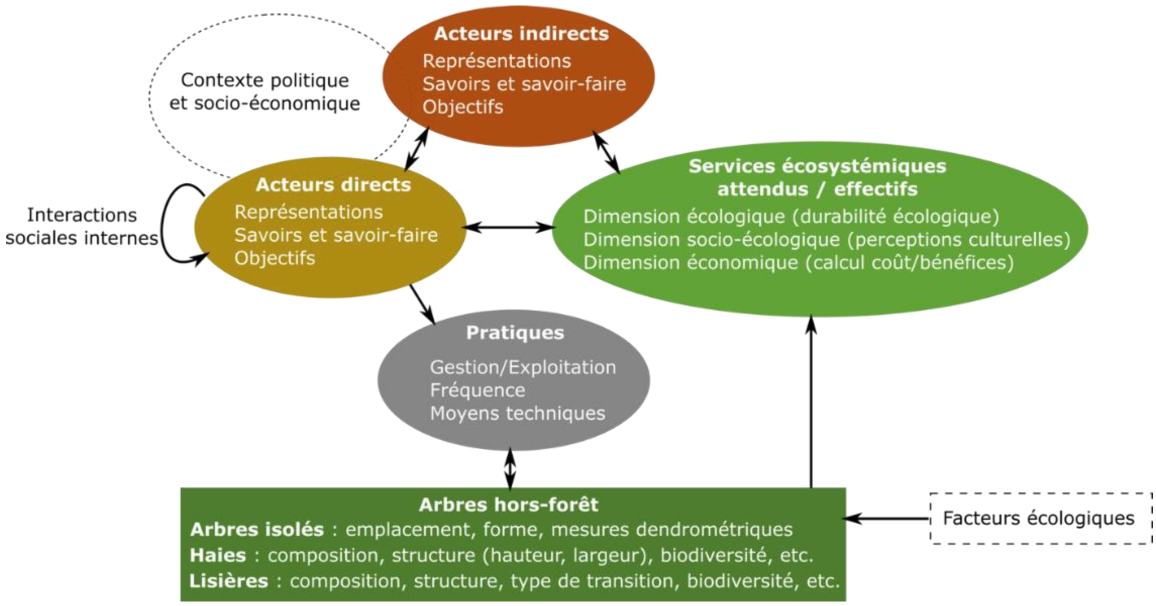

Figure 1 : Cadre conceptuel de la gestion des forêts rurales et des interactions sociales associées du projet ACTAFORSE.

Les pratiques y sont considérées comme étant le fait d'acteurs directs (gestionnaires des arbres) et le résultat de diverses configurations sociales. Par exemple, la gestion d'une haie peut dépendre d'un seul acteur (haie entre les deux champs d'un même agriculteur) ou de deux (haie frontalière entre deux propriétés). Celle d'une lisière peut à l'inverse faire intervenir divers acteurs (forestiers, agriculteurs, chasseurs, etc.) tandis que la gestion d'un arbre isolé est généralement à la discrétion d'un seul agriculteur. Des interactions sociales plus ou moins complexes existent donc, selon l'espace arboré considéré et selon le nombre et la nature des acteurs et de leurs relations interpersonnelles.

Dans le même temps, les pratiques autour des forêts rurales sont motivées par les services que les acteurs en attendent ou tentent de favoriser. Ces services écosystémiques (SE) sont généralement classés en trois catégories : les SE d'approvisionnement, qui regroupent les productions alimentaires animales et végétales, de matériaux, ou encore d'énergie ; les SE de régulation, qui regroupent les mécanismes de purification de l'eau, de maintien des sols, ou encore de régulation de la qualité de l'air ; et les SE culturels, liés aux activités récréatives dans les écosystèmes, à l'esthétique des paysages, ou encore à la connaissance et aux savoirs liés aux écosystèmes. Par exemple, un agriculteur gère ses bois paysans de sorte à bénéficier de bois de chauffe tous les ans, de bois de construction de manière occasionnelle, voire même de champignons (Du Bus de Warnaffe et al. 2006, Sourdril et al. 2006).

A l'inverse, les forêts rurales apparaissent parfois comme une source de contraintes et de nuisances pour les activités agricoles, amenant à des réponses spécifiques de la part des agriculteurs. Ces nuisances expliquent notamment le déclin des haies qui représentent une gêne à la mécanisation accrue des parcelles agricoles. Pour désigner ces diverses contraintes et nuisances, le concept de disservices écosystémique (DSE) a récemment été proposé dans la littérature spécialisée (Zhang et al. 2007, Shackleton et al. 2016). Les DSE regroupent ainsi les impacts négatifs des écosystèmes et de leur fonctionnement sur le bien-être humain, de par les coûts qu'ils engendrent, les impacts sur la sécurité et la santé des personnes, ou encore les nuisances culturelles qu'ils génèrent (Lyytimäki et Sipilä 2009).

2.3. Objectifs et problematique du projet ACTAFORSE

Si les recherches en agroforesterie se sont surtout intéressées aux SE fournis par les arbres dans les systèmes agricoles et aux pratiques de gestion les plus adaptées, elles ont prêté peu d'attention à la vision que peuvent en avoir les agriculteurs. Par ailleurs, les contraintes et nuisances liées à la présence d'arbres dans ou à proximité des champs sont souvent éludées. Pour combler ce manque de recherche, le projet ACTAFORSE s'est intéressé aux perceptions et représentations que les agriculteurs ont de la forêt rurale compte tenu du contexte dans lequel ils évoluent, en portant une attention similaire aux services et disservices perçus par les agriculteurs. En outre, il a tenté de comparer les perceptions des agriculteurs à des mesures biophysiques de services et disservices, afin d'en identifier les décalages éventuels.

Le premier objectif de ce projet était donc de comprendre comment les agriculteurs se représentaient les services et disservices associés aux forêts rurales, ainsi que l'influence du contexte sociotechnique et institutionnel sur ces perceptions. Nous avons pour cela conduit des entretiens auprès d'agriculteurs dans le Sud-Ouest de la France, près de Toulouse.

Le second objectif était de mesurer les principaux services et disservices à travers un inventaire des espaces arborés à l'échelle des exploitations agricoles. Nous avons pour cela associé un travail de cartographie et d'inventaires dendrométriques et floristiques dans les exploitations gérées par les agriculteurs enquêtés.

3. Matériels et méthodes

3.1. Site d'etude

Le site d'étude retenu pour le projet ACTAFORSE se situe à environ 60 km au Sud de Toulouse (43°13'02.63"; 0°52'53.76" ; Figure 2) au sein du site atelier « Vallées et coteaux de Gascogne » et de la Zone Atelier Pyrénées-Garonne (ZA PYGAR). La région se caractérise par une succession de coteaux et de vallées dominée par la chaîne des Pyrénées à l'horizon. Le climat y est tempéré avec des influences atlantiques et méditerranéennes : la température annuelle moyenne est de 13,8°C et les précipitations sont de 638 mm (https://donneespubliques.meteofrance.fr).

Historiquement, les systèmes agricoles y étaient dominés par des systèmes de polyculture-élevage associant céréaliculture (blé et maïs notamment) et élevage bovin semi-extensif pour la production de viande et de lait (Choisis et al. 2010). Depuis la révolution verte, les exploitations agricoles (et le parcellaire) sont devenues moins numéraires et les restantes se sont agrandies, avec une tendance pour certaines à une spécialisation dans la céréaliculture pure. Plus récemment, des fermes labellisées « Agriculture Biologique » sont apparues. L'ensemble de ces changements passés et en cours a ainsi une influence sur la place des forêts rurales dans le paysage (Figure 3), mais également sur les rapports entre ces forêts et les agriculteurs (Sourdril 2008).

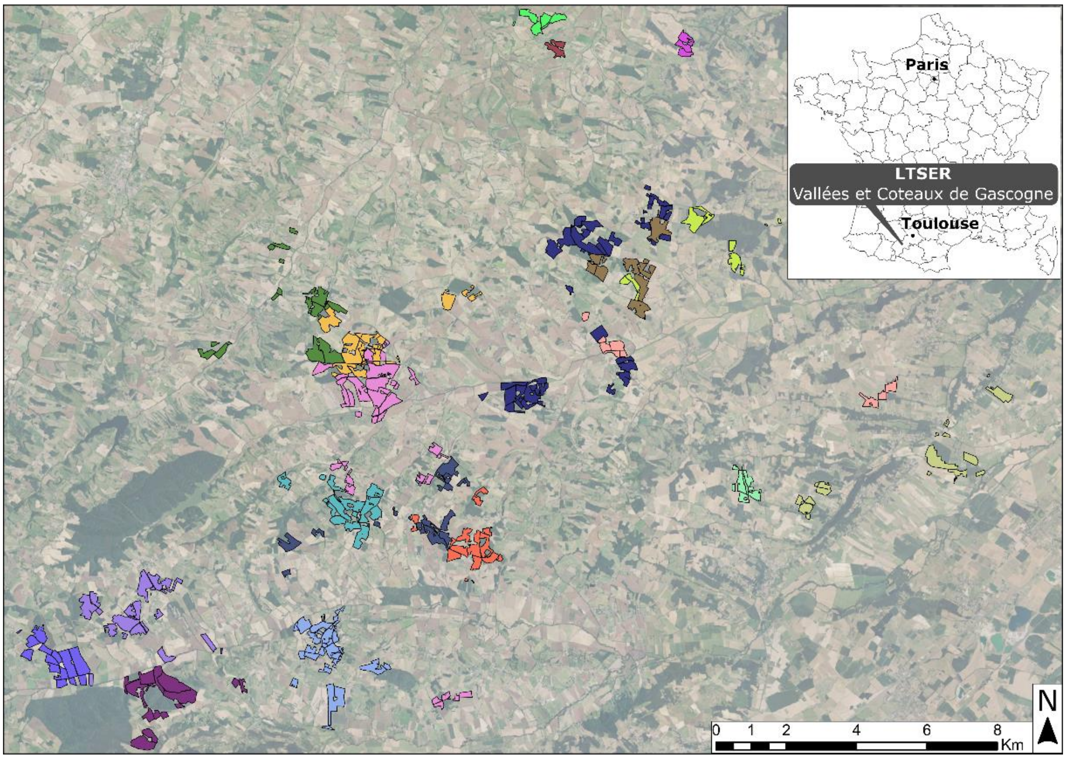

Figure 2 : Localisation du site d'étude et des 19 exploitations agricoles enquêtées dans le cadre du projet ACTARFORSE.

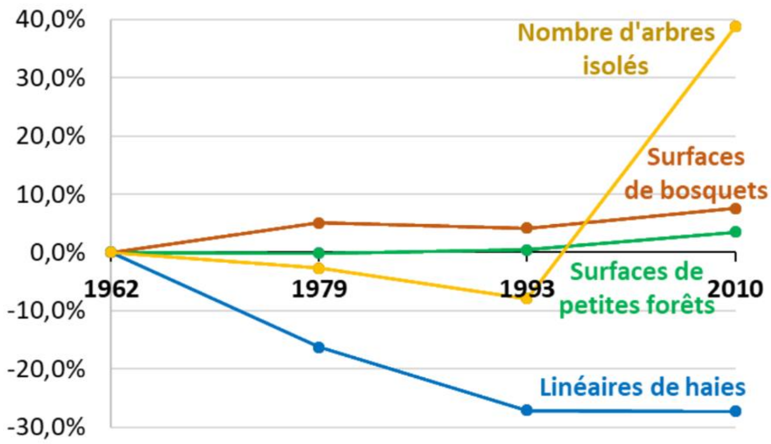

Figure 3 : Evolution des différents types d'espaces arborés composant la forêt rurale dans les coteaux de Gascogne entre 1962 et 2010. Source : Blanco et al. (2019).

3.2. Evaluation des services et disservices perçus par les agriculteurs

Des entretiens semi-directifs ont été conduits auprès des agriculteurs de la zone entre Novembre 2016 et Mars 2017 pour évaluer leurs perceptions des services et disservices associés aux forêts rurales. Tout d'abord, des entretiens préliminaires ont été conduits auprès de 26 agriculteurs pour délimiter les contours de la recherche et tester certaines méthodes d'enquêtes (notamment l'utilisation de photographies aériennes comme support à la discussion). Ensuite, des entretiens approfondis, d'une à deux heures, ont été conduits avec les 19 agriculteurs ayant accepté de participer à cette recherche.

Les entretiens visaient à explorer quatre grandes questions :

- Quels types d'espaces arborés les agriculteurs ont-ils sur leur exploitation et comment les nomment-ils ?
- Quels acteurs sont impliqués dans la gestion de ces espaces ?
- Quels services associés à ces espaces sont particulièrement importants aux yeux des agriculteurs ?
- Quels disservices associés à ces espaces sont particulièrement nuisibles ou contraignants à leurs yeux ?

Afin de collecter puis analyser de manière standardisée les données, nous avons utilisé un guide d'entretien semi-directif ainsi qu'une procédure d'élicitation directe des modèles mentaux des agriculteurs sous forme de carte cognitive. Les détails concernant cette procédure sont présentés dans les Annexes 1 et 4.

3.3. Cartographie et mesure des services et disservices

Afin de mieux comprendre la répartition des différents types d'espaces arborés et de leurs services et disservices potentiels, un travail cartographique de différenciation des espaces arborés a été entrepris fin 2017 dans les 19 exploitations concernées par les enquêtes précédentes. A partir de cette cartographie, des inventaires dendrométriques et floristiques ont été entrepris en Avril-Mai 2018 dans le cadre d'un stage de M2 pour évaluer certains services et disservices clés.

A partir des entretiens avec les agriculteurs, nous avons identifié différents types d'espaces arborés à la forêt rurale et défini des critères de différenciation (Tableau 1). Ce travail nous a permis d'établir une carte de ces différents espaces par photo-interprétation. Des inventaires dendrométriques et floristiques ont ensuite été conduits dans 344 placettes réparties de manière stratifiée dans les différents types d'espaces arborés : 50 dans des alignements de bord de route, dans des 50 bosquets, 49 dans des forêts, 50 dans des haies, 45 au niveau d'arbres isolés, 50 en lisière et 50 dans des ripisylves. Selon les types d'espaces, jusqu'à 68 variables ont été collectées dans chaque parcelle, dont des variables dendrométriques, de diversité végétale ligneuse, de gestion et de conditions environnementales. Nous avons notamment évalué à partir de ces relevés trois SE clés : le volume de bois de chauffe, le volume de bois de construction, et le service de conservation de la biodiversité.

Tableau 1: Catégories et types d'espaces arborés composant la forêt rurale selon leurs critères d'identification.

Catégorie	Code	Type d'espace	Critère
Arbres hors-forêt	R	Ripisylves et bords de cours d'eau	Espace arboré linéaire de plus de 25 m de long situé à moins de 10 m d'un cours d'eau et sans interruption de plus de 10 m.
	A	Alignements de bord de route	Espace arboré linéaire de plus de 25 m de long situé à moins de 10 m d'une route ou d'un chemin et sans interruption de plus de 10 m.
	H	Haies	Espace arboré linéaire de plus de 25 m de long sans interruption de plus de 10 m et (i) moins de 20 m de large ou (ii) plus de 20 m de large mais une seule rangée d'arbre dominant.
	I	Arbres isolés	Espace arboré non linéaire de moins de 0,05 ha et situé à plus de 10 m d'un cours d'eau ou d'une route.
	B	Bosquets	Espace arboré non linéaire dont 0,05<S<0,5 ha.
Bois paysans	F	Cœur de forêt	Espace arboré non linéaire et continu s'étendant sur une surface de plus de 0,5 ha. Espace arboré non linéaire dont S>0,5 ha, situé dans des îlots agricoles ou sur des parcelles forestières identifiées à partir des entretiens avec les agriculteurs.
	L	Lisières	Espace arboré situé à moins de 10 m de la bordure des îlots PAC (Politique Agricole Commune) mais qui fait partie d'un espace arboré qui continu au-delà des 10m (un bosquet, un bois).

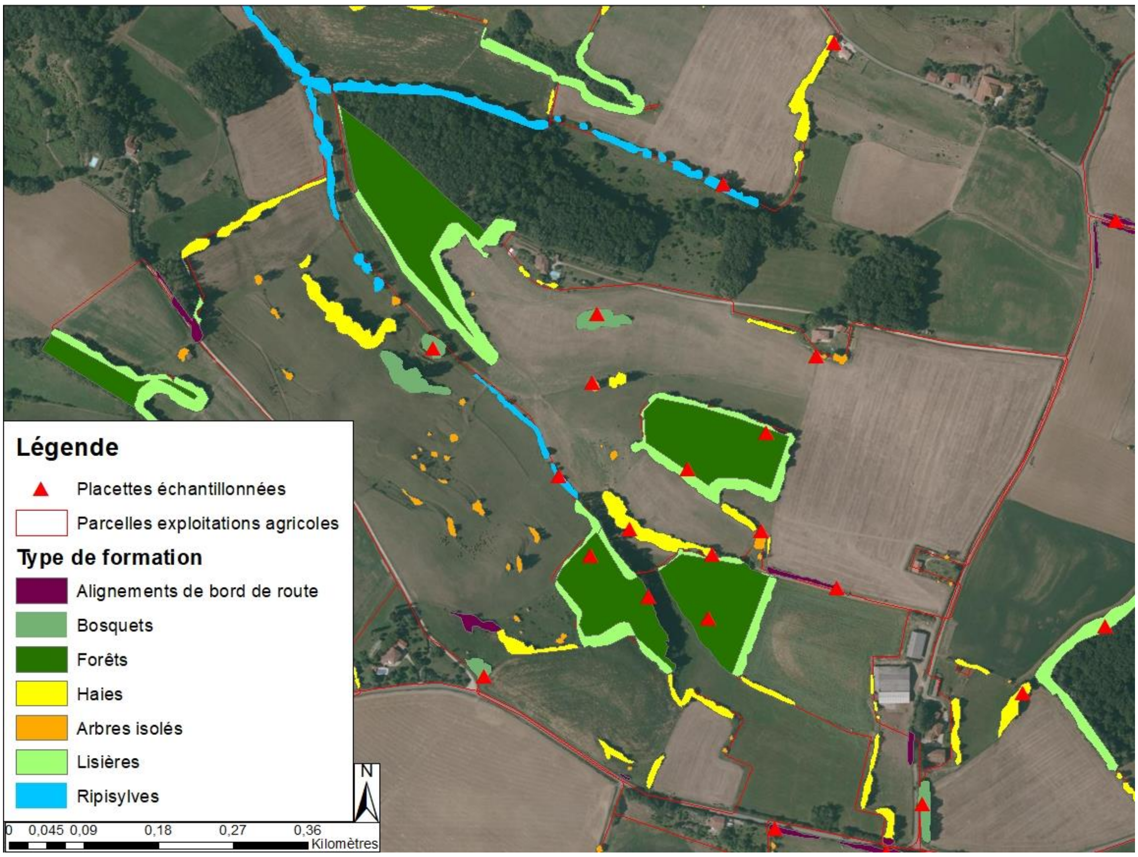

Figure 4: Illustration du plan d'échantillonnage sur une portion d'exploitation agricole

4. Synthèse des principaux résultats

4.1. Evaluation socio-culturelle des (dis)services associes aux forets rurales

4.1.1. Principaux services et disservices évoqués par les agriculteurs

Les agriculteurs rencontrés ont évoqué lors des entretiens un total de 29 SE, 18 DSE, et 7 autres types de contributions positives et négatives associés aux forêts rurales (Figure 5). Parmi les SE cités par les agriculteurs, 8 correspondaient à des services d'approvisionnement, parmi lesquels le bois de chauffage (N=16), les champignons (N=10) et les fruits et noix (N=9) semblent particulièrement importants pour eux. Les SE de régulation étaient plus nombreux aux yeux des agriculteurs, puisque ces derniers en ont dénombrés 13 au total, dont le contrôle de l'érosion (N=12), l'effet brise-vent des haies pour les cultures (N=6) et les animaux (N=6), ainsi que la contribution des espaces arborés à la qualité de l'air (N=6). Deux services culturels ont été particulièrement mis en avant liés au rôle des espaces arborés, d'une part dans l'esthétique du paysage (N=11), d'autre part dans le maintien du vivant, non pas dans une dimension instrumentale mais pour sa valeur intrinsèque (N=7).

Concernant les 18 DSE cités par les agriculteurs, nous avons relevé 5 disservices d'ordre matériel ou économique, 3 disservices liés à la santé et à la sécurité des personnes, ainsi que 10 disservices concernant spécifiquement les activités agricoles. En particulier, c'est la gêne qu'occasionne les arbres pour le passage des engins agricoles dans le cadre d'une agricole mécanisée qui a été le DSE le plus évoqué (N=12), suivi par la charge de travail supplémentaire qu'impose l'entretien des haies et autres espaces arborés situés en bordure des champs (N=8).

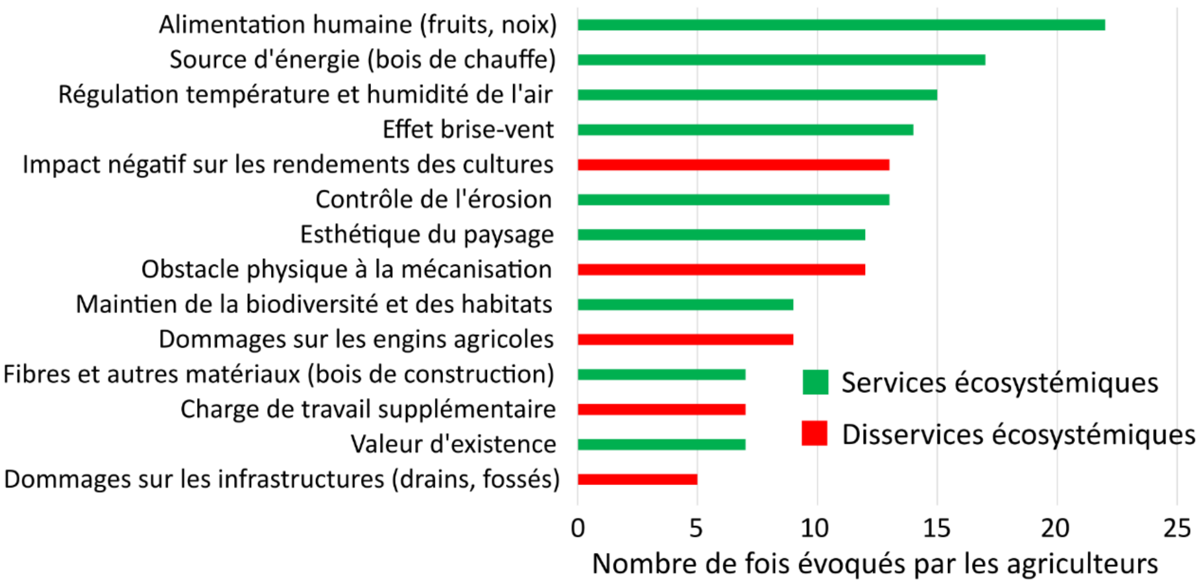

Figure 5 : Liste et occurrence de citation des services et disservices évoqués par au moins 5 agriculteurs lors des entretiens.

4.1.2. Variabilité des perceptions parmi les agriculteurs

Des analyses multivariées (cf. Annexe 4) ont permis de constater que les agriculteurs avaient des perceptions différentes, en particulier selon leur système de production (Figure 6). Ainsi, les agriculteurs en céréaliculture biologique ont des perceptions similaires et plus proches de celles des agriculteurs en polyculture-élevage conventionnelle que de celles des agriculteurs en céréaliculture conventionnelle. Ces différences dans les perceptions s'expliquent surtout par les disservices que les agriculteurs : parce que ces disservices s'expriment de manière plus marquée dans les systèmes de céréaliculture (e.g. compétition entre les arbres et les cultures, dégâts occasionnés par les branches d'arbres sur les rétroviseurs des tracteurs lors des épandages et travaux du sol), ils sont davantage mis en avant par les céréaliculteurs. A l'inverse, dans les systèmes d'élevage semi-extensif, ces disservices ne s'expriment pas, tandis que les forêts rurales rendent de nombreux services (e.g. ombrage pour les animaux, protection contre les intempéries).

Une analyse qualitative des entretiens a en outre révélé que les agriculteurs avaient globalement deux visions de la façon de concilier maintien des espaces boisés et maintien des activités agricoles. D'un côté, certains agriculteurs défendaient un modèle dans lequel les espaces boisés seraient séparés des espaces agricoles, dans une logique de *land sparing*. De l'autre, d'autres agriculteurs constataient la limite du déclin des arbres hors forêt, et de ses conséquences néfastes, comme par exemple pour la lutte contre l'érosion :

> *"Mais après y'avait des anciens qui avaient mis des haies, des talus dans les champs à l'époque, aujourd'hui on a un problème de ravinement hein. Ça c'est nous qui l'avons fait, vu qu'on a fait sauter les haies et les talus."* (Agriculteur A18, Déc. 2016)

Ainsi, ces agriculteurs défendaient plutôt un modèle de type *land sharing*, dans lequel des efforts accrus seraient faits pour conserver les arbres hors forêt sans toutefois contrevenir trop fortement à la rentabilité des activités agricoles.

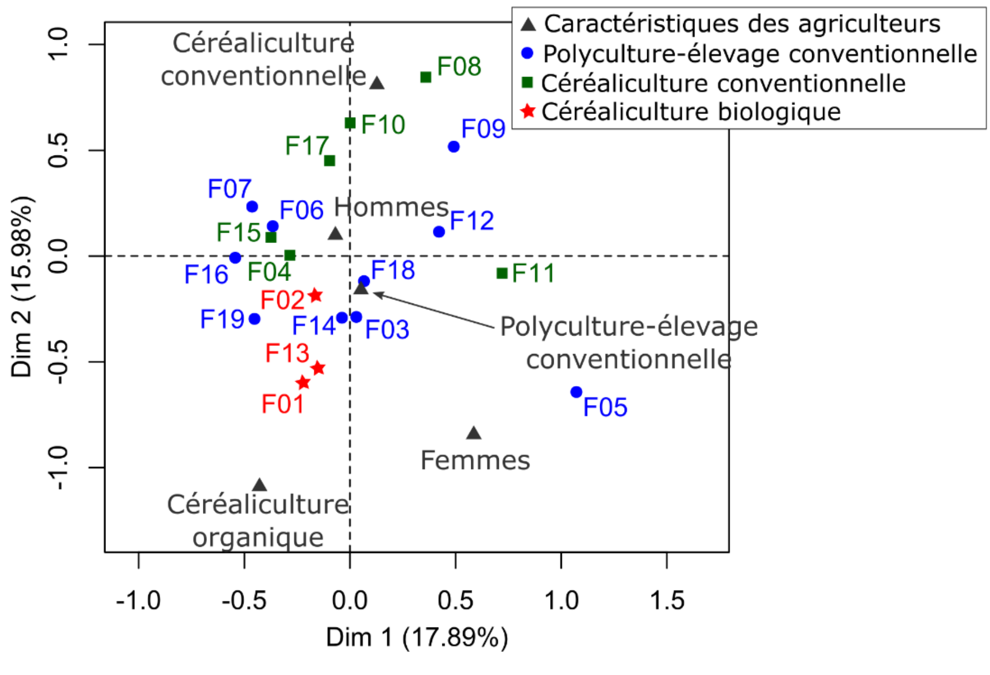

Figure 6 : Projection des agriculteurs selon leurs perceptions des (dis)services associés à la forêt rurale dans les deux premières dimensions d'une analyse des correspondances multiples.

4.1.3. Liens entre forêt rurale, acteurs et (dis)services

Lors des entretiens avec les agriculteurs, des cartes cognitives individuelles ont été construites (cf. Annexe 1) de façon à illustrer et analyser la représentation que les agriculteurs ont des relations entre les forêts rurales, les acteurs intervenant dans leur gestion, et les (dis)services associés (Figure 7).

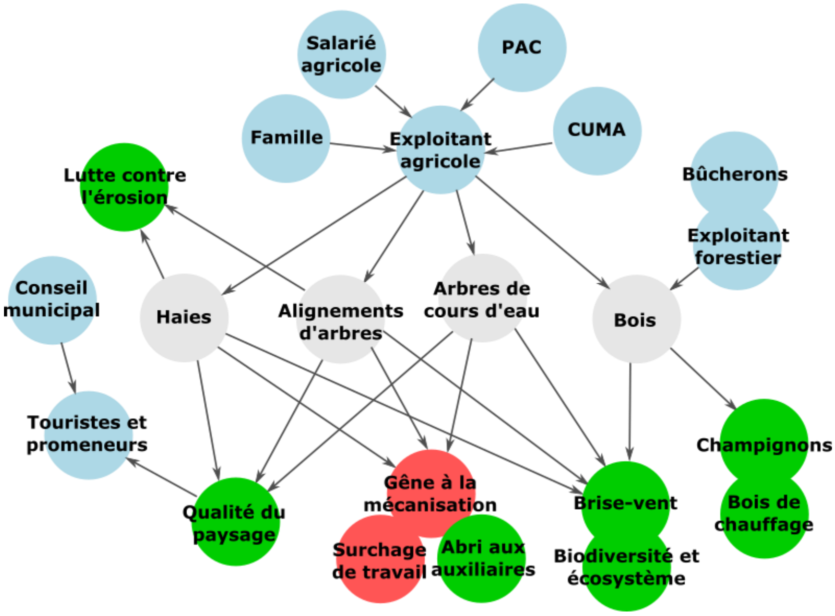

Figure 7 : Exemple de modèle mental obtenu auprès d'un agriculteur, mettant en relation (i) les formations arborées de son exploitation (en gris), (ii) les services (en vert) et disservices (en rouge) associés, et (iii) les acteurs intervenant de manière directe et indirecte dans leur gestion (en bleu).

Parmi les types d'espaces arborés, les bois paysans, petits bois paysans privés appartenant aux agriculteurs, ainsi que les haies, ont été les plus évoqués, respectivement par 17 et 16 agriculteurs. Certains informateurs ont néanmoins tenu à différencier, parmi les espaces linéaires généralement assimilés à des haies, ceux situés en bord de parcelle (N=9) de ceux situés en bord de rivière ou d'un fossé drainant (N=7).

Parmi les acteurs identifiés, le chef d'exploitation et sa famille occupent une place privilégiée dans la gestion des forêts rurales. Ces derniers ont parfois recours à des bûcherons (généralement de manière informelle) pour l'exploitation de bois de chauffe dans les bois paysans. Enfin, la Politique Agricole Commune (PAC) est ressortie comme une institution clé qui oriente les décisions de gestion des agriculteurs de manière substantielle, notamment via les seuils minimums de surfaces d'intérêt écologique qu'elle impose ainsi que via le contrôle des dynamiques d'enfrichement des champs et pâturages.

En agrégeant les cartes cognitives individuelles des agriculteurs, une vision synthétique des représentations dominantes des agriculteurs a pu être proposée (Figure 8). Nous constatons notamment que les haies et les arbres bordant les parcelles sont perçus comme les sources principales de disservices par les agriculteurs, alors que ces espaces rendent aussi de nombreux services. A l'inverse, les bois paysans ont été rarement associés à des disservices, tandis qu'ils fournissent eux aussi une diversité remarquable de services selon les agriculteurs.

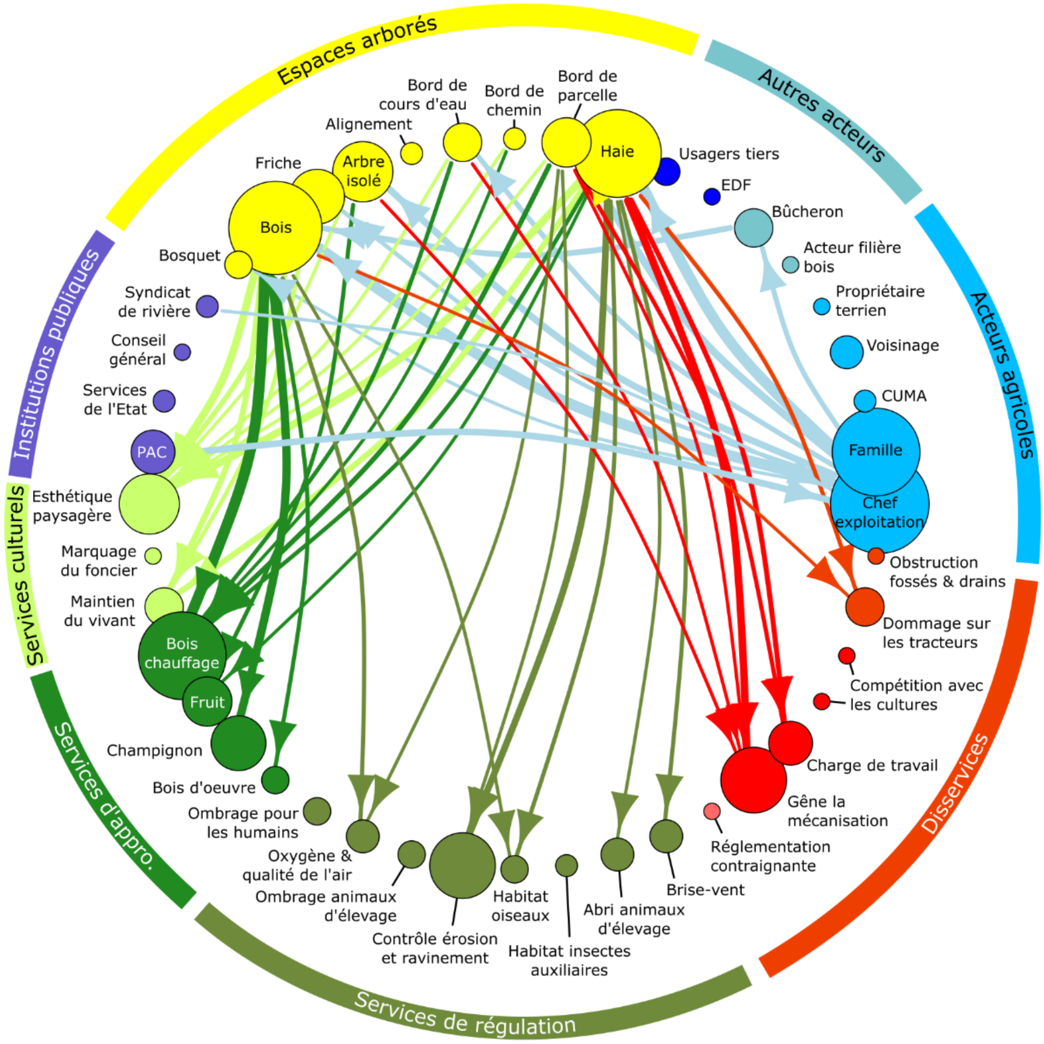

Figure 8 : Carte cognitive agrégée des liens entre espaces arborés, acteurs et institutions, et (dis)services écosystémiques établie à partir des cartes cognitives individuelles des agriculteurs enquêtés.

4.2. Evaluation des services potentiels fournis par les forets rurales

4.2.1. Diversité ligneuse dans les espaces arborés

Un total de 65 espèces ligneuses a été inventorié dans les 344 placettes, avec notamment 6 espèces présentes dans plus de 50% des placettes : le prunellier (*Prunus spinosa* L.), la ronce (*Rubus fruticosus* L.), les aubépines (*Crategus sp.*), le cornouiller sanguin (*Cornus sanguinea* L.), les chênes (*Quercus sp*) et l'églantier (*Rosa canina* L.) (Figure 9). Selon le type d'espaces arborés, la richesse en espèces ligneuses variait entre 31 (pour les alignements de bords de route où la richesse est la moins forte) et 41 (pour les haies et bosquets où la richesse est la plus forte).

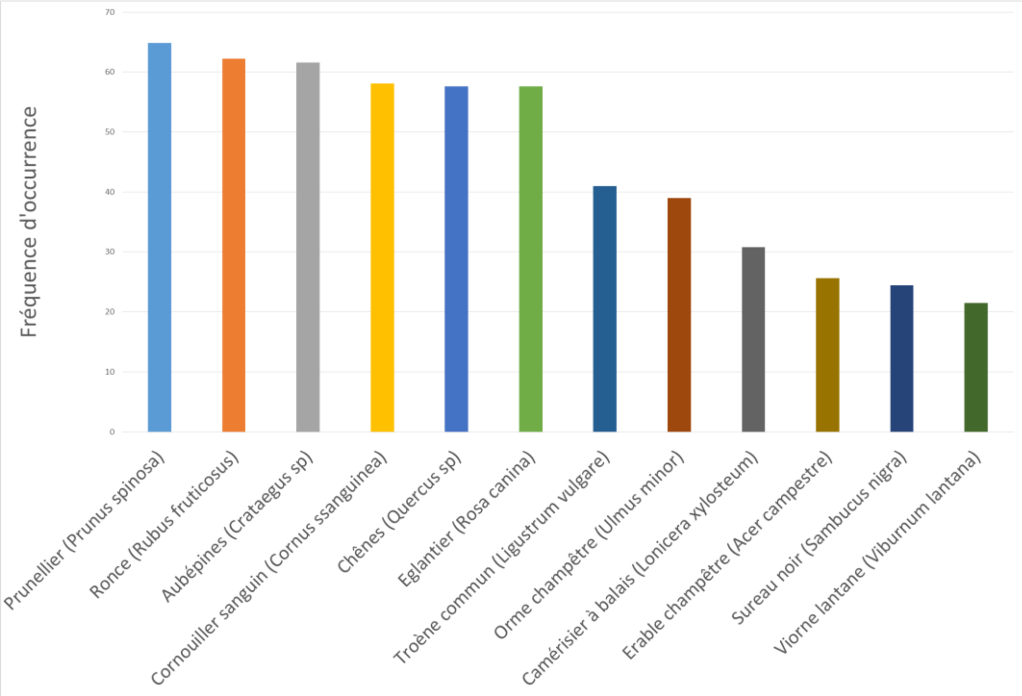

Figure 9 : Fréquence d'occurrence des 14 espèces ligneuses présentes dans plus de 20% des placettes tous types d'espaces arborés confondus.

Des analyses multivariées réalisées à partir de la composition spécifique des placettes ont montré que les différents types d'espaces arborés étaient similaires, avec néanmoins une distinction entre, d'un côté, les forêts et bosquets, et, de l'autre, les autres types d'espaces (Figure 10 ; Figure 11).

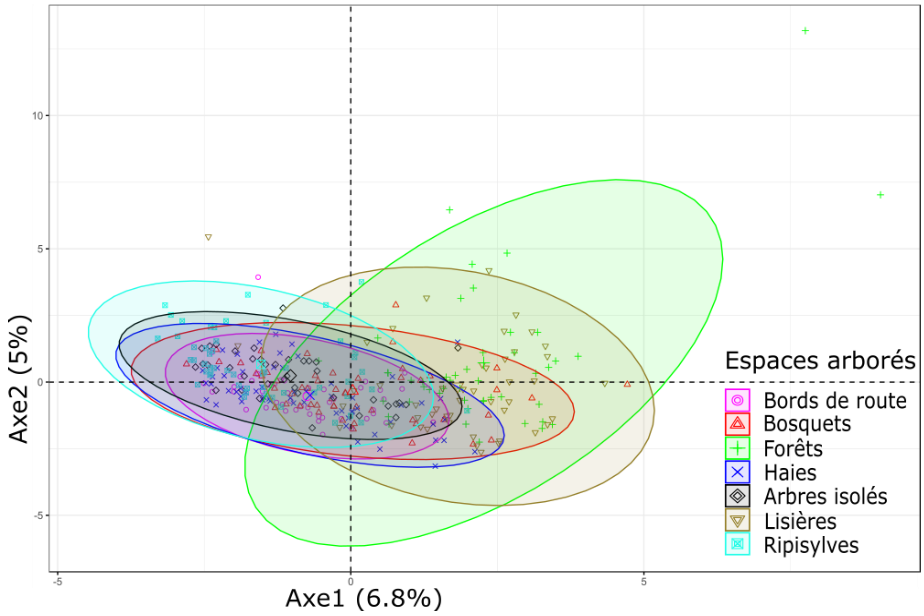

Figure 10 : Graphe des individus issus d'une ACP réalisée à partir de la composition ligneuse des placettes inventoriées. Les espèces présentes dans seulement une placette ont été retirées.

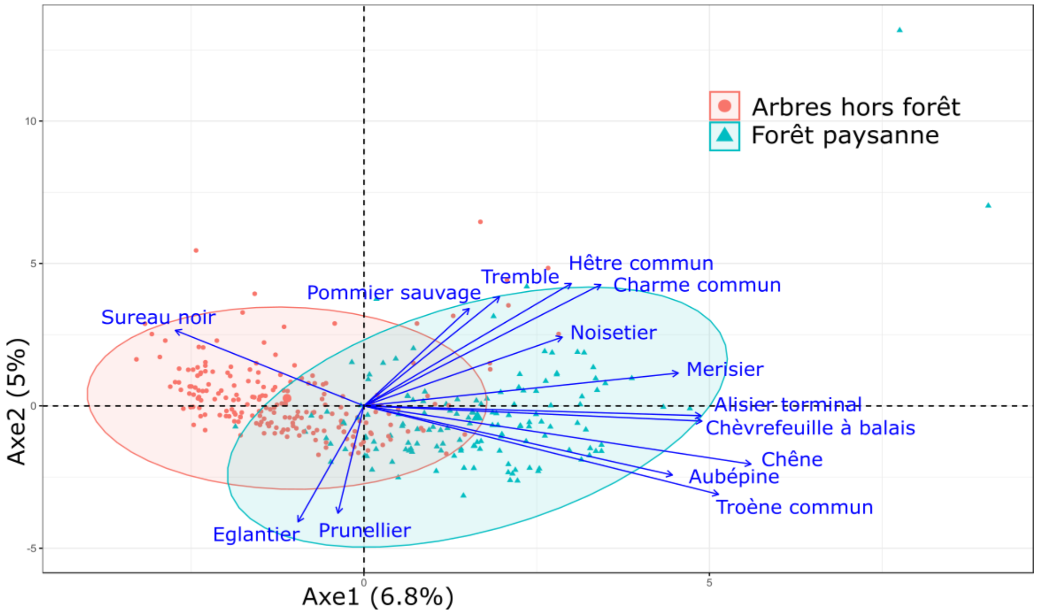

Figure 11 : Biplot présentant les 15 variables de matrice de la présence/absence contribuant le plus aux variations de composition floristique. Les ellipses représentent les deux groupes déterminés par une classification ascendante hiérarchique.

Selon les types d'espaces arborés, la richesse spécifique (moyenne ± écart-type) était comprise entre 4,13 ± 2,13 pour les arbres isolés et 9,56 ± 2,12 pour les lisières. Néanmoins, la surface des placettes d'échantillonnage étant différente selon le type de formation (éléments ponctuels vs linéaires vs surfaciques), la richesse dite surfacique (i.e. pondérée par la surface de la placette) a été utilisée pour comparaison les types d'espace arborés et leur contribution au service de conservation de la biodiversité.

Une analyse de variance (de type ANOVA) a ainsi établi des différences de richesse surfacique entre les types d'espace arboré (F6=0,069 ; p<0.01): les bosquets, forêts et arbres isolés affichaient une richesse spécifique ligneuse significativement plus faible que les lisières, les haies, les bords de route et les ripisylves (Figure 12).

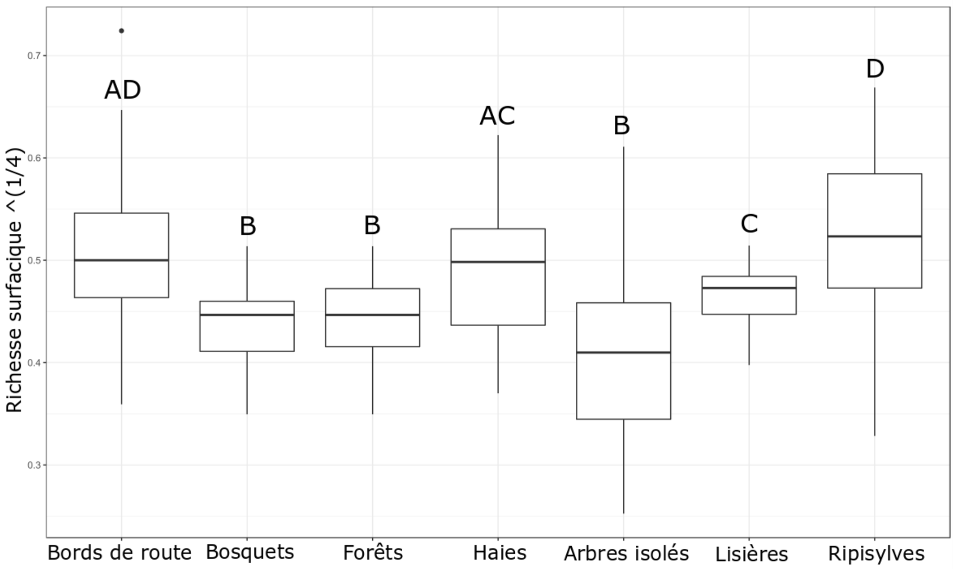

Figure 12 : Richesse surfacique corrigée selon le type d'espace arboré.

4.2.2. Evaluation des volumes de bois de chauffe et de construction

Le volume moyen de bois de chauffe à l'hectare calculé sur l'ensemble des placettes était de 69,69 ± 72,69 m^3/ha. Les forêts, lisières et ripisylves, avec, respectivement contenaient les volumes les plus importants, avec respectivement 89,70 ± 73, 101,02 ± 78,75 et 88,00 ± 73,94 m3/ha. Les autres espaces présentaient des volumes moindres avec 64,28 ± 64,53m3/ha pour les alignements de bord de route, 38,38 ± 44,62 m3/ha pour les bosquets, 59,68 ± 71,83 m3/ha pour les haies et 44,66 ± 77,05 m3/ha pour les arbres isolés. Une ANOVA a confirmé l'influence du type d'espace arboré sur le volume de bois chauffe (F6=21,001, p<0.01), avec trois groupes se dégageant (Figure 13).

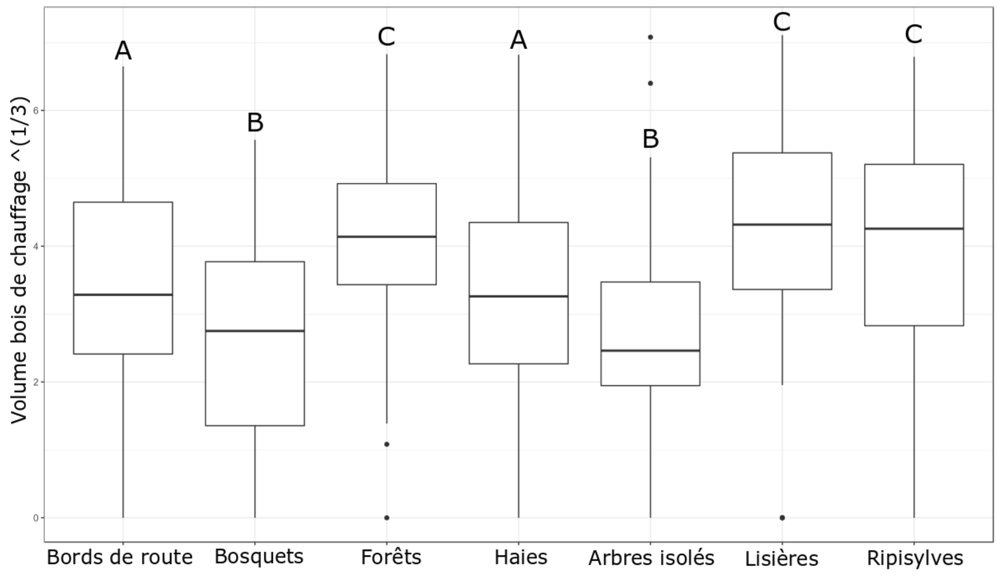

Figure 13 : Volume de bois de chauffe corrigé selon le type d'espace arboré

Le volume moyen de bois d'œuvre calculé sur l'ensemble des placettes était de 81,24 ± 209,48 m3/ha. Avec un volume moyen de 228,34 ± 466,09 m3/ha, les ripisylves contenaient la plus forte densité de bois d'œuvre, tandis que les bosquets affichaient la plus faible densité (20,94 ± 34,84 m3/ha). Une ANOVA a confirmé l'influence du type d'espace arboré sur le volume de bois d'œuvre (F6=9,594, p<0.01), avec trois groupes se dégageant (Figure 14).

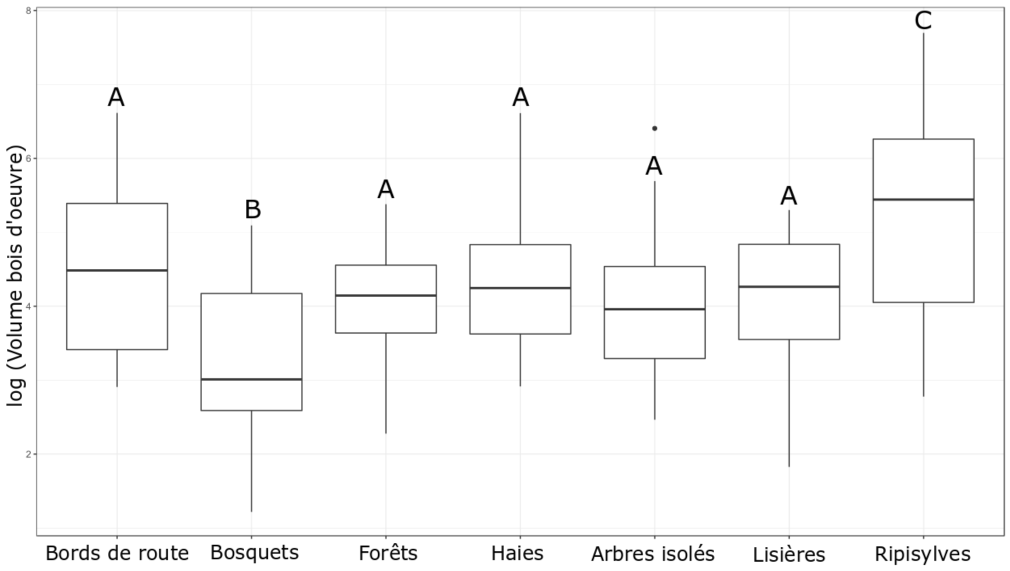

Figure 14 : Volume de bois d'œuvre corrigé selon le type d'espace arboré

Finalement, à partir des services de production de bois de chauffe et de construction, et de maintien de la biodiversité ligneuse, nos résultats indiquent que les ripisylves et les lisières agroforestières fournissent les plus hauts niveaux de services, tandis que les bosquets et arbres isolés fournissent les niveaux de services les plus bas (Tableau 2).

Tableau 2 : Synthèse des niveaux de services écosystémiques selon les types d'espace arboré. Pour chaque service, le gradient de couleur indique son niveau relatif, de jaune pour les valeurs les plus faibles, à rouge pour les valeurs les plus fortes (basé sur les tests de comparaison multiples consécutifs aux ANOVAS)

	Bords de route	Bosquets	Forêts	Haies	Arbres isolés	Lisières	Ripisylves
Richesse surfacique							
Volume de bois de chauffage à l'hectare							
Volume de bois d'œuvre à l'hectare							

4.3. SYNTHESE DES PRODUCTIONS LIEES AU PROJET

Pour aller plus loin, la liste exhaustive des productions scientifiques et sociétales associées au projet sont présentées ci-dessous, avec le cas échéant les liens internet vers ces productions. Les annexes 1 à 4 contiennent en outre les différents articles publiés (ou en voie de l'être) dans des revues scientifiques indexées.

4.3.1. Articles dans des revues indexées :

1. Blanco, J., Sourdril, A., Deconchat, M., Barnaud, C., San Cristobal, M., Andrieu, E., **resoumis après révision mineure**. How farmers feel about trees: perceptions of ecosystem services and disservices associated with rural forests in southwestern France. Ecosystem Services. [Annexe 4]
2. Blanco, J., Dendoncker, N., Barnaud, C., Sirami, C., **2019**. Ecosystem disservices matter: towards their systematic integration within ecosystem service research and policy. *Ecosystem Services* 36: 100913. https://doi.org/10.1016/j.ecoser.2019.100913 [Annexe 3]
3. Teixeira, F. Z., Bachi, L., Blanco, J., Zimmermann, I., Welle, I., Carvalho-Ribeiro, S. M., **2019**. Perceived ecosystem services (ES) and ecosystem disservices (EDS) from trees: insights from three case studies in Brazil and France. *Landscape Ecology*. https://doi.org/10.1007/s10980-019-00778-y [Annexe 2]
4. Blanco, J., Sourdril, A., Deconchat, M., Ladet, S., Andrieu, E., **2019**. Social drivers of rural forest dynamics: a multi-scale approach combining ethnography, geomatic and mental model analysis. *Landscape and Urban Planning* 188: 132–142. http://doi.org/10.1016/j.landurbplan.2018.02.005 [Annexe 1]

4.3.2. Présentations et posters dans des colloques scientifiques

Présentations orales

1. Andrieu, E. Deconchat, M., Blanco, J., Sourdril, A., **2018**. Comment les agriculteurs perçoivent-ils leurs arbres ? Aborder les projets agroforestiers avec les agriculteurs et appréhender leurs perceptions multiples. Croisons les regards #3, Journée d'échanges du RMT AgroforesterieS. 7 Septembre 2018. Paris, France. https://prodinra.inra.fr/record/454658
2. Blanco, J., Sourdril, A., Deconchat, M., Andrieu, E., **2017**. Comprendre les représentations sociales pour comprendre les paysages : potentiels et limites de la notion de services écosystémiques. *Rencontres d'Ecologie des Paysages - REP 2017*. 23-26 Octobre 2017. Toulouse, France. http://prodinra.inra.fr/record/410847
3. Blanco, J., Deconchat, M., Andrieu E., Ladet, S., Sourdril, A., **2017**. How do farmers' representations influence landscapes? A multi-scale approach combining mental modelling and forest monitoring in South-western France. *IALE 2017 European Landscape Ecology Congress*. 12-15 Septembre 2017. Gand, Belgique.
4. Blanco, J., Sourdril, A., Deconchat, M., Ladet, S., Andrieu, E., 2017. Appréhender les représentations des agriculteurs vis-à-vis des forêts paysannes. Apportes et limites d'une approche combinant services écosystémiques et modèles mentaux. *Journées d'échanges "Agroforesterie et Grandes Cultures". 5-6 Septembre 2017*. Chaussy, France. http://prodinra.inra.fr/record/406759

Posters

1. Andrieu, E., Ladet, S., Calatayud, F., Blanco, J., Sourdril, A., Deconchat, M., 2019. Trees in agricultural landscapes: understanding past changes for a better management. *4th World Congress on Agroforestry*. 20-22 Mai 2019. Montpellier, France.

2. Blanco, J., Sourdril, A., Deconchat, M., Andrieu, E., 2019. Farmers compose with ecosystem services and disservices for managing rural forests: insights from a French case study. *4th World Congress on Agroforestry*. 20-22 Mai 2019. Montpellier, France.
3. Blanco, J., Deconchat, M., Andrieu E., Ladet, S., Sourdril, A., 2017. How do farmers' representations influence landscapes? A multi-scale approach combining mental modelling and forest monitoring in South-western France. *IALE 2017 European Landscape Ecology Congress*. 12-15 Septembre 2017. Gand, Belgique. http://prodinra.inra.fr/record/407633

4.3.3. Actions de vulgarisation

1. Participation à la rédaction d'une actualité sur le site internet du PSDR-Occitanie (Mai 2019). https://www.psdr-occitanie.fr/PSDR4-Occitanie/Le-projet-SEBIOREF/Resultats-Scientifiques/SEBIOREF-Colloque-Agroforesterie-2019
2. Présentation d'un poster lors de la rencontre « Des arbres dans nos assiettes » organisé par la Fondation de France, 19 Mai 2019, Montpellier. Titre du poster: Gestion et perceptions des espaces arborés par les agriculteurs des coteaux de Gascogne.
3. Sélectionné par le département « Sciences pour l'Action et le Développement » de l'INRA pour la rédaction d'un « fait marquant » au titre de l'année 2018. Fiche de synthèse du projet ACTAFORSE. Disponible sur : http://2025.inra.fr/climat/FM2018-SAD-Forets-paysannes-contribution-a- Climat-3

4.3.4. Travail d'étudiants et rapports de stage

1. André-Alphonse, T. Evaluation des services écosystémiques dans les espaces arborés des paysages ruraux du Sud-Ouest de la France. Rapport de stage de M2. 35 pages.
2. Projet tutoré avec 4 étudiants du Master « Ecosystèmes et Anthropisation » de l'ENSAT. Inventaire par photo-interprétation des espaces arborés dans la zone agricole du LTSER « Vallées et Coteaux de Gascogne ». Oct.-Dec. 2017.

5. Discussion et perspectives

5.1. Principaux enseignements du projet ACTAFORSE

Quatre principaux enseignements découlent du projet ACTAFORSE :

- **Les forêts rurales, sources de services pour les agriculteurs** : nos enquêtes auprès d'agriculteurs aux profils différents ont montré que, pour eux, les forêts rurales étaient une source importante de services variés. Les agriculteurs de la région étudiée utilisent encore beaucoup les forêts rurales pour se chauffer ou comme source de revenus complémentaires par l'exploitation et la vente de bois de chauffe et de bois d'œuvre ; ce qui montre l'importance de ces forêts pour l'économie des exploitations agricoles et des familles. Pour nombre d'entre eux qui ont constaté les problèmes d'érosion suite à des arrachages trop intenses de haies, les forêts rurales offrent aussi une variété de services de régulation à l'agriculture qu'il est nécessaire de conserver. Enfin, les services culturels, liés à l'esthétique paysagère notamment, sont tout aussi importants dans les discours des agriculteurs, et constituent autant de leviers à la promotion de l'arbre dans les campagnes.

- **Les forêts rurales, sources de disservices pour les agriculteurs** : dans le même temps, les forêts rurales posent de nombreuses contraintes aux agriculteurs. La principale est liée à la difficulté de faire cohabiter l'arbre et les cultures dans un système agricole reposant sur la mécanisation des travaux et sur la recherche d'économies d'échelle par agrandissement des parcelles et des exploitations. Les agriculteurs ont ainsi du mal à accepter les surcoûts économiques et en charge de travail liés à la gestion de certains espaces arborés, notamment les linéaires d'arbres en bordure de parcelles. Tandis que certains acceptent ces contraintes et pertes économiques, la majorité des agriculteurs rencontrés préfèrent encore enlever les espaces arborés les plus problématiques, ce qui dépend pour beaucoup de leur emplacement et des modes d'utilisation du sol.
- **Des services et disservices conditionnés par les pratiques et les institutions** : la méthode des modèles mentaux nous a permis de mieux comprendre les liens entre SE, DSE, pratiques et institutions. Ainsi, nos enquêtes indiquent que certains services sont peu valorisés à l'heure actuelle, alors que cette valorisation pourrait être un levier considérable de promotion des forêts rurales. Par exemple, l'exploitation du bois d'œuvre des bois paysans est difficilement rentable, voire même faisable, du fait d'un manque d'adaptation de la filière bois à ce genre de petits massifs forestiers dispersés. A l'inverse, les contraintes imposées par la PAC, et notamment l'incohérence entre les piliers I et II, renforcent certains disservices pour les agriculteurs. Ces derniers, plutôt que de maintenir davantage d'arbres comme ils le sont incités par la PAC, préfèrent ainsi en enlever par peur de perdre des subventions et d'être encore plus contraints dans le futur. Ces effets pervers semblent être à l'origine d'une certaine part de l'érosion des forêts rurales.
- **Un potentiel difficile à évaluer** : avec une focale sur trois services clés, nos inventaires indiquent que les forêts rurales ont un potentiel considérable pour fournir divers services dans les paysages agricoles. Néanmoins, ce potentiel reste méconnu car la diversité des types d'espaces arborés soulève de nombreux enjeux méthodologiques pour évaluer ces services. Les ripisylves et autres formations linéaires sont particulièrement prometteuses, tandis que les bosquets (dont certains sont le symptôme de l'abandon des terres les moins propices à l'agriculture) offrent un potentiel plus limité.

Finalement, le projet ACTAFORSE a permis de montrer que, dans les coteaux de Gascogne, le maintien de la forêt rurale est fortement conditionné par (i) l'évolution des pratiques agricoles, (ii) les capacités de valorisation des services « forestiers » dans un paysage tourné vers l'agriculture, et (iii) la capacité des politiques publiques à atténuer ou compenser les disservices associés. Si le premier point requiert sans doute une refonte systémique du modèle agricole dominant à l'heure actuelle, représentant un objectif de long terme, les deux autres peuvent donner lieu à une réflexion plus spécifique (à l'échelle des territoires), avec des retombées potentielles à plus court terme.

5.2. Limites et perspectives de recherche

Nous pouvons finalement tirer deux limites ainsi que deux perspectives de recherche à la suite du projet ACTAFORSE.

La première limite de ce projet a été sa propension à travailler sur les représentations des agriculteurs, en prêtant peu d'attention aux autres acteurs du territoire. Bien que des entretiens aient été conduits auprès d'acteurs de la filière bois ou d'acteurs impliqués dans la gestion de l'environnement (e.g. syndicat de rivière en particulier), il aurait été utile de recueillir de manière plus systématique les représentations d'autres acteurs pour mettre en perspective de manière plus approfondie nos résultats sur les représentations des agriculteurs.

La seconde limite porte sur l'approche biophysique qui s'est limitée à l'évaluation de trois services et d'aucun disservices. Si des contraintes logistiques et de calendrier ne nous ont pas permis de conduire une évaluation avec davantage de SE et DSE, il aurait été pertinent d'offrir une vision plus détaillé du potentiel de la forêt rurale en matière de SE et DSE. L'absence d'un telle évaluation ne nous a en outre pas permis d'aborder la question du décalage potentiel entre les perceptions des agriculteurs (i.e. valeur socio-culturelle des SE/DSE de la forêt rurale) et les mesures de terrain (i.e. valeur biophysique).

Pour aller plus loin, il serait opportun de conduire une telle évaluation multi-SE/DSE des forêts rurales, avec en particulier un suivi dans le temps. Non seulement, ce suivi permettrait de mieux suivre la dynamique d'arrachage/plantation des forêts rurales en lien avec des stimuli d'ordre socio-économiques ou politiques, mais également de caractériser la dynamique interne des SE/DSE au sein de la forêt rurale qui peut s'expliquer par une évolution des pratiques de gestion par exemple.

La seconde perspective de recherche porte sur l'approfondissement des questions soulevées par la façon dont les agriculteurs agissent et réagissent aux évolutions et prérogatives de la PAC. En effet, il semble que ce soit cette dernière qui soit la clé pour comprendre de nombreux comportements, ce qui est vrai pour les pratiques agricoles *stricto sensu*, mais qui semble l'être aussi pour les pratiques de gestion de la forêt rurale. Entre la formulation des directives PAC à l'échelle européenne, leur adaptation au niveau national, et leurs déclinaisons locales, il ressort de nos résultats que les acteurs locaux du milieu agricole (agriculteurs, conseillers, agents de l'Etat) interprètent ces directives d'une manière qui leur est propre, avec des conséquences substantielles sur leurs effets concrets. Si le projet ACTAFORSE a touché du doigt certains des effets indésirables de ce décalage entre directives, interprétations et effets mesurés, il serait opportun d'approfondir ces questions pour des politiques publiques plus efficaces.

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7. Annexes

Annexe 1

Blanco, J., Sourdril, A., Deconchat, M., Ladet, S., Andrieu, E., **2019**. Social drivers of rural forest dynamics: a multi-scale approach combining ethnography, geomatic and mental model analysis. *Landscape and Urban Planning* 188: 132–142. http://doi.org/10.1016/j.landurbplan.2018.02.005

Landscape and Urban Planning 188 (2019) 132–142

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

Research Paper

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

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ARTICLE INFO

Keywords:
Non-industrial private forest
Trees outside forests
Ecosystem services
Local ecological knowledge
Agroforestry landscape
Social representations

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.

1. Introduction

Trees are part of agricultural landscapes: almost half of the agricultural areas in the world have a tree cover of > 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

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https://doi.org/10.1016/j.landurbplan.2018.02.005
Received 16 August 2017; Received in revised form 9 January 2018; Accepted 13 February 2018
Available online 07 March 2018
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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 et al., 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 (Fig. 1). This hilly region (200–400 m 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 (Fig. 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 1184 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.), 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 (Fig. 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).

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, Durrieu, Labbe, Andreassian, & Tangara, 1999). According to the IGN classification, 4 types of rural forest components were distinguished: woodlands (area > 0.5 ha and width > 25 m), groves (area comprised

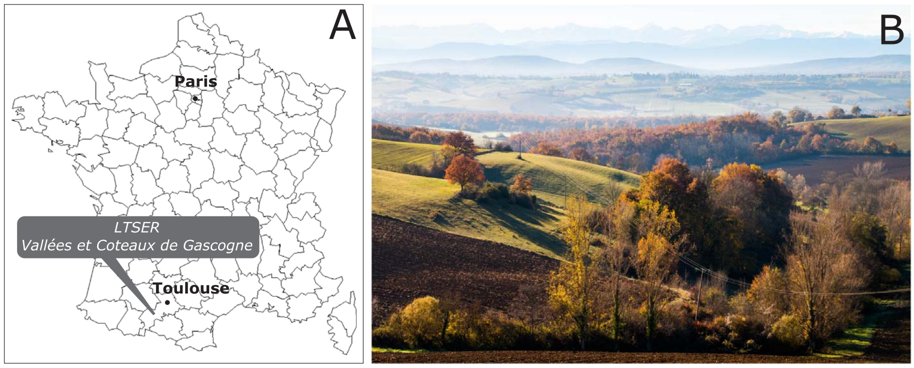

Fig. 1. (A) Location of the LTSER platform *Vallées et Coteaux de Gascogne* and (B) photograph illustrating the landscape topography and rural forest components.

between 0.05 and 0.5 ha, width > 20 m), hedgerows (width < 20 m) and scattered trees (area < 0.05 ha, crown diameter > 3 m). 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,

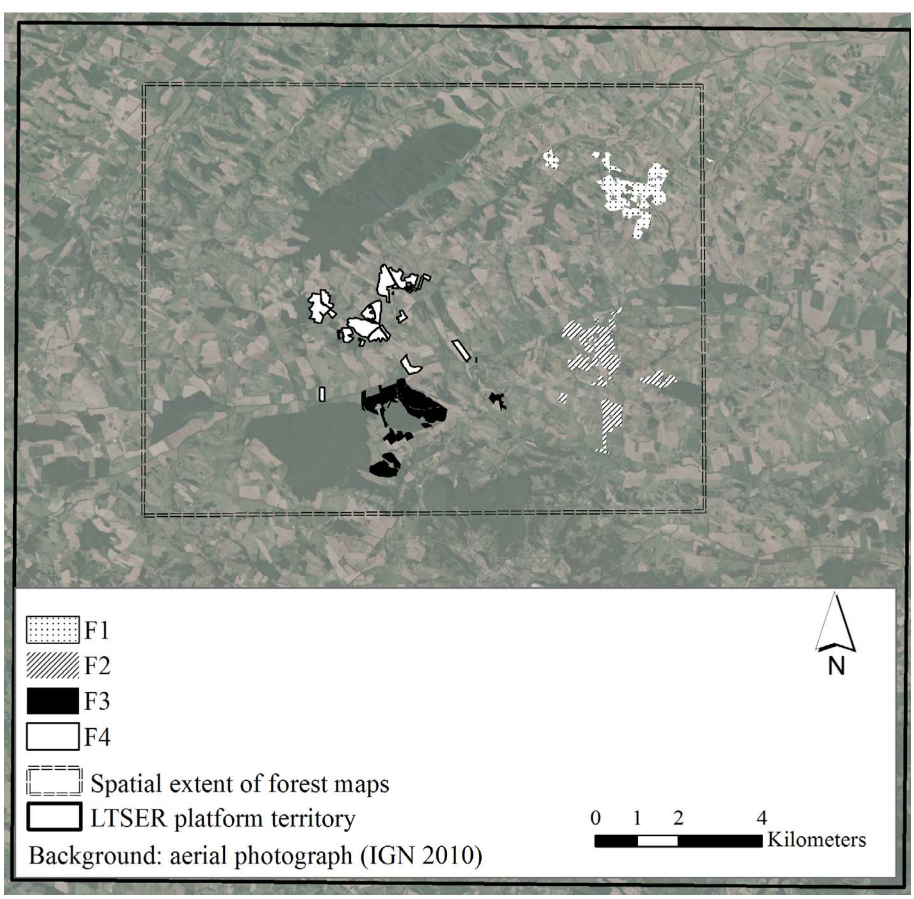

Fig. 2. Map of the four case-study farms and spatial coverage of the forest maps used for the GIS analysis inside the LTSER *Vallées et Coteaux de Gascogne*.

Fig. 2) was carried out to investigate (i) f arm-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 < 1% (Table 1). Between 1850 and 2010, woodland areas increased from 2692 to 3012 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 2692 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%, Fig. 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.

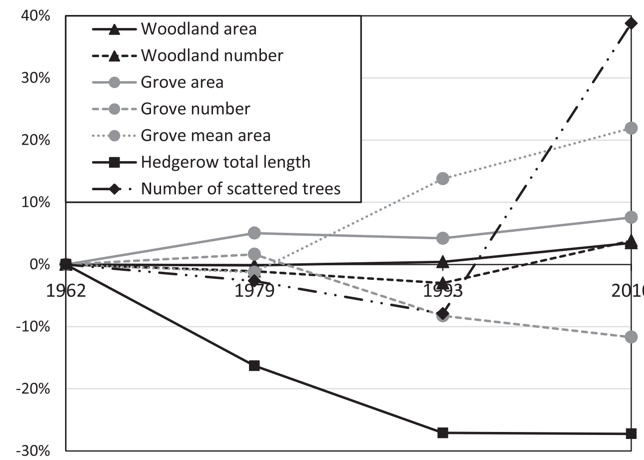

Fig. 3. Patterns of change in rural forest components (in %) with 1962 as the baseline. Woodland dynamics are marked by black triangles, including woodland area (plain line) and number (dashed line). Grove dynamics are marked by grey circles, including grove area (plain line), number (dashed line) and 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.

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%) (Fig. 3).

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 Fig. 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 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)	2911 (366)	2907 (362)	2923 (355)	3012 (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	6719	6540	6186	9324

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 (Fig. 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).*

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%

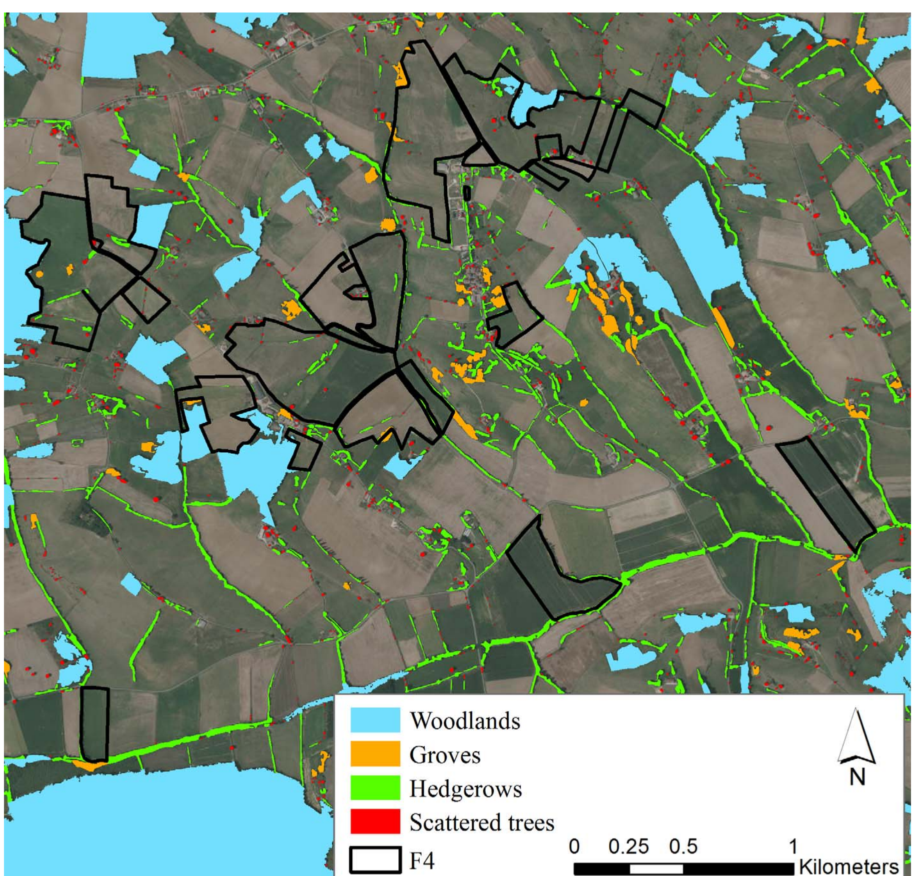

Fig. 4. Digitalization output of rural forest components around F4 farm, with a differentiation between woodlands, groves, hedgerows and scattered trees.

were turned into hedgerows, groves or woodlands. The total number of scattered trees decreased by -7.9% from 1962 to 1993 (Fig. 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%, Fig. 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, Fig. 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 (Fig. 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 (Fig. 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 (Fig. 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, Fig. 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 (Table 3). However, only two farmers reported groves and the grove-related ES were not specific to groves (they were also woodland-related, Fig. 5).

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).

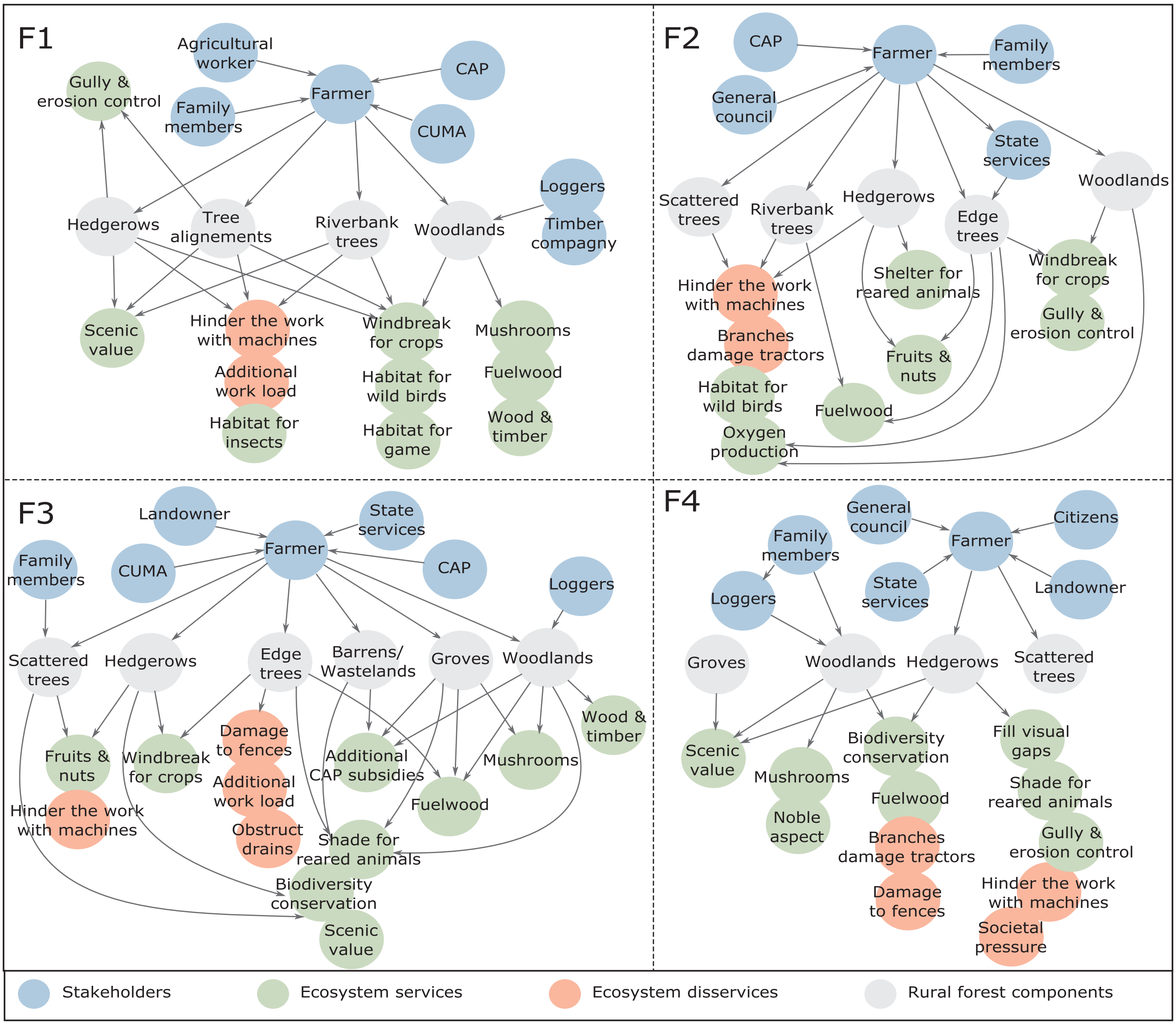

Fig. 5. Individual mental models of F1, F2, F3 and F4 farmers regarding the management of rural forest components (grey circles) by stakeholders (blue circles) and associated ecosystem services (green circles) and disservices (pink circles). Arrows symbolize identified links between different stakeholders, between stakeholders and rural forest components, or between rural forest components and ecosystem services and disservices. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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).

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 m 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 (Fig. 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).

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 (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, Fig. 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 Fig. 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 (Fig. 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 (Fig. 3).

Interviews confirmed a widespread result in the literature, that hedgerow management is influenced by land use (Baudry, Jouin, & Thenail, 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 (Fig. 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 (Fig. 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, ongoing 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.

Acknowledgements

This work was supported by grants from the 'Fondation de France'. We would also like to thank the farmers and inhabitants of the Canton of Aurignac for their willingness to participate to our research since 2003. We are also grateful to Dr. Emily S. Huff and Mr. Paul Catanzaro for their review of our earlier draft, and to Michael Paul for the language editing.

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Annexe 2

Teixeira, F. Z., Bachi, L., Blanco, J., Zimmermann, I., Welle, I., Carvalho-Ribeiro, S. M., **2019**. Perceived ecosystem services (ES) and ecosystem disservices (EDS) from trees: insights from three case studies in Brazil and France. Landscape Ecology. https://doi.org/10.1007/s10980-019-00778-y

Landscape Ecol
https://doi.org/10.1007/s10980-019-00778-y

RESEARCH ARTICLE

Perceived ecosystem services (ES) and ecosystem disservices (EDS) from trees: insights from three case studies in Brazil and France

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Received: 31 March 2018 / Accepted: 28 January 2019

Abstract
Context The landscape approach and the ecosystem services (ES) framework have been widely used to investigate human-nature relationships and orient landscape planning and management. However, ecosystem disservices (EDS) and their influence on how people interact with ecosystems have received less attention.
Objective We aimed at assessing people's preferences and perceptions of forest ES and EDS in three contrasted case studies. In the meantime, it aims at discussing the potential of considering both ES and EDS in landscape preference and sociocultural valuation studies.
Methods Interviews with stakeholders were conducted in an agroforestry landscape (France), in the Atlantic Forest and in the Pampa grasslands (Brazil). Identified ES and EDS were classified into a common typology and analyzed through discourse analysis and quantitative methods to assess the variability in ES/EDS perceptions among respondents and among forest types.
Results Respondents cited 19 ES classes and 11 EDS classes, with strong variability among case studies. Contrasted perceptions and preferences among respondents were revealed. In the agroforestry landscape, EDS were particularly emphasized by people

Fernanda Zimmermann Teixeira, Laura Bachi and Julien Blanco shared authorship.

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s10980-019-00778-y) contains supplementary material, which is available to authorized users.

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and contributed to the variability in people's perceptions. In the Atlantic forest landscape, forested areas tended to contrast based on cultural ecosystem services. In the Pampa case study, EDS were particularly salient in people's preferences concerning exotic forest plantations.

Conclusions This study suggests that different types of forested areas produce specific ES/EDS, suggesting their complementarity at the landscape scale. The combination of ES and EDS therefore offers a promising research avenue for more consistent ES sociocultural valuations and for improving management recommendations.

Keywords Sociocultural valuation · Preferences · Perceptions · Place-based research · Forest ecosystems · Landscape values

Introduction

Despite the widespread call for science to engage with society in order to reverse the ongoing ecological crisis, comprehensive approaches are still lacking to address this multifaceted challenge (Agrawal and Ostrom 2006). Landscape approaches (Arts et al. 2017) and the Ecosystem Services (ES) framework have been widely used in both research and policy making, and showed to be promising to improve the science-policy interface and tackle environmental challenges (Wood et al. 2018). Considerable resources have effectively been devoted to assess ES and landscapes at different scales of governance for better targeting land use policy and steering away from unfavorable trends of land use change (Willemen et al. 2010, 2012). On the one hand, the expansion of areas of agriculture and silviculture at the expense of native forest areas have been highlighted as one of the main causes of biodiversity erosion and ES depletion in a vast number of biomes worldwide (Green et al. 2005; Lapola et al. 2014). On the other hand, the intensification of land use in the most productive agricultural areas has led to farmland abandonment and forest regeneration in less productive areas (van der Zanden et al. 2018). As trees and forests provide multiple ES to human societies, this recovering may contribute to restoring the material and non-material benefits provided by landscapes (Torralba et al. 2016). Yet, for some local stakeholders, forest encroachment can be perceived as a negative outcome associated with a decline in agricultural activities and rural exodus (van der Zanden et al. 2018), and with landscape closure. Similarly, the increase of forest areas for silvicultural exploitation has drawn particular attention. Therefore, there is a context-dependent mismatch between ecological processes and the associated ES supply, and the way people perceive and use the processes, i.e. ES demand (e.g. Baró et al. 2015). As a consequence, it is today critical to better assess and map ES demand in order to better inform on stakeholders' preferences, perceptions and views toward environmental management (Wolff et al. 2015).

Studies following "the landscape approach" have actively focused on people's perceptions and preferences for forested landscapes (Carvalho-Ribeiro and Lovett 2011; Carvalho-Ribeiro et al. 2016). Sheppard and Meitner (2005, p. 7) define preferences for forests as "the degree to which a person or group prefers a situation or feature over other situations or features" and they also argue that these may vary according to whether scenic beauty (attractiveness) or management strategy (for either food/fiber production or biodiversity conservation) is under consideration (functional relationship) (Carvalho-Ribeiro and Lovett 2011). Perceptions, on the other hand, are defined by Antrop (2000, p. 19) as "complex learning processes, analyses the observation immediately and interactively and links the results with our knowledge and past experience". If perceptions are known to be more intangible and difficult to grasp than preferences (Carvalho-Ribeiro et al. 2016), sociocultural valuation of ES aims at assessing the importance people assign to ES (Scholte et al. 2015) and allows an assessment of both ES and EDS cognitive values, at the crossroad between preferences and perceptions.

ES and landscape preferences studies have shown that people have a multidimensional relationship with trees and forests. People value forests for their provisioning ES such as timber or firewood, for their regulating ES such as flood regulation, and for their cultural ES such as recreation. Yet, because people do not value equally these different aspects, they have contrasted preferences. For example, one picking up berries will prefer small shrub forests while a lumberjack will value forests managed for timber; one looking for scenic beauty may not be aware of the issues involved into ecological management

(Carvalho-Ribeiro and Lovett 2011). Research on landscape preferences and perceptions generally distinguishes the direct managers of landscapes (e.g. farmers, foresters, etc.) from people with no direct role on landscape management (Ovaskainen and Kniivila 2005; Carvalho-Ribeiro and Lovett 2011; Carvalho-Ribeiro et al. 2013). These two broad groups have contrasted landscape preferences (Martín-López et al. 2012; Iniesta-Arandia et al. 2014; Garrido et al. 2017), which has important implications for landscape planning and management (Almeida et al. 2016; Ramos et al. 2016).

Besides differences between people in ES preferences, research has highlighted that people sometimes perceive ecosystem disservices (EDS) related to trees and forests (Agbenyega et al. 2009; Blanco et al. 2018). EDS are defined as the ecosystem generated functions, processes and attributes that result in perceived or actual negative impacts on human wellbeing (Shackleton et al. 2016). They are generated by three different processes. First, an ecosystem function or attribute may impact human wellbeing directly. Mangroves, for example, might be associated to source of malaria outbreaks (Friess 2016). Second, an EDS may cause a diminished flow of ES. For example, crop raiding by mammals living in forests is an EDS resulting in crop production depletion (Ango et al. 2016). Third, an EDS may cause the loss of a supporting or regulating ES (Shackleton et al. 2016), such as forest wildfires (Ninan and Kontoleon 2016). Thus, forests provide simultaneously ES and EDS. However, most research efforts to date have focused on ES (Sell et al. 2007; Farley 2012; Lambin et al. 2014) and, despite the emerging attention on EDS, perceived negative impacts of ecosystems on human wellbeing remains overlooked.

In this paper, we report results from three case studies where ES/EDS preferences regarding trees and forests were assessed using a common ES/EDS framework. Using both "the landscape" and the ES approaches, we explored how different stakeholders (farmers, tourists, local residents) perceive ES and EDS from trees and forests, as well as how different types of forests are perceived. The three case studies were selected to show contrasted contexts and challenges for landscape management and, thus, to illustrate the complementary of the ES and EDS concepts for assessing the sociocultural value of forested areas in different socioecological contexts. Case studies were analyzed separately, as they use different approaches and methods (Simensen et al. 2018). All three case studies were further assessed using a common ES/EDS framework to highlight how landscape preferences may help to understand land use change and eventually reverse unsustainable land use trends. Finally, we discuss the strengths and limitations of the ES/EDS concepts to unravel landscape preferences and perceptions, and we identify key research perspectives.

Methods

Study areas

Agroforestry case study

The first case study is a temperate agricultural landscape, located in southwestern France (43°13′02.63″; 0°52′53.76″) in the Canton of Aurignac, about 80 km south-west of the city of Toulouse, and is part of the Long-Term Socio-Ecological Research (LTSER) platform *Vallées et Coteaux de Gascogne* (Fig. 1). This hilly agricultural landscape is part of the Pyrenees mountains piedmont and is dominated by mixed farming combining crop cultivation (maize and wheat are the dominant crops), and livestock raising (mostly cows for meat and milk production) on meadows and grasslands. Trees are omnipresent in this landscape, especially in the form of hedgerows, small forest patches and scattered trees (Fig. 1). Their management is mostly undertaken by farmers and is very dependent on the timing and type of agricultural activities. Yet, while trees and forests were used as a source of multiple forest resources by farmers, a decline of these traditional uses has been occurring as a result of the modernization of rural livelihoods, which has impacted management practices (Sourdril et al. 2012). Furthermore, their dynamics over the last decades—characterized by an overall decline of hedgerows but a stability of small forest patches—were shown to be ultimately linked to changes in the agricultural systems (i.e. the industrialization of agriculture) and in the rural society (i.e. rural exodus and the decline in the number of active farmers, Blanco et al. 2018). Thus, the main challenge in this case study was to understand how local farmers perceive and manage trees and forests so as to

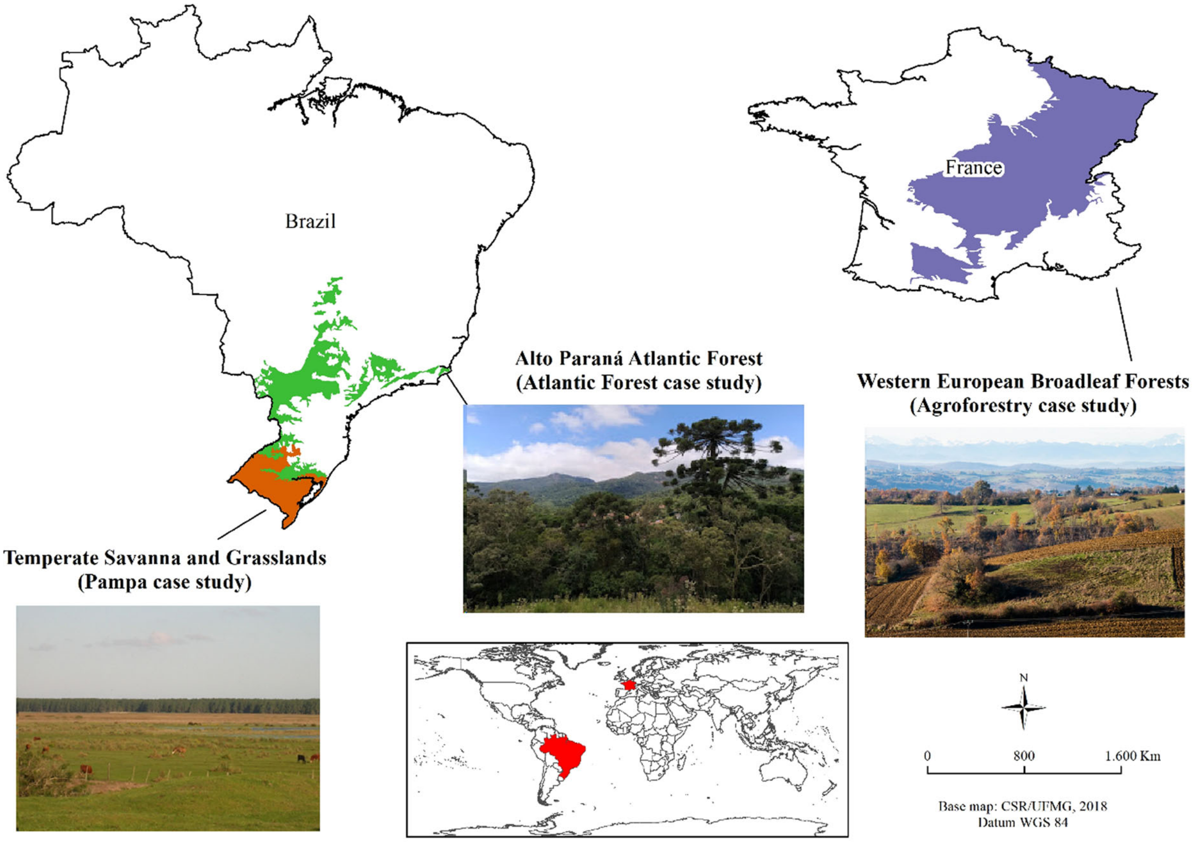

Fig. 1 Map of the study areas for the three case studies showing the ecoregions for the three areas

eventually reconcile forest conservation with agriculture.

Atlantic case study

The second case study was conducted in the Alto Paraná Atlantic Forest ecoregion (Fig. 1) which is part of the Atlantic Forest biome, one of the most threatened Brazilian biomes and a biodiversity hotspot (Bellard et al. 2014). In southeastern Brazil, the Atlantic Forest in the *Serra da Mantiqueira,* a mountain range and ecological reserve of the Atlantic Forest, has predominant High Mountainous Forest, Dense Ombrophilous Forest and Araucaria Forest (*Araucaria angustifolia*) (Siqueira 2012). These forested areas located in the high altitudes of the *Serra da Mantiqueira* constitute a touristic hotspot of the Monte Verde district, especially in winter. Thus, the main challenge in this case study was to understand how different stakeholders (i.e. tourists, local residents, and tourism entrepreneurs) perceive trees and forests and their associated ES and EDS.

Pampa case study

The third case study was developed in the Pampa biome in Southern Brazil, one of the most species-rich grasslands in the world (Overbeck et al. 2007), in the ecoregion of Temperate Savannas and Grasslands (Fig. 1) (Olson and Dinerstein 2002). The expansion of agriculture, particularly soybean and rice plantations, is the main threat to the conservation of grasslands in this region, and it causes substantial land use changes. Furthermore, afforestation mainly with pines and eucalyptus tree plantation for commercial purposes is currently causing major changes in this region covering around 2 million ha (Overbeck et al. 2007), with further conversion of large areas of grassland into planted commercial forests over the next few years. Thus, the main challenge in this case study was to understand how local residents in rural areas perceive the ongoing landscape changes and, in particular, the expansion of eucalyptus plantations, and how they relate these changes to ES and/or EDS.

Data collection

Agroforestry case study

In-depth interviews were conducted to assess farmers' perceptions of ES and EDS associated with trees and forests. A total of 26 farmers were investigated in a preliminary phase in order to design the interview protocol. This face-to-face interview protocol was fully applied to 18 farmers between January and March 2017. For each interview, farmers were firstly asked to describe their management practices regarding trees and forests in their farms, and to explain their motivations. In particular, they were asked about (i) what types of forested areas they had on their farms, (ii) the ecosystem services (i.e. the advantages and benefits) they got from these forested areas, and (iii) the ecosystem disservices (i.e. the drawbacks and constraints) they suffered from them. Secondly, farmers were asked to provide a synthesis of the most important ES and EDS to them, and to associate these ES and EDS to above-mentioned forested areas (for further details see Supplementary Material S1 and Blanco et al. 2018). It resulted, for each farmer, in a mental model linking, in particular, forested areas with their ES/EDS as perceived by the informant.

Atlantic forest case study

In order to access landscape users' preferences in the Monte Verde district, 175 structured interviews using a photo-questionnaire were conducted with residents (75) and tourists (100) between November 2016 and July 2017 (Carvalho-Ribeiro et al. 2013; Schirpke et al. 2016). The questionnaire was divided into two blocks of questions (for further details see Supplementary Material S2). In the first one, interviewees were prompt to relate land cover patterns to cultural ES in the touristic landscape, focusing on the places they visited (for tourists) or on the places they use in their daily life (for local stakeholders). They were asked to answer to the questions: "Is there any place in Monte Verde that you do not like? Why?" The second block of questions aimed at having a deeper understanding of people's preferences by asking questions about their preferences related to forest land covers and a sequence of photographs of the spatial patterns of land cover from the *Serra da Mantiqueira* in the Alto Paraná Atlantic Forest ecoregion.

Pampa case study

In this case study, local residents living near eucalyptus plantations were interviewed using semi-structured questionnaires to investigate their preferences about the presence of eucalyptus plantations. These surveys were part of the environmental licensing process of eucalyptus plantations at the state level, including monitoring the socioeconomic impacts of silviculture. We investigated the direct and indirect impacts of afforestation in the economic dynamic of the municipalities and the preferences of the communities living around areas with silviculture in relation to landscape changes, environmental impacts, and actions of the company that owns the silviculture areas. Between 2010 and 2017, semi-structured surveys were applied to 1444 people that lived near eucalyptus afforestation areas in 29 municipalities in Rio Grande do Sul state. Municipalities with large stands of eucalyptus plantations were selected for the surveys and interviews were carried out close to when eucalyptus stands were managed (planting and cutting) in each municipality. The questionnaires had about 50 questions focusing on the perceived environmental and socioeconomic alterations due to the presence of eucalyptus plantations. Each survey lasted between 30 min and 1h15 min. This manuscript explores the results obtained from these surveys in relation to one of those 50 questions: "Were there landscape alterations with the presence of eucalyptus plantations? If yes, how?" (for further details see Supplementary Material S3).

Data analysis

Classification of perceived ES and EDS

A common ES/EDS typology was used to classify the answers obtained in the three case studies that used different methods of landscape characterization (Simensen et al. 2018). For ES, we used the 5.1 version of the Common International Classification of Ecosystem Services (CICES, Haines-Young and Potschin 2018), that accounts for provisioning, regulating, and cultural ES. For EDS, there is no such an internationally accepted classification and existing proposals in the literature remain generally context-specific (e.g. for urban ecosystems, Lyytimäki 2014). We therefore created our own EDS typology on the basis of (i) the classification proposed by Shackleton et al. (2016) that distinguishes economical, health-related and cultural EDS, and (ii) the answers provided by informants. As a result, and consistently with the CICES, we obtained a hierarchical classification where each ES/EDS type (e.g. provision ES) contains several ES/EDS classes (e.g. plants used for nutrition), and where each ES/EDS class contains one to several ES/EDS (e.g. wild fruits, mushrooms, etc.).

Agroforestry case study

All interviews were recorded and transcribed to allow discourse analysis with NVivo 11 (QSR International Pty Ltd. 1999–2017). From interviews and mental models, we identified nine different types of forested areas that were relevant to farmers. For each forested area, we calculated the number of ES/EDS cited by farmers. We assumed that important ES/EDS to farmers would be those that are frequently cited, and we calculated the number of occurrences for each ES/EDS as a quantitative indicator of its importance to farmers. For example, firewood was cited by six farmers as an ES associated with hedgerows; the number of occurrences for the ES 'firewood' for hedgerows is therefore 6.

ES/EDS in Brazil: Atlantic Forest and Pampa case studies

In order to identify subgroups of landscape users in the Atlantic Forest and in the Pampa case studies, we performed a multiple correspondence analysis (MCA) for each one of these two Brazilian ecoregions. We used categorical data such as age class and educational level to identify subgroups of residents and tourists in the Atlantic Forest and Pampa case studies based on their profiles. The subgroups were numbered in order to assist data interpretation. Subsequently, we performed a correspondence analysis (CA) to associate the different subgroups' profiles from the Atlantic Forest and the Pampa case studies with ES/EDS and forest types mentioned by them. In the output, the regions of the two-dimensional map from the CA were named based on the preferences of the subgroups within each region. MCA and CA analyses were done using the packages *factoextra* and *FactoMineR* in R software (Nenadic and Greenacre 2007; R Core Team 2017).

For the Atlantic Forest case study, a content analysis on the open questions of the photo-questionnaire was conducted. We started by reading the answers from the photo-questionnaire to classify the EDS and identifying the forest types associated to ES/EDS classes for the different landscape user groups. Major forest types mentioned were: Araucaria forest (located at high altitudes in the Atlantic Forest biome), Atlantic forest with species such as *samambaia*, *manacá-da-serra* tree, and others. Other forest types mentioned were eucalyptus and pine tree plantations associated to silviculture. Then, the answers related with the preference for ES/EDS classes and forest types by the landscape user groups (e.g. local residents vs tourists) received a binary code (0 for the ES/EDS and forest types that were not preferred, and 1 for the ES/EDS and forest types that were preferred). The frequency of the answers for each user group (form the MCA) was used to create a contingency table for the correspondence analysis (CA) of the Atlantic Forest case study. The answers related to the preferences for ES/EDS from the Pampa case study also received binary codes and the sum for each subgroup was used to create a contingency table for correspondence analysis (CA).

Results

Overview of the ES/EDS cited by people in the three case studies

A total of 19 classes of ES (including five provisioning, eight regulating and six cultural services) and 11 classes of EDS (including five economic, two health and four cultural disservices) associated with trees and forests were identified in the three case studies (Table 1). In addition, people perceived economic benefits associated with forest conservation, in particular through tourism activities and employment opportunities. The number and nature of ES and EDS varied between the three case studies suggesting an influence of the local context on people's perceptions. In the Agroforestry case study, farmers cited 18

ES and 8 EDS classes, which illustrates the importance of forested areas in their livelihood as well as the competition between trees and agriculture. While regulating ES show synergies between agriculture and trees (e.g. trees regulate erosion), economic EDS also illustrate the perceptions of antagonisms (e.g. trees compete with crops). Beyond material contributions, trees were also important to several non-material aspects (e.g. cultural ES/EDS) which illustrates the cultural significance of forested areas in this region. In the Atlantic Forest case study, cultural ES were the most cited with five classes of cultural ES and only one class of provisioning ES and one class of regulating ES (Table 1). This result indicates the non-material

Table 1 Number of informants citing each class of service/disservice in the different case studies

Type	Classes of ES and EDS (CICES 5.1 Code, if available)	Agroforestry case study	Atlantic Forest case study	Pampa case study
Provision ES	Wild plants used as a source of energy (1.1.5.3)	16	–	–
	Wild plants used for nutrition (1.1.5.1)	15	–	–
	Fiber and other materials from wild plants (1.1.5.2)	5	86	–
	Wild animals used for nutrition (1.1.6.1)	4	–	–
	Biomass for agricultural use (1.3.1.1)	1	–	–
Regulation ES	Filtration by plants (2.1.1.2)	1	–	–
	Visual screening (2.1.2.3)	1	–	–
	Control of erosion rates (2.2.1.1)	12	–	–
	Water flow regulation (2.2.1.3)	2	–	–
	Wind protection (2.2.1.4)	11	–	–
	Maintaining nursery populations and habitats (2.2.2.3)	8	–	–
	Decomposition and fixing process and their effect on soil quality (2.2.4.1)	1	–	–
	Regulation of air temperature and humidity (2.2.6.2)	11	52	9
Cultural ES	Health, recuperation or enjoyment (3.1.1.1)	–	139	–
	Passive or observational interactions (3.1.1.2)	1	27	–
	Existence value (3.2.2.1)	7	132	13
	Option or bequest value (3.2.2.2)	2	–	–
	Resonant in terms of culture or heritage (3.1.2.3)	3	82	7
	Aesthetic experiences (3.1.2.4)	11	172	119
Other benefits	Economic benefits (tourism, work generation)	–	103	1
Economic EDS	Work charge	7	–	–
	Physical obstacle	12	–	267
	Impact on agricultural production	9	–	–
	Damages on equipment and infrastructures	10	19	–
	Legislative constraints	3	–	–
	Other economic costs	4	–	1
Health EDS	Safety issues caused by dead biomass production	3	–	–
	Dangerous animals	2	–	–
Cultural EDS	Damage on panoramic view	–	–	121
	Isolation	–	–	16
	Decrease in existence value	–	–	127

The ES classification is based on the CICES 5.1. The EDS classification is inspired by Shackleton et al. (2016) but adapted to this study relationship between forests and informants, consistently with the aesthetic and recreational dimension of this landscape. EDS were hardly ever mentioned in the Atlantic Forest case study, (the only EDS cited was that tree roots and leaves damage local infrastructure). Finally, in the Pampa case study, economic and cultural EDS were particularly salient in local residents' interviews (five classes of EDS were cited, Table 1). This suggests that eucalyptus planted forests are poorly appreciated by people that perceive them as a source of material and non-material EDS (Fig. 2a). Consistently with local residents' negative attitude towards planted forests, no provisioning ES was cited, which suggests a non-material negative perception of eucalyptus planted forests. Overall, in distinguishing material (i.e. provisioning and regulating ES, economic and health EDS) and non-material (i.e. cultural) ES/EDS (Fig. 2b), forested areas were mostly perceived as a source of (i) material ES/EDS in the Agroforestry case study, (ii) non-material ES in the Atlantic forest case study, and (iii) EDS in the Pampa case study.

Contrasted ES/EDS perceptions according to forested areas in the Agroforestry study case

In the Agroforestry case study, the 18 farmers (16 men and 2 women) were between 31 and 68 years old. Nine of them had a conventional mixed farming system (combining crop cultivation and animal raising), six of them had a conventional crop cultivation system, and three had an organic crop cultivation system. All farmers had forested areas on their farmland that were regrouped into nine different types on the basis of interviews. The number of occurrences of ES/EDS classes differed between the different types of forested areas (Table 2). Hedgerows and woods were perceived as the best sources of ES (74 and 73 occurrences, respectively). For example, hedgerows were appreciated for firewood and fruit production, for their role on erosion control and on wildlife conservation, and for their participation in the landscape scenic value. Woods were particularly cited as a source of timber, firewood and mushrooms, contributing to air quality and to a positive impact on ecosystems and landscape scenic value. Conversely, groves, tree alignments and heathlands showed the lowest occurrences of ES. In the meantime, farmers associated 8 EDS to forested areas, in particular with hedgerows, edge trees and isolated trees (Table 2). Most cited EDS were associated with the fact that those trees hinder farmers working with tractors and other mechanized tools, cause damages to these machines and on infrastructures (such as buildings and ditches) and thus represent extra labor due to management requirements to reduce these EDS. On the contrary, heathlands, groves and tree alignments were associated with less EDS, certainly because they have less spatial overlap with agricultural plots.

Finally, results showed that the different types of forested areas had a contrasting balance between perceived ES and EDS (Fig. 3). Some forested areas, especially hedgerows, had high scores for both ES and EDS, whereas other areas, especially tree alignments

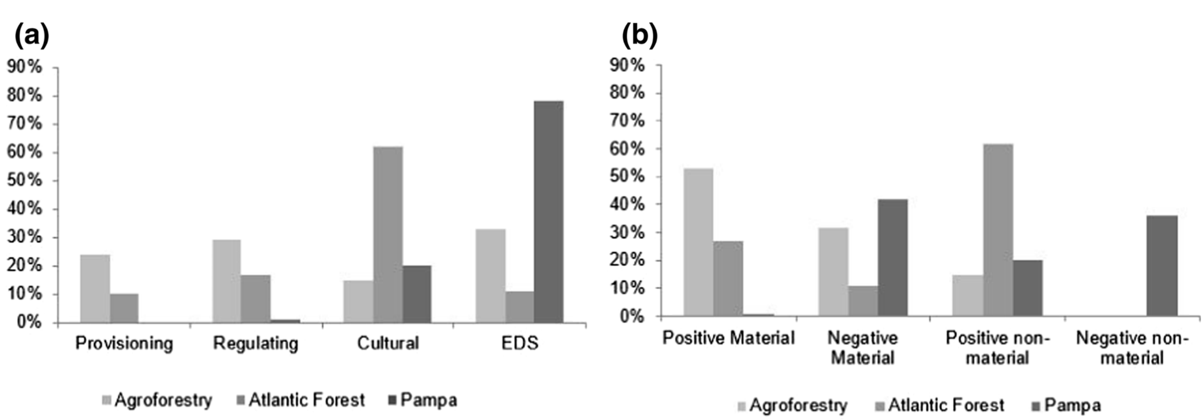

Fig. 2 Proportion of interviewees' responses for each type of: **a** ecosystem services (including provisioning, regulating, and cultural ES), and ecosystem disservices; and **b** contributions: positive material, negative material, positive non-material, and negative non-material

Table 2 Number of occurrences of each ES/EDS class during interviews with farmers according to the types of forested areas in the Agroforestry case study

Type	ES and EDS classes	Hedgerows	Woods	Isolated trees	Heathlands	Edge trees	Riverbank trees	Road trees	Groves	Tree alignments
Provision ES	Wild plants used as a source of energy	6	13	2	1	5	5	4	2	2
	Wild plants used for nutrition	7	12	6	2	1	1	2	4	–
	Fiber and other materials from wild plants	–	7	–	–	2	3	–	–	–
	Wild animals used for nutrition	1	1	–	1	–	1	–	1	–
	Biomass for agricultural use	–	–	–	1	–	–	–	–	–
	Total	14	33	8	5	8	10	6	7	2
Regulation ES	Filtration by plants	1	–	–	–	–	–	–	–	–
	Visual screening	1	–	–	–	–	–	–	–	–
	Control of erosion rate	9	3	–	–	3	3	1	–	2
	Water flow regulation	1	1	–	–	1	1	–	–	–
	Wind protection	8	5	–	2	3	1	–	1	1
	Maintaining nursery populations and habitats	10	4	2	2	3	3	1	1	2
	Decomposition and fixing process and their effect on soil quality	2	–	–	–	2	–	–	–	–
	Regulation of air temperature and humidity	7	7	7	2	5	5	4	1	1
	Total	39	20	9	6	17	13	6	3	6
Cultural ES	Passive or observational interactions	2	2	–	1	–	–	–	1	–
	Existence value	6	7	3	5	3	2	3	2	1
	Option or bequest value	3	3	1	2	1	2	1	3	–
	Resonant in terms of culture or heritage	1	1	2	–	1	–	–	–	–
	Aesthetic experiences	9	7	4	6	4	4	4	3	2

Table 2 continued

Type	ES and EDS classes	Hedgerows	Woods	Isolated trees	Heathlands	Edge trees	Riverbank trees	Road trees	Groves	Tree alignments
	Total	21	20	10	14	9	8	8	9	3
Total ES		74	73	27	25	34	31	20	19	11
Economic EDS	Work charge	5	2	1	1	4	3	1	1	2
	Physical obstacle	10	2	6	–	4	4	2	1	1
	Impact on agricultural production	11	4	4	4	5	3	4	2	1
	Damages on equipment and infrastructures	6	5	2	–	5	3	2	1	1
	Legislative constraints	3	2	2	1	2	2	–	1	–
	Other economic costs	3	1	1	2	1	–	–	–	–
Health EDS	Safety issues caused by dead biomass production	–	–	–	–	1	–	1	–	–
	Dangerous animals	–	–	1	–	1	–	–	–	–
Total EDS		38	16	17	8	23	15	10	6	5

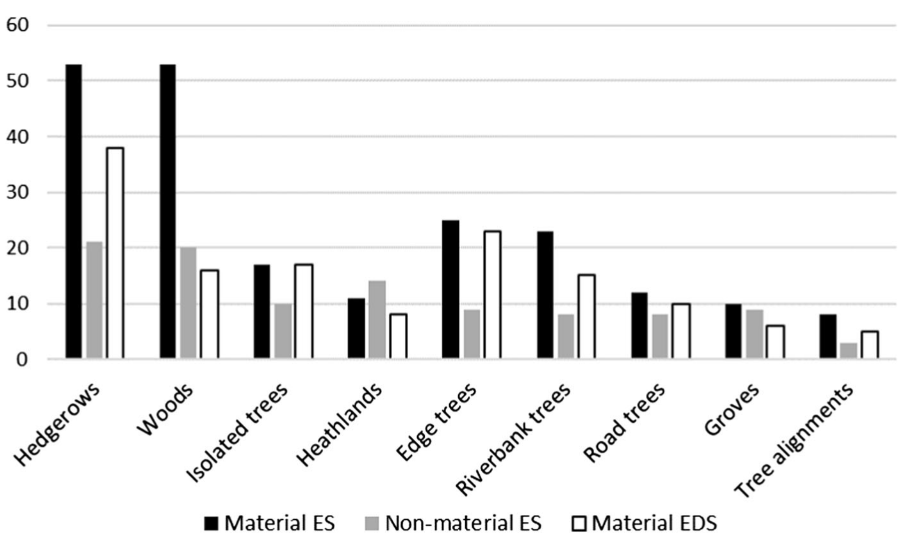

Fig. 3 Number of occurrences for material and non-material ES/EDS as cited by farmers according to the type of forested areas in the Agroforestry case study. Note that no non-material EDS were cited in this case study

and groves, had low scores. In addition, edge trees and riverbank trees had similar scores for ES, but edge trees provided more EDS than riverbank trees (Fig. 3). Finally, woods and isolated trees had similar EDS score, but woods provided much more ES than isolated trees.

Contrasted preferences between stakeholders in the Atlantic case study

In the Atlantic Forest case study, the 175 interviewees were between 18 and 81 years old. More than 50% of the tourists were visiting the region for the first time, whilst the residents were long-term residents (between 10 to 30 years in the area). Only 20% of the residents were farmers in conventional farming, with farm sizes ranging from 10 to 24 ha. The other 80% of residents had direct economic incomes from tourism, as owners of lodging, food and transport facilities or as attendants in restaurants and souvenir stores. Despite these differences, 98% of residents and tourists perceived the landscape scenic value, i.e. a cultural ES, as the most important ES. In particular, Araucaria forest was the most appreciated forest type for this ES. Both residents and tourists also perceived the damages to infrastructures as the main EDS. For 63% of residents, heritage was the second most cited ES, and was mainly associated with the Atlantic forest type, as symbol of place-based identity. A large majority of tourists (89%) cited existence value and health or enjoyment benefits as two important cultural ES. According to the interviews, these ES reinforced their motivations to visit the area in search of enjoyment, stress relief and personal growth. Yet, tourists also perceived provisioning ES (63% of them), in particular fiber. On the contrary, residents rather insisted on air quality regulation (69%). Overall, pine forest was the less appreciated forest type among residents and tourists, mentioned by less than 10% of informants.

The subgroups from the Atlantic Forest study case were plotted in a two-dimensional map using a correspondence analysis (CA) that explained 84.6% of the variability (Fig. 4). On the right side of the first dimension were youngest informants (from 18 to 30 years old) with high education level, named the "new generation". These subgroups particularly cited cultural ES such as heritage and observational value in association with Araucaria forest and eucalyptus plantation. They were also associated with economic benefits derived from touristic activities. The subgroups within the "new generation" quadrant contrasted with the ones within the "old faithful" quadrant, which was represented by elderly people (from 40 to 81 years old), who tended to rather value Atlantic forest and pine forest. The tourists' subgroups were present in two quadrants, i.e. "fun and rest enthusiast" and the "experience enthusiast" (Fig. 4, on the left side of the plot). The subgroups within the "fun and rest enthusiast" quadrant were characterized by graduated and post-graduated adults (from 30 to 40 years old). These subgroups are associated with cultural ES such as health or enjoyment, which also clusters with the Araucaria forest. The most cited EDS by these subgroups was infrastructure damage caused by the traffic of heavy trucks doing the transportation of eucalyptus on the roads used by local residents and tourists to access the district of Monte Verde, which can influence negatively the image of the destination. The subgroups within the "experience enthusiast" quadrant were characterized by young adults, adults and elders (from 20 to 70 years old) with high education. The short distance of these subgroups to existence value and aesthetics as major cultural ES reinforce the interest of tourists for scenic contemplation. Yet, they also cited fiber as a crucial provisioning ES, which appeared to be linked to the wood house raw material found in the tourist commerce center. Finally, all tourist subgroups cited heritage and observational values as two important cultural ES, which are closer in the graph and, therefore, can be related with Araucaria forests and eucalyptus plantations (Fig. 4).

Resident perceptions of exotic plantations in the Pampa case study

In the Pampa case study, most interviewees were over than 50 years old (average 53 ± 15 SD) and almost half of them had not concluded elementary school. Most of the interviewees owned small rural properties (46% of interviewees owned properties with less than 50 ha), while a small proportion was composed of workers from nearby properties (cattle raisers and farmers). From all interviewees, 823 respondents (57%) mentioned that they noticed landscape alterations and 690 (47.7%) associated these alterations to eucalyptus plantations. For those who mentioned landscape alterations, eucalyptus plantations were especially perceived as a physical obstacle (cited by 39%), associated with a decrease in existence value (19%) and of panoramic view (18%). On the other hand, part of the residents that mentioned landscape alterations considered that eucalyptus plantation positively contributed to landscape scenic value (17%), but very few informants cited existence value (2%)

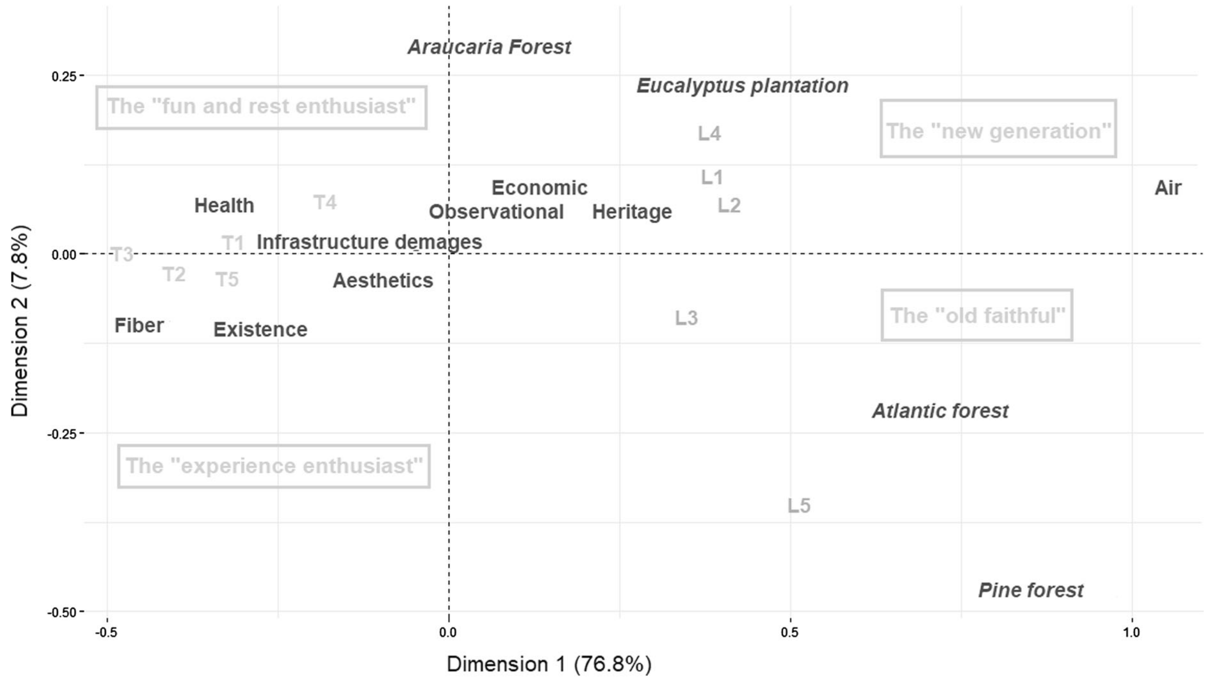

Fig. 4 Correspondence analysis plot showing the position of the subgroups of stakeholders (in dark grey, "L" for local residents; in light grey, "T" for tourists), ES/EDS (in bold) and forest types (in italic) from the Atlantic Forest case study. The names given to the quadrants are within gray boxes

and air quality regulation (1%). Thus, eucalyptus plantations were also receiving a positive appreciation.

A CA was used to plot subgroups of informants in a two-dimension map that explains 79.4% of the variability (Fig. 5). On the right side of the first axis, "Region I" shows the subgroups characterized by young adults and adults (from 18 to 30 years old) graduated from high school. These subgroups were associated with isolation as the main EDS, as well as with existence value as the main ES. The subgroups within "Region II" were represented by adults and elders (from 20 to 77 years old) graduated from high school. Part of the interviewees from this region has mentioned aesthetics as a cultural ES, while some have mentioned the decrease in existence value and in panoramic view as EDS. The proximity between these ES and EDS categories on the right side of the two-dimensional map suggests that they were mentioned by people with similar profiles from "Region II". On the left side of the map (Fig. 5), the subgroups within "Region III" are composed by young adults (from 18 to 20 years old) with high school and adults and elders (from 40 to 90 years old) with incomplete elementary school. They emphasized the physical obstacles created by eucalyptus plantations, such as blockage of cell-phone signal and the loss of heritage value. Furthermore, these subgroups cited economic benefits associated with eucalyptus plantations (creation of jobs, regional economic activity), which indicates the positive outcomes expected from plantations on young residents' employment opportunities. Yet, they also acknowledged that plantations are visual obstacles decreasing the panoramic view valued by them. Finally, the CA map showed that EDS were frequently cited, i.e. they are located in the center of the map (Fig. 5), and that only a minority of informants recognized eucalyptus plantations as a source of ES.

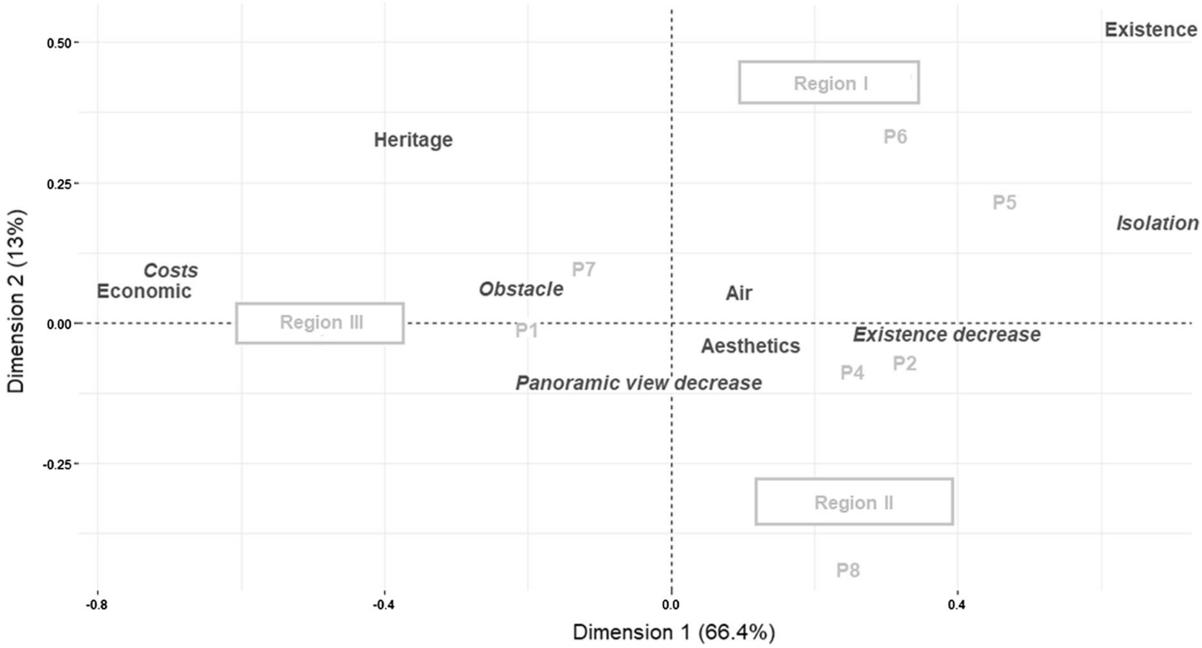

Fig. 5 Correspondence analysis plot showing the position of the subgroups of stakeholders (in grey, "P" for subgroups), ES (in bold) and EDS (in italic) from the Pampa case study. The subgroups resulted from the Multiple Correspondence Analysis based on education level and age of the interviewees. All ES and EDS refer to one forest type, the exotic eucalyptus plantation. We divided the graph in regions (within gray boxes) to better discuss the answers of the subgroups

Discussion

People's preferences and perceptions: lessons for local management

In combining three case studies in contrasted landscapes, this paper illustrated the interest of landscape preference studies to reveal local dynamics and provide site-specific recommendations for landscape management. In the Agroforestry case study, we found that farmers cited more ES than EDS, suggesting an overall positive attitude towards trees. This result echoes with other studies in Europe on farmers relationships with trees in wood-pastures in Sweden (Garrido et al. 2017), and on farmers attitudes towards agroforestry (García de Jalón et al. 2017). In regions where trees and forests are part of the history and identity of the place, they tend to be positively perceived by local stakeholders, including farmers. Yet, we also found that farmers perceive multiple EDS associated with forested areas, and value the different types of forested areas differently. In particular, some forested areas, such as hedgerows, were associated with high levels of both ES and EDS. Some other areas, such as woods, offered high levels of ES but low levels of EDS. Finally, other areas were linked with low amounts of both ES and EDS. Considering that in the Agroforestry case study region, hedgerows and isolated trees have declined over the last decades while woods have been relatively stable (Blanco et al. 2018), our results have two implications. First, the overall positive perception of farmers towards trees does not necessarily imply a positive attitude (i.e. a management in favor of the maintenance of trees), because farmers are also affected by EDS and by other economic, social and/or legal constraints (Tsonkova et al. 2018). Second, it seems that the more EDS perceived by farmers, the more farmers tend to remove forested areas, notwithstanding the level of ES. Indeed, while woods and hedgerows had similar values in terms of ES (Table 2), hedgerows were a more prominent source of EDS for farmers, which may partly explain their decline. Finally, our results in the Agroforestry case study have allowed to identify ES that are important to farmers. These ES could serve as incentives to incite farmers to replant hedgerows and other trees outside forests on their farmland. For example, as firewood is a well-known ES among farmers, helping them to better value this firewood may contribute to the promotion of trees on farmlands. Meanwhile, our study also allowed to identify the main EDS that prevent farmers from maintaining trees on their farms. Decision makers should better account for these EDS to design ad-hoc policies.

In the Atlantic Forest case study, we also found a positive vision of people regarding forested areas. Because of the touristic value of this landscape, people, and especially tourists, rather valued the non-material dimensions of forests. Yet, local residents and entrepreneurs also had high preferences for cultural ES, in addition to economic outcomes, and associated native forests with their identity and sense of belonging. This result evidences the consolidation of the cultural values of the Atlantic forest such as aesthetics (Krieger 2001), that in turn is associated to economic benefits from the forest related to tourism. Unfortunately, the ES framework from CICES has a limited classification to represent the advantages of ecosystems as cultural ES, that's why the economic benefit perceived by the local residents has to be in a separate type called "other benefits". Finally, this testifies that forests produce several ecosystem services that enable tourism development, create jobs and generate income for local people, characterizing a kind of value chain. Furthermore, stakeholders in this case study easily associated ES/EDS with specific types of forests (i.e. dense Atlantic forest, Araucaria forest), as well as their respective potential for tourism. Finally, we did not find any disjuncture between aesthetics and ecology in this case, as raised by Gobster et al. (2007). Indeed, all forest types were associated with both regulating and cultural ES, suggesting a convergence between societal demands and the maintenance of important ES.

In the Pampa case study, we highlighted the importance of EDS to local residents associated with eucalyptus plantations. Furthermore, our results illustrate the low social acceptancy of planted forests and exotic species by people in this region, where native grasslands historically occupied the landscape. Former studies have shown that the perceptions of forests by local people depend on the local forest history: in areas where forests were historically absent, people tend to poorly value forests (Elands et al. 2004; Ní Dhubháin et al. 2009). Henderson et al. (2016) also identified that forest plantations are significantly less desirable than other landscape types by landowners in the Pampa region. This preference is related to the subjective dimensions of the landscape recognized by local residents in a region where the landscape was historically composed mostly by grasslands, resulting in a cultural dimension related to people's cultural identity. An attempt to counteract the EDS associated with planted exotic forests and to consider the subjective meanings of the landscape in land management could be to regulate their expansion through establishing limits in stand size and environmental zonation per municipality. This is currently being done at the state level in Pampa grasslands in southern Brazil through the Environmental Zoning for Silvicultural Activity (FEPAM 2010; Gautreau and Vélez 2011), although not free of political pressure.

Capturing people's perceptions of ecosystem services and disservices by bridging ES and the landscape approaches: lessons for research

By bridging across "the landscape" and ES approaches this paper was able to identify commonalities between the three case studies, which could have several implications for future studies on landscape preferences and people's perceptions. Firstly, we showed that stakeholders have different preferences in relation to forests because of contrasted individual and collective visions and objectives, but also because of site-specific differences. On the one hand, our results suggest that local stakeholders, such as farmers and local residents, tend to have a more complex and holistic vision of forests, whereas external stakeholders, such as tourists, tend to perceive only a few aspects of forests' contributions. For example, the Agroforestry case study illustrates how forests could be important for local people (Sourdril et al. 2012), but at the same time, a source of problems and issues. On the other hand, we saw that local perceptions of forests vary among case studies according to the history and livelihoods (Da Ponte et al. 2017). Thus, while sociocultural valuation of ES allowed gaining a better understanding of how people value ES, exploring the underlying factors of this valuation represents a challenge for future research.

Secondly, in our three case studies, people were concerned with different types of EDS associated with forests. The concept of EDS has been applied in urban forest studies (e.g. Lyytimäki et al. 2008; Conway and

Yip 2016) to help balance between the positive and negative contributions of green areas in cities. However, less research has investigated EDS associated with forests in rural landscapes (but see Ango et al. 2014; Hansen 2014). As our results suggest, this lower interest in EDS than in ES from researchers is detrimental to (i) the ES assessments undertaken in the purpose of helping decision makers and (ii) our understanding of the links between human and ecological systems. As suggested by Schaubroeck (2017), studying both ES and EDS would enable a more balanced assessment of nature's contributions to human well-being. As illustrated by our case studies, people consider that the same ecosystem attribute can simultaneously be a source of services and disservices. Furthermore, as shown by the Agroforestry and Pampa case studies, enhancing the ES supply could also enhance the EDS supply. In planting eucalyptus, provisioning ES such as fiber may effectively increase, while discomforts are locally generated (issues with cell-phone signal, decrease in scenic value). Thus, if decision makers are only advised on the basis of ES assessments and through recommendations focused on ES maximization only, EDS could also increase unexpectedly and induce negative feedbacks. Assessing ES/EDS bundles represents a promising way to counteract this issue (Campagne et al. 2018). Another important contribution of this work is to highlight that EDS are part of both people's preferences and perceptions. Thus, if we aim at better understanding people's views and behavior regarding ecosystems, EDS should be more systematically introduced in sociocultural valuation surveys. This integration may help to better analyze the link between people's perceptions, their actions, and their influence on ecosystems. For example, the Agroforestry case study illustrated the potential influence of how people perceive EDS on their action on the landscape; despite their association with several ES, hedgerows declined because they were a source of EDS in the new agricultural settings. Woods that provided also ES were not an important source of EDS, which may partly explain their maintenance (Blanco et al. 2018). The combination of ES and EDS therefore appear as a promising enterprise for enlarging our understanding of the socioecological processes that occur in anthropogenic landscapes worldwide. For this assessment to be comprehensive, the bridge across the diversity of methods of "the landscape approach" (Simensen et al. 2018) and of ES approach are of utmost value.

Limits and perspectives of this research

Assessing the sociocultural value of ecosystem services and disservices is not an obvious enterprise and several methods have been used in the literature (Scholte et al. 2015). Firstly, because of the different methods presented in this paper, comparisons among case studies were not relevant, even if we have been able to draw common lessons. There is no perfect method and it is important to be aware of their limitations and strengths according to the research purpose (Simensen et al. 2018). In-depth interviews (the method used in the Agroforestry case study) are a recognized method to investigate people's relationships with nature and to enter in their multidimensionality and complexity (Oreszczyn 2000). They are especially important in landscape research to analyze how stakeholders deal with a complex world. Our results therefore showed that this method was able to capture a greater diversity of ES and EDS. However, in-depth interviews require long investigation periods and long transcription and analysis phases at the expense of the number of interviewees, which prevents conducting large-scale analyses and limits statistical treatment. In contrast, questionnaires (used in the Atlantic Forest and Pampa case studies) allowed working with large samples and the identification of global trends. As they provide easy to catch quantitative data, questionnaires may also have a greater impact on decision makers. Yet, although they allow testing a given hypothesis, questionnaires fail to deal with "outside of the box" phenomena and to tackle complex situations. Therefore, when working with questionnaires (including photo-questionnaires) we are more likely to be assessing landscape preferences rather than capturing more complex perceptions. In order to have the best of the two worlds, it is therefore common in the literature to combine a preliminary research phase based on in-depth interviews with key informants, and a second phase based on questionnaires submitted to a larger sample of people (e.g. Limburg et al. 2010). This could be a perspective of research for the French case study.

Secondly, one main limitation of this study comes from the lack of consisting EDS classification. Over the last decades, research on ES had advanced significantly, including internationally accepted classifications of ES—such as the European classification (CICES) that we used in this study (Haines-Young and Potschin 2018) and the US classification (FEGS-ES, Landers and Nahlik 2013). For this research, we had no problem in using this classification, designed thanks to a large amount of research and expertise in contrasted socioecological systems and contexts, to design our surveys and to analyze interviews. On the contrary, as no such internationally accepted classification of EDS exists, it was more challenging to find a satisfactory way to classify EDS, in particular given the specificity of each case study. We think that research on EDS should be reinforced in order to design a relevant classification that could be of great help to researchers and managers.

Conclusions

This study explored stakeholders' perceptions of the ES and EDS associated with trees in three case studies with contrasted management challenges. While research has been mainly focusing on the positive contributions of forests to human wellbeing (i.e. forest-related ES), our results emphasized the simultaneous existence of negative contributions (i.e. forest-related EDS). Firstly, we showed that forests are perceived as a source of either ES, either EDS, but that most people acknowledge both ES and EDS simultaneously. Secondly, we highlighted that, just as ES, EDS are differently perceived by people, according to individual objectives, backgrounds and sociocultural attributes. Thirdly, we emphasized that ES and EDS perceptions differ according to forest types, but also according to forest management, which highlights that ES and EDS are co-produced by ecosystem function and attributes and human management choices. Finally, in combining ES and EDS concepts to address landscape preference and perceptions, this study allowed to advance in the understanding of people's attitudes towards different types of forests and landscapes. On the basis of local perceptions and preferences of landscape users and managers, we were able to formulate recommendations for landscape planning and management in the three case studies. Yet, because EDS is an emerging and debated concept, critical conceptual and methodological issues remain to be addressed before it could become an operational concept, including the development of an internationally accepted classification and definition. As our results suggest, a promising research perspective would be to integrate ES and EDS in a consistent framework in order to better analyze the complexity of human-nature material and non-material interactions, and to facilitate the dialogue among stakeholders, researchers and policy makers.

Acknowledgements From the Agroforestry case study, we would like to thank the Grants from the 'Fondation de France' that supported this work. We are grateful to the farmers and inhabitants of the Canton of Aurignac, to the tourists, entrepreneurs and local residents of Monte Verde district, and to the local inhabitants of the Pampa biome who participated in these interviews for their willingness to participate in our research. We also appreciate the collaborators of the Atlantic Forest and the Pampa case studies for data collection. FZT received a postdoctoral fellowship from the 'Coordenação de Aperfeiçoamento de Pessoal de Ensino Superior' (PNPD/CAPES).

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Annexe 3

Blanco, J., Dendoncker, N., Barnaud, C., Sirami, C., **2019**. Ecosystem disservices matter: towards their systematic integration within ecosystem service research and policy. Ecosystem Services 36: 100913. https://doi.org/10.1016/j.ecoser.2019.100913

Ecosystem Services 36 (2019) 100913

Contents lists available at ScienceDirect

Ecosystem Services

journal homepage: www.elsevier.com/locate/ecoser

Ecosystem disservices matter: Towards their systematic integration within ecosystem service research and policy

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ARTICLE INFO

Keywords:
Human-nature relationships
Decision-making
Policy for sustainability
Socio-cultural valuation
Integrated valuation

ABSTRACT

Ecosystem disservices (EDS) highlight the negative effects of nature on human well-being. Like ecosystem services (ES), EDS impact economic and non-economic aspects of human life within social-ecological systems (SES). The concept of EDS has been much debated, with strongly differing opinions regarding its utility and implications. In this opinion paper, we emphasize its relevance and complementarity to the ES concept for analyzing SES, and advocate applying EDS to SES research more systematically. Firstly, we highlight that though EDS are now sometimes studied, they remain neglected compared to ES. Secondly, we propose five reasons why EDS and ES are complementary concepts. Thirdly, we suggest that EDS are critical to understanding stakeholders' behavior regarding ecosystems. Drawing on existing studies, we illustrate how stakeholders in SES simultaneously perceive and benefit or suffer from ES and EDS. We further suggest that, under certain conditions, EDS may influence people's behavior more than ES. Such 'EDS-biased behavior' implies that, under certain circumstances, targeting EDS reduction may be more effective than targeting ES increase to encourage nature-friendly behaviors. Finally, we provide five recommendations to further integrate ES and EDS in research, as a pathway towards improving the understanding of SES and the effectiveness of sustainability policies.

1. Ecosystem disservices: a debated concept

Ecosystem disservices (EDS) have been defined as "the ecosystem generated functions, processes and attributes that result in perceived or actual negative impacts on human wellbeing" (Shackleton et al., 2016). Like ES, EDS are co-produced by ecological and human factors within social-ecological systems (SES). Initially introduced in research on agricultural (O'Farrell et al., 2007; Swinton et al., 2007; Zhang et al., 2007) and urban systems (Lyytimäki and Sipilä, 2009), the EDS concept has since been strongly debated. On one hand, EDS were claimed to reinforce the tendency of human societies to pay too much attention to the negative impact of nature (Shapiro and Báldi, 2014) and to potentially undermine biodiversity conservation (Villa et al., 2014). In addition, some authors argued that the EDS concept promotes a black-and-white approach that ignores the possibility that every ecosystem may contribute to either ES or EDS, depending on the context (Saunders and Luck, 2016). On the other hand, the EDS concept was advocated as a way to better balance the positive and negative effects of nature on human well-being and to better assess its net contribution (Dunn, 2010; Schaubroeck, 2017). For some authors, studying EDS may help minimize them without compromising the resilience of ecosystems (Lyytimäki, 2015), and achieve more balanced policies for sustainability (Schaubroeck, 2017; Shackleton et al., 2016).

In this opinion paper, we argue that EDS are very likely to influence real-world SES. Thus, empirical research should test the relevance and utility of the EDS concept for putting ES into practice (see Special Issue "Putting ES into practice", Ecosystem Services, Volume 26B, available August 2017). We first highlight that the EDS concept remains poorly investigated in the peer-reviewed literature. We then emphasize that EDS, in combination with ES, can help elucidate important dimensions of SES. Drawing on existing studies, we further suggest that EDS may have more influence than ES on stakeholders' behavior toward ecosystems. Finally, we propose five recommendations for the better integration of EDS in ES research and policy.

2. An expanding, yet understudied, concept

The number of papers and citations on EDS illustrates that this concept is gaining momentum in the literature (Table 1). Although the conceptual framework is not yet entirely stabilized (Campagne et al.,

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https://doi.org/10.1016/j.ecoser.2019.100913
Received 29 January 2018; Received in revised form 8 March 2019; Accepted 12 March 2019
2212-0416/

Table 1
Literature on ES and EDS between 1976 and 2018 in Web of Knowledge core collection [literature search performed on March 5th 2019 with the queries TS = (service* NEAR (ecosystem* OR landscape*)) for ES literature and TS = ((disservice* OR dis-service* OR dys-service* OR disservice*) NEAR (ecosystem* OR landscape*)) for EDS literature]. Queries are meant to show the gap between ES and EDS literature. Yet we acknowledge that both ES and EDS have been the focus of research long before these terms were coined.

	ES literature	EDS literature
First paper published in	1976	2006
First ten papers published by	1990	2010
Number of papers published in 2018	4864	46
Total number of papers published	27,441	194
Mean number of citations per paper	22.8	28.2
Mean number of citations for papers published after 2009*	16.2	23.6
Number of citations of the most cited paper	6870	607

* This indicator suggests that EDS papers are more cited than ES papers not only because of the late emergence of EDS literature (and the continuous increase of publications and citations with time), but also because they address an important topic for SES research.

2018), the EDS concept has been applied to a diversity of SES (e.g. urban, Gómez-Baggethun and Barton, 2013; agricultural, Ango et al., 2014; forest, Agbenyega et al., 2009; and aquatic, Limburg et al., 2010). It has also been used for a diversity of purposes, in particular to understand people's perceptions (Teixeira et al., 2019), to identify bundles of ES and EDS (Campagne et al., 2018), to assess EDS-related financial costs (Mackenzie and Ahabyona, 2012) and to inform management in conservation areas (Hansen, 2014). Based on this empirical research, EDS conceptual frameworks and classifications have progressively gained substance (Lyytimäki and Sipilä, 2009; Shackleton et al., 2016; Von Döhren and Haase, 2015).

The consideration of EDS remains however extremely limited compared to the consideration of ES (Table 1). In particular, EDS are absent from most recent ES conceptual advances (Costanza et al., 2017; Haines-Young and Potschin, 2018), and are insufficiently taken into account in the framework of nature's contributions to people (NCP, Díaz et al., 2018). Whereas NCP are acknowledged to be either positive or negative according to the context, none of the 18 NCP listed by Díaz et al. (2018) correspond to a negative NCP. This suggests that ES and EDS have yet to be integrated within a single and operational framework.

3. Integrating EDS within ES frameworks will help in understanding important social-ecological interactions

ES research has proven effective to elucidate important dimensions of SES, such as how people perceive and behave towards ecosystems (e.g. King et al., 2015; Martín-López et al., 2012). In particular, ES research has highlighted that different stakeholders value ES differently (Jacobs et al. 2016). Because of antagonisms between ES (one ES may increase at the expense of another, Deng et al., 2016), a given management choice may therefore benefit certain stakeholders and be detrimental to others (Barnaud et al., 2018). However, ES research generally overlooks the negative impact of ecosystems with regard to human well-being, which was emphasized by the introduction of the EDS concept (Dunn, 2010). We here summarize the main reasons why EDS and ES are distinct from and complementary to each other, in order to better understand SES:

1. *EDS encompass the diversity of the adverse impact of ecosystems*. EDS have different manifestations (Shackleton et al., 2016) and origins (Campagne et al., 2018). They may be manifested via a direct negative impact on human well-being (e.g. animal attacks on humans, Silwal et al., 2017), or via a negative impact on an ES supply (e.g. pests affecting crop production, Wielgoss et al., 2014). Moreover, EDS may be generated by ecosystem functioning (e.g. volatile organic compounds emitted by forests, Kesselmeier et al., 2000), or by the response of ecosystems to human practices (e.g. resistant weed invasion following pesticide spraying, Barot et al., 2017).
2. *EDS and regulating ES are driven by distinct processes*. In response to the claim that regulating ES already account for the EDS they regulate (Villa et al., 2014), we argue that studying drivers of EDS differs from studying drivers of ES. For example, crop pathogen dissemination and mutualism between crop-damaging species are governed by processes that are not necessarily the same as processes that govern species involved in the regulation of these crop-damaging species (Wielgoss et al., 2014). Furthermore, in some cases, EDS regulation seems to more effective through the implementation of adequate human infrastructures rather than through the promotion of regulating ES (e.g. fences to limit crop damage caused by large mammals, Harich et al., 2013). The joint understanding of EDS and of regulating ES is therefore necessary to identify the most suitable mitigation strategies.
3. *EDS allow better integration of a multiplicity of values*. ES research now emphasizes the importance of integrating people's subjectivity and different value systems in ES assessments (Dendoncker et al., 2018; Jacobs et al., 2016). Such inclusive valuations must acknowledge that some people perceive something as a service, while others see it as a disservice (e.g. wildlife, Rescia et al., 2008; Silwal et al., 2017). Coupling ES and EDS will enable better inclusion of different visions and understanding of associated social conflicts (Barnaud et al., 2018).
4. *EDS are different from ES trade-offs*. Because of antagonisms between ES, some ES may decline due to the increase of other ES. Such antagonisms result in a "we cannot have it all" situation where stakeholders may have to choose which ES to promote (Turkelboom et al., 2018). In addition, due to synergies between ecological processes, ES and EDS may simultaneously increase (or decrease). For example, pathogen transmission or attacks on humans may increase as wildlife spreads (Caron et al., 2013; Silwal et al., 2017). Such cases reflect an "everything has a cost" situation where stakeholders may have to choose whether to promote an ES or to mitigate an EDS. These trade-offs between ES and EDS differ from trade-offs between ES, and should be better accounted for in research and environmental policies (Shackleton et al., 2016).
5. *EDS emphasize that adverse impact is co-produced by humans and ecosystems.* ES result from a co-production process between human and ecological factors that allow them to flow towards the society (Costanza et al., 2017; Palomo et al., 2016). For example, timber production depends on ecological factors underlying tree growth, and on forest management practices such as tree planting, nursing, and harvesting. Similarly, and contrary to the claim that EDS mainly result from mismanagement (Villa et al., 2014), EDS are co-produced by humans and ecosystems (Lyytimäki et al., 2008). For example, cultural EDS (and ES) associated with birds depend on the abundance and richness in bird species populations as well as on human population density, which jointly influence human-avian interactions (Cox et al., 2018). It is only by understanding EDS coproduction processes that we will identify ways to mitigate them.

4. Stakeholders' actions may be more influenced by EDS than by ES

In addition to the five points mentioned above, we argue that it is critical to include EDS in ES research because, under some circumstances, EDS may influence people's actions more than ES do. This 'EDS-biased behavior' hypothesis is supported by several studies and for different types of stakeholders. For instance, mangroves in Thailand were drained to limit diseases, despite the strong recognition of mangrove-related ES (Friess, 2016). In South-Africa, some transhumant herders' movements were driven by the will to avoid EDS (such as poisonous plants and boggy areas), rather than to seek ES (O'Farrell et al., 2007). In Canada, residents listed more ES ($N = 11$) than EDS ($N = 10$) associated with urban trees (Conway and Yip, 2016). Yet, they started cutting trees down after having experienced tree falls. In France, farmers similarly associated more ES ($N = 17$) than EDS ($N = 6$) with farm trees (Blanco et al., 2018). Yet they removed many trees partly because of EDS such as the extra labor required to manage hedgerows and impediments to mechanization that trees may represent.

These examples show that people value both ES and EDS. However, some of their actions are driven by their perceptions of EDS rather than by their perceptions of ES. Thus, people's actions may be biased towards EDS reduction, though they realize this will impact the ES supply. Yet, because personal motivations, background, culture and experiences influence people's decisions regarding environmental conservation (Amacher et al., 2003; Chouinard et al., 2008; Home et al., 2014), we may expect a wide variability in how EDS influence individual behavior patterns.

While further research should test the generality of this phenomenon across a wide range of contexts, this could have significant impacts on ES research and policy. This 'EDS-biased behavior' hypothesis implies that the lack of awareness on ES may not be the main driver of nature-unfriendly behaviors, contrary to a widely accepted view (Buij et al., 2017; Shapiro and Báldi, 2014). To encourage nature-friendly societies, targeting EDS reduction may be more effective than targeting ES increase.

5. Five recommendations to reinforce the EDS concept in research and policy

We support the claim formulated by previous authors that an integrated assessment of ES and EDS will help towards a more holistic understanding of the role of nature with regard to human well-being, and towards more effective and innovative sustainability policies (Lyytimäki, 2015; Schaubroeck, 2017). We further argue that developing place-based research and building a grounded body of knowledge on EDS represents the main avenue towards operationalizing this concept. Building on knowledge gaps identified in the literature, we propose five recommendations for a better ES/EDS integration in research:

1. *Build an operational and locally-adaptable EDS classification.* ES classifications (Haines-Young and Potschin, 2018; Landers and Nahlik, 2013) have proven instrumental to develop place-based research and build a substantial body of knowledge. Despite several proposals (Gómez-Baggethun and Barton, 2013; Lyytimäki, 2014; Shackleton et al., 2016), we still lack an operational EDS classification that would fit to a broad range of SES. The pursuit of ES/EDS research in various SES will allow the development of robust EDS classifications.
2. *Include EDS and ES in both biophysical and socio-cultural assessments.* The combination of different disciplines and methods to represent multiple values of nature is increasingly advocated for formulating ad-hoc policies (Dendoncker et al., 2018; Jacobs et al., 2016). While EDS research has so far been dominated by qualitative approaches (Von Döhren and Haase, 2015), reinforcing quantitative assessments of EDS is necessary to achieve integrated ES/EDS valuations (e.g. Campagne et al., 2018; Dorresteijn et al., 2017).
3. *Consider ES/EDS bundles, trade-offs among EDS, and between ES and EDS*. Considering multiple ES and EDS is critical to identify ES/EDS bundles (Campagne et al., 2018), and potential antagonisms and synergies among EDS and between ES and EDS (Barot et al., 2017). Highlighting these relationships will improve our understanding of conflicting or shared interests among stakeholders, and will further help facilitate negotiations and provide a basis for the conception of ad-hoc management and policy instruments (Barnaud et al., 2018).
4. *Consider spatial and temporal variations in EDS supply and demand.* Changes in the supply and demand make ES and EDS spatially and temporally variable. For instance, crop raiding varies across seasons and in function of the distance to forests (Warren et al., 2007). Forests were associated with fear and anxiety in medieval times, whereas they now provide inspiration and recreation (Pilli, 2018). Similarly, ES and EDS are context-dependent as they depend on where people live (Dorresteijn et al., 2017), their livelihood, or their beliefs and traditions (Lyytimäki et al., 2008). Developing research on the spatial and temporal dimensions of ES/EDS will contribute to a better understanding of multi-scale SES dynamics.
5. *Accounting for ES/EDS co-production processes in research and policy*. ES and EDS are co-produced by ecosystems and human societies (Bennett et al., 2015; Palomo et al., 2016). Yet, operationalizing this co-production concept remains a critical challenge (Fischer and Eastwood, 2016). In particular, distinguishing the respective roles of human and ecological factors in the co-production of EDS may be difficult. For example, floods result from the interaction between rainfall events and inappropriately designed human infrastructures; wildfires depend on the interaction between human activities and ecosystem attributes. The multiple implications of ES/EDS co-production processes still need to be tackled in order to improve ES/EDS conceptual and operational frameworks.

To conclude, the ES concept is gaining momentum as an analytical research framework and as an operational tool for decision and policy making (Grêt-Regamey et al., 2017). Since the Millennium Ecosystem Assessment, its application to a diversity of contexts has triggered repeated and profound reworking of the initial framework (Costanza et al., 2017; Díaz et al., 2018; Haines-Young and Potschin, 2018). There is now growing evidence that EDS need to be equally considered to improve our understanding of people's views and actions with regard to ecosystems. In addition, we believe that investigating who suffers from EDS, how people react to EDS and how this impacts ES opens up stimulating research avenues for the ES community. An integrated ES/EDS framework will not only contribute to achieving a more holistic understanding of SES, but will also contribute to the better integration of the perspectives of different stakeholders and practitioners. By including a wider range of different values, ES/EDS research will eventually provide valuable insights for rethinking policies for sustainability towards greater effectiveness and equitability.

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Annexe 4

Blanco, J., Sourdril, A., Deconchat, M., Barnaud, C., San Cristobal, M., Andrieu, E., **révision mineure**. How farmers feel about trees: perceptions of ecosystem services and disservices associated with rural forests in southwestern France. *Ecosystem Services*.

How farmers feel about trees: perceptions of ecosystem services and disservices associated with rural forests in southwestern France

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Abstract

Rural forests, including the wooded areas primarily managed by farmers (e.g. farm forests, hedgerows, isolated trees), are critical for the sustainability of agricultural landscapes. Yet with agricultural industrialization, rural forests have been in decline in many regions across Europe. To reverse this trend and promote the sustainable use of farmland, 'greening' measures have been introduced by the EU's Common Agriculture Policy (CAP) in recent years. However, their effectiveness depends on local farmers' values and reaction to these measures. In this study, we investigated the socio-cultural value accorded to rural forests in southwestern France by interviewing 19 farmers. The positive and negative contributions cited were categorized as ecosystem services/disservices and analyzed using qualitative and quantitative methods. The results indicate that farmers in this region have mixed views, as they cited 32 positive and 25 negative contributions (material and non-material) of rural forests. They felt trees provide services (e.g. erosion control, windbreak) and disservices to agriculture (e.g. decline in yield, damage to tractors and infrastructures). Depending on their farming practices, farmers had contrasting opinions on how to reconcile rural forests and agriculture. Our results suggest that CAP greening measures need to better target rural forest conservation and further adapt to local contexts.

Keywords

Trees on farm; local knowledge; landscape preferences; farmer studies; Ecological Focus Areas; agroforestry

1. **Introduction**

The industrialization of agriculture since the Second World War has had a dramatic impact on European agricultural landscapes and their ability to sustain biodiversity (Cardinale et al., 2012). Agricultural mechanization and the extension of the surface area of farmland have contributed to a decrease in the wooded areas managed by farmers in several regions in Europe, including France (Blanco et al., 2019b; Burel and Baudry, 1990), the UK (Petit et al., 2003), and Spain (Arnaiz-Schmitz et al., 2018), as well as in Canada (Schmuki et al., 2002). In contrast, less productive agricultural land has experienced a dynamic of land abandonment and bush encroachment (e.g. Pereira and Martinho, 2017).

Wooded areas located in rural landscapes and managed by farmers (termed ‘rural forests’ in this study) include woods owned by farmers and what are commonly known as trees outside forests (TOF), such as hedgerows, isolated trees and copses. As rural forests play a key role in the functioning of agricultural landscapes, their decline has had a major impact on biodiversity and the supply of ecosystem services. For instance, hedgerows have an important function in pest and weed control and pollination (Dainese et al., 2017), as well as in creating biodiversity corridors (Dondina et al., 2016). They also provide significant non-material contributions to human well-being, such as improving the scenic value of landscapes (Oreszczyn and Lane, 2000). Isolated trees are also key assets for local biodiversity conservation, as they favor the circulation of species between forested patches (Manning et al., 2006; Sebek et al., 2016), and for local use, as they often provide edible fruits.

In recent years, one of the aims of the European Union’s Common Agricultural Policy (CAP) has been to encourage rural forests to promote the sustainable use of farmland. Since 2013, a green payment scheme of Pillar I linked 30% of the payment EU farmers receive from the CAP to three greening measures, including the reserve of 5% of their arable land as Ecological Focus Areas (EFAs) (Articles 43 to 47 of EU Regulation No. 1307/2013). While these can include agroforestry areas and trees on farms (European Commission, 2017), the real contribution of these greening measures in promoting rural forests has been the subject of debate. For instance, in the case of wood pastures, the tree density mandated in the CAP is below the current tree density in several regions (Jakobsson and Lindborg, 2017). Moreover, the majority of EFA options available for European farmers encourage the implementation of productive types of EFA (i.e. nitrogen-fixing crops, catch crops and fallow land) rather than unproductive ones (i.e. landscape features, including TOF, Pe'er et al., 2017). This calls into question the relevance of such a global one-size-fits-all policy for local systems and for the conservation of rural forests. Yet social psychology has shown that farmers are not driven solely by profit maximization and financial incentives (Home et al., 2014). Other forms of motivation exist, such as environmental concern (Chouinard et al., 2008) or preexisting socio-cultural norms and practices (Sourdril et al., 2012). Thus, in order to ensure effective agricultural policy that is suitable for specific contexts, it is important that studies take into account – beyond strictly economic considerations – the socio-cultural settings that influence local people's perceptions and how farmers interact with their environment, as well as how they may react to public policies.

The socio-cultural valuation of ecosystem services (ES) has proven effective in identifying the multiple values local people assign to ecosystems (Martin-Lopez et al., 2007). For example, a study on rural forests in Sweden showed that farmers value wood pastures for the provisioning ES they provide (e.g. meat and milk production), as well as their cultural ES, in particular their heritage value (Garrido et al., 2017). These perceptions may however differ between local farmers. For instance, in a study in Paraguay, Da Ponte et al. (2017) reported contrasting uses and perceptions between individual farmers according to factors such as farm size and the type of farming system practiced. Moreover, some studies have highlighted that rural forests could also be associated to various ecosystem disservices (EDS) by farmers who mentioned actual or perceived negative impacts to their well-being (Shackleton et al., 2016). In Ethiopia, rural forests were perceived as a source of pests and wild mammals that affect crops and livestock (Ango et al., 2014; Dorresteijn et al., 2017). In France, some farmers blame trees for competing with crops and obstructing mechanized work (Blanco et al., 2019b). These mixed positive and negative perceptions of rural forests are more or less pronounced depending on the local technical, social and cultural context of the agricultural system (Dorresteijn et al., 2017). As a consequence, place-based research in different regions is crucial in order to guide locally relevant policy and enhance rural forest conservation.

In this study, we focused on the region of southwestern France to investigate how local farmers perceive and manage rural forests in this area, collecting the information through in-depth interviews.

A common practice in ES assessments is either to invite respondents to choose and/or rank the services to be assessed (and valued) from a list (La Notte et al., 2017), or to introduce the ES concept to respondents and ask them to explain their perceptions by means of this concept (e.g. Smith and Sullivan, 2014). While these practices can be very fruitful, they do not allow an assessment of whether the ES concept adequately reflects perceptions or effectively integrates different worldviews (Tadaki et al., 2017). To at least partly address these limitations, we used a semi-directed interview procedure that consisted of asking farmers about the advantages and disadvantages they associated with rural forests, using lay language and without introducing them to the ES concept. Their answers were then categorized as ES and EDS in a second step.

In this paper, we first present the information collected in the interviews, outlining how farmers in our case study manage rural forests and perceive the associated ES and EDS. Next, we investigate the variability in these perceptions, and how this reveals farmers' contrasting views. Finally, we discuss how the concept of ES/EDS can be used to analyze farmers' perceptions and attitudes, and how this can be used to guide both future research and agricultural policies.

2. Materials and methods

2.1. Study site

The study was conducted during Nov. 2016–March 2017 in southwestern France, near the city of Toulouse (43°13'02.63"; 0°52'53.76", Figure 1), in the district of Aurignac, which is part of the '*Pyrénées-Garonne*' Long-term Social-Ecological Research site. The southern part of the study area is hilly (200–400 m a.s.l.), lying in the Pyrenean piedmont. The terrain is a succession of alternating hills and valleys crossed by a dense network of watercourses, bordered to the south by the Pyrenees mountain chain. The northern area is the beginning of the Garonne valley and consists of plains and hills. The climate is temperate, with Atlantic and Mediterranean influences. The average annual temperature is 13.8°C, and annual precipitation is 638 mm (Source: 1981–2010 data from the Toulouse-Blagnac meteorological station, https://donneespubliques.meteofrance.fr).

Historically, mixed farming combining cereal cultivation (wheat, maize) and livestock rearing (for both milk and meat production) used to be the dominant system (Choisis et al., 2010). However, over recent decades, the number of farms has drastically declined, while the remaining farms have increased in size and become specialized in crop cultivation (Table S1, Suppl. material 1). More recently, society's increasing demand for organic products, as well as financial aid from the CAP to promote this type of farming, has led to the emergence of organic farms.

In this agricultural landscape, rural forests consist of small forest patches owned by farmers (i.e. farm forests) and rural TOF (urban TOF were not considered in the study). Most farms host a few woods that are scattered across the landscape and are mainly managed using a coppice-with-standards system. This management technique leads to woodland composed of (i) a lower story treated as coppice that provides firewood year-round, and (ii) an upper story of unevenly aged trees (the standards) that provide timber more occasionally (Du Bus de Warnaffe et al., 2006). Croplands and grasslands also have TOF that were traditionally managed for multiple purposes, especially to provide supplementary livestock forage, firewood, mushrooms, game and materials for handicrafts (Sourdril, 2008).

Following our interviews with farmers, and for the sake of clarity, we organized rural forest components into five categories (forests: forest & grove; TOF: isolated tree, hedgerow, riverbank, edge trees) and used this terminology in the analysis (Table 1).

2.2. Pilot interviews and interview design

This study focused on farmers involved in crop cultivation and mixed farming, the two dominant farming systems in the district of Aurignac (Table S1, Suppl. material 1). To include diverse profiles, we selected both organic and conventional farmers. A total of 30 Aurignac farmers were contacted by phone and asked to participate in the study, of which 26 agreed to an initial face-to-face interview. These 26 pilot interviews of around 20 minutes in length took place between November 2016 and January 2017 and had the aim of (i) collecting data to build a more detailed interview protocol, and (ii) asking farmers' consent to participate in a second, more detailed interview. Of the 19 farmers who agreed to participate in the next phase, there were contrasting profiles in terms of farm surface area (from 13 to 250 ha), forest estate (from no forest to more than 12 ha of forest), age (from age 30 to 60+) and farming system practiced (Table S2, Suppl. material 1). However, most were male conventional farmers (there were 2 women and 3 organic farmers), which is explained by the low proportion of women farm managers and the scarcity of organic farms in this area (Choisis et al., 2010).

2.3. Interview procedure

The detailed interviews were conducted between January and March 2017, with each lasting around 2 hours. All interviews were recorded (except one due to technical issues) and consisted of four sections (Suppl. material 2). The first section collected general information about the farm (e.g. farm surface area, farming system, etc.) and the farmer (e.g. age, gender, secondary occupation, etc.). The second section aimed to collect spontaneous information on agricultural plots and rural forests on the farm. It was conducted as an open-ended discussion facilitated by an aerial photograph of the farm and its surroundings in which all rural forest components were visible (~ 1/8000 resolution). The interviewer pointed out specific rural forest components in the photograph and asked the farmer about their associated advantages and disadvantages, as well as about management practices (section 2, Suppl. material 2). The third section of the interview was more directed, asking the farmer to list the contributions he/she associated with rural forests through two questions: (i) What advantages, or benefits, are particularly important to you regarding forested areas? (ii) What disadvantages, or constraints, are of particular concern to you? Because respondents may not spontaneously come up with everything that might be relevant during such an exercise (Diniz et al., 2015), the interviewer prompted them with suggestions (that the farmer could confirm or not) on the basis of information obtained during the second section of the interview. Finally, the fourth section of the interviews aimed at collecting data on the use of firewood and its commercialization. These interviews allowed us to collect, for each farmer, a list of advantages and disadvantages related to rural forests.

2.4. Hierarchical classification of positive and negative contributions

The advantages and disadvantages listed by farmers were summarized and any synonyms were grouped together (Table S3 and S4, Suppl. material 1). This resulted in a final list of 32 positive contributions of rural forests (FPCs) and 25 negative contributions (FNCs). Following the hierarchical classification methods commonly used for ES (e.g. the CICES classification, Haines-Young and

Potschin, 2018), we defined these contributions as specific ecosystem services or disservices (with codes) and grouped them into larger ES/EDS classes (Table 2). The FPCs that fit the ES definitions proposed in version 5.1 of the European CICES classification (Haines-Young and Potschin, 2018) were classified as ES. The FPCs that did not fit these definitions were classified as ‘Other positive contributions’. Similarly, some FNCs corresponded to ecosystem disservices (defined as ‘the ecosystem generated functions, processes and attributes that result in perceived or actual negative impacts on human wellbeing’; Shackleton et al., 2016). Due to the lack of a widely accepted EDS classification system, we adapted existing classifications (Gómez-Baggethun and Barton, 2013; Lyytimäki, 2014; Shackleton et al., 2016) to categorize these FNCs (Table 2). The FNCs that were not EDS were classified as ‘Other negative contributions’.

2.5. Analyses of farmers’ perceptions regarding rural forests

To investigate how farmers perceived and managed rural forests, we combined both quantitative and qualitative analyses. First, we tested whether our sampling effort was sufficient to allow a good appraisal of the diversity of FPCs and FNCs perceived by farmers. To this end, we examined the level of data saturation with FLAME 1.2, an Add-In running in an EXCEL® environment that analyzes free-lists (Pennec et al., 2012). Data saturation may be understood as the point in our data collection (i.e. from a given number of interviews) when no new FPC or FNC was added by a new interview. As each farmer produced two lists, two distinct tests of data saturation were performed: one for FPCs and one for FNCs.

Secondly, a comprehensive qualitative analysis of interview data was performed to understand farmers’ perceptions and management choices regarding rural forests. Interviews were transcribed and encoded with NVivo 11 (QSR International Pty Ltd., 1999–2017). Four axes structured the analysis: (i) the influence of FPCs and FNCs on farmers’ well-being and activities, (ii) the type of forested areas associated with FPCs and FNCs, (iii) the rural forest management strategy and how it has changed, and (iv) divergences between farmers’ discourse and perceptions.

Finally, to further explore variability in farmers’ perceptions, Multiple Correspondence Analyses (MCA) were performed with the package FactoMineR (Husson et al., 2017) in R (R Core Team, 2017). For these analyses, each farmer was considered as an observation and was characterized by the FPCs and FNCs he/she cited as variables. Different MCAs were performed on the basis of different analytical options. We selected the results obtained from the most relevant MCA, i.e. the analytical option that reduced bias due to its sensitivity to rare items and that limited the number of variables. This MCA was performed with 19 observations (i.e. the 19 farmers), 25 active variables (i.e. the main classes of FPC and FNC cited by farmers) and 9 supplementary variables (i.e. the socio-economic attributes of farmers). For each observation and active variable, the value was '1' if the corresponding class of FPC/FNC was cited by the farmer, and '0' otherwise. Further details on analytical options and procedures are found in Suppl. material 3.

The following results are from these quantitative and qualitative analyses. The farmers' quotes were translated from French by a professional translator.

3. Results

3.1. General results

Farmers as a whole cited more FPCs (*N*=32) than FNCs (*N*=25) (Table 2). This trend was also true at an individual level (paired Student test, *t-value*=10.0, $p < 0.01$) with, on average, 7.3 FPCs (SD=1.6; median=7) and 3.2 FNCs (SD=1.1; median=3) listed per farmer. According to the saturation test, the full set of 32 FPCs was obtained after interviewing 9 farmers, and the 25 FNCs after interviewing 8 farmers. Of the 32 FPCs, 5 were cited by more than 50% of the farmers (Table 2): firewood, gully and erosion control, fruits and nuts, landscape scenery and mushrooms. Only one FNC was cited by more than 50% of the farmers: the fact that trees hinder working with tractors.

Of the 32 FPCs, 29 were classified as ES, while 3 remained outside the scope of the CICES classification system. This resulted in 19 classes of FPC, including 18 classes of ES and 1 class of 'Other positive contributions' (Table 2). Of the 25 FNCs, 21 were classified as EDS, while 4 were outside the EDS definition. This resulted in 12 classes of FNC, including 10 classes of EDS and 2 classes of 'Other negative contributions' (Table 1). In total, we obtained 31 classes of rural forest contributions, including 25 cited more than once. Classes of FPC tended to be more frequently cited than classes of FNC (Figure 2).

3.2. A SOURCE OF FIREWOOD AND TIMBER

The most cited FPC was firewood (*N*=17), whereas timber was less frequently mentioned (*N*=5). All but one farmer was using firewood at the time of the study, and 11 farmers stated it as their main source of energy for heating, complemented by oil or electric heating systems. Firewood is mainly harvested from crop-edge TOF that require regular pruning. Pruning is done in winter, when agricultural work is low intensity: *"We get a lot of wood for heating from around [field] edges, wood in streams, things like that. Or we prune back the branches that reach the tractor cabins and prevent us from working"* (F09). In addition, TOF and fallen forest trees constitute a substantial source of firewood: *"If there is an oak that's been uprooted in the woods, I collect it to use it in my stove"* (F09). Farmers therefore opportunistically make use of fallen TOF that have to be removed from fields to allow agricultural work (Figure 3, left). Farmers also get firewood from preventive tree harvesting: *"We just cut down a big oak by the outbuildings as it looked like it was going to fall down […]. We did it with a friend who had a crane"* (F12). They tend to prefer the option that takes the least time and technical equipment for firewood provisioning. As a consequence, most farmers no longer harvest firewood themselves by coppicing. One reason given is lack of time and the labor involved, as well as the arduous nature of the task: *"I used to go [to the woods to get firewood], but now I don't go any more. I'm too old. It's too tiring. […] Because you have to get it, put it in the log splitter, then collect the pieces and stack them…"* (F02). Another reason is that tree harvesting demands skill (e.g. knowledge about how to cut down a tree properly and judge its fall) and special machines (e.g. a log splitter, an old tractor that can be taken into the woods) that farmers do not necessarily own. In these cases, three strategies were identified. First, farmers may ask a knowledgeable neighbor or relative for help: *"If trees have to be cut down, I don't do that because I'm not much of an expert at that. But I have a neighbor who's a bit older than me who comes over and knows how to do it. If I tell him to cut down three or four trees, he'll cut them down"* (F06). Requests for help such as this are part of a custom of reciprocal assistance: *"If I have equipment, for instance, that my neighbor doesn't have, I'll go and help him get rid of a tree that has fallen down in his yard, or wherever. Then the neighbor will help me out too"* (F08). Second, farmers may call upon informal loggers (especially retired farmers or unemployed relatives) who are paid in kind with half of the harvested wood. Third, farmers may rely on professional loggers who are paid on the basis of the number of cubic meters of stacked wood harvested: *"A few years ago, we got some Portuguese [laborers] to come … they cut down the trees and made it into firewood"* (F06). The harvested firewood is mostly used for personal consumption, though two respondents sell part of it informally for cash.

As regards timber, in the last decade, only two farmers harvested it from trees on their land. Today, new buildings and homes are built mainly with purchased timber and non-wood materials. Yet according to the interviews, every 20 to 30 years farmers sell standing timber from their forests to local timber companies for additional income. After the timber is logged, farmers say they can "*get some wood on the side*" by collecting the biggest pruned branches for firewood (Figure 3, right). However, the farmers asked about this practice stated that selling timber is hardly profitable these days, which discourages some of them: *"I tried one day to get an estimate for selling some wood [… but] when I saw the selling price it would get, I gave up […]. It's nothing"* (F04).

3.3. NON-LIGNEOUS PRODUCTS AND NON-MATERIAL CONTRIBUTIONS OF RURAL FORESTS

Fruits and nuts were a frequently cited FPC. These are mostly collected from TOF, in particular isolated or edge trees. Walnuts (*Juglans spp.* L.), figs (*Ficus carica* L.), plums (*Prunus domestica* L.) and sloes (*Prunus spinosa* L.) were the most cited non-ligneous products. Fruits and nuts are collected, processed and used for personal consumption by families, or might be given to a neighbor in return for a service rendered. These uses encourage farmers to maintain fruit trees on their farms, notwithstanding certain associated disadvantages: *"Yes, that's a fig tree. I drive around it [with the tractor]. It's been getting in my way for a long time now […] though I don't mind getting the figs!"* (F02). In addition, many farmers highlighted the environmental value of fruit trees, in particular for pollinators and frugivores: *"We're really glad to see the fruit, even if we don't eat it. And the birds are happy. And the bees! The bees (laughs)! Because if us farmers don't do it, who's going to?*" (F07).

Mushrooms were another non-ligneous forest product particularly appreciated by farmers. When the climate is favorable, farmers go to woodland areas to harvest them, either on their own land or outside of it. Likewise, both countryside and city dwellers frequently harvest mushrooms in farmers' woods:

"Here, everyone goes to the woods to gather mushrooms, no one stops them […] as long as they don't take them all" (F18). This practice is tolerated as long as people do not damage property (especially fences) or harvest large quantities to sell at local markets: *"Here it's unbelievable – during mushroom season, when there are thunderstorms, [people collect them to] sell in the market. I can't stand that. […] But when people get them for themselves, that's OK, it doesn't bother me"* (F12).

Finally, rural forests provide significant non-material services, in particular those related to scenic value and landscape identity: *"The landscape is much prettier with a few woods and hedges than if it were bare! I'm not an ecologist, far from it, but I'm not a total destroyer either"* (F18). Respondents consider rural forests to be integral to the undulating landscape, as they occupy hilly terrain that is difficult to cultivate mechanically. In this area, trees and hills are two inseparable characteristics, in contrast to the flat and deforested areas in the plain. The presence of trees testifies to the maintenance of the traditional activity of herding: *"A cereal farmer […] has big fields, with nothing in the middle to get in the way. While in the mixed crop–livestock farming we do, the livestock rearing always takes up about as much space as a wood – a parcel we can't plough – so we keep those parts"* (F05).

3.4 Rural forest contributions to agriculture

From the viewpoint of the farmers we interviewed, rural forests contribute both positively and negatively to agriculture. The different types of contributions they identified are shown in Figure 2. Based on their own experiences and observations, farmers were prone to cite the positive effect of erosion control (Table 2): *"There was a hedge there, and a track with a hedge over there. Further on there was a bank, but all that's been removed, and now when there's a thunderstorm, [… the earth] slides down to here"* (F18). Aside from the role of rural forests in limiting erosion, farmers also stressed the impact of land use and tillage on erosion: *"The erosion […] also comes from the ways of working here. If you plough, there are a lot more gullies than if you just work the topsoil or use a light harrow, for instance. When you leave the organic matter on the surface, there's less gullying"* (F09). Rural forests were perceived as being an asset for livestock, in particular for their sheltering function. Interestingly, if some patches of forest are left open to cattle, for farmers the purpose of this practice is mainly for forest clearing, not initially to provide an additional forage area: *"The advantage is that* *[the cows] go [into the wood, where] at least they trample the brambles – what little they can trample. The fact that the wood is cleared, to start with, allows grass to regrow there. Then the cows can go and eat this fresh grass*" (F05). Another positive contribution considered important for agriculture is the role of rural forests as landmarks. Isolated trees mark specific features (such as springs), and hedgerows mark out farm boundaries. They also protect crops next to a grazing pasture: *"With a neighbor who raises livestock, it's better to have a hedge than a fence, in the end. Because cattle can get through a fence, but they can't get through a hedge,"* (F08). On the other hand, farmers rarely mentioned the role of trees in sheltering useful insects, filtering pollution, or improving soil quality (Table 1): the exception was a 31-year-old woman (i.e. the youngest respondent).

As regards negative contributions to agriculture, the first cited FNCs were related to the impact on mechanized cultivation of fields, as trees constitute physical obstacles that may damage tractors. Regular pruning is practiced to mitigate these FNCs: *"[The hedges] cause us problems in places where we work with tractors. In the cabin – ping ping ping – we get banged about ... I have to cut them back a bit"* (F05). However, regular pruning translates to extra cost and workload: *"Every year you have to go over the hedges. It's 20 hours with the flail mower every year: 30 hours of work, the diesel fuel, the equipment [...] it costs quite a bit in the end if you really count it up"* (F08). Some farmers consequently prefer to remove edge trees, which also enables them to extend their fields: *"Over there, I pulled up a hedge; here there was another hedge that cut my field in two, so I pulled it up about ten years ago. This colza field was six fields to begin with – now there's only one"* (F17).

The other main FNCs cited concerned the negative impact of trees on crop production. Some farmers considered that trees compete with crops for light, nutrients and water, while others emphasized one or the other of these aspects in particular: *"In a field of corn, you'll see a ring [where corn doesn't grow] around an oak. That shows you the spread of the roots – it's not because of the shade"* (F04). In addition, farmers highlighted indirect FNCs, such as the fact that TOF and woods shelter pests and wild mammals that can damage crops, especially roe deer.

3.5. Contrasting perceptions and views of farmers

In addition to identifying the aspects that predominated in the farmers' discourse, our analyses revealed contrasting views between farmers. First, the MCA revealed a gradient spanning from organic farmers to farmers of conventional crop systems, with farmers in conventional mixed systems in an intermediate position (Figure 4A). Figure 4B and Table 3 highlight the active variables driving these patterns of variability, with the first axis tending to oppose a cluster of ES from a cluster of negative contributions lacking ES. Secondly, our qualitative analysis corroborated this trend, revealing contrasting views between farmers on how to balance FPCs and FNCs. On the one hand, some farmers promoted a 'land sparing' model, i.e. spatial separation of agriculture and forests: *"I don't agree with inventorying the trees at field edges so that we can't cut them down when we want, but inventorying forests to limit cutting them down, like in the Amazon, I'm all in favor of that"* (F08). These farmers were prone to criticizing CAP directives for being too constraining, and were expecting further legislative restrictions in the future: *"So what's going on these days [is] you see [mechanical] diggers pulling up hedges and trees because [farmers are] anticipating future regulations"* (F09). On the other hand, some farmers tended to criticize the 'land sparing' vision, highlighting its roots in the post-war agricultural model: *"In our minds, we're still back in the intensive farming methods of the 1970s and 1980s. After the war, you had to produce enough to feed people, to get the economy going again, and I think this attitude is still there deep down"* (F05). These farmers were particularly aware of the negative impact of tree removal and advocated for a compromise between trees and agriculture at field scale: *"The old timers put in hedges, put up banks in the fields, [whereas] today we've got this problem with gully erosion. That's our doing, because we got rid of the hedges and the banks"* (F18). They were more favorable to recent CAP developments, although they warned about unintended effects and strategies to bypass the rules (for example, in the mandate to dedicate 5% of arable land to areas beneficial to biodiversity, farmers have the option to leave land fallow rather than keeping trees or hedges): *"Some farmers influenced by the CAP are afraid that if there's a yard of hedge that goes over into a field, they'll be penalized. […] The CAP and the interpretation of the CAP have had a very harmful effect on the survival of hedges. There are some farmers with Ecological Focus Areas that* *they choose to leave fallow. […] A lot of farmers would rather have zero trees […] that's the perverse effect of the CAP on the landscape"* (F03).

4. Discussion

4.1. The multiple dimensions of rural forest ES and EDS to farmers

Our results found that the respondents perceive trees as providers of multiple both positive and negative contributions. These findings are consistent with other research conducted in farming communities in temperate and tropical environments (Garrido et al., 2017; Genin et al., 2013; Smith and Sullivan, 2014) and emphasize the complex interdependence between agricultural and forest systems.

Unsurprisingly, the most frequently cited FPCs were provisioning services, in particular for food and fuel. Provisioning ES are known to be important to local stakeholders and landowners who directly depend on ecosystems for their livelihood (Garrido et al., 2017), whereas regional stakeholders attach greater value to regulating ES (Agbenyega et al., 2009; Hein et al., 2006). In line with other studies (Da Ponte et al., 2017; Dorresteijn et al., 2017; Garrido et al., 2017), we found that the 'service' of firewood is important to farmers, who mainly use it for personal consumption. Firewood effectively generates savings on energy expenses and allows the exploitation of byproducts from tree pruning, a necessary management practice for trees around the edges of agricultural plots. Thus, harvesting firewood has an undeniably rational economic basis, which may be linked to the willingness of farmers to maintain some traditional forestry uses (Andrieu et al., 2011).

Aside from provisioning services, several regulating ES were acknowledged by farmers, in particular those related to air temperature regulation, protection from wind, and erosion control. These services were generally seen as profitable to agriculture as they enhance some provisioning ES, especially food production.

At the same time, rural forests were also seen as a source of EDS by farmers, a reality that has been recognized in an increasing number of studies (Dorresteijn et al., 2017; Lugnot and Martin, 2013; Mackenzie and Ahabyona, 2012). The most frequently cited FNC – trees represent physical obstacles to mechanization – illustrates the difficulty of reconciling mechanized agriculture with trees (see also

Ango et al., 2014) and confirms the link between the mechanization of agriculture and the decline of TOF (Blanco et al., 2019b; Petit et al., 2003). The loss of agricultural production – caused by tree competition with crops or crop raiding by wildlife – was the second most frequent category of FNC cited by informants; this represents a major source of concern for farmers worldwide (Ango et al., 2016; Mackenzie and Ahabyona, 2012). Finally, two other frequently evoked FNCs were the additional work involved in rural forest management, as well as the additional costs associated with the damage caused by trees.

Another noteworthy result concerned the importance of non-material ES for farmers. As has been found elsewhere, farmers in the study region attach great importance to the landscape's scenic value and identity, as well as to traditional land-use practices, and rural forests play a part in this. Similar to other landscape components, they are a feature that farmers have inherited from previous generations and will transmit to subsequent generations. This heritage and legacy value occupies an important place in farmers' discourse, suggesting that their perceptions include a vision of the landscape's history as well as its future. This non-material contribution of rural forests was also embedded in certain provisioning ES. For instance, farmers continue to harvest firewood and collect fruits, nuts and mushrooms, not only to meet material needs, but also to maintain certain traditional practices and types of social interactions. These provisioning services could therefore be considered 'cultural subsistence services', i.e. provisioning ES that are deeply related to social traditions, beliefs and norms (Pascua et al., 2017). In our case study, we found that some provisioning ES (e.g. the harvesting of firewood from hedgerows) are partly valued by local stakeholders because of their underlying cultural value (e.g. the maintenance of mutual aid networks between farmers). As we based our categories on the CICES ES classification system, and to avoid double counting, these services were classified as provisioning ES, though they could equally have been classified as cultural subsistence services since both material and non-material aspects mattered to farmers. It is important to keep in mind that such classification choices may have a significant influence on the overall results of socio-cultural valuation studies.

4.2. Variability in farmers' perceptions of rural forest ES/EDS

The study revealed variability in farmers' views and perceptions of rural forests. This result reinforces the importance of studying individual perceptions rather than systematically considering farmers as a homogeneous group of stakeholders (Vanclay, 2004). In the MCA (Figure 4B and Table 3), we observed a significant contribution of FNC in explaining the variability between farmers. This result highlights the need to better take into account perceived EDS in socio-cultural valuation studies, so as to more accurately identify differences between people's perceptions, and ultimately to better understand the variability in their behavior.

Secondly, in accordance with other studies (e.g. Da Ponte et al., 2017), we found correlations between farmers' perceptions and the type of farming they practiced. Our qualitative analysis confirmed that farmers with a mixed crop–livestock farming system were more favorable to TOF than farmers solely cultivating crops. This may be explained by the various ES that TOF provide to livestock and by the low EDS associated with TOF in pastures (in contrast with TOF in cropland). This supports studies that have shown that the maintenance of diversified pastoral systems contributes to the conservation of farm trees (Hartel et al., 2017; Pfund et al., 2011).

Finally, farmers differed in the options they envisioned as a way to reconcile rural forests and agriculture at landscape scale. While they all agreed on the necessity of managing trade-offs between these two landscape elements, they advocated for either a 'land sharing' or a 'land sparing' scenario. Farmers that supported the former approach highlighted the multiple ES rural forests supply to agriculture and why this made them willing to bear the associated EDS. For instance, some farmers maintain isolated fruit trees in their fields notwithstanding the inconvenience for mechanized cultivation. Others purposely let hedgerows grow and do not manage them in order to enhance biodiversity despite an observed increase in pests and the risk of getting reduced CAP subsidies due to the loss of arable areas eligible to Pillar I direct payments. In contrast, farmers who argued for a 'land sparing' model emphasized the negative impact of rural forests on crop production and mechanized cultivation. They considered that many forested areas could be better exploited by converting them into agricultural land, leaving only the least fertile or least accessible land forested. For instance, one farmer had recently bought a forested parcel and planned to convert it to enlarge a crop field, arguing that agricultural areas should be cleared of trees and remain separate from forest areas. These different points of view echo current uncertainties regarding how to effectively reconcile food production and biodiversity conservation in agricultural landscapes and highlight the need for further research (Fischer et al., 2014).

4.3. CHANGE AND STABILITY IN THE SUPPLY AND DEMAND OF ES

Our findings highlighted both trends – continuity and change over time – in perceptions of the supply and demand of ES provided by rural forests. For example, respondents noted a pattern of change in firewood demand, which has decreased in recent decades as houses have been progressively equipped with fossil fuel-based central heating systems. Another example is that while people in the area used to use diverse forest products to make handicrafts or homemade alcohol or for forage (Sourdril, 2008), our interviews confirmed the virtual disappearance of these traditional practices and the resulting decline in rural forest domesticity (Sourdril et al., 2012). Some of these changes are associated with changes in French laws – for example, homemade alcohol production is now strictly regulated. Others are explained by the development of alternative options, in particular for firewood, handicrafts and livestock forage. As a consequence, these factors seem to have contributed to lowering the value farmers assign to rural forest ES. Similarly, changes in agricultural practices over recent decades (e.g. mechanization) seem to have reinforced certain FNCs. The expansion of the surface area of farms, alongside a decline in the available workforce due to rural exodus, have exacerbated the difficulty for farmers to properly manage woodland. Because of the increase in cropland and the mechanization of cultivation, tree–crop competition has become a more salient issue for farmers, with a more significant impact on perceived farm profitability. Finally, the use of ever-larger machines has the result that trees further hinder mechanized work. As demand for particular ES has changed, farmers have adapted their farms, in particular by removing TOF (Blanco et al., 2019b) and abandoning certain management practices dedicated to enhancing FPCs (e.g. local sylvicultural practices aimed at increasing wood production). These changes in farmers' practices have impacted the supply of ES/EDS, highlighting the critical role of human agency relative to ecosystem function in the services/disservices provided (Spangenberg et al., 2014).

Other perceptions of ES/EDS show stability over time, sometimes despite contextual changes. In some cases this is due to a certain disconnection between scientific and farmer knowledge. For example, over the last two decades, scientific literature has generally reached a consensus on the overall positive impact of hedgerows on crop yields (Baudry et al., 2000; Van Vooren et al., 2017), soil fertility (Torralba et al., 2016), and pollutant filtration (Brauman et al., 2007). Yet farmers either disagreed with these findings or were not aware of them. One reason for this gap lies in the fact that farmers' learning is mostly based on empirical observation and experience. For example, farmers realized the efficacy of hedgerows in controlling erosion as they observed the occurrence of landslides after their removal. But less visible effects are less likely to shift perceptions. As one farmer explained, a decrease in yields next to hedgerows (caused by local tree–crop competition) is more visible than an increase in yields in the middle of a field (due to the reduction of wind speed provided by the hedgerow). This is consistent with the findings of Salliou and Barnaud (2017) who reported poor farmer awareness regarding processes that are seemingly hard to grasp, such as landscape-scale biological control. A further factor is that farmers and scientists use different indicators to assess rural forest contributions. Farmers tend to consider the actual impacts of trees on their farms and overall activities: in terms of additional labor, required knowledge and skills, and economic returns (Salliou and Barnaud, 2017). In contrast, research focuses on woodland impact on biophysical processes, and generally overlooks the impact on farming activities. A final factor is certainly related to the loss of local knowledge associated with the modernization of agricultural systems on the one hand, and insufficient availability of scientific findings among farmers on the other. The transfer of research findings from the experimental context to real-world, local settings remains a particular challenge. While scientists have a role to play in ensuring this transmission of knowledge, it also requires the engagement of agricultural advisors and agencies that have frequent interactions with farmers and that favor changes in agricultural practices.

To conclude, the poor awareness of farmers regarding some key positive contributions of rural forests to agriculture is worrisome: "lack of information affects people's abilities to place a value on ecosystem attributes" (Bingham et al., 1995). To tackle the challenge of conserving rural forests, research should aim to better integrate farmers' questions and concerns in order to produce knowledge that could be better operationalized locally (Duru et al., 2015). Engaging agricultural support agencies and agricultural advisors/consultants in this co-production process could further help to promote changes in farmers' practices.

4.5. Methodological challenges and implications for research

Our results highlighted the complementarity of ES and EDS for understanding the perceptions and behavior of farming communities regarding rural forests. As Table 2 illustrates, the ES concept was quite effective to capture most of the FPCs cited by farmers. Only 3 FPCs were not considered as ES according to the definitions we used (Haines-Young and Potschin, 2018); these were related to benefits that farmers directly or indirectly derive from ecosystems or ES conservation (e.g. additional CAP subsidies). In contrast, the classification of FNCs as EDS was more challenging due to the lack of a widely accepted EDS conceptual framework and classification system. Just as ES are distinct from the benefits derived from them (e.g. firewood production is distinct from the economic benefits obtained by the sale of firewood), EDS should be distinct from the costs they induce (Campagne et al., 2018; Shackleton et al., 2016). Yet we found the delineation between the two was sometimes fuzzy. For example, we classified as EDS 'damage to tractors caused by trees', 'management costs' and 'additional workload'; however, they could be considered as a set of direct and indirect costs caused by the EDS 'growth of tree branches in fields'. While these kinds of considerations have received a lot of attention for ES and allowed the construction of widely accepted definitions of what ES are/are not, this work remains to be done for EDS (Blanco et al., 2019a).

A second challenging aspect concerns the methodology used in this study. We conducted in-depth interviews with 19 farmers, encountering each of them twice. This approach allowed a very fine-scale description of how farmers in the local area perceive rural forests and their behavior in relation to these, as well as a thorough understanding of the complexity of their management choices. However, the choice of a semi-structured interview protocol, to enable a mixed approach combining qualitative and quantitative analyses, required some trade-offs between the length of the interview necessary to uncover complex processes and perform a relevant qualitative analysis, and the number of interviews necessary to allow robust statistical analyses and a representative sample size. An examination of the level of data saturation ensured that our sample was large enough to permit a good overview of the FNCs and FPCs perceived by farmers, which required around 10 interviews (see section 3.1). We also targeted the region's dominant farming systems when selecting the respondents. Thus, we are quite confident that our results are illustrative of the farming community in the study area. Yet while the trends revealed by the MCA corroborated the qualitative analyses, it would be valuable in future research to increase the number of farmers in order to further test certain hypotheses, in particular regarding the influence of the type of farming system and gender on farmers' relationships with rural forests.

4.6. Implications for agricultural policies

Our findings revealed different attitudes among farmers regarding CAP greening measures. Most felt these imposed additional constraints and additional labor. While some farmers acknowledged these measures may have an overall positive impact on rural forest conservation, others were more skeptical and highlighted the unintended consequences of the policy in practice and bypass strategies. For example, as agricultural areas eligible for CAP payments can be reduced if the spread of hedgerows is not properly managed, some farmers prefer to remove them in favor of productive Ecological Focus Areas (EFAs) such as nitrogen-fixing crops, catch crops or fallow land. Interview responses suggested that farmers were encouraged to do this by agricultural advisors from public agencies. This phenomenon confirms the reluctance of European farmers to classify rural forests as EFA (Pe'er et al., 2017). Thus, to better promote rural forest conservation, two different thresholds could be defined: a minimum area of productive types of EFA and a minimum area of unproductive types of EFA (i.e. specific landscape features such as hedgerows and isolated trees). Furthermore, rather than one-size-fits-all targets, these thresholds should take into account the specificity of local contexts and current realities: e.g. landscapes with a current high level of wooded areas should have higher targets than landscapes with a lower level of wooded areas. In this objective, a more bottom-up approach could be taken for deciding the most relevant thresholds for a specific region, based on the expertise of local agricultural advisors and support services.

Moreover, as illustrated by the uses of rural forests pointed out by our respondents and the many provisioning services derived from them, we argue that rural forests should not be considered unproductive areas. Better recognition of their products and services and more support in exploiting these could help farmers obtain more benefits from rural forests, which could incite them to conserve this productive asset. For example, creating supportive measures to promote local firewood markets could be one way to improve economic advantages from woodlands.

Lastly, some farmers raised the issue of constant changes to CAP directives, which generates economic uncertainty. For example, they worried about the possibility of a ban on tree-felling in the future, which led them to begin removing wooded areas from their farms as a precaution. While we lack data to assess the extent of these removals, our interviews confirmed this negative result of CAP greening measures on rural forests based on farmers' perceptions of the directives and an ever-changing and unclear agenda. As other authors have argued, it seems crucial for CAP measures to be better targeted and adapted to local contexts (Jakobsson and Lindborg, 2015) and for the wider agenda to be clearer. This could be achieved, for example, by adding some flexibility regarding the expansion of hedgerows over cropland and meadows to ensure that farmers would not be afraid of reductions in direct payments if hedgerows extend into arable lands. Furthermore, if one hedgerow is registered as an EFA, it should be able to be easily substituted by another hedgerow on the farm, so that farmers can more easily adapt their farms to a changing socio-economic and environmental context. In short, the indicators used to allot CAP subsidies should better integrate two antagonistic objectives: the maintenance of rural forests and other types of EFAs that favor the ecological functioning of agricultural landscapes, and the ability of farmers to adapt their farms and practices to a changing environment.

5. Conclusion

Understanding how local landscape and ecosystem managers perceive, use and manage an environment and its natural resources is increasingly acknowledged as a critical step in better targeting environmental policies and improving their effectiveness. With this perspective in mind, this study aimed to assess through interviews how farmers from an agricultural region in southwestern France perceive and manage rural forests, which are key ecological features for the functioning and sustainability of agricultural landscapes. Combining qualitative and quantitative methods, the results showed that rural forests are perceived as a source of multiple ecosystem services and benefits. Furthermore, the material and non-material aspects of rural forests are often deeply intertwined. For instance, the harvesting of firewood from TOF offers the means to acquire provisioning ES and to regulate tree encroachment in cropland, as well as to maintain certain social interactions such as mutual-aid networks. The results also illustrated the reality that for farmers, rural forests also represent a source of ecosystem disservices. These impacted farmers' well-being either directly (e.g. risk to their safety, damage to tractors) or indirectly by reducing certain ES (e.g. decline in yields caused by tree–crop competition). Some EDS were reinforced by inadequate legislative frameworks, such as the loss of CAP subsidies if forested areas expand over cropland, which illustrates that EDS, like ES, are coproduced by human and ecological factors. The findings showed that ES and EDS were perceived differently between farmers, with EDS the main source of variability in farmers' perceptions. Hence, this study illustrates how a combination of ES and EDS can help to explore the complexity of local perceptions of ecosystems and contribute to achieving a more accurate, exhaustive vision of views and attitudes. Including ecosystem disservices in socio-cultural valuations of the environment is a key challenge for future research on social-ecological systems. Finally, by highlighting how global policies can be differently received by local stakeholders, we advocate for the adaptation of CAP greening measures to local realities and a more stable CAP agenda to avoid farmers reacting in anticipation of potential future restrictions. More specifically, CAP greening measures should define indicators that target the maintenance of rural forests (i.e. a minimum area of rural forests per farm) while allowing farmers to change the location of the trees on their farm to enable them to adapt to changing socio-economic and environmental contexts.

6. Acknowledgements

This work was supported by grants from the *Fondation de France*. We would also like to thank the interviewed farmers for kindly agreeing to participate in the study.

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Tables

Table 1: Terminology used in this article to refer to the 5 rural forest components (including forests and TOF) identified from farmers' interviews, and their associated definition within the scope of this study.

Table 2: List of the rural forest positive (FPC) and negative contributions (FNC) identified from interviews with farmers and classified as ecosystem services (based on CICES 5.1, see Haines-Young and Potschin, 2018), disservices, and other positive and negative contributions. The N column represents the number of farmers who evoked the FPC/FNC. The codes were used in statistical analyses.

Table 3: Main contributors of the Multiple Correspondence Analysis for the two first axis (Dim 1 and Dim 2): only individuals and variables with a large quality of representation into the axes are reported (individuals with cos2*>0.5, active variables with eta2¥>0.5, supplementary qualitative variables with eta2>0.5 and supplementary quantitative variables with |cor¶|>0.3).

Table 1: Terminology used in this article to refer to the 5 rural forest components (including forests and TOF) identified from farmers' interviews, and their associated definition within the scope of this study.

Rural forest components		**Definitions established from farmers' interviews**
Trees Outside Forests (TOF)	Isolated tree	A single tree located in the middle, or on the border, of agricultural plots (including pastures and crop fields).
	Hedgerow	A continuous and impassable row of trees and/or shrubs located in the middle, or on the border, of agricultural plots.
	Riverbank	Row of trees associated with a water course or a ditch.
	Edge trees	Lines of trees and tree rows located at the border of agricultural plots that can be crossed by humans and livestock.
Forests	Forest (and grove)	Woody area with trees and shrubs that could be used for firewood and/or timber production.

Table 2: List of the rural forest positive (FPC) and negative contributions (FNC) identified from interviews with farmers and classified as ecosystem services (based on CICES 5.1, see Haines-Young and Potschin, 2018), disservices, and other positive and negative contributions. The N column represents the number of farmers who evoked the FPC/FNC. The codes were used in statistical analyses.

	Classes of FPC and FNC (Code)	**Positive & negative contributions**	**N**
	18 classes of ES (CICES 5.1 code)	*29 ecosystem services (Code)*	
Provisioning	Wild plants - energy (S1.1.5.3)	Firewood (P1)	17
	Wild plants - nutrition (S1.1.5.1)	Fruits & nuts (P2)	11
		Medicinal plants (P3)	1
		Mushrooms (P4)	10
	Wild animals - nutrition (S1.1.6.1)	Habitat for game (P5)	4
	Wild plants - Fiber and other materials (S1.1.5.2)	Wood & timber (P6)	5
		Picket fence (P7)	2
	Biomass for agricultural use (S1.3.1.1)	Pastoral areas & resources (P8)	1
Regulation	Regulation of air temperature and humidity (S2.2.6.2)	Shade & fresh air for humans (R1)	5
		Oxygen production and air quality (R2)	6
		Shade for reared animals (R3)	4
	Control of erosion rates (S2.2.1.1)	Gully & erosion control (R4)	13
	Maintaining nursery populations & habitats (S2.2.2.3)	Habitat for wild birds (R5)	5
		Habitat for insects (R6)	4
	Wind protection (S2.2.1.4)	Shelter for reared animals (R7)	8
		Windbreak effect for crops (R8)	6
	Water flow regulation (S2.2.1.3)	Slow down water flows (R9)	2
	Decomposition and fixing processes and their effect on soil quality (S2.2.4.1)	Humus production (R10)	1
		Soil aeration (R11)	1
	Filtration by plants (S2.1.1.2)	Remove nitrates and other chemicals (R12)	1
	Visual screening (S2.1.2.3)	Fill gaps in the visual landscape (R13)	1
Cultural	Aesthetic experiences (S3.1.2.4)	Landscape scenic (C1)	11
		Visual aspect of wood construction (C2)	1
	Observational interactions (S3.1.1.2)	Quietness (C3)	1
		Participate in a living countryside (C4)	1
		Noble aspect (C5)	1
	Resonant in terms of culture (S3.1.2.3)	Landmark (C6)	3
	Existence value (S3.2.2.1)	Biodiversity and ecosystem conservation (C7)	7
	Option or bequest value (S3.2.2.2)	Reserve holdings & patrimony (C8)	2
	10 classes of EDS (ad-hoc code)	*14 ecosystem disservices (Code)*	
Material	Damage to equipment (D1.1)	Branches damage tractors (MD1)	7
		Risks for fences (MD2)	2
	Damage to infrastructure (D1.2)	Risks for buildings (MD3)	1
		Roots damage buildings (MD4)	1
		Roots obstruct ditches and drains (MD5)	3
	Economic costs (D1.3)	Expensive management (MD6)	2
		Low economic profitability (MD7)	1
Agricult ure-	Physical obstacle (D2.1)	Hinder work with machines (AD1)	11
		Low accessibility in wet periods (AD2)	1
	Workload (D2.2)	Additional workload (AD3)	7
		Habitat for pests (AD4)	2

	Causes of decrease in crop production (D2.3)	Overall competition causing yield loss (AD5)	4
		Local root competition (AD6)	2
		Rainfall interception (AD7)	2
		Light interception (AD8)	3
	Causes of decrease in livestock production (D2.4)	Risks for reared animals (AD9)	2
	Competition for land (D2.5)	Occupy surfaces that could be better valorized (AD10)	1
Health/ security	Animal bites (D3.1)	Habitat for the pine processionary (HD1)	1
		Habitat for hornets (HD2)	1
	Dead biomass production (D3.2)	Risks and inconvenience of leaf falls (HD3)	2
		Risks for humans of branch falls (HD4)	1

Other classes of positive contributions (code)	*3 other positive contributions (code)*	
Economic benefits (PC1.1)	Economic valorization of least fertile lands (PC1)	1
	Low management expenses (PC2)	1
	Additional CAP subsidies (PC3)	2

Other classes of negative contributions (code)	*4 other negative contributions (code)*	
Legislative constraints (NC1.1)	Mandatory regulation (NC1)	1
	Uncertainties on future changes in regulations (NC2)	1
	Fewer areas eligible for CAP subsidies (NC3)	1
Social pressure (NC1.2)	People do not understand farmers' need to cut down trees (NC4)	1

Table 3: Main contributors of the Multiple Correspondence Analysis for the two first axis (Dim 1 and Dim 2): only individuals and variables with a large quality of representation into the axes are reported (individuals with cos2*>0.5, active variables with eta2[¥]>0.5, supplementary qualitative variables with eta2>0.5 and supplementary quantitative variables with |cor[¶]|>0.3).

	Individuals		**Active variables**		**Suppl. qualitative variables**		**Suppl. quantitative variables**	
	Id	Cos2	Id and name	Eta2	Name	Eta2	Name	Cor
Dim 1 (17.9%)	F05	0.61	S1.1.5.3-Wild plant for energy	0.53	-	-	Age	-0.33
			S3.1.2.4-easthetic experiences	0.60				
			NC1.1-legislative constraints	0.61				
Dim 2 (16.0%)	-	-	D2.3-decrease in crop production	0.57	Farming system	0.41	FarmArea	0.30
			D1.3-economic costs	0.52			No of cited FNC	0.41

* represents the quality of the representation for individuals on each axis.
[¥] Square of the correlation ratio between each variable and each axis.
[¶] Correlation coefficient between each quantitative variable and each axis.

Figures

Figure 1: Location of the study site and map of the 19 farms managed by the interviewed farmers (each color represents a different farm, and each polygon is an agricultural block as defined by the Common Agricultural Policy). Background: aerial photograph (© IGN 2015).

Figure 2: Number of times each class of rural forest contributions was cited by farmers. Only classes with at least two citations are represented. Black bars represent ecosystem services; black dashed-line bars represent other positive contributions; grey bars represent ecosystem disservices; grey dashed-lined bars represent other negative contributions.

Figure 3: Left: Firewood resulting from edge trees pruning, and a fallen tree waiting to be harvested. Right: a farmer collecting remaining logs and branches from his forest after it has been harvested by a timber company. (Photographs from February 2017, J. Blanco).

Figure 4: Multiple Correspondence Analysis outcomes:(A) Projections on the two first axes of the individuals (organic farmers in red; farmers with conventional cropping systems in green; farmers with conventional mixed systems in blue) and of the supplementary qualitative variables (i.e. gender (M/F) and farming system, grey triangles); (B) Graphs of the active categories to the first two axes of the MCA (red triangles: the 20 most contributive categories; light red triangles: the other categories). The codes used to identify the active variables are those presented in Table 2.

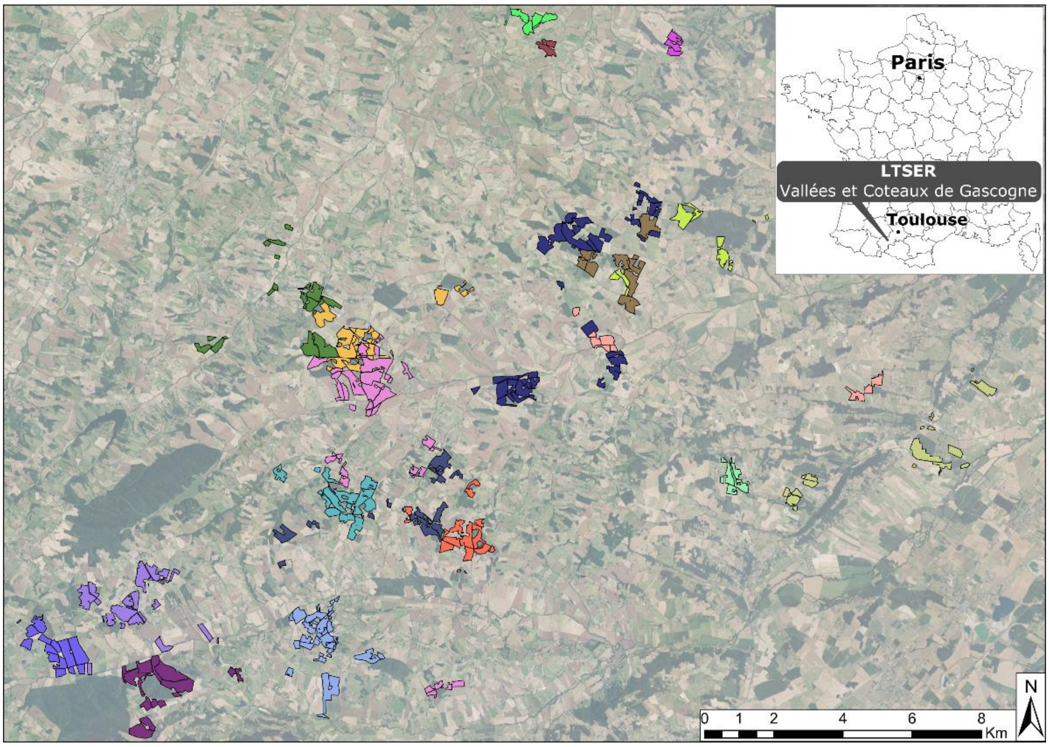


Figure 1: Location of the study site and map of the 19 farms managed by the interviewed farmers (each color represents a different farm, and each polygon is an agricultural block as defined by the Common Agricultural Policy). Background: aerial photograph (© IGN 2015).

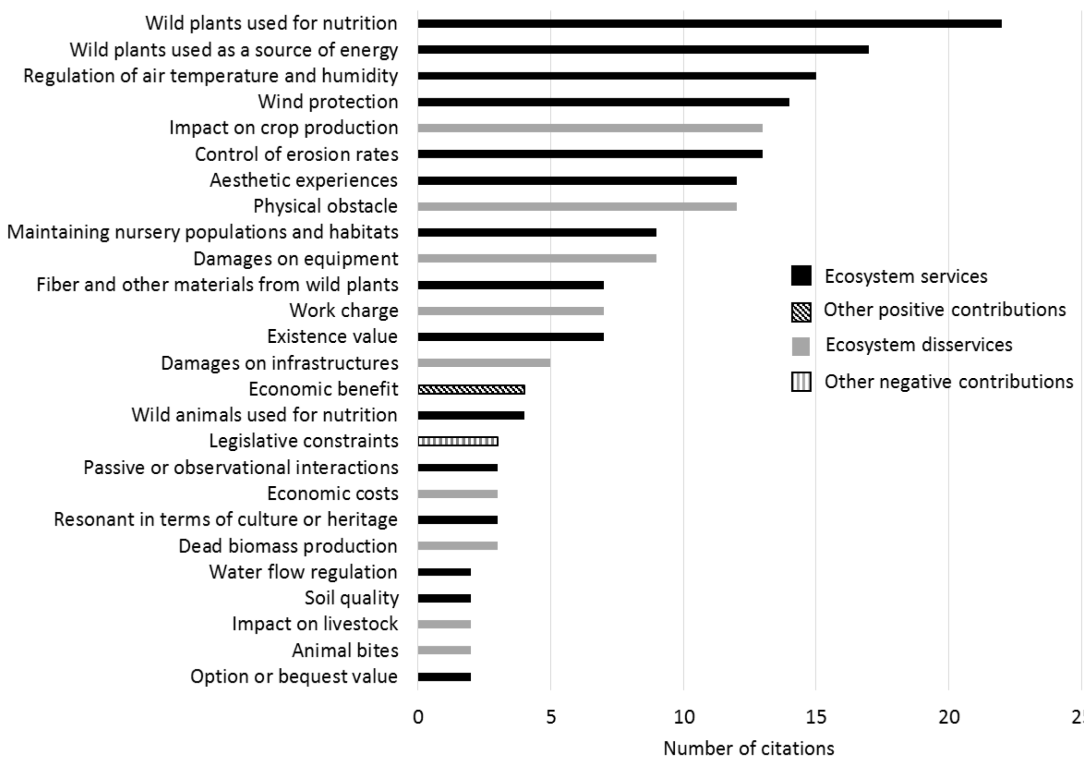


Figure 2: Number of times each class of rural forest contributions was cited by farmers. Only classes with at least two citations are represented. Black bars represent ecosystem services; black dashed-line bars represent other positive contributions; grey bars represent ecosystem disservices; grey dashed-lined bars represent other negative contributions.

Figure 3: Left: Firewood resulting from edge trees pruning, and a fallen tree waiting to be harvested. Right: a farmer collecting remaining logs and branches from his forest after it has been harvested by a timber company. (Photographs from February 2017, J. Blanco).

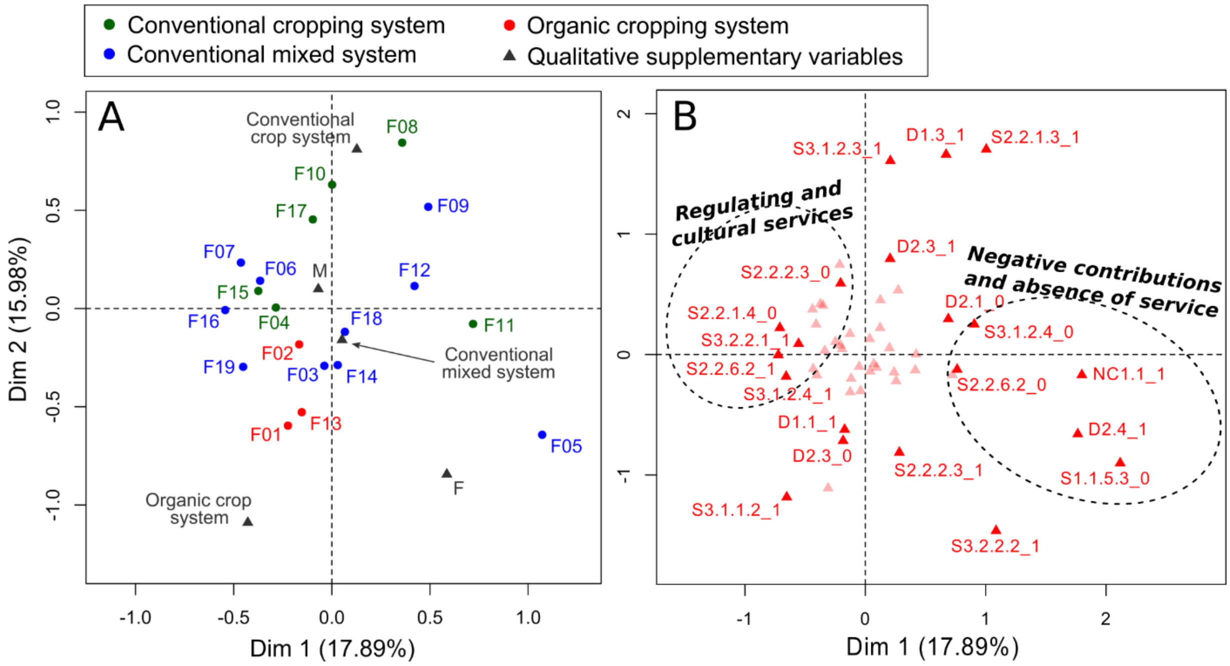


Figure 4: Multiple Correspondence Analysis outcomes:(A) Projections on the two first axes of the individuals (organic farmers in red; farmers with conventional cropping systems in green; farmers with conventional mixed systems in blue) and of the supplementary qualitative variables (i.e. gender (M/F) and farming system, grey triangles); (B) Graphs of the active categories to the first two axes of the MCA (red triangles: the 20 most contributive categories; light red triangles: the other categories). The codes used to identify the active variables are those presented in Table 2.

Supplementary material 1

Table S1: Main characteristics of the farms located in the Canton of Aurignac in 1988 and in 2010 according to data from the French agricultural statistics and assessment service (available at http://recensement-agricole.agriculture.gouv.fr/)

	In number (and percentages of the total)		**In surface area (ha)** (and percentages of the total)	
Year	**1988**	**2010**	**1988**	**2010**
Types of farming systems				
- Crop systems	41 (11%)	79 (35%)	1,321 (11%)	2,866 (35%)
- Mixed farming systems	183 (47%)	47 (21%)	5,374 (43%)	3,332 (27%)
- Cattle-based systems	114 (29%)	59 (26%)	4,068 (33%)	3,788 (31%)
- Other	52 (13%)	40 (18%)	1,597 (13%)	753 (7%)
Total	390	225	12,360	10,739
Farmers' age				
- <40 year-old	79 (20%)	42 (19%)	3,120 (25%)	3,291 (30%)
- 40-50 year-old	73 (19%)	45 (20%)	2,760 (22%)	2,127 (20%)
- 50-60 year-old	113 (29%)	74 (33%)	3,536 (29%)	4,245 (40%)
- >60 year-old	125 (32%)	64 (28%)	2,944 (24%)	1,075 (10%)
Total	390	225	12,360	10,739

Table S2: Main characteristics of the 19 interviewed farmers, of their farm and woodland estate, and total number of rural forest positive (FPC) and negative contributions (FNC) identified from interviews.

Farmer	Age	Gender	Farming system	Farm surface area* (ha)	No of blocks[¶]	No of woodlots	Woodlot total area (ha)	No of FPCs	No of FNCs
F01	59	F	Organic crop system	13.4	2	0	0.00	8	3
F02	66	M	Organic crop system	61.3	5	1	0.82	8	2
F03	54	M	Conventional mix farming	129.0	14	10	11.00	9	3
F04	68	M	Conventional crop system	114.8	15	1	1.92	7	2
F05	39	M	Conventional mixed farming	139.5	23	5	9.85	7	4
F06	55	M	Conventional mixed farming	123.5	19	4	4.73	8	4
F07	45	M	Conventional mixed farming	110.3	17	4	4.20	7	3
F08	52	M	Conventional crop system	248.7	40	3	1.13	10	6
F09	NA	M	Conventional mixed farming	108.8	9	5	5.42	7	4
F10	NA	M	Conventional crop system	72.2	9	3	12.01	7	2
F11	31	F	Conventional crop system	38.6	8	2	0.40	6	3
F12	58	M	Conventional mixed farming	94.4	15	3	3.13	4	4
F13	43	M	Organic crop system	24.8	3	3	3.91	10	2
F14	60	M	Conventional mixed farming	121.8	31	2	1.15	7	2
F15	63	M	Conventional crop system	51.2	10	0	0.00	4	3
F16	40	M	Conventional mixed farming	165.2	12	5	6.80	9	4
F17	36	M	Conventional crop system	103.2	19	1	0.39	7	4
F18	50	M	Conventional mixed farming	250.8	42	5	5.89	6	2
F19	48	M	Conventional mixed farming	152.7	22	2	4.60	8	4
Total				2124.2	315	59	77.36	32	25

* Farm surface area was assessed from the 2014 version of the RPG, which is the French version of the European Land Parcel Identification System (LPIS).
¶ Blocks are the geographical entities in the RPG data, defined as one or several contiguous agricultural plots managed by the same farmer.

Table S3: List of the 32 “Rural Forest Positive Contributions” (FPC) and corresponding “advantages” (in French and in English) cited by farmers during interviews.

Rural Forest Positive Contributions (FPC)	Corresponding advantage (French)	Corresponding advantage (English)	Farmers
Firewood (P1)	Bois de chauffage	Firewood	F01, F02, F03, F04, F06, F07, F08, F09, F12, F13, F14, F15, F16, F17, F18, F19
	Economies sur les dépenses d'énergie	Savings on energy expenses	F10
Fruits & nuts (P2)	Fruits (au moins les voir)	Fruits (seeing them at least)	F01, F07
	Noix	Walnuts	F02, F18
	Manger des cerises	Eat cherries	F04
	Nourriture	Food	F08
	Fruits	Fruits	F09, F12, F13, F14, F16
Medicinal plants (P3)	Plantes médicinales	Medicinal plants	F13
Mushrooms (P4)	Champignons	Mushrooms	F03, F05, F06, F08, F09, F13, F16, F18, F19
	Cèpes	Ceps	F17
Habitat for game (P5)	Abri pour le gibier	Shelter for game	F02, F03
	Refuge pour gibier	Refuge for game	F05
	Gibier	Game	F08
Wood & timber (P6)	Bois d'œuvre	Timber	F04, F06, F07
	Bois de construction	Timber	F16
	Grumes	Timber logs	F03
Picket fence (P7)	Piquets	Pickets	F09
	Piquets d'acacia	Pickets in acacia wood	F17
Pastoral areas & resources (P8)	Pacage	Grazing	F05
Shade & fresh air for humans (R1)	Ombrage	Shade	F01, F02
	Ombre quand il fait chaud	Shade when the weather is hot	F04, F08
	Ombre pour les hommes et tracteurs	Shade for humans and tractors	F15
Oxygen production and air quality (R2)	Fraîcheur	Fresh air	F04
	Rend de l'O2	Produce oxygen	F04
	Qualité de l'air	Air quality	F06, F17
	Pour l'oxygène	For oxygen	F08
	Production d'oxygène	Oxygen production	F14
	Oxygène	Oxygen	F15
Shade for reared animals (R3)	Ombre pour les vaches	Shelter for cows	F06
	Fraîcheur l'été (vaches)	Fresh air during summer (for cows)	F07
	Ombre pour les animaux	Shade for animals	F16, F19
Gully & erosion control (R4)	Evite le ravinement	Avoid gully	F01
	Tient la terre	Keep soils still	F02
	Erosion	Erosion	F03, F06, F14

	Erosion des fossés et talus	(Regulate) erosion of ditches and banks	F05
	Tient les berges	Keep banks still	F06
	Tenue des digues	Keep banks still	F08
	Limite l'érosion	Regulate erosion	F09, F10
	Tenir le talus	Holding banks	F12
	Tenir le talus des ruisseaux	Holding banks along water streams	F17
	Tient la bordure des fossés et talus	Hold ditches and banks	F18
	Contre l'érosion	Against erosion	F19
Habitat for wild birds (R5)	Abri pour les volatiles (sauvages)	Shelter for volatiles (wild)	F01
	Abri pour les oiseaux (palombes)	Shelter for birds (pigeons)	F02
	Abri pour la faune sauvage	Shelter for fauna	F03
	Vie de l'écosystème (oiseaux)	Life of ecosystems (birds)	F13
	Bénéfique pour les oiseaux	Positive to birds	F14
Habitat for insects (R6)	Equilibre pour les cultures	Maintain a balance for crops	F03
	Refuge pour la biodiversité	Refuge for biodiversity	F04
	Refuge pollinisateurs	Refuge for pollinators	F05
	Abri à insectes	Shelter for insects	F11
Shelter for reared animals (R7)	Abri pour les volatiles (domestiques)	Shelter for volatiles (domestic)	F01
	Abri pour les vaches	Shelter for cows	F05, F11
	Abri naturel pour les animaux	Natural shelter for animals	F09
	Protège les animaux du vent	Protect animals from wind	F09
	Abri pour les vaches (orage)	Shelter for cows (during storms)	F12
	Coupe le vent pour les vaches	Windbreak for cows	F14
	Abri pour les bêtes	Shelter for animals	F18
	Protection pour l'élevage	Protection for rearing	F17
Windbreak effect for crops (R8)	Couper le vent (céréales)	Windbreak (cereals)	F03
	Abri du vent	Protect from wind	F08
	Brise-vent	Windbreak	F11
	Protection naturelle des cultures	Natural protection of crops	F13
	Coupe le vent des cultures	Windbreak for crops	F14
	Effet brise-vent	Windbreak effect	F16
Slow down water flows (R9)	Ralenti l'écoulement	Slow down water flows	F08
	Ralenti l'eau	Slow down water flows	F09
Humus production (R10)	Humus des feuilles	Humus from leaves	F11
Soil aeration (R11)	Racines aèrent le sol	Roots allow soil aeration	F11
Remove nitrates and other chemicals (R12)	Collecteur de nitrates	Collect nitrates	F11
Fill gaps in the visual landscape (R13)	Coupe le vide visuel	Fill visual gaps	F19
Landscape scenic (C1)	Beauté	Beauty	F01
	Esthétique	Esthetics	F02
	Paysage (visuel)	Landscape (visual experience)	F03
	côté visuel	Visual aspect	F04
	Paysage (esthétique)	Landscape (esthetics)	F06
	Aspect visuel	Visual aspect	F07
	Maintien du paysage	Landscape maintenance	F10

	Décoration/ beau	Beautiful	F13
	Joli	Beautiful	F15
	Côté paysager	Landscape interest	F16
	Aspect dans le paysage	(Visual) aspect in the landscape	F19
Visual aspect of wood construction (C2)	plus joli que le fer	(Wood is) more beautiful than iron (for buildings)	F07
Quietness (C3)	Calme	Quietness	F01
Participate in a living countryside (C4)	Campagne plus vivante	More living countryside	F13
Noble aspect (C5)	Noble	Noble	F19
Landmark (C6)	Repère	Mark	F08
	Délimitation des parcelles	Delineation of properties	F10
	Marquage des limites	Mark (properties') boundaries	F17
Biodiversity and ecosystem conservation (C7)	Ecologique	Ecological (advantage)	F02
	Vie de la nature	Life of nature	F06
	Faune	Faune	F07
	Protection de l'écosystème	Protection of the ecosystem	F10
	Protection de l'écosystème et de l'environnement	Protect the ecosystem and the environment	F13
	Biodiversité	Biodiversity	F16
	Vie sauvage	Wildlife	F19
Reserve holdings & patrimony (C8)	Patrimoine	Patrimony	F05
	Préserve un patrimoine	Conserve a patrimony	F13
Economic valorization of least fertile lands (PC1)	Rentabiliser parcelles non cultivées	Make non-cultivated plots profitable	F10
Low management expenses (PC2)	Peu de charges d'entretien	Low management expenses	F10
Additional CAP subsidies (PC3)	Economique (aides PAC)	Economic (CAP subsidies)	F16
	Aides de la PAC	CAP subsidies	F18

Table S4: List of the 25 ‘Rural Forest Negative Contributions’ (FNC) and corresponding ‘disadvantages’ (in French and in English) cited by farmers during interviews.

Rural Forest Negative Contributions (FNC)	**Corresponding disadvantage (French)**	**Corresponding disadvantage (English)**	**Farmers**
Branches damage tractors (MD1)	Casse les rétroviseurs	Break side mirrors	F01
	Dommage au matériel	Damages on material	F01
	Repousses de branches (tracteur)	Branches grow (issue for tractors)	F02
	Branches abîment le matériel agricole	Branches damage agricultural equipment	F05
	Dégâts sur les machines par les branches	Damages on machines caused by branches	F06
	Abîme les machines si pas entretenu	Damage machines if not properly managed	F14
	Abîme les cabines et les rétroviseurs des tracteurs	Damage tractors' cabins and side mirrors	F18
	Abîme les cabines	Damage tractors' cabins	F19
Risks for fences (MD2)	Risque de rupture sur les clôtures	Risk to break fences	F16
	Entretien pour les clôtures	Need to be managed for fences	F19
Risks for buildings (MD3)	Danger pour les bâtiments	Danger to buildings	F12
Roots damage buildings (MD4)	Racines gênent les bâtiments	Roots may damage buildings	F12
Roots obstruct ditches and drains (MD5)	Empêche entretient des ruisseaux	Obstruct water stream management	F07
	Bouche les fossés	Obstruct ditches	F15
	Bouchage des drains dans les fossés	Obstruct drains inside ditches	F16
	Dégâts sur la digue	Damage riverbanks	F17
Expensive management (MD6)	Coût de l'entretien	Management cost	F08
	Coût	Overall cost	F09
Low economic profitability (MD7)	Faible rentabilité	Low profitability	F10
Hinder work with machines (AD1)	Gêne aux manœuvres	Hinder maneuvers	F01, F13, F16
	Gêne le passage	Hinder the way	F02
	Gêne pour la mécanisation	Hinder field mechanization	F03, F04
	Gêne par les branches	Hindering effect of branches	F07
	Contournement avec les engins	Machines have to avoid them	F09
	Obstacle pour le travail des champs	Obstacle to working in fields	F10
	Gêne si pas entretenu	Hinder if not properly managed	F14
	Salissement (empêche l'accès)	Mess the place (preventing the access)	F17
	Gêne pour le travail	Hinder working (in the field)	F18
	Gêne selon là où elles sont	May hinder work (according to their location)	F19
Low accessibility in wet periods (AD2)	Trop d'humidité à l'automne	Too moist during fall season	F15
Additional workload (AD3)	Beaucoup de travail	A lot of work	F03
	Regagne le champ	Spread to fields (if not managed)	F06
	Travail	Workload	F08, F17

	Travail en entretien	A lot of work for managing	F13, F15, F16
Habitat for pests (AD4)	Abri pour les ravageurs	Habitat for pests	F10
	Amène quelques nuisibles	Bring some pests	F11
Overall competition causing yield loss (AD5)	Moins de rendement	Reduced yields	F07
	Empêche développement des cultures	Undermine crop growth	F09, F12
	Rien ne pousse dessous	Nothing grows below	F11
Local root competition (AD6)	Nuisance possible pousse des céréales	Potential harm for crop growth	F04
	Prend de l'eau sur les cultures	Take water from crops	F08
	Perte de rendement pendant l'été	Yield loss in summer	F18
Rainfall interception (AD7)	Moins d'eau pour les cultures	Less water available for crops	F06
Light interception (AD8)	Ombre sur les cultures	Produce shade on cropped areas	F06, F08, F17
Risks for reared animals (AD9)	Gestion pour l'entretien	Required management (for mitigating risks to animals)	F05
	Problème de sécurité (tempêtes)	Security issues (in case of storms)	F08
	Danger pour les vaches	Danger to cows	F12
Occupy surfaces that could be better valorized (AD10)	Surfaces cultivables en moins	Reduce cropped areas	F05
Habitat for the pine processionary (HD1)	Chenilles processionnaires	Pine processionary	F01
Habitat for hornets (HD2)	Nids de frolons	Hornet nests	F04
Risks and inconvenience of leaf falls (HD3)	Feuilles	Dead leaves	F02
	Feuilles (Sali)	Leaves (mess the place)	F07
Mandatory regulation (NC1)	Règlementation trop contraignante	Regulation too restrictive	F05
Uncertainties on future changes in regulations (NC2)	Evolution de la règlementation	Regulation changes	F09
Fewer areas eligible for CAP subsidies (NC3)	Superficie déduite de la PAC	Areas excluded from CAP	F11
People do not understand farmers' need to cut down trees (NC4)	Les gens ne comprennent pas qu'on coupe	People do not understand we cut (trees down)	F19

Supplementary material 2: detailed interview guideline

Interviewer(s): Date:

General individual information

Last name: Age: Id:
First name: Sex: □ M □ F

Postal address:

Phone: (home) ________________________ (cellphone) ________________________

No of children (and age):

Education: ____

Additional job: □ No □ Yes, specify (job name, no of hours per week/month): ____________

1. Information about the farm

Farming system: ____ Organic/conventional: ______

Legislative status: ___________________________ No of work labor: ________________

Surface area: _____________

	2015-2016	2016-2017
Surface area for crops		
Surface area for temporary meadows		
Surface area for permanent meadows		
Livestock **(No of head, type of production)**		

2. Discussion about the farm and rural forests

On the basis of an aerial photograph of the farm and its surroundings, conduct an open-ended discussion with the farmer about the farm and rural forests.

- Point different agricultural plots and ask information about land use, ownership, slope, etc.

Focus on the information that has a link with farm trees or forests and ask further details. Examples: if the farmer cites a problem related to erosion, ask what types of measures have been taken to mitigate this problem, ask if hedgerows or other types of forested areas are effective to mitigate it, etc.

- Point different farm trees (e.g. scattered trees, hedgerows, riverbanks) and ask information about ownership, advantages and disadvantages, management practices

Focus on the terms used by farmers to name the different types of forested areas, and fill the "Spontaneous identification" column of the following table. Keep track on the cited advantages and disadvantages. Ask about the stakeholders who intervene in the management.

- Ask about forest plots and their management: locate each woodlot owned by the farmer on the map, ask information about how it is managed.

Focus on most common forest products (firewood, timber, mushrooms) and ask for other types of advantages and disadvantages. Ask information about the stakeholders who intervenes to harvest firewood and timber.

Notes:

3. Perceptions about rural forests

1) Types of forested areas present on the farm

Notice:

- **Spontaneous identification**: from the information formerly obtained
- **Co-construct typology and definition**: from the spontaneous identification, discuss with the informant the differences between the different types of forested areas in order to reach an agreement on the different type of forested areas and how to distinguish them from one another.

Spontaneous identification	Co-construct typology	Definition / Main characteristics
1- 2- 3- 4- 5-	1- 2- 3- 4- 5-	1- 2- 3- 4- 5-

2) Identification of the main stakeholders, advantages and disadvantages associated with rural forests

Notice:

- **Stakeholders**: Ask the informant for a synthesis of the main stakeholders intervening in the management of rural forests or influencing him/her in the management of rural forests.
- **Advantages**: Ask the informant for a synthesis on the main advantages, benefits and positive outcomes that are important to them associated with rural forests.
- **Disadvantages**: Ask the informant for a synthesis of the main disadvantages, constraints and negative outcomes that are important to them associated with rural forests.

Stakeholders	Advantages	Disadvantages
1- 2- 3- 4- 5-	1- 2- 3- 4- 5-	1- 2- 3- 4- 5-

Notes:

3) Mental model about rural forest management

On stickers, report the following items:

- The different types of forested areas co-construct with the farmer
- The different advantages and disadvantages cited
- The different stakeholders

With the use of the black board, co-construct a mental model with the farmer highlighting the links between: (i) Stakeholders and forested areas; and (ii) forested areas and disadvantages and advantages

Make a final oral synthesis of the mental model and ask for potential missing information or input.

Notes:

4. Use of firewood

No of houses heated with the firewood from the farm: _____ Total no of people : ____

Houses	Heating system	Annual quantity of firewood and other energy sources	% of firewood coming from farm trees and from forests

Main tree species used for firewood:

French name	Local name	Origin (farm tree/forest tree)	Overall quality (from 0 to 10)

Do you sell firewood? □ Yes □ No

Tree species	Origin (farm tree/forest tree)	Annual quantity sold (m^3)	Price (€/m^3)	Customers (type of people, place of residence)

Supplementary material 3: Multiple Correspondences Analyses (MCA)

This document exposes the main analytical steps followed to conduct MCA on the basis of rural forest positive and negative contributions (FPC and FNC) cited by the 19 farmers of our study.
A total of four MCAs were performed to explore variability in farmers' perceptions. For each MCA, we present (i) the dataset used, (ii) the active and supplementary variables that are considered by the MCA, and (iii) the main results.

Results are presented through a short text and 4 figures:

- The "MCA factor map" is the plot of the farmers in the first two dimensions of the MCA (farmers are colored according to farming systems);
- The "graph of the variables" is the plot of the active variables in the first two dimensions of the MCA and highlights 20 most contributing variables;
- The "Supplementary variables on the MCA factor map" is the circle of correlations between supplementary quantitative variables and the MCA two first dimensions. These variables include (for each farmer) the farm surface area (FarmArea), the number of agricultural blocks (Blocks), the number of woodlots (Woods), the total area of woodlots (WoodArea), the farmers' age (Age), the number of FPCs cited during the interview (PCtot) and the number of FNCs cited during the interview (NCtot);
- The eigenvalue screeplot.

In addition, a table highlights the main contributions and correlations observed in the MCA:

- Individuals with Cos2>0.5, which indicates a significant quality of representation of these individuals in the construction of a given MCA axis;
- Active variables with eta2>0.5, which indicates a significant contribution of these variables in the construction of a given MCA axis; eta2 represents the square of the correlation ratio between each variable and each axis;
- Supplementary qualitative variables with eta2>0.5, which indicates a significant qualitative correlation between these variables and the corresponding MCA axis;
- Supplementary quantitative variables with cor>0.3 or cos < -3, which indicates a positive or negative correlation between these variables and the corresponding MCA axis.

Finally, we explain in this document what motivated each MCA. Only the MCA N°4 was presented in the main article as it was considered as the most robust for the following reasons:

- The eigenvalue screeplot shows a net gap after the first two dimensions;
- The analysis is based on a more limited number of variables (due to a low number of observations) than for the other analyses;

- The most rarely cited FPC and FNC are not included to limit issues due to the sensitivity of MCA to rare items.

1. MCA based on all the FPC and FNC cited by farmers

Dataset 1:

A first MCA was performed on the basis of all the FPCs and FNCs cited by farmers. The dataset used was composed with 19 rows (one row for one farmer) considered as 19 observations. Each farmer was characterized by a set of 66 variables, including:

- 57 active variables: these variables corresponded to the 57 FPCs and FNCs identified in this study from the advantages and disadvantages cited by farmers (Table S2 and S3, Suppl. material N°2). For the farmer *i* and the variable *j*, the cell [i,j] received the value "1" if the farmer *i* cited the FPC (or FNC) corresponding to the variable *j*, and "0" otherwise.
- 9 supplementary variables that corresponded to (i) socio-economic characteristics of the farmer and its farm (farmer's age and gender, size of the farm, type of farming system, size of the forest estate) and (ii) two quantitative indicators associated with his/her perceptions (the number of FPCs he/she cited during interviews, and the number of FNCs).

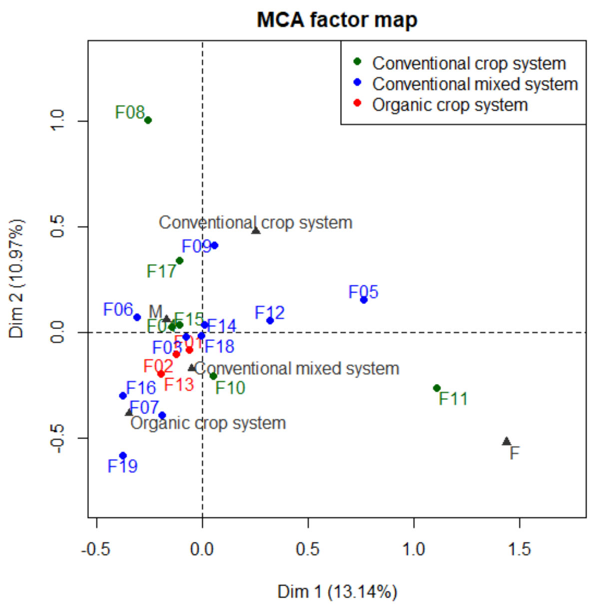
MCA N°1 computing:

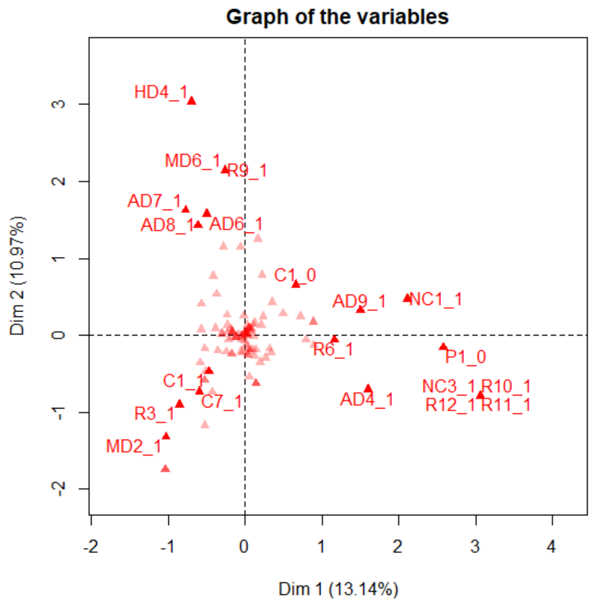
The first MCA was computed on the basis of the 57 active variables. In other words, the MCA studies differences and similarities between farmers only on the basis of the 57 cited FPCs and FNCs. Supplementary variables are used only to study how they correlate with the dimensions of the MCA. Detailed information on the MCA statistical method is available in Husson et al. (2017).

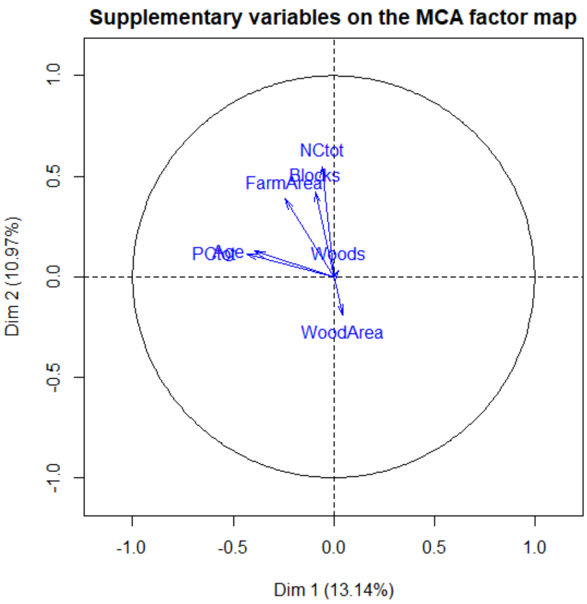
Results of the MCA N°1:

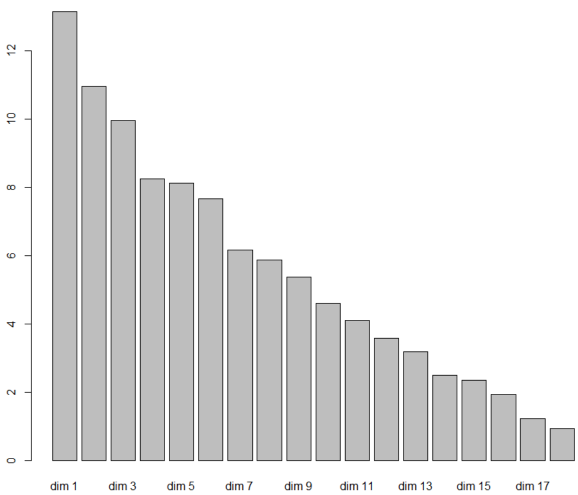
Results are presented in the following figures and table. As expected due to the sensitivity of MCAs to rare items, variability is mostly driven by the FPCs and FNCs that were rarely cited by farmers (such as R10, R11 and NC3 that were each reported by one farmer).

In order to reduce the influence of these rarely cited items, we therefore conducted a second MCA without them.









MCA N°1	Dim 1 (13.14%)		Dim 2 (10.97%)	
Individuals (main contributors)	**Id**	**Cos2**	**Id**	**Cos2**
	F08	0.612	F08	0.671
Active variables (main contributors)	**Id and name**	**Eta2**	**Id and name**	**Eta2**
	P1-firewood R2-oxygen and air quality R10-humus production R11-soil aeration NC3-less area eligible to the PAC	0.782 0.518 0.518 0.518 0.518	MD6-expensive management HD4-risk for humans R9-slow down water flows	0.541 0.513 0.541
Supplementary qualitative variables (main correlations)	**Name**	**Eta2**	**Name**	**Eta2**
	-	-	-	-
Supplementary quantitative variables (main correlations)	**Name**	**Cor**	**Name**	**Cor**
	No of cited FPC Farmer's age	-0.433 -0.394	No of blocks Farm area No of cited FNC	0.424 0.387 0.546

2. MCA based on the FPC and FNC cited by at least two farmers

Dataset 2:

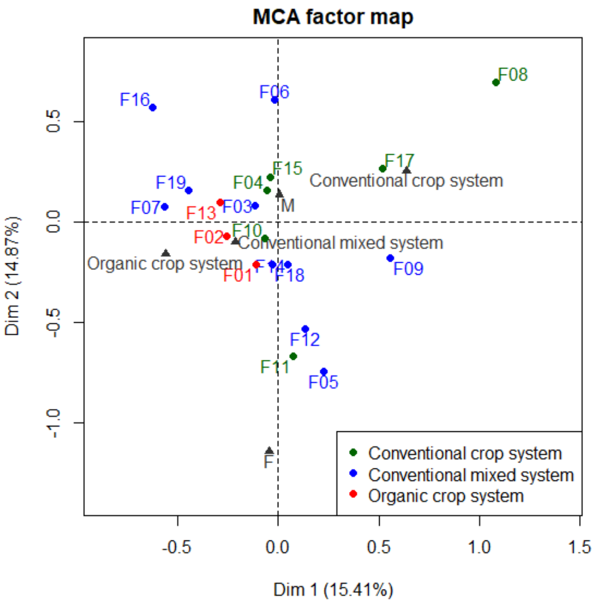
A second MCA was performed on the basis of the FPCs and FNCs cited by at least two farmers. This choice was motivated by the sensitivity of MCAs to rare items highlighted in the first MCA. We therefore chose to remove from the analysis the FPCs and FNCs cited only once, which concerned a total of 12 FPCs and 12 FNCs (see Table 2 in the article). Our new dataset was therefore composed with 19 rows (one row for one farmer) characterized by a set of 42 variables, including:

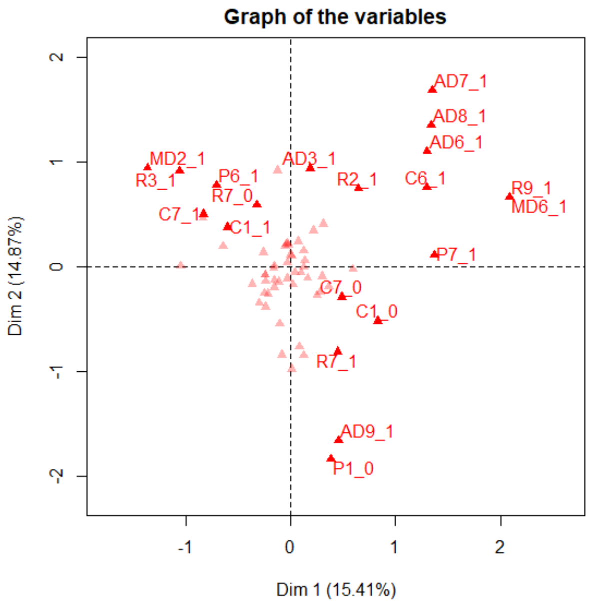
- 33 active variables: these variables corresponded to the 33 FPCs and FNCs cited by at least two farmers.
- 9 supplementary variables (the same as in Dataset 1)

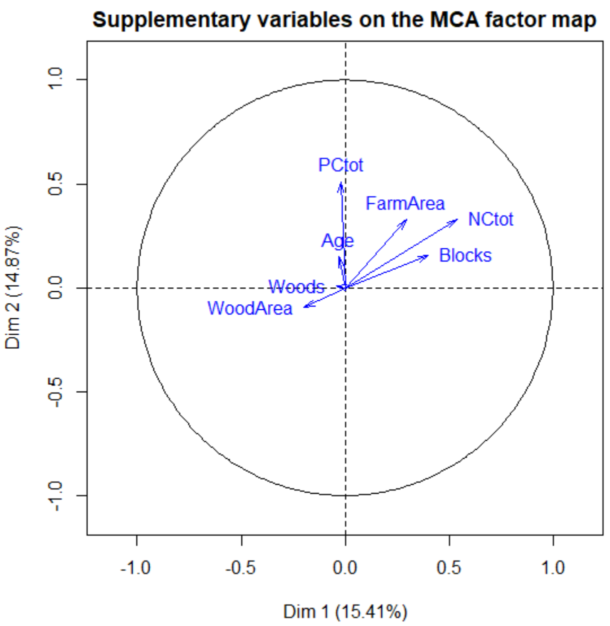
Results of the MCA N°2:

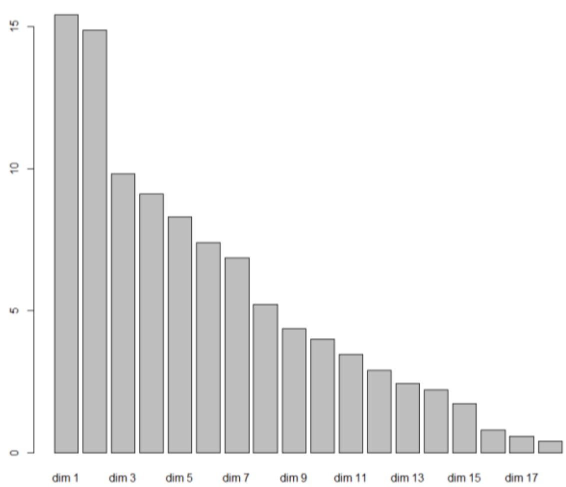
Results are presented in the following figures and table. This analysis showed the contribution of two FPCs (R9 and C1) and two FNCs (MD6 and AD3) in the construction of the two first axes. Similarly, the MCA N°1, MCA N°2 identified F08 as an outlier. Moreover, it also showed the correlation of the size of the farm (No of farm blocks and farm area) and of the total number of cited FNCs and FPCs with the first two dimensions.

These results suggest that farmers with a larger farm (or in a conventional farming system) tended to cite more FNCs than farmers with a smaller farm.









MCA N°2	Dim 1 (15.41%)		Dim 2 (14.87%)	
Individuals (main contributors)	**Id**	**Cos2**	**Id**	**Cos2**
	F08	0.579	-	-
Active variables (main contributors)	**Id and name**	**Eta2**	**Id and name**	**Eta2**
	MD6-expensive management R9-slow down water flows C1-landscape scenic	0.513 0.513 0.501	AD3-additional workload	0.514
Supplementary qualitative variables (main correlations)	**Name**	**Eta2**	**Name**	**Eta2**
	-	-	-	-
Supplementary quantitative variables (main correlations)	**Name**	**Cor**	**Name**	**Cor**
	No of blocks No of cited FNC	0.400 0.539	No of cited FPC No of cited FNC Farm area	0.511 0.328 0.327

3. MCA based on the classes of FPC and FNC

Because of the low number of observations (19 farmers) compared to the high number of active variables (33 FPCs/FNCs for the MCA N°2), we performed additional MCA on the basis of the classes of FPC and FNC. Indeed, using classes of FPC and FNC instead of FPCs and FNCs themselves allowed reducing the number of variables used to describe farmers from 57 (Dataset 1) to 31 (Dataset 3).

Dataset 3:

A third MCA was performed on the basis of the classes of FPC and FNC associated with farmers' perceived FPCs and FNCs (see Table 2 in the article). The dataset 3 was therefore composed with 19 rows (one row for one farmer) characterized by a set of 40 variables, including:

- 31 active variables: these variables corresponded to the 31 classes of FPC and FNC defined in the Table 2 of the article. For the farmer *i* and the variable *j*, the cell [i,j] received the value "1" if the farmer *i* cited at least one FPC (or FNC) belonging the class corresponding to the variable *j*, and "0" otherwise.
- 9 supplementary variables (the same as in Datasets 1 and 2)

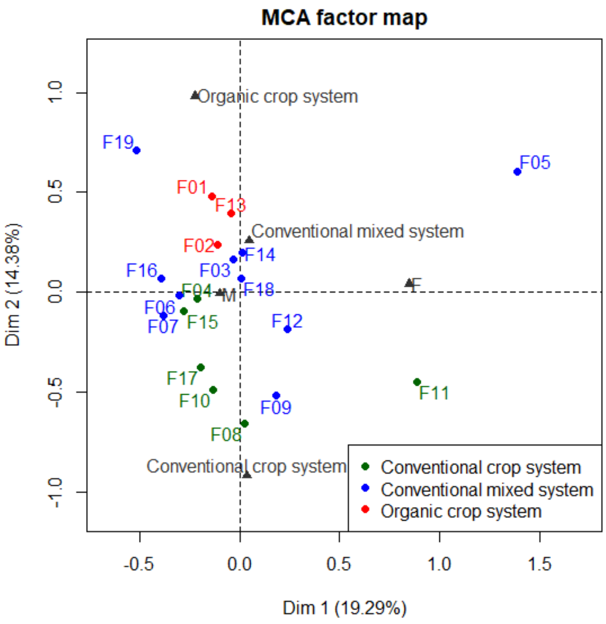
Results of the MCA N°3:

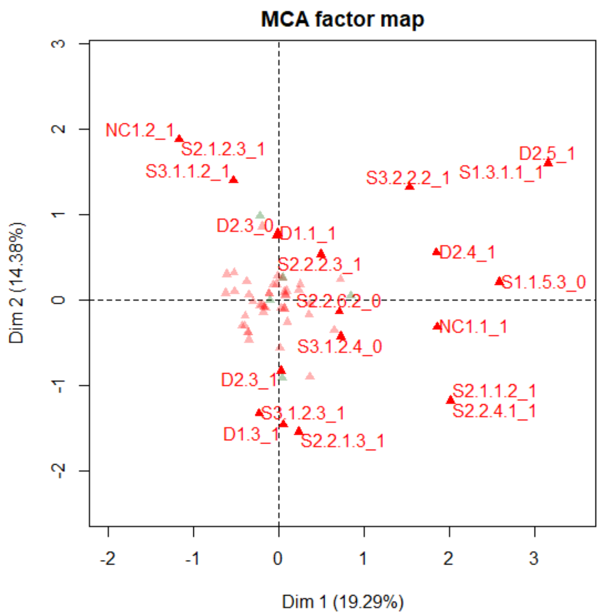
Results are presented in the following figures and table.

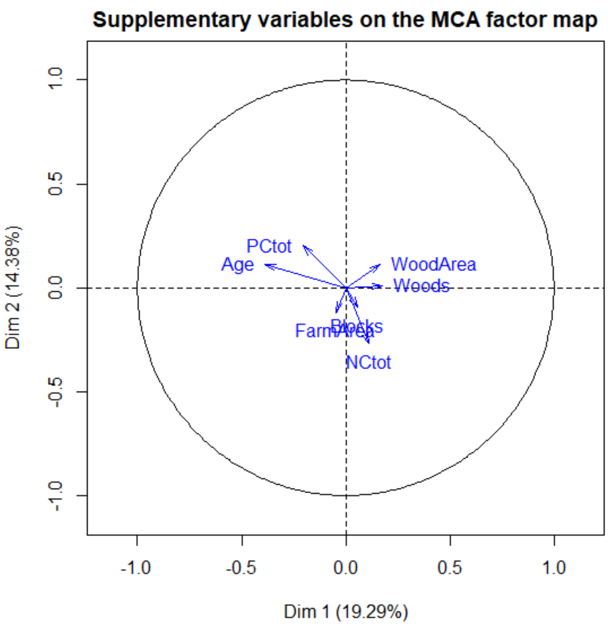
F05 was identified as the main contributor of the axis 1.

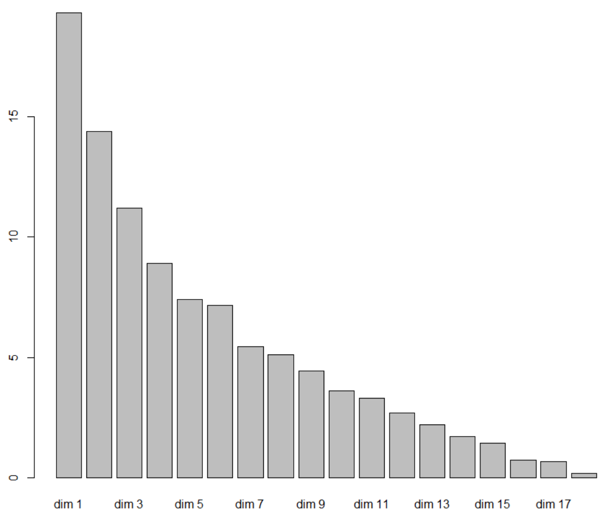
Main contributing variables to the two first axis were relative to 2 classes of FPC and 3 classes of FNC.

The only supplementary variable that tended to correlate with the MCA axes was the farming system.









MCA N°3	Dim 1 (19.29%)		Dim 2 (14.38%)	
Individuals (main contributors)	**Id**	**Cos2**	**Id**	**Cos2**
	F05	0.715	-	-
Active variables (main contributors)	**Id and name**	**Eta2**	**Id and name**	**Eta2**
	D2.5-competition for land S1.1.5.3-wild plant for energy S1.3.1.1-biomass for agriculture NC1.1-leglislative constraints	0.554 0.787 0.554 0.650	D2.3-decrease in crop production	0.514
Supplementary qualitative variables (main correlations)	**Name**	**Eta2**	**Name**	**Eta2**
	-	-	Farming system	0.455
Supplementary quantitative variables (main correlations)	**Name**	**Cor**	**Name**	**Cor**
	-	-	-	-

4. MCA based on the classes of FPC and FNC cited at least twice

Finally, in order to take into account the sensitivity of MCAs to rare items, we performed a fourth MCA on the basis of the classes of FPC and FNC cited by at least two farmers. This MCA is the one presented in the main article.

Dataset 4:

A fourth MCA was performed on the basis of the classes of FPC and FNC cited by at least two farmers. We removed from the dataset 3 the classes FPC and FNC cited only once, which concerned a total of 6 classes of FPC and FNC (see Table 2 in the article). The dataset 4 was therefore composed with 19 rows (one row for one farmer) characterized by a set of 34 variables, including:

- 25 active variables: these variables corresponded to the 25 classes of FPC and FNC cited by at least two farmers. 9 supplementary variables (the same as in all previous Datasets)

Results of the MCA N°4:

Results of the MCA are presented in the following figures and table, as well as in the main article.

The main observation that contributes to the first axis is F05.

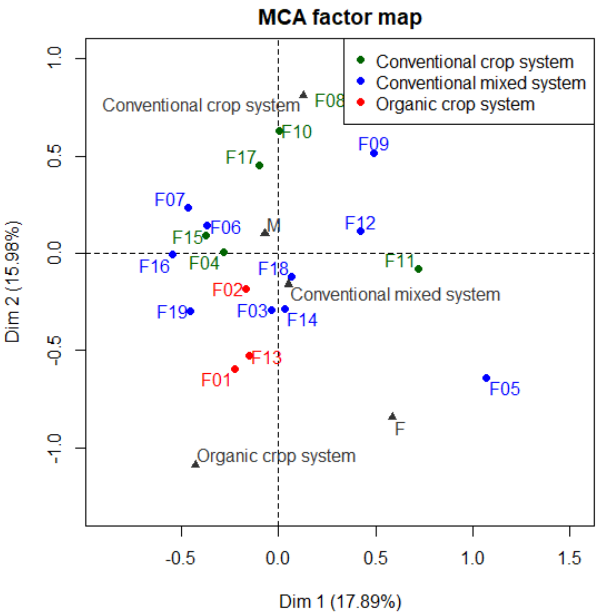
The active variables contributing to the first two dimensions of the MCA are 2 classes of FPC and 3 classes of FNC.

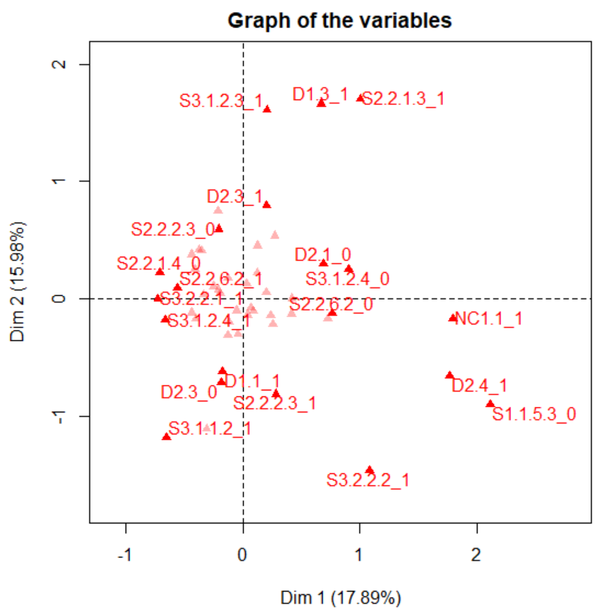
Finally, four supplementary variables tended to correlate with the axes displaying the highest variability observed in farmers' perceptions. Three of these were associated with socio-demographic characteristics (farm area, farming system and farmer's age) while one was the number of FNCs cited during interviews.

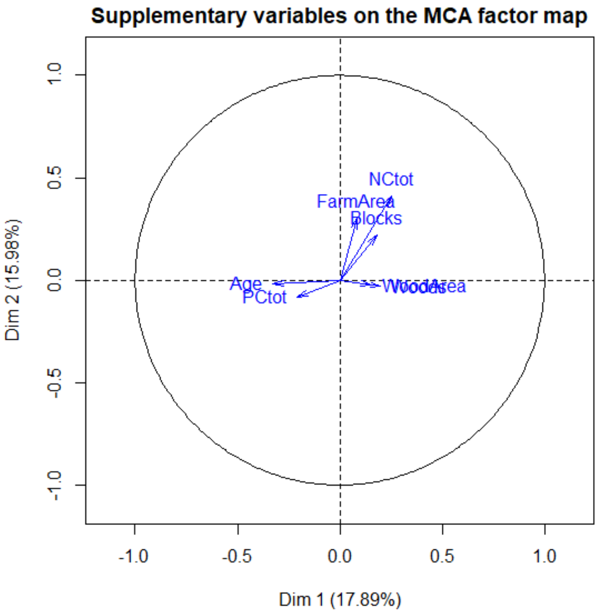
Results corroborate previous MCAs and indicate an influence of the farming system and farm area on farmers' perceptions.

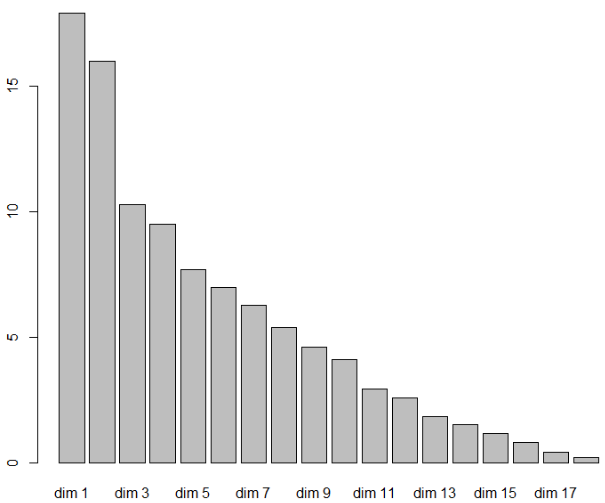
References

Husson, F., Lê, S., Pages, J., 2017. FactoMineR: Multivariate Exploratory Data Analysis and Data Mining.









MCA N°4	Dim 1 (17.89%)		Dim 2 (15.98%)	
Individuals (main contributors)	**Id**	**Cos2**	**Id**	**Cos2**
	F05	0.609	-	-
Active variables (main contributors)	**Id and name**	**Eta2**	**Id and name**	**Eta2**
	S1.1.5.3-wild plant for energy S3.1.2.4-aesthetic experiences NC1.1-leglislative constraints	0.527 0.596 0.607	D2.3-decrease in crop production D1.3-economic costs	0.570 0.517
Supplementary qualitative variables (main correlations)	**Name**	**Eta2**	**Name**	**Eta2**
	-	-	Farming system	0.408
Supplementary quantitative variables (main correlations)	**Name**	**Cor**	**Name**	**Cor**
	Farmer's age	-0.327	Farm area No of cited FNC	0.302 0.411