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Exploration of synergies and trade-offs between ecosystem services on farms in France's marshy Atlantic coastal area

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Exploration des synergies et arbitrages entre services écosystémiques au sein des exploitations agricoles : application au cas des marais littoraux atlantiques.

Exploration of synergies and trade-offs between ecosystem services on farms in France's marshy Atlantic coastal area

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Soutenu à Rennes le 12 septembre 2018

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List of abbreviations

CAP: Common Agricultural Policy

CEC: Cationic Exchange Capacity

CICES: Common International Classification of Ecosystem Services

EFESE: french assessment of ecosystems and ecosystem services (Evaluation Française des Ecosystèmes et des Services Ecosystémiques)

ES: Ecosystem Services

GHG: GreenHouse Gas

ISI: Institute for Scientific Information

OM: Organic Matter

N: Nitrogen

1. Introduction and literature review

Since industrial and intensive farming systems are reaching their limits (Griffon et al., 2011), agroecological systems are increasingly being explored with a view to developing solutions to environmental and socio-economic problems (Wezel et al., 2009).

Agroecological systems aim at favouring sustainable use of natural resources and replacing the use of synthetic inputs by ecosystem services (ES). This concept of ES was defined by the Millennium Ecosystem Assessment (MEA, 2005) as “the benefits people derive from ecosystems”. As there are multiple ES (provisioning, support, regulation and cultural), the main challenge of agroecological systems lie in the joint provision of diversified ES including support for sufficient agricultural production.

In order to design production systems balancing the different ecosystem services with agricultural production, a strong challenge for research is therefore to understand the relationships between the different ES and the way farming activities impact them. Currently, relationships between ES are often considered either at plot level or at large levels (landscape, region, country, continents, Seppelt et al., 2011). However, the plot level is often too small to properly capture ecological processes. On the other hand, as organization level increases so does degree of complexity in management. Indeed, decisions influencing ES provision at landscape or regional levels depend on many stakeholders (i.e. decision-makers in landscape planning, farmers, industries, citizens, etc.). To overcome these limitations, farm level seems to be a relevant level of organization that combines benefits of both plot and landscape levels: decisions depend on only one stakeholder (i.e. the farmer) and there are levers to overcome trade-offs due to complementarity among farm aspects. There is however little knowledge on ES provision at farm level whereas farmers make prime decisions concerning ES management.

Hence, the objective of this work was first to **understand synergies and trade-offs occurring at farm level and then to identify levers to overcome trade-offs.**

Specifically, our study will focus on crop-livestock farming systems in French Atlantic marshy coast area. Firstly, definitions and classification issues will be addressed through a preliminary literature review. Secondly, we combined two complementary approaches to understand the relationships between ES: (i) a scan of relationships between ES through a systematic literature review, (ii) a phase of interviews to delve into a specific context. We finally construct a transversal analysis to compare the results of literature review with the farmers' perception.

1.1. Classification of ecosystem services

The various reviews and articles on the subject show that different authors have classified ES in different ways. These classifications often overlap but show differences that deserve to be carefully considered and analysed before choosing an approach. Costanza et al. (2017) compared ES classifications of the Millennium Ecosystem Assessment (MEA, 2005), Costanza et al. (1997), the Economics of Ecosystems and Biodiversity (TEEB, 2010) and the Common International Classification of Ecosystem Services (CICES, 2017). These classification systems all split services into four groups: provisioning, regulating, supporting and cultural.

Provisioning services

These ES represent material or energy outputs from ecosystems. They encompass food production, fresh water supply and raw materials (fibre, energy, etc.). Other resources like genetic, ornamental and medicinal resources are mentioned in most classifications.

Regulating services

These ES refer to ecological processes that enable ecosystem regulation. They include air quality regulation, climate regulation, disturbance regulation (natural hazards), water regulation, waste treatment, erosion control, pollination and biological control (pest and diseases). Soil formation and maintenance of soil fertility are also mentioned in most systems but are considered by the MEA as supporting services.

Supporting services

These ES refer to habitat for species and biodiversity maintenance. Hence, the only common supporting service among classification is biodiversity maintenance. In this respect, nutrient cycling is mentioned by Costanza et al. (1997) and by the MEA (2005). Photosynthesis and primary production are also considered by the MEA (2005) as supporting services. Additionally, gene pool protection is mentioned by the TEEB (2010) and the CICES (2007).

Cultural services

This category includes recreational activities, eco-tourism and aesthetic values. The MEA and the TEEB also considered cultural services such as spiritual and educational values.

Another classification has been established by the EFESSE programme led by INRA (2017). It is quite close to the above classifications except that there are only three categories of ES: provisioning, regulation and cultural services. Support services are not taken into account because biodiversity maintenance is considered not as a service but as a biophysical driver of ES. An additional difference

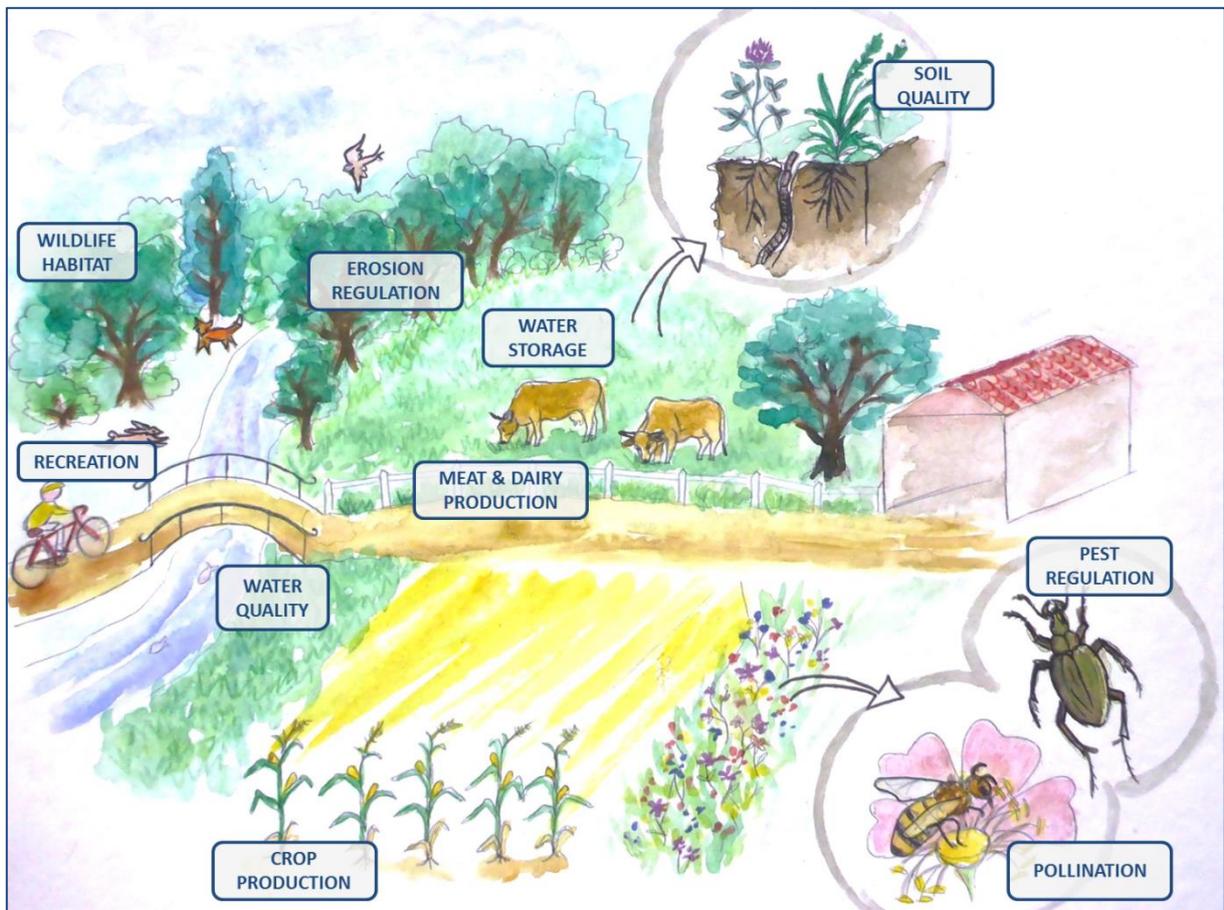


Figure 1 : Illustration of ecosystem services at farm level (by Cécile Richard in July 2018)

concerns provisioning services which include nutrient production but not food production, because it is viewed as a result of interactions between regulation services and anthropogenic inputs. In this case, regulation and cultural services in the EFSE classification are similar to those of the CICES and the TEEB.

Zhang et al. (2007) suggest a different classification of ES that includes both ES and dis-services to and from agriculture. Supporting and regulating ES provided by natural ecosystems are ES to agricultural ecosystems whereas provisioning and non-marketed services are ES from agricultural ecosystems. This classification is close to that of the MEA, apart from the category “non-marketed services” composed by water supply, soil conservation, climate change mitigation, aesthetic landscapes and wildlife habitat. Moreover, pest damage and competition for resources are considered as ecosystem dis-services to agroecosystems whereas habitat loss, nutrient runoff and pesticide poisoning are dis-services from agricultural ecosystems. Finally, ecosystem dis-services caused by agriculture have a self-reinforcing feedback effect on ecosystem dis-services by enhancing them and on ES by decreasing them (e.g. habitat loss for pests’ natural enemy can cause a plague of pests). After familiarizing ourselves with these different frameworks, the classification that we chose to fit our objectives was mainly based on the CICES classification ([appendix A](#)) which provides a broad basis for studying ES. We however modified it by deleting some ES (e.g. plants cultivated by aquaculture) or adding others depending on the study context (e.g. heritage species conservation). Hence, in our classification we considered that:

- Provisioning services include feed and food production (meat, dairy, crops) as we focused on the farm scale and our interview approach was to take into account all aspects of food production. This category also includes fresh water supply and raw materials.
- Regulation services combine both support and regulation ES because the distinction between them may not always be evident.
- Cultural services consist of recreation, education, religious use (i.e. nature can be considered as sacred and associated with religious customs), cultural heritage and aesthetic values.
- Dis-services to and from agriculture are taken into account. Regulation of pest, weeds and disease are considered as ES because they counter dis-services to agriculture. Likewise, levers for human-induced pollution mitigation are addressed because they alleviate dis-services from agriculture.

Major ES such as crop production (i.e. forage and grain) for animal feed, meat and dairy provided by cattle, soil quality reliant on soil fauna and nutrient cycling, water storage enabled by pastures and recreational services related to landscape maintenance, are illustrated ([figure 1](#)) to provide a clearer picture of which ES were provided at farm level in French Atlantic marshy coast area.

1.2 Different study approaches to interactions between ES

Overall, many papers focused on one or several ES but relationships between them were not systematically described.

In the MEA (2005), ES were mostly considered individually for their impact on human well-being, although some parts of the report also deal with interactions between ES. Various other approaches were also found: some authors studied ES two-by-two (Bennett et al., 2009; Birkhofer et al., 2015) while others have considered them as bundles which are “sets of services that appear together repeatedly” (Raudsepp-Hearne et al., 2010).

Different types of interactions were also considered: interactions between drivers (MEA, 2005; Birkhofer et al., 2015) and between ES; trade-offs between ES (Zhang et al., 2007; Rodriguez et al., 2006); and both synergies and trade-offs between them (MEA, 2005; Bennett et al., 2009; Raudsepp-Hearne et al., 2010; Tichit et al., 2012; Howe et al., 2014; Dumont et al., 2016; Geertsema et al., 2016).

1.3. Synergies and antagonisms

First, it was necessary to understand authors’ definitions of synergy, antagonism and trade-off. This was a base to choose our own vocabulary for this study. Secondly, we suggested a typology for drivers underlying synergies and trade-offs.

Definition of concepts by authors

From one author to another, situations of synergism were defined differently. According to the MEA (2005), there are synergies between ES when the resulting effect is larger than the sum of each ES effect. So ES can be bound by positive or negative synergies depending on the overall effect, respectively beneficial or adverse. This is also the perspective of Raudsepp-Hearne et al. (2010) in their analysis, whereas Bennett et al. (2009) consider synergies as positive or neutral interactions between ES. Likewise, Geertsema et al. (2016) perceive synergies as win-win situations.

Concepts of antagonism and trade-off were clearly distinguished by Dumont et al. (2016). Antagonisms between ES occur when the supply of one or several services is penalized by the supply of other services. This can be a consequence of biophysical interactions among ES (Kremen and Miles, 2012) or due to time variability in services supply (Koch et al., 2009), or else to spatial coincidence (Ryschawy et al., 2015). Trade-offs on the other hand depend on the stakeholders concerned by the provision of ES (Howe et al., 2014) and on political decisions. However, antagonism was often combined with the notion of trade-off (MEA, 2005; Rodriguez et al., 2006; Bennett et al., 2009).

In this case, a trade-off referred to a situation where some services were favoured – intentionally or not – over other services.

As Haase et al. (2012) reported in their analysis framework, others are also used. In Bennett et al. (2009) and Geertesema et al. (2016), synergies are considered as win-win situations and trade-offs as win-lose or lose-win situations. But Haase et al. also define the following situations: win-no change when there is an improvement for one ES and no change for the others; lose-no change when there is a decline in one ES and no change for the others; loss when there is a mutual decline in ES and finally; and finally no change.

Thus, there was no consensus in vocabulary used to study relationships between ES.

Choice of vocabulary

Hence, it was necessary to precise the vocabulary selected for our study. Even though expressions “win-win”, “win-lose”, “win-no change” and “lose-no change” were more rigorous, we chose to keep key words that were more appropriate to our subject and more often encountered in literature. Thus, from the biophysical perspective we used “synergy” to refer to situations where several ES were influenced in the same way (positively or negatively) and “antagonism” to refer to situations where ES were impacted concurrently in different way. From the ES management perspective, “trade-off” referred to situations where the farmer chose to favour one or another ES between antagonistic ES. In other words, an antagonism between several ES leads to a trade-off from the moment when the farmer decides which ES to favour.

Drivers of synergies and trade-offs

Beside the question of relationships between the different ES, some authors looked for the drivers underlying these relationships. A typology was suggested by Gonzalez-Esquivel et al. (2015) who put forward 3 types of drivers: agricultural practices (e.g. grazing management, fertilization, seeding), land use management (e.g. crop rotation, crop association) and management regime (organic or conventional regime). We drew on this typology and considered that our study was not concerned by the third type (i.e. management regime). Moreover, we completed it with another type of driver covering practices related to non-production areas (e.g. introduction of grass strips, hedges, ponds). Hence, we considered 3 types of drivers: agricultural practices, land use management and non-production areas.

Table 1: Search queries used on ISI Web of Knowledge (A. Courcier)

#1: TS= (farm* OR agricultur* OR "agricultural land*" OR "arable land*" OR "farming land*" OR "cultural land*" OR "arable field\$" OR "crop farm\$" OR "livestock farm*" OR "meadow land*" OR "agroecosystem\$" OR "agro-ecosystem\$" OR "agrosystem\$" OR "agro-system\$" OR "integrated system\$" OR "farming system\$" OR "production system\$" OR "crop* system\$" OR pasture\$ OR grassland\$ OR meadow\$ OR "grass field\$" OR "prairie landscape\$" OR graz* OR rangeland\$ OR pastoral* OR "land use" OR "land-use" OR "field use")
#2: TS= ("ecosystem service\$" OR "ecosystem good\$" OR "environmental service\$")
#3: TS= farm*
#4: TS= (synerg* OR "win-win" OR benefi* OR "co-benefi*" OR "win-no lose" OR "trade-off\$" OR tradeoff\$ OR "trade off\$" OR compromise\$ OR antagonis* OR arbitra* OR driver\$ OR Pareto)
#5: TS= (wetland\$ OR "wet land\$" OR "wet area\$" OR swamp\$ OR marsh* OR floodplain\$ OR "flood plain\$" OR "alluvial plain\$" OR "wet meadow*" OR "wet grassland*")
Final query: #5 AND #4 AND #3 AND #2 AND #1

2. Methodology

2.1. Methodology for literature review

The aim of the literature-based search was to find articles where relationships between ES were studied and had resulted in synergies and/or trade-offs. The database searched was ISI Web of Knowledge, an information gateway composed of several electronic bibliographical databases.

Relevant terms and words were collected from the first step of the literature review (i.e. review summarized in introduction) in order to build search queries that were compatible with the ISI Web of Knowledge.

Constructed queries focused on i) agricultural systems, ii) ecosystem services, iii) relationships between services and iv) wetland environments (table 1). Within each query, terms were separated by the Boolean operator “OR” (i.e. resulting in an inclusive disjunction) so we added another query to insist on agricultural subject area (table 1), knowing that those 5 queries were combined with the Boolean operator “AND” (i.e. resulting in a conjunction).

The conjunction of the 5 queries yielded 106 results (database was queried on the 26th June 2018). The first step was to scan titles and abstracts in order to select significant papers. Criteria of selection included organization level (landscape, farm or plot/field) and a direct relation to agriculture, and excluded studies focused only on land use planning and policies, or that covered mainly ES by an economic or sociological approach. In the end, 26 articles were selected.

We then extracted information from these 26 papers and 7 additional articles found previously during preliminary literature review. Information was collected with a reading grid, the purpose of which was to capture information such as organization level, studied drivers, their effects on ES and resulting antagonisms and synergies between them (appendix B). An extra row was used to add comments when information could not be captured by determined categories, for instance we could specify that crop association enhanced pest regulation especially for phytophageous insects and airborne diseases. All papers were recorded on the same spreadsheet to facilitate comparison among them. This grid provided a basis for analysis using Excel functionalities such as filters and graphics construction.

2.2. Methodology for interviews

In order to complete the review of literature, a set of interviews was conducted with farmers so as to analyze the relationships between ES in the specific context of crop-livestock farming systems in French Atlantic marshy coast area. First, the objectives of the questionnaire were to identify ES on the farm and the relationships between them (i.e. antagonism and synergy), trade-offs made through practices and land use, incentives and consequences of the farmer's choices, and finally the mitigation levers of trade-offs between production services and other types of services.

These objectives had to be translated into questions to put to the farmer. As the framework of ES mainly emerged from the scientific field and was not likely to be familiar to farmers, it was decided not to use this term during interviews, but rather to speak about the benefits of agricultural production for society in general.

The first version of the questionnaire was tested with the farm manager within the research laboratory of Saint-Laurent-de-la-Prée. This preliminary interview enabled to improve its fluidity and consistency. Finally, the questionnaire ([appendix C](#)) consisted of an introduction to capture i) objectives and present interview progress, ii) a general description of the farm, iii) a discussion on practices and decision making in eight areas (choice of crop rotation, soil fertility management, water management, weeds control, pest and disease regulation, animal feeding, animal health management and landscape maintenance), and lastly iv) a conclusion summing up the interview and affording an opportunity to the farmer to examine a specific topic in greater depth or to expand on others.

Initial contact was made with local farmers (i.e. within a 70-kilometer radius) by postmail to explain the purpose of the study. They were then contact by phone to make an appointment. The farmers in question had previously been approached by our research laboratory of Saint-Laurent-de-la-Prée for an inquiry, except for one farmer whose contact details were supplied by one of his peers. A total of 8 farmers were interviewed within the departments of Charente-Maritime and Deux-Sèvres. There were 5 suckler cow and 3 dairy cow production systems, all of which were crop-livestock farming systems. Regarding the type of agriculture, 6 farms were conventional, one organic and one transitioning to organic farming.

Each interview lasted from an hour and a half to 4 hours. They were recorded on a dictaphone and by note-taking when possible. The records were listened to and relevant information was transcribed. The analysis aimed at translating farmers' speech into synergies and antagonisms between ES, and identifying drivers of farmers' decisions that resulted in trade-offs. Interviews furthermore enabled to collect verbatim phrases to illustrate the results analysis.

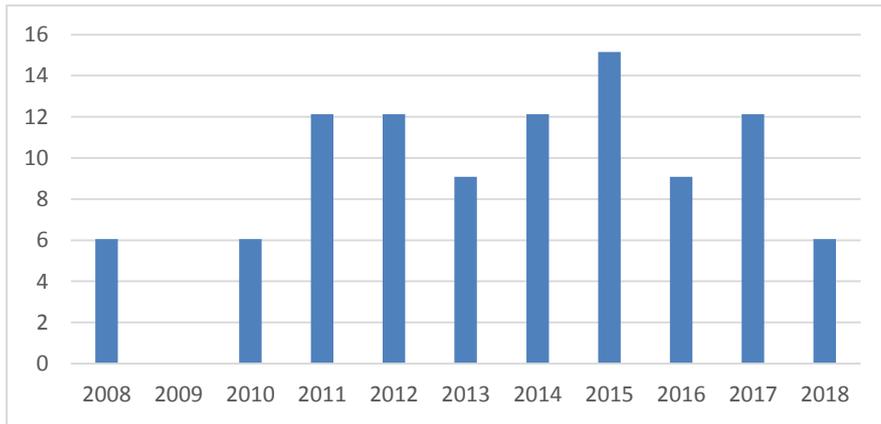


Figure 2: Publication of the 33 papers over time (in %) (A. Courcier)

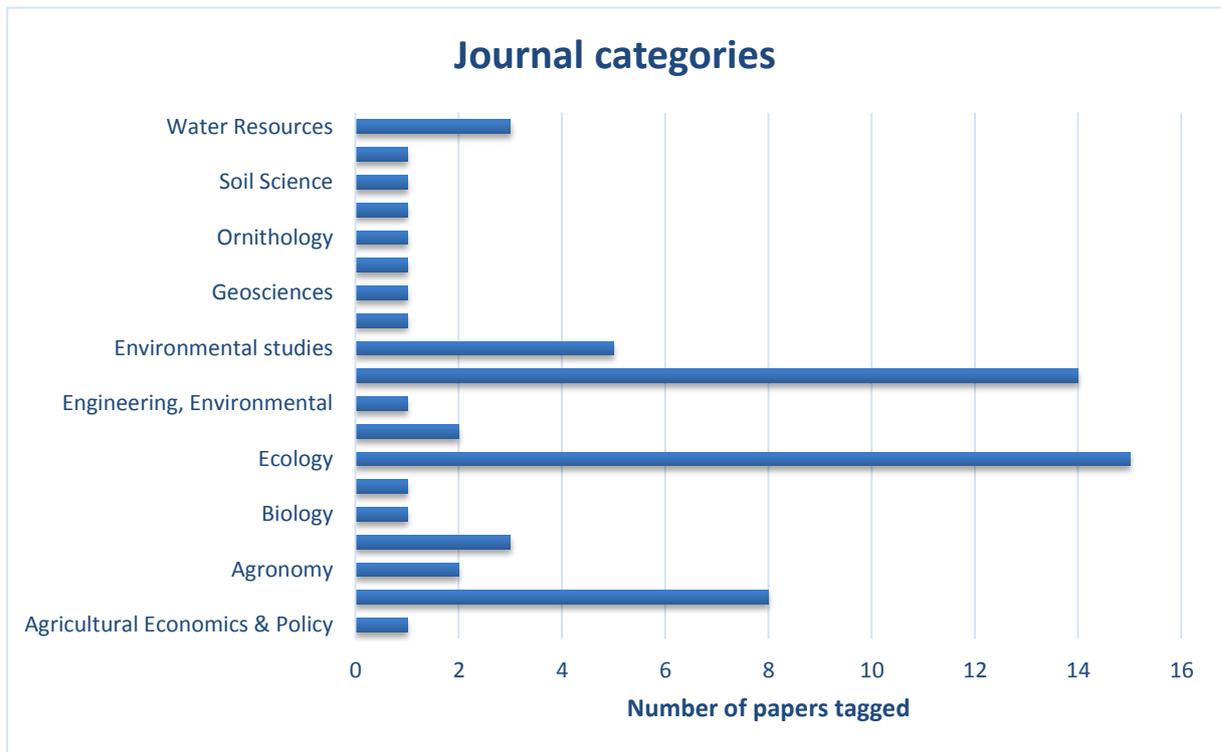


Figure 3: Number of papers per journal category (A. Courcier)

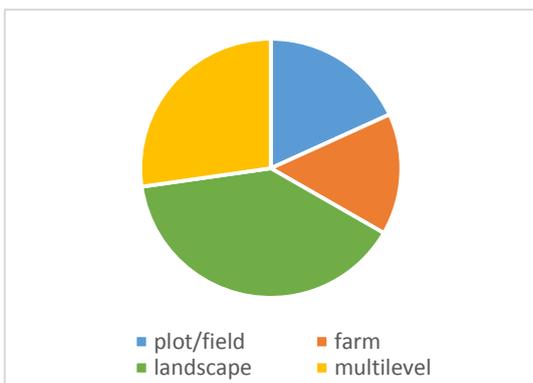


Figure 4: Distribution of publications per organization level (A. Courcier)

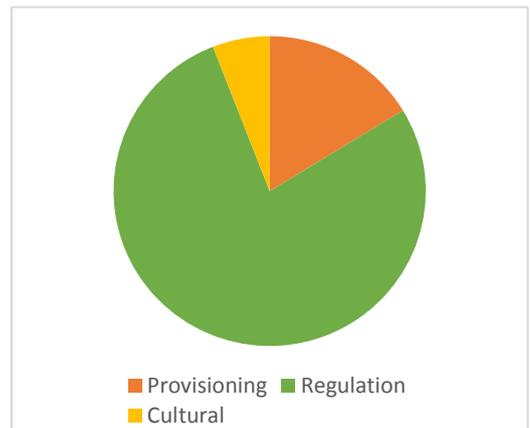


Figure 5: ES studied per category (A. Courcier)

3. Results

3.1. Results of the literature search

3.1.1. Overview of the corpus

Publication features

This corpus of 33 articles was published between 2008 and 2018. Publications were relatively constant over time (figure 2) but the corpus size was not large enough to extrapolate. This sample of 33 articles came from 24 different journals, and primarily from *Agricultural Systems*, *Agriculture, Ecosystems and Environment*, *Ecology and Society* and *Science of the Total Environment*. In order to identify the main fields of knowledge related to the corpus, Web of Science Categories tagged with cited journals were scanned (one paper could be tagged with one or several Web of Science Categories). Among the 19 fields found, Ecology, Environmental Sciences and Agriculture were the most common. But there were also more unexpected fields of knowledge like Ornithology, Water Resources and Geosciences (figure 3).

Levels of organization

The three main levels of organization studied were the landscape level (13 articles), the plot (i.e. from few square meters to several hundred square meters) or field level (6 articles), and the farm level (5 articles). Other papers covered several levels, so they were categorized as “multilevel approach” (9 articles). Clearly, the landscape level was the most frequently adopted by authors (figure 4), which is coherent given the large scale at which most ecological processes occur.

Types of services and drivers

Within these 33 articles, 270 ecosystem services were inventoried and sorted according to the chosen classification. Regulation services represented nearly 80% of them, while cultural services accounted for only 6% (figure 5). Finally, among the different drivers identified in the literature as having an effect on services, more than half were agricultural practices and the rest were evenly distributed between land use drivers and semi-natural areas drivers (figure 6). This illustrates the strong bias in the way different aspects of ES are covered by the literature.

Which level for which type of ecosystem services?

For each organization level, we counted articles dealing with each ES category. In order to refine regulation service designation, this category was divided into 7 groups: water quality; soil quality; pest, disease and weed regulation; baseline flow regulation; pollination; habitat and biodiversity; air and climate regulation.

Table 2 shows that habitat and biodiversity services were the most commonly studied regardless of organization level. It therefore seems that farm level was prone to exploration of provisioning

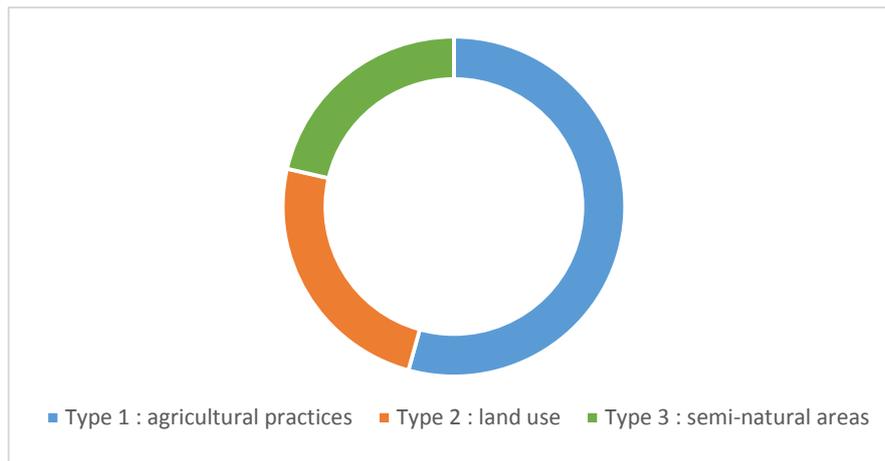


Figure 6: Types of driver (A. Courcier)

Table 2: ES studied according to each level (A. Courcier)

ES / level	plot/field	farm	landscape	multilevel
provisioning	4	5	7	4
cultural	1	0	4	3
water quality	2	3	4	2
soil quality	4	3	3	5
pest/disease/weeds	0	1	2	4
baseline flows	3	3	6	5
pollination	1	0	1	4
habitat/biodiv	6	4	11	8
air and climate	2	1	5	3
total	6	5	13	9

Table 3: ES studied according to each driver (A. Courcier)

ES / driver	Agricultural practices (1)	Land use (2)	Semi-natural areas (3)
provisioning	20	18	5
cultural	4	9	3
water quality	13	8	8
soil quality	19	20	4
pest/disease/weeds	1	13	3
baseline flows	19	16	5
pollination	1	3	2
habitat/biodiv	39	9	16
air and climate	7	5	2
total	123	101	48

services as all articles at farm level dealt with this category. Finally, cultural services were treated essentially at landscape level and in a multilevel approach, which probably means that those approaches are the most appropriate for such services. In more general terms, articles at the plot/field and farm levels covered regulation and provisioning services quite evenly, but neglected cultural services. Conversely, the landscape and multilevel approach primarily covered the regulation category, followed by the provisioning and finally the cultural categories.

For the plot/field level, all 6 articles covered habitat and biodiversity services whereas pest, disease and weed regulation was not mentioned (table 2). Provisioning services were found in 4 articles and cultural services in only one article.

At farm level, the 5 articles covered provisioning services but none of them considered cultural services (table 2). Among regulation services, habitat and biodiversity was the most studied, and pollination was not considered.

At the landscape level, 4 articles out of 13 dealt with cultural services. For instance, Ondiek et al. (2016) assessed impacts on ecotourism, religious use, educational, aesthetic and recreational values. Moreover, 7 papers treated provisioning services (table 2) and 11 concerned habitat and biodiversity services.

In the multilevel approach, habitat and biodiversity services were also the most studied ones. For example, De Steven and Lowrance (2011) addressed impacts of riparian forest buffers on wildlife habitat services in the USA at farm and landscape levels. The provisioning category was treated in 4 articles out of 9, and the cultural category in 3 articles.

Overall, regulation services were the most studied and cultural services were rather neglected. Concerning regulation services, there was a significant focus on habitat and biodiversity services whereas others were less studied. At farm level, there is a clear need to i) deal with cultural services as they were not addressed at all, ii) deal more evenly with regulation services, iii) proceed with the study of provisioning services.

Which driver for which ecosystem service?

For any type of driver, regulation services are the most studied. Provisioning services were influenced quite evenly by both agricultural practices and land use, whereas cultural services were not especially influenced by any kind of driver. Moreover, it seems that land use drivers influenced ecosystem services in the most balanced way when semi-natural areas drivers were clearly aimed towards habitat and biodiversity services.

Agricultural practices concerned habitat and biodiversity services the most (table 3), representing almost one third of relationships between drivers and ES. Rouquette et al. (2011), for instance, who studied impacts of drainage practices on wildlife habitat provision, pointed this out.

Agricultural practices involved provisioning services (16% of the relationships) and cultural ones (only 4%). For land use drivers, soil quality was concerned by one fifth of all relationships (table 3). For instance, the influence of organic fertilizer provided by faeces on nutrient cycling and soil quality was studied by Navedo et al. (2015) in Extremadura's rice fields in Spain. Provisioning services were involved in 18% of the relationships and cultural services in 9%. Finally, semi-natural areas influenced habitat and biodiversity services the most (one third of relationships). This is described by Ruggiero et al. (2008) who studied the effects of artificial ponds in the Toulouse area in France. Provisioning and cultural services were influenced to a lesser extent (respectively 10% and 6%).

3.1.2. Results at the farm level

The following section focuses mainly on the articles that study processes at the farm level. Among multilevel articles, those at “field and farm level” and “farm and landscape level” were also selected in order to capture as much information as possible. Some examples were also taken from articles at other levels when they supported the analysis of farm-level drivers.

Type 1 drivers: agricultural practices

Regarding agricultural practices, most of the synergies reported occurred among regulation services, while antagonism always involved a provisioning service. There were however 2 synergies involving both provisioning and regulation services (Gonzalez-Esquivel et al., 2015; Kragt et al., 2014). Levers were also applied to mitigate antagonisms between provisioning and regulation services. In that respect, Fan et al. (2018) have looked into fully coupled industrial feedlots (i.e. recycling both liquid and solid manure) and Christianson et al. (2014) have described techniques (i.e. woodchips bioreactors and controlled drainage) that improve water quality.

Soil management

Regarding soil fertility management, fertilizer was found to be a source of trade-off between avocado production and water quality due to nutrient accumulation (Gonzalez-Esquivel et al., 2015)¹. Christianson et al. (2014)¹ have pointed out, however, that N rates' application and timing could mitigate this trade-off for crop production. Lower N rates and application in spring influenced water quality positively in their study conducted in the US Midwest. Composting and manuring practices were moreover found to increase microbial and invertebrate diversity which directly enhanced nutrient cycling services in farming systems in Central Europe and in strawberry agroecosystems in California (Kremen and Miles, 2012). Gaba et al. (2015)² described a synergy between soil OM content and nutrient cycling service brought by mulching and minimum tillage.

¹ US Midwest

² Review

In mixed crop-livestock farming systems in Western Australia, stubbles retention were found to enhance forage production as well as soil quality, thus enabling a greater grain production afterwards (Kragt et al., 2014)³. This groundcover provided by stubbles increased biodiversity habitat service. However, stubbles retention increased water retention resulting in a rise of groundwater tables which is undesirable in this region because it increases dryland salinity. This practice was therefore shown to be a source of antagonism.

In the Oconee River watershed (Piedmont, USA), reduced or no-till farming systems favoured erosion regulation, water infiltration and soil quality by raising N stocks (Kremen and Miles, 2012). Gleason et al. (2011)⁴ found in the Prairie Pothole Region (USA) that tillage induced a negative synergy as it decreased wetlands' water depth, erosion regulation, and water quality, because sedimentation increased turbidity and provided a favourable milieu for aquatic plant seeds and invertebrates' eggs that were buried with sediments. These amplified erosion and sedimentation processes moreover resulted in decreased water retention. Even though Gleason et al. (2011) were more focused on the landscape level, their results were also relevant at farm level.

Overall, soil fertilization degraded water quality because of nutrient accumulation (Gonzalez-Esquivel et al., 2015) but precautions could be taken to mitigate this impact (Christianson et al., 2014). It was found that soil quality could be enhanced by OM input and minimum tillage (Kremen and Miles, 2012; Gaba et al., 2015) and that could result in enhanced crop production (Kragt et al., 2014).

Water management

Gleason et al. (2011) related a trade-off due to drainage. This practice increased crop production services but reduced flood regulation and other ecosystem services linked to wetlands (i.e. wildlife habitat, water purification, groundwater recharge, climate regulation and erosion regulation).

Grazing management

Other practices such as reducing stocking density apparently led to synergy between water quality (due to fewer N losses) and floristic diversity that both increased (Groot et al., 2012⁵; Jouven and Beaumont, 2008⁶). Jouven and Beaumont (2008) also described a trade-off due to late first forage cut, which increased floristic diversity but decreased forage quality and quantity at the second cut. They found that optimal threshold sward height for paddock change increased biodiversity and enhanced herbage quantity and quality, which directly improved meat production services.

³ mixed crop-livestock farming systems western Australia

⁴ Prairie Pothole Region (USA)

⁵ mixed organic farm (NL)

⁶ simulated farms - baseline from Auvergne region

Farm management type

In both conventional (i.e. use of chemical pesticides, synthetic fertilizers and mechanization) and traditional (i.e. associated crops, occasional chemicals, animal manure and compost, animal traction) management regimes, Gonzalez-Esquivel et al. (2015)⁷ found antagonism between maize production service and soil OM content. They however provide no indication as to which practice impacts which ecosystem service. These authors also described synergies within an organic orchard in central Mexico: herb functional diversity was enhanced by organic management and consequently increased avocado pollen-carrier species richness. According to their results, organic management also improved erosion regulation and avocado production service. In farming systems in Central Europe, inter alia, Kremen and Miles (2012)⁸ reported a synergy in organic no-till farming systems between increased soil OM content and increased water retention. They found moreover that higher weed abundance in organic systems increased natural pest enemies and wild pollinator species, resulting in enhanced pest regulation and pollination services. However, weed abundance decreased crop production so this resulted in an overall antagonism. Furthermore, diversified systems (inter alia in Sweden and Tanzania) enabled improvement of soil quality, water retention, and erosion regulation resulting overall in regulation of increased extreme events (i.e. drought, deluge, and hurricane).

As regards global farm management, fully coupled industrial feedlots (i.e. recycling both liquid and solid manure) in China contributed to lower GHG emissions resulting in improved climate regulation services (Fan et al., 2018)⁹. Air quality was also improved due to lower ammonia emissions, while less N discharge into water enhanced water quality (Fan et al., 2018). Hence, fully coupled industrial feedlots were shown to be a mitigation lever for environmental impacts without affecting milk production.

Type 2 drivers: land use

Overall, the articles studied reported that land use drivers led to synergies. Among these, 6 concerned both regulation and provisioning services (Gonzalez-Esquivel et al, 2015; Groot et al., 2012; Kremen and Miles, 2012; Gaba et al., 2015; Christianson et al.; 2014). It is clear that production service enhancement is often a direct consequence of regulation services enhancement (i.e. pollination, soil quality, nutrient cycling, water acquisition, pest and disease regulation).

⁷ Agroecosystems in central Mexico

⁸ Worldwide review

⁹ China

Introduction of legumes

Whether they were cultivated for production, intercrops or cover crops, legumes enhanced services of forage production, nutrient cycling through symbiotic N fixation, soil quality (SOC content, SOM content, N mineralization), habitat and biodiversity, baseline flows regulation (water infiltration, erosion regulation) and water quality by mitigating nutrient leaching (Groot et al., 2012; Kragt et al., 2014; Kremen and Miles, 2012; Gaba et al., 2015). In the case of fava bean and maize intercropping, there was an increase in maize production due to adsorption of phosphorus by fava bean. Fava bean production was improved as well, due to the plant's deeper root system that enables it to draw nutrients not available to maize (Kremen and Miles, 2012; Gaba et al., 2015). Moreover, field experiments in Denmark showed that N fixation by intercropped legumes was higher than for a sole-cropped legume, which enhanced nutrient cycling services (Kremen and Miles, 2012). Grain and legume association improved water acquisition because species with deeper root systems transferred water towards shallow layers which benefited plants around (Gaba et al., 2015). This way, legumes cultivation brought a synergy between ecosystem services previously mentioned. There was nevertheless an exception in western Australian farming systems when legumes were implemented as a pasture phase in a rotation with grain crops: in this case there was a decrease of grain production service and this resulted in a trade-off with other services (Kragt et al., 2014).

Crop rotation

In central Mexico, Gonzalez-Esquivel et al. (2015) found that crop rotation of maize and legumes, mechanical weed control, application of green manure and animal traction induced synergy by increasing soil CEC, enhancing insect pest regulation (mainly due to manure and straw application on roots), and improving maize production service.

When specifically considering crop rotation, nutrient cycling service were found to be better owing to a better N availability, and regulation of weed, disease and pest was improved (Kremen and Miles, 2012; Gaba et al., 2015). Improved weed regulation was due to crop type diversity promoting diverse weed communities but with fewer individuals, which decreased their competitiveness. In the US Midwest, Christianson et al. (2014)¹⁰ reported that implementation of perennial crops in rotation – in this case alfalfa – increased erosion regulation, soil quality and water quality by N trapping. The same results were described for grass-crop rotation with additional benefits for biodiversity services and pest and weed regulation (Fan et al., 2018). Hence, crop rotation is a source of synergy between all those ecosystem services.

¹⁰ US Midwest

Cover crops

Christianson et al. (2014) described the effects of winter cover crops in the US Midwest: water quality was improved by N trapping in the field and other services such as soil quality, erosion regulation and crop production also increased. More broadly across the US, Tomer et al. (2014)¹¹ reported consistent results, specifying that increased water quality was due to nutrients and herbicide leaching mitigation, and that scavenging of N after grain harvest contributed to enhanced nutrient cycling service.

Intercropping

Intercropping had a positive impact on nutrient cycling service for both P and N availability compared to sole crops (e.g. for pea and barley), wildlife habitat, pollination and crop production, which was directly linked to pollination service (Gaba et al., 2015). Kremen and Miles (2012) specified that weed regulation was enhanced by planting smother crops (i.e. competitive crops aimed at weed suppression). Pest regulation was improved by resource dilution, as host plants are surrounded by other plants in intercropping practices, through habitat fragmentation provided by diverse microclimates and also through allelopathy processes (Gaba et al., 2015). Referring to a large-scale study in Yunnan Province (China), Kremen and Miles (2012) reported that interplanting resistant and disease-susceptible varieties of rice or barley had allowed a better regulation of aerial fungal pathogen. Thus it enhanced disease regulation which directly improved grain production service.

Type 3 drivers: semi-natural areas

Lastly, semi-natural areas were mainly a source of synergies among regulation services. Provisioning services were involved in one antagonism with biodiversity (Smukler et al., 2010) and in one synergy (Stewart et al., 2017). Another synergy concerned cultural services (Lindell et al., 2018).

Buffer zones

Referring to different crop types and study sites (e.g. watermelon production in California, canola fields in Canada) Kremen and Miles (2012) found that the implementation of grass strips, hedgerows and semi-natural areas increased floral diversity, which was favourable to natural pest enemies and finally improved pest regulation.

Smukler et al. (2010)¹² showed that riparian and hedgerow habitats enhanced carbon storage in the soil of an organic farm in California. This increased soil OM inputs and soil aggregate stability, thus resulting in improved water infiltration. These authors specified that these results relied on a few species of woody perennials.

¹¹ Review (USA)

¹² Organic farm in California

They also pointed out that non-production habitats were a source of antagonism between increased biodiversity and decreased crop production service due to a reduced surface area available and to interference in this non-production habitats with weeds control.

Ponds

Ponds were studied at all levels (Ruggiero et al., 2008¹³; Stewart et al., 2017¹⁴; Smukler et al., 2010) and were found overall to increase biodiversity (i.e. odonate diversity, duck abundance, and syrphid and bee abundance) with positive effects on crop pollination and direct enhancement of strawberry production. Ponds were also shown to enable sediment and nutrient retention, which improved water quality (Stewart et al., 2017; Smukler et al., 2010).

In wetland-rich Piedmont-Coastal Plain region, the presence of riparian forest buffers improved water quality service and wildlife habitat (De Steven and Lowrance, 2011)¹⁵. This synergy relied on buffer width and connectivity. Enhanced water quality was also related to other vegetative buffers because they mitigated nutrient leaching, increased pollutants removal (Kremen and Miles, 2012) and trapped sediments (Tomer et al., 2014). Finally, citing results of a study conducted in Cobb Creek subwatershed (USA), Tomer et al. (2014) related that buffers also improved erosion regulation service.

Amenities for vertebrates

Lindell et al. (2018)¹⁶ studied the consequences of the introduction of nest boxes, roosts and perches, as well as native species reintroduction and uncultivated field borders. Even though this study focused on the landscape level, its results were also relevant at farm level. There was an increase in vertebrate conservation (mainly birds, bats, frogs and toads), which enhanced pest regulation by insectivorous vertebrates but at the same time decreased pest regulation because of frugivorous birds. Cultural services such as wildlife watching and tourism were ultimately improved by vertebrate conservation.

Globally, there was not always consensus in the literature because synergies and trade-offs depended much on the study context. Hence, interviews with farmers enable to focus on one specific context and examine relationships between ES in a greater depth.

¹³ Toulouse region (Astarac)

¹⁴ Sweden (cropland, semi-natural vegetation and a pond)

¹⁵ wetland-rich Piedmont-Coastal Plain region

¹⁶ Worldwide review

3.2. Results of interviews with farmers

Overall, surveys conducted with farmers showed that a lot of trade-offs were spontaneously performed by farmers (e.g. drivers impacting landscape maintenance and wildlife habitat such as hedges maintenance). The same antagonisms (e.g. straw production and OM input) could moreover result in different decisions (i.e. some farmers preferred straw production and others OM input). This shows that personal dimensions (i.e. personal values, production targets, time management and well-being) and global environment (i.e. natural, economic, legal and social/societal environments) are key factors in farmers' decisions.

Farm contexts

Different contexts were identified through interviews with farmers. Even though each farm belonged to a specific context, 4 types of context stood out:

- 1) Farming system (conventional agriculture) based on suckler cattle breeding (rustic breed: Maraîchine) with natural grasslands and crops for animal feed, located in the Poitevin wet marshlands (freshwater) and high lands and engaged in agri-environmental measures (CAP).
- 2) Farming system (conventional agriculture) based on dairy cattle breeding with natural grasslands and crops for animal feed, located in Rochefort dried marshlands (freshwater) and engaged in agri-environmental measures (CAP).
- 3) Farming system (organic agriculture) based on suckler cattle breeding with natural grasslands and crops for animal feed, located in high lands near the Poitevin marshlands and engaged in agri-environmental measures (CAP).
- 4) Farming system (converting to organic agriculture), based on dairy cattle breeding with natural grasslands and crops for animal feed, located in the Rochefort dried marshlands (freshwater) and engaged in agri-environmental measures (CAP).

As most synergies and trade-offs were related to their local context, references were specified when necessary.

Type 1 driver: agricultural practices

According to the farmers, agricultural practices mostly influenced both production and regulation services. Overall, they were more often involved in trade-offs than in synergies. There was not any clear tendency within trade-offs as they favoured one or another category of service, depending on the farmer. This driver type was moreover a source of mitigation lever, especially for overcoming antagonisms between water quality and production services. Cultural services were mentioned less

and were concerned by both synergy and trade-offs with production services. They referred to heritage value and landscape maintenance.

Soil management

A farmer explained that reducing mineral fertilization over time, using management software, improved water quality in surrounding marshlands without impacting crop yields.

“I rarely exceed 160 units of N for wheat whereas it used to be 200 in the past. In the end, it led to leaching and the yield wasn’t higher.”

According to him, improved water quality led to decreases in duckweed (*Lemna sp.*) and the reappearance of water lilies (*Nymphaea sp.*). This practice echoes the results of Christianson et al. (2014) who reported improved water quality after a decrease in N rates. It was also a mitigation lever for invasive species reduction and consequently overall biodiversity enhancement, and furthermore alleviated the economic burden related to fertilizer costs (in context n°1).

Crop stubbles could either be harvested for straw production or left on the soil to be shredded as an OM input. The farmers interviewed reported that stubbles retention was a source of antagonism between soil quality enhancement due to OM input, as described by Kragt et al. (2014), and a decrease in straw production service. The resulting trade-off depended on the crop type. For instance, pea stubbles are palatable to cattle so it was harvested for forage production, whereas rapeseed stubbles were shredded because they were less palatable. Farmers could also increase their economic product by selling this straw production (in context n°1).

Soil inoculation with bacteria was performed to enhance degradation of OM from cow dung. It aimed at improving soil life activity, soil porosity and consequently water flow in the soil. Thus, this practice should result in a synergy between soil biodiversity, soil quality and water infiltration (in context n°2). Note that this was not described in reviewed papers.

Water management

Irrigation was a driver resulting from a trade-off fostering crop production and depleting water resources (in context n°1). Farmers who chose to stop irrigation, fostered water resources in spite of maize production (in context n°3). However, choosing seeds resistant to drought was a lever used by one of the farmers to overcome this antagonism (in context n°2).

Moreover, some farmers implemented drainage in wet plots cultivated for cash crops (in context n°1). This was a trade-off favouring crop production service over regulation services (i.e. water quality, biodiversity, flood regulation), as Gleason et al. (2011) found in Prairie Pothole Region (USA).

Grazing management

When farming systems included herd grazing, it was mostly driven by the farmer's personal values, animal welfare awareness, and an inclination towards self-sufficiency (in context n°1).

"The farming system reflects who the person is, the farmer."

Thus, personal values drove the choice of grazing over milk production in spite of higher yield potential in barns.

"You accept the idea of producing less since your cows are grazing."

Rotational grazing was primarily implemented for good quality herbage production, but farmers also claimed that it had positive impacts on pest and disease control. Such synergy between services was not addressed in the literature.

Over-seeding was not always satisfactory (in context n°1), but when it was (in context n°2) the farmer stated that this practice enabled him to counter invasive plant species and balance floristic diversity to provide nutritive herbage for cattle. In this case, grasslands were over-seeded with clover in order to enhance protein intake (in context n°2).

Concerning mowing speed, it impacted wildlife preservation as many vertebrates nest in fields. Farmers who chose to adopt reduced mowing speed (i.e. 5 km/h) did it with the aim of enhancing wildlife conservation at the expense of personal time invested (in context n°1). Mowing dates also had an effect on this nesting aspect. Late mowing was implemented in order to improve biodiversity and vertebrate habitat preservation, but it decreased forage nutritional quality, as reported by Jouven and Beaumont (2008). There was then a trade-off to make between those ecosystem services (in context n°1).

Plant protection

In the articles reviewed, this topic was raised indirectly through comparison of farm management types, whereas in interviews farmers gave specific examples of mitigation levers and trade-offs.

Technical training for wheat disease detection (i.e. observation, counting and treatment threshold determination) made it possible to reduce pesticide use. Hence, it supposedly was a lever for water pollution mitigation, biodiversity conservation and disease control. Alleviation of economic burdens related to pesticides costs and personal time investment dedicated to training completion were also taken into account (in context n°1).

Biological pest control was another lever to avoid water pollution and loss of biodiversity related to pesticide use. One farmer (in context n°3) explained that he had placed the eggs of *Trichogramma sp.* in maize fields, and that these insect parasitoids attacked the eggs of corn borers (*Ostrinia nubilalis*).

One farmer adopted late sowing in order to enhance weed regulation, but at the expense of yield potential and hence of production service. Accordingly, this practice represented a trade-off between these two services (in context n°3).

Animal breeds

This topic was not addressed by any of the papers scanned for the literature review. Thus, there was no reference that can be related here.

Choice of the rustic Maraîchine cattle breed was aimed at increasing heritage species conservation service as well as cultural service related to this heritage conservation. Disease control may also be increased with this breed, especially during the calving period in which sanitary treatment was reduced compared with other breeds. Other deciding factors were taken into account, such as facilitating management, and little time investment. However, this breed's productivity is relatively low, which decreased meat production service and therefore economic benefits (in context n°1).

The choice of Maraîchine breed was thus a trade-off favouring cultural and regulation services over production service, which was not the case for Bazadaise breed. One farmer claimed that the latter rustic breed should lead to synergy between those services because Bazadaise meat was considered as a high quality product with a niche market.

In order to enhance locomotion for cattle grazing, one farmer chose to target his genetic selection toward strengthening the cattle's legs. According to him, hoof callus was also increased through this genetic selection, which enabled better protection against wounds and infections. This practice was therefore expected to produce synergy between milk (in context n°2) production and disease regulation.

Animal health management

As for animal breeds, none of the papers reviewed addressed animal health management, so there was no reference to cite here.

Stopping systematic anti-parasite treatment and relying on coproscopic examination decreased the use of medication. Thus, farmers could cut back on their health management budget, there were fewer biocidal agents in the environment, and animal antibiotic resistance could be expected to be lower. This supposedly resulted in a lever for pollution mitigation, probable antibiotic resistance reduction, and an alleviated economic burden (in context n°1).

Likewise, aromatherapy for herd health management was expected to lead to similar results. When essential oils fully replaced antibiotics, this practice avoided environmental pollution by biocidal agents and animal antibiotic resistance. There was also economic burden alleviation, and the economic product was moreover enhanced because the waiting period for marketing after using these products was not necessary, according to French legislation (in contexts n°1 and 2).

Type 2 driver: land use

Regarding land use, there were more synergies involving production and regulation services than trade-offs. As previously reported for type 1 driver, there was no clear trend within trade-offs. Here, cultural services were not treated at all by farmers.

Cultivated species

Farmers planted alfalfa because of its alleged high competitiveness and covering ability, especially against thistle (*Silybum sp.*). In addition, alfalfa seeds were harvested to be stored or sold. This choice of species should result in a synergy between forage and seed production, and nutrient cycling service provided by N symbiotic fixation and weed regulation. Concerning legume cultivation, not all of the ES highlighted in the literature (Groot et al., 2012; Kragt et al., 2014; Kremen and Miles, 2012; Gaba et al., 2015) were mentioned by farmers (i.e. soil quality, habitat and biodiversity, water infiltration and erosion regulation). When seeds were sold, the related economic product was an additional driver of this land use, and when they were stored they represented economic burden avoidance as they saved seed provision costs. Moreover, alfalfa was involved in agri-environmental measures aimed at safeguarding little bustards (*Tetrax tetrax*). The contract requested a late mowing date and finally led to another incentive for alfalfa cultivation (in context n°3).

Meslin (in this case pea, wheat and faba bean) cultivation was claimed to result in a synergy between enhanced forage and grain production, weed regulation, and nutrient cycling service owing to the presence of legumes in the mix. Meslin could also be planted as a catch crop (i.e. cover crop harvested for animal feed) in order to accommodate water quality regulation – due to nutrient leaching mitigation (Kremen and Miles, 2012) – and forage production service (in context n°1).

As sainfoin (*Onobrychis sp.*) is a melliferous plant that enhances auxiliary fauna as well, one farmer introduced it to increase pollination service, pest control and forage production (in context n°3).

This same farmer chose disease-resistant wheat in order to do away with pesticides. This represented a trade-off that fostered disease control without pesticide use, over grain production (in context n°3).

In another system (in context n°1), rapeseed cultivation was ended because it required too much pesticide treatment, which was costly. This economic burden avoidance could also be an incentive for associated crop cultivation (i.e. rapeseed intercropped with clover, phacelia or vetch), which would prevent pesticide use and result in a positive synergy between soil and water quality, pest control, and biodiversity conservation.

Crop rotation

One farmer chose to extend crop rotation duration in order to enhance both weed regulation and soil fertility (in context n°3), as reported by Kremen and Miles (2012) and Gaba et al. (2015). Integrating pea, for instance, was claimed to enhance nutrient cycling (by increasing N symbiotic fixation), weed regulation and forage production services. According to this farmer and these authors, it resulted in a synergy between these services. He also explained that drastic reduction of straw cereal share in the rotation (i.e. introducing 3-to-4-year gap between each straw cereal) was a decision that favoured weed regulation over cereal, forage or litter production (in context n°3).

Cover crops

In France, winter cover crops are compulsory in some contexts in order to reduce nitrate leaching and consequently preserve water quality. Moreover, farmers can either harvest cover crops or leave them on the ground after rolling or shredding them. Harvesting produced synergy between forage or grain production and water quality, while leaving cover crops on the ground resulted in synergy between nutrient cycling, soil quality and water quality services. Additionally, cover crops also enhanced weed and erosion regulation, and provided wildlife habitat (Gaba et al., 2015; Tomer et al., 2014). Synergies associated with this land use were however possible only at the expense of financial and personal time investment by the farmer.

Arable lands and grasslands

The farmers interviewed acknowledged the key role of water storage that grasslands had in wetlands, which Schrama et al. (2013) also mentioned in their study. Preserving grasslands was therefore seen as a driver of synergy between this regulation service and forage production. In this context, arable lands were sometimes converted into pastures. Farmers thus enhanced regulation services linked to grasslands (MEA, 2005) (i.e. carbon storage, biodiversity, pollination, water storage, water quality, landscape maintenance) and forage production, but decreased grain production service (in context n°1). Others converted pastures into arable lands by financial necessity. The trade-off was then inverted for the benefit of maize production (in context n°1).

Type 3 driver: semi-natural areas

Semi-natural areas led quite equally to synergies and trade-offs involving all 3 categories of ecosystem services. When a trade-off impacted production, it was more specifically crop production, whereas when a synergy involved a production service it was for wood production. Moreover, the cultural service discussed here was landscape maintenance.

Buffer zones

Reed beds were claimed to reduce crop production because of land occupation and pest damage enhancement. Thus, they represented an antagonism between biodiversity habitat and crop production, and were not developed by farmers (i.e. trade-off in favour of crop production service).

Likewise, grass strips decreased arable land availability and consequently crop production service as described by Smukler et al. (2010). They were mostly implemented in order to comply with current legislation to mitigate river contamination by chemicals (in context n°1). Grass strips were however sometimes developed over and above the legal requirements, for their auxiliary fauna habitat function (Kremen and Miles, 2012) and claimed recreation value (i.e. horseback riding on shredded grass strips). In this case, there was expected to be synergy between water quality, biodiversity habitat and recreation value. Lastly, the economic burden of maintenance costs (i.e. shredding) ended to limit the expansion of grass strips (in context n°1).

Most farmers planted or maintained hedges to enhance erosion regulation (i.e. windbreak function for crops), biodiversity habitat, water flow regulation in wet soils, and firewood production (trimming provided wood for personal use or for sale). Furthermore, hedges represented an emblematic landscape feature in this region and therefore increased heritage landscape maintenance. These farmers were convinced of this heritage aspect.

“It is part of nature, I’ve never understood the removal of hedges during land consolidation and now they pay to put them back.”

However this synergy should be qualified because hedges sometimes represented an impediment to the circulation of farm implements and created shade on crop fields (in context n°1).

Pollard ash trees (*frênes têtards*) are also emblematic landscape features in the Poitevin marshlands. They have been reported to improve biodiversity habitat services and bank erosion regulation (caused by water flow and pest galleries). These trees moreover provided shade for grazing and fences for pastures (in context n°1). The farmers therefore reported synergy between these services.

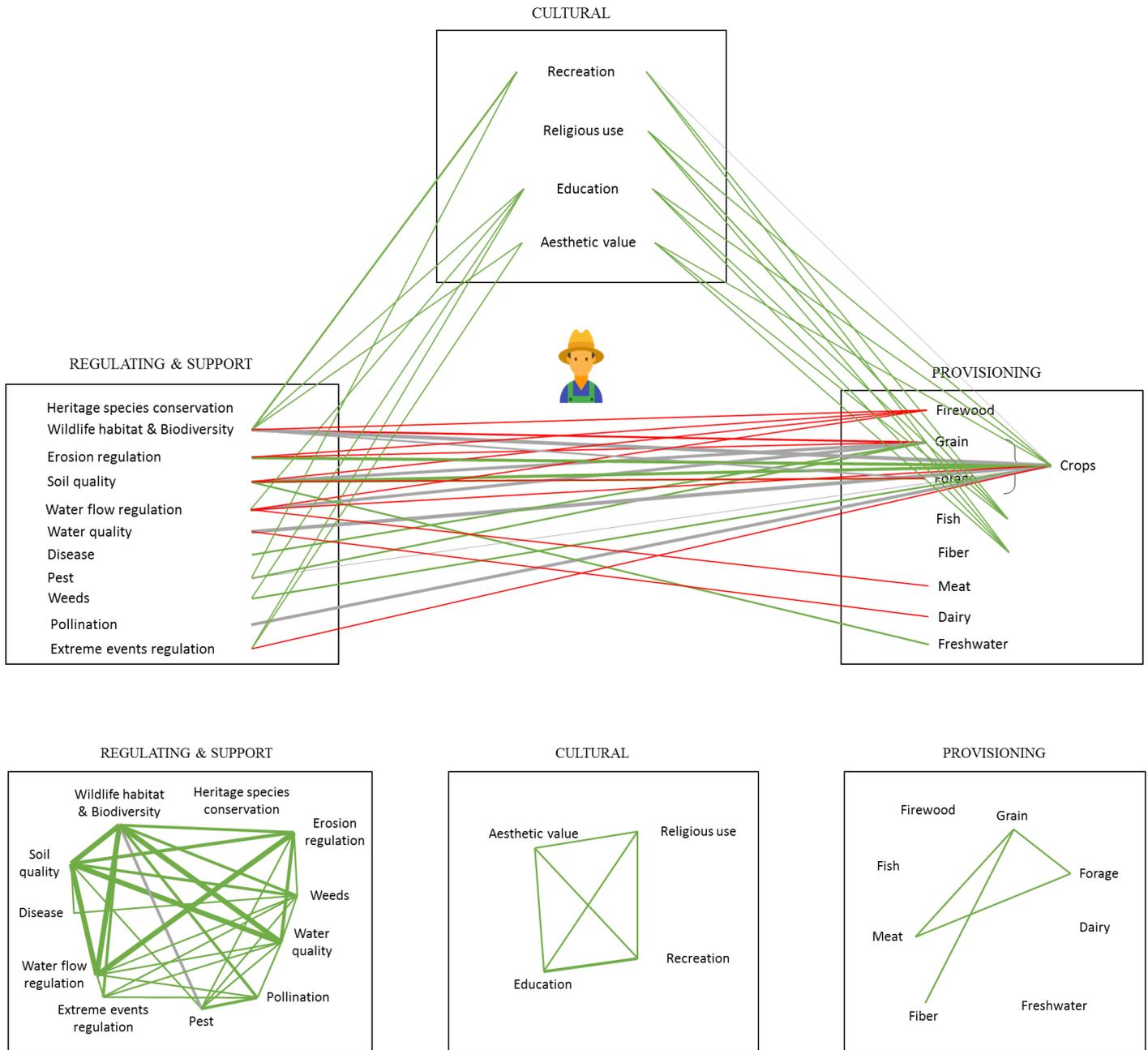
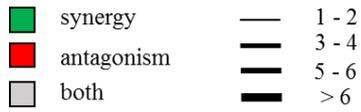


Figure 7: Relationships between and within ES categories described in literature (A. Courcier)

3.3. Conceptual representation of results

Overall representation

In order to schematize the results of literature review and interviews with farmers, synergies between services were represented by green lines and antagonisms by red lines. Grey lines were used to indicate mixed relationships (i.e. with both synergies and antagonisms). The first part of the diagram represented relationships between the 3 different categories of services, while the second part of the diagram represented relationships within each category. Line thickness then gave an indication of the occurrence of relationships described in articles or interviews.

Results from literature review (figure 7)

What stands out is that relationships reported between cultural and regulation categories, and between cultural and provisioning categories, were synergies (except for the crop-recreation relationship, where there were both synergies and antagonism), whereas between provisioning and regulation services both antagonisms and synergies were reported. Between those 2 categories, antagonisms were predominant and many relationships between services were mixed (i.e. there were both synergies and antagonisms). Still, some synergies were reported, mainly between crop provisioning and erosion regulation or soil quality.

Most intra-category relationships between services were synergies, except for the one between pest regulation and wildlife habitat & biodiversity. Note that relationships among cultural or provisioning categories were far less studied than those among regulation categories. In particular, relationships between wildlife habitat & biodiversity, and water quality and soil quality, as well as between wildlife habitat & biodiversity, soil quality and waterflow regulation were the most studied in the literature.

Results from interviews (figure 8)

The farmers interviewed described fewer relationships between cultural and regulation categories, and between cultural and provisioning categories than did the literature. There were also fewer cultural services identified (i.e. no mention of religious use and education), although most farmers did highlight the cultural heritage service, which did not appear in the literature. The relationships reported here were all synergies. The results were mixed between provisioning and regulation services, but synergies were predominant, contrary to the literature. Note that the provisioning services mentioned by farmers were not exactly the same as the ones described in the literature: while litter and seed provisioning were discussed in the interviews, fibre and fish provisioning were not mentioned.

Intra-category relationships between services were not found within cultural category, and there were only 2 within the provisioning category (one antagonism and one synergy). On the other hand,

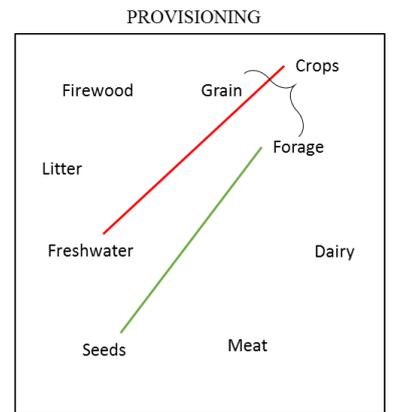
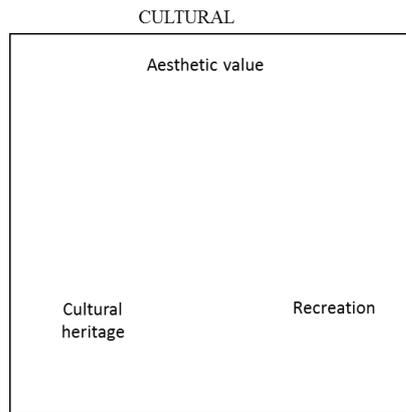
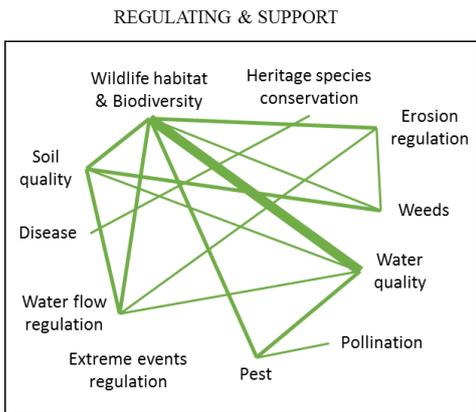
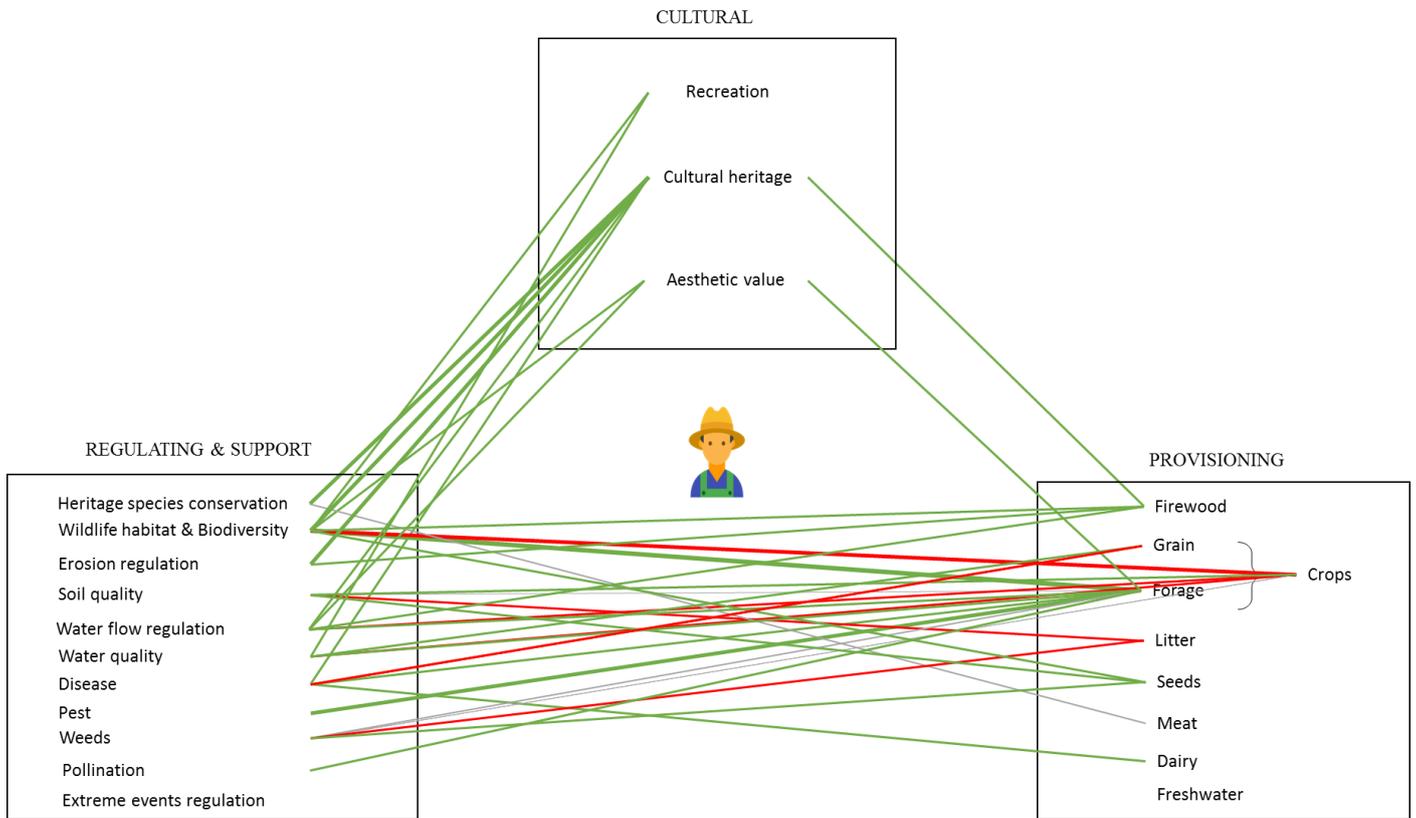


Figure 8: Relationships between and within ES categories reported in interviews (A. Courcier)

there were many synergies within regulation category especially between wildlife habitat & biodiversity and water quality.

Decision process

While the literature mainly described the impacts of farming activities on the biophysical aspect of ES, interviews provided a new perspective. They show synergies and trade-offs between services as a consequence of the farmer's decisions within the context he was confronted to. Thus, this farm-level study aims at considering the farmer's influence on ecosystem services provisioning. In this respect, farmers' decision process was represented as a balance (figure 9) where external constraints (i.e. natural, legal, economic, social/societal) and personal objectives¹⁷ (i.e. production targets, personal values, time management and well-being) are to be considered. The farmer makes his decisions according to his personal values¹⁷ (i.e. his priorities and paradigm) and finally manages his farming system according to 3 types of driver: agricultural practices, land use and semi-natural areas (figure 9).

These 3 types of driver positively or negatively influenced ES. Figure 10 reported some examples taken from the literature and interviews in order to illustrate the farmers' decision process. Solid lines represented positive impacts resulting from decision process and dotted lines stood for negative impacts. In short, a driver induced either synergies among services, if the arrows go in the same direction, or else trade-offs if the arrows point in opposite directions.

For instance, the choice of the Maraîchine breed was driven by the personal values of farmers such as preserving the local cultural heritage and breeding rustic cattle that can live quite autonomously. But this choice was not compatible with farmers' objective to sell their meat production at the best price, owing to the carcass conformation of Maraîchines. Finally, after weighing up the pros and cons, farmers who chose to breed Maraîchines enabled a synergy between 3 services: heritage species conservation, cultural heritage, and disease regulation (figure 10).

Moreover, the decision to plant cover crops was often driven by legislation, whereas seeding these crops represented an economic burden for farmers and increased their work load. This legal constraint therefore took precedence over objectives regarding income and time management. Finally, this decision process resulted in a synergy between 5 regulation services: wildlife habitat, weed regulation, water quality, soil quality, and erosion regulation (figure 10).

¹⁷ As defined by Ohlmer et al. (1998) "values express the farmer's needs and motives; goals and objectives express the means to follow those values."

Discussion

As previously raised, it appeared that cultural ES were far less studied than others (i.e. regulation and provisioning ES). This disproportion was probably due to a lack of measurability of cultural services which makes them difficult to assess, and to an unclear definition of cultural services (Howe et al., 2014). To illustrate this ambiguity in cultural ES definition, Christianson et al. (2014) considered that water quality technologies had enhanced “cultural service of knowledge systems as they all required increased knowledge related to agricultural management”. Howe et al. (2014) also suggested that the neglect of cultural ES “may also be due to the fact that as they are often not captured by monetary valuations, there is a general lack of interest in these types of services.” Consequently, further research is necessary to clarify this notion of cultural ES. As these ES are intangible, definitions should be even more precise than for other ES.

According to interviews content, farmers were very much conscious of their role in heritage landscape maintenance. This service was not addressed in literature, it should then be addressed as a cultural ES because of its heritage aspect. Moreover, it was a strong incentive for farmers to preserve non-production areas. For instance, pastures landscapes were conducive to leisure activities (hunting, fishing, boat trips, biking, hiking, etc.). Most farmers considered this aspect of their work as a motivation while others took it for granted. This was an illustration of the different profiles encountered during interviews. The predominant profile was characterized by awareness of negative impacts from agriculture to natural environment and the will to mitigate these impacts. However, this profile of farmers claimed economic constraints to be too strong which finally drove most of their decisions. Another profile was highly motivated by preservation of environment and managed the whole farm system for this purpose. This profile of farmers was supported by economic incentives for converting or having already converted to organic agriculture. At the opposite, the last profile was mostly driven by pursuit of profit and was not convinced of negative impacts of their practices on environment.

Concerning synergies and trade-offs described by farmers, they have been directly derived from interviews. Thus, they remain subjective and relevant in a certain context. Furthermore, results from interviews were qualitative so impacts on ES could not be more precisely defined than by “increase” or “decrease”. Hence, this approach can lead to a wide range of interpretation.

As previously mentioned, trade-offs and synergies depended on a specific context. For instance, Kragt et al. (2014) found that stubbles retention was a source of antagonism between several

enhanced services and rise of groundwater tables which was undesirable in this region (i.e. Western Australia) because it increased dryland salinity. However, for farmers interviewed, this practice (i.e. stubbles retention) was a source of antagonism but not for the same reasons. According to them, it led to an antagonism between soil quality enhancement and decrease of straw production. Thus, many synergies and trade-offs are not generalizable and should be cautiously handled.

Conclusion

Firstly, the literature review and interviews with farmers showed that synergies mostly occurred among regulation services. Semi-natural areas in particular were a source of synergies among regulation services, and production service enhancement was often a consequence of enhanced regulation services (e.g. pollination, nutrient cycling, pest and disease regulation).

Secondly, the results highlighted the fact that antagonisms generally involved a production service and another category (i.e. regulation or cultural services). Levers were implemented to mitigate antagonisms between provisioning and regulation services (e.g. controlled drainage for nutrient leaching mitigation).

From the farmers perspective, it seemed that many trade-offs were made spontaneously. For instance, the importance of maintaining hedges was often obvious to them because of its key role in landscape maintenance and wildlife habitat. The same antagonisms (e.g. straw production and OM input) could moreover result in different decisions (i.e. some farmers favoured straw production and others OM input). This emphasized the influence of the farmer's personal dimensions (i.e. personal values and objectives) and his global environment (i.e. natural, economic, legal and social/societal environments) on farmers' decisions.

Overall, this farm-level study has furthered our understanding of farmers' decision process and its influence on ES provision. In this respect, the findings reported in the literature and from the interviews were complementary. It would moreover have been interesting to interview more farmers in order to better reflect reality and the different profiles of farmers. The analysis was additionally limited by inconsistent results found through search queries. These queries should therefore be redefined in order to target all relevant papers on the subject. With this extra information (i.e. from additional interviews and papers), the analysis would be more accurate on both the biophysical aspects (i.e. ES and relationships among them) and the sociological aspects (i.e. farmers' perspectives and issues). As these two dimensions (i.e. biophysical and sociological) are intertwined, they should be addressed together to foster agroecological transition at farm level.

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Appendix A: Classification of ES used in the present study based on CICES V5.1 (2018)

Section	Division	Group	Class	Terminology used
Provisioning	Biomass	Cultivated terrestrial plants for nutrition, materials or energy	Cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes	crop production (grain, forage) ; herbage production ; forage quality ; plant material
			Fibres and other materials from cultivated plants, fungi, algae and bacteria for direct use or processing (excluding genetic materials)	straw production
			Cultivated plants (including fungi, algae) grown as a source of energy	wood production
		Reared animals for nutrition, materials or energy	Animals reared for nutritional purposes	meat production ; fish provision
		Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Fibres and other materials from wild plants for direct use or processing (excluding genetic materials)	thatching grass, reeds, papyrus
	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from plants, algae or fungi	Seeds, spores and other plant materials collected for maintaining or establishing a population	seed provision
	Water	Surface water used for nutrition, materials or energy	Surface water used as a material (non-drinking purposes)	water acquisition ; water quantity
		Ground water for used for nutrition, materials or energy	Ground water (and subsurface) used as a material (non-drinking purposes)	

Regulation & Support	Transformation of biochemical or physical inputs to ecosystems	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Bio-remediation by micro-organisms, algae, plants, and animals	denitrification by microbes
	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Control of erosion rates	erosion regulation
			Hydrological cycle and water flow regulation	wave attenuation ; coastal protection ; flood regulation ; water retention ; water infiltration ; groundwater recharge
			Wind protection	wind protection
			Fire protection	wildfire regulation
		Lifecycle maintenance, habitat and gene pool protection	Pollination	pollination
			Maintaining nursery populations and habitats (Including gene pool protection)	species richness ; species abundance ; functional diversity ; biodiversity (habitat) ; wildlife habitat
			Heritage species conservation	heritage species conservation (Maraîchine cattle breed)
		Pest and disease control	Pest control (including invasive species)	pest regulation
			Disease control	disease regulation
			Weeds regulation	weeds regulation
		Regulation of soil quality	Decomposition and fixing processes and their effect on soil quality	soil quality ; SOC content ; SOC decomposition ; N mineralisation ; SOM content ; OM decomposition ; nutrient cycling ; soil moisture ; soil penetrability
		Water conditions	Regulation of the chemical condition of freshwaters by living processes	water quality
		Atmospheric composition and conditions	Regulation of chemical composition of atmosphere and oceans	climate regulation ; carbon storage ; air quality

Cultural	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Physical and experiential interactions with natural environment	Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions	wildfowling ; waterfowl hunting ; birdwatching ; wildlife watching ; recreational fisheries
			Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions	recreation
			Characteristics of living systems that enable education and training	educational excursions
			Characteristics of living systems that are resonant in terms of culture or heritage	heritage landscapes maintenance
			Characteristics of living systems that enable aesthetic experiences	aesthetic value
		Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment	Elements of living systems that have sacred or religious meaning

Appendix B: Extract of the reading grid used to analyze results from literature search

Author, title and date	Location	Level of organization	Drivers (D) studied	D type	Ds evolution	Relationship D - ES	Ecosystems services (ES) impacted			Relationships among ES	Direct Antagonism / Synergy (= between ES)	Indirect A / S (= via driver)	Comments
							Provisioning	Regulation	Cultural				
Groot et al., Multi-objective optimization and design of farming systems, 2012	mixed organic farm (NL)	farm	legumes production	2	↗	↗	fodder						
		farm	legumes production	2	↗	↗ through ↗ symbiotic N fixation		nutrient cycling			IS		
		farm	straw as litter	1	↗	↗ through incorporation with manure		SOM content					
		farm	herd size	1	↘	↗ through ↘ N losses		water quality					
Kragt et al., Quantifying ecosystem services trade-offs from agricultural practices, 2014	mixed crop-livestock farming systems (2) western Australia	farm	length of lucerne pasture phase in a rotation with grain crops	2	↗	↘	grain production						
		farm	length of lucerne pasture phase in a rotation with grain crops	2	↗	↗ through ↗ groundcover		SOC content			IA		
		farm	length of lucerne pasture phase in a rotation with grain crops	2	↗	↗ through ↗ groundcover		N mineralisation					
		farm	length of lucerne pasture phase in a rotation with grain crops	2	↗	↗ through ↗ groundcover		biodiversity habitat					

		farm	length of lucerne pasture phase in a rotation with grain crops	2	↗	↗ through ↗ groundcover		erosion regulation						
		farm	length of lucerne pasture phase in a rotation with grain crops	2	↗	↗ through ↗ groundcover		water infiltration						
		farm	stubbles retention	1	↗	↗	forage production					I A	forage for sheep	
		farm	stubbles retention	1	↗	↗		SOC content						
		farm	stubbles retention	1	↗	↗		N mineralisation		↗ SOC and ↗ N mineralisation	D S			
		farm	stubbles retention	1	↗	↗ through ↗ soil quality	grain production		↗ soil quality	↗ grain yield				
		farm	stubbles retention	1	↗	↗ through ↗ groundcover		biodiversity habitat						
		farm	stubbles retention	1	↗	↗ through ↘ water loss		water retention						in this region : ↗ groundwater tables ↗ dryland salinity (undesirable)
Smukler et al., Biodiversity and multiple ecosystem functions in an organic farmscape, 2010	organic farm in California	farm	riparian corridors, hedgerows, drainage ditches, tailwater ponds	3	↗	↗		native plant diversity						in comparison with production fields
		farm	riparian and hedgerows habitats	3	↗	↗		carbon storage			D S		I S	due to a few species of woody perennials
		farm	riparian and hedgerows habitats	3	↗	↗ through ↗ SOM inputs and ↗ aggregate stability		water infiltration						
		farm	tailwater ponds	3	↗	↗		water quality					reduced sediments in irrigation runoff by 97%	

		farm	non-production habitats	3	↗	↗		biodiversity					IA	especially plant diversity
		farm	non-production habitats	3	↗	↘ through ↘ surface available and interference with weeds control	crop production						IA	
Gaba et al., Multiple cropping systems as drivers of providing multiple ecosystem services: from concepts to design, 2015	review	field and farm	cereal legume association	2	↗	↗ through symbiotic fixation of atm N		N use efficiency					IS	↗ competition for N due to deeper root system of cereals : ↗ legumes reliance on symbiotic fixation
		field and farm	cereal legume association	2	↗	↗ through different depth of root system	water acquisition							species with deep root sytems transfer water towards shallow layers wich benefits plants around
		field and farm	cereal legume association	2	↗	↗ through legume rhizosphere processes		nutrient cycling (P)						P uptake by maize ↗ with faba bean association
		field and farm	crops association	2	↗	↗ through resource dilution (host plant among other plants)		pest regulation					IS	especially phytophageous insects
		field and farm	crops association	2	↗	↗ through habitat fragmentation (diverse microclimates)		pest regulation						especially airborne diseases
		field and farm	crops association	2	↗	↗		wildlife habitat						for spatial crop diversity

		field and farm	crops association	2	↗	↗		pollination			D S	
		field and farm	crops association	2	↗	↗ through ↗ pollination	crop production					
		field and farm	crop sequences (temporal rotation)	2	↗	↗ through life cycle disruption		pest regulation				
		field and farm	cover- and intercropping	2	↗	↗ through allelopathy		pest regulation			I S	especially soilborne diseases
		field and farm	cover- and intercropping	2	↗	↗ through ↘ nutrient leaching		water quality				
		field and farm	cover- and intercropping	2	↗	↗		biodiversity				
		field and farm	minimum tillage and mulching	1	↗	↗		SOM content			D S	
		field and farm	minimum tillage and mulching	1	↗	↗ through ↗ SOM content		nutrient cycling				

Appendix C: Questionnaire used for interviews with farmers

1. Introduction

- Présentation

Je m'appelle Ariane Courcier, je viens de l'école d'agronomie de Rennes et je suis en stage de fin d'études à l'INRA de St Laurent de la Prée. J'étudie les **bénéfices** que la production agricole apporte à la **société** humaine en général, qui touchent aussi bien les **ressources alimentaires**, que la préservation de l'**environnement** ou encore les bénéfices **culturels** comme l'entretien des paysages. Il y a eu une phase de recherche bibliographique en amont et maintenant la deuxième phase se passe sur le terrain, sur les exploitations agricoles.

L'entretien va se dérouler en 4 parties (introduction, description générale de l'exploitation, discussion sur vos pratiques, conclusion).

- Objectifs de l'entretien

Cet entretien est a pour but de **comprendre vos objectifs**, comment ils se traduisent dans le **choix de vos pratiques** et quels sont les bénéfices pour votre activité et pour la société. Les questions que je vais vous poser ne sont pas très techniques, elles visent surtout **vos motivations** dans vos prises de décision.

- Utilisation des données

Je vais prendre des notes de l'entretien et vous enregistrer si vous êtes d'accord. L'enregistrement me sert à compléter mes notes. Les données seront utilisées dans mon mémoire de fin d'études et dans le projet mené par l'INRA, mais votre nom n'y apparaîtra pas. A vous de me dire s'il y a des choses que vous ne voulez pas communiquer et dans ce cas je n'utiliserai pas ces informations.

«Avant de commencer, est-ce que vous avez des questions ?»

2. Description générale de l'agriculteur et de l'exploitation

Quelles études avez-vous suivies ?

Travaillez-vous avec des conseillers ? Qui ?

Êtes-vous membre d'un groupe d'agriculteurs ?

Comment vous tenez-vous informé des nouvelles pratiques ? Formations ?

Travaillez-vous avec vos voisins ? Quel genre de collaboration ? Echangez-vous sur vos pratiques ?

Ont-ils des pratiques différentes des vôtres ?

Quelle est la taille de votre exploitation ?

Quels sont les différents ateliers ? Quel est le poids/la surface de chacun ?

Quels sont les débouchés pour chaque atelier ? (litière, alimentation animale, humaine, énergie ...)

Depuis quand gérez-vous l'exploitation ?

Combien de personnes travaillent sur l'exploitation ?

Pouvez-vous me décrire votre environnement : sol, climat, régime hydrique, paysage (cours d'eau, mare, fossés, friche, forêts) ?

3. Discussion sur vos pratiques et vos décisions

3.1. Choix de la rotation des cultures (espèce, surface, temps)

Pouvez-vous me décrire votre rotation de cultures ? Pourquoi ce choix ?

Espèces cultivées ? Dans les prairies ? Proportion de légumineuses ? Pourquoi ce choix ?

Proportion de sol couvert pendant l'hiver ?

Quelle surface est dédiée à chaque culture ?

Surface de céréales, légumineuses, autres fourrages, prairies permanentes

Quelle durée pour chaque culture ?

3.2. Gestion de la fertilité du sol

Comment favorisez-vous la teneur en MO de vos sols ? Importance des organismes du sol pour vous ?

Quelle proportion de fertilisation organique et chimique ?

Quelles quantités de fumier et lisier produites ? Comment les gérez-vous ?

Y a-t-il beaucoup de lessivage des nutriments ?

Quels sont vos leviers pour minimiser l'impact sur la qualité de l'eau ?

Quelles est l'importance des zones tampons sur votre exploitation ? Comment les favoriser ?

Y a-t-il des problèmes d'érosion ? Comment pouvez-vous la limiter ?

Contraintes du sol : portance, texture, capacité de rétention d'eau.

3.3. Gestion de l'eau

Contraintes du régime hydrique : irrigation, drainage. Pourquoi ce choix ?

Adaptation des cultures

Régulation inondations ?

3.4. Gestion des adventices

Lutte chimique : quantité d'herbicides ?

Lutte mécanique : travail du sol ? Semis direct ? TCS ?

Couverts végétaux ? Association de cultures ? ...

Pourquoi cet ITK ?

Comment minimiser son impact négatif ?

3.5. Gestion des maladies et ravageurs

Quels ravageurs/maladies touchent vos cultures ?

Comment les gérez-vous ? Auxiliaires de culture (carabes, coccinelles, vers, murg, parasites ...) ?

Quantité de pesticides ? Pourquoi cet ITK ? Comment minimiser son impact négatif ?

3.6. Gestion de l'alimentation du troupeau (pâturage et concentrés)

Quelle composition ? Quelles proportions ? D'où vient l'alimentation ? Autonomie ?

Comment faites-vous votre planning de pâturage ? Pourquoi ce choix ?

Est-ce que vous fauchez les refus ? Etalage des bouses ?

Entretien des bords de champs ? Bords de fossés ?

3.7. Gestion sanitaire du troupeau (parasites et maladies)

Quelles sont vos pratiques ? Antibiotiques (préventif/curatif) ? Alternatives ?

3.8. Conservation du patrimoine (génétique, culturel, éléments typiques du paysage)

Pourquoi cette race bovine ?

Variétés végétales locales ?

Qu'est-ce qui est important pour vous dans ce que vous produisez ?

Quantité ? Qualité ? Savoir-faire ? Patrimoine ? Satisfaction consommateurs ? Prix ?

Paysage

Y a-t-il des arbres ? A quoi servent-ils ?

Combien de mètres de haies ? Comment sont-elles entretenues ? A quoi servent-elles ?

Fournissent-elles du bois de chauffage ? Quelle quantité ?

Quelle proportion/surface d'ombre et d'abri y a-t-il ? Est-ce que vous intégrez ça dans votre gestion du pâturage ? En particulier en été ?

Y a-t-il des bandes enherbées ? A quoi servent-elles ? Plantes mellifères ?

Quelle surface de roselières ? A quoi servent-elles ? Intérêt pour vous ?

Quels loisirs de plein air y a-t-il dans le coin (randonnée/promenade, vélo, chasse, pêche, observation faune/flore, tourisme) ?

Y a-t-il de la cueillette sur la ferme ? (baies, fleurs, champignons)

Selon vous, quel rôle joue le paysage dans ces loisirs ?

Quel est votre impact sur

La conservation d'espèces (ordinaire/patrimoniale, domestique/sauvage)

Régulation des incendies ?

Intégrez-vous cet aspect (impact sur la nature) dans vos décisions ? Comment ? Par exemple ?

Passé Présent Avenir

Y a-t-il eu des changements récents dans vos pratiques et vos productions ?

Quelles questions vous posez-vous sur vos pratiques ? Quelles sont vos difficultés ?

Que souhaitez-vous changer (à court et long termes) ? Comment ?

Comment cela se traduit dans vos objectifs ?

Arbitrages

Parmi tous les aspects de votre production, lesquels peuvent s'opposer ?

Comment privilégiez-vous une dimension plutôt qu'une autre ?

Comment vous faites pour allier les deux ?

Quels outils utilisez-vous dans vos décisions de gestion ?

«Je pense que nous avons tous les éléments»

4. Conclusion

Nous avons abordé le choix de la rotation des cultures, la gestion de la fertilisation, la gestion de l'eau, la gestion des adventices, la gestion des maladies et ravageurs, conservation du patrimoine, la gestion de l'alimentation du troupeau et la gestion sanitaire du troupeau.

→ Manque-t-il quelque chose ? Que voudriez-vous ajouter ?

→ Avez-vous des idées d'agriculteurs que je pourrais interviewer (pratiques différentes)

Merci pour le temps que vous m'avez accordé. Je vous enverrai dans les semaines qui suivent un premier compte-rendu de notre entretien puis je vous enverrai mon mémoire quand il sera finalisé donc vers la fin du mois d'août. Et pour l'INRA, cet entretien servira à explorer différentes pratiques dans le cadre de la transition agro-écologique de leur exploitation agricole.

Abstract

Relationships among ecosystem services were investigated at farm level. Firstly, a literature review based on 33 articles provided an overview of synergies, antagonisms and trade-offs between ecosystem services. Secondly, interviews were held during the spring of 2018 with 8 farmers in French Atlantic marshy coast area (in the departments of Charente-Maritime and Deux-Sèvres) who managed different types of farming systems (e.g. organic and conventional systems; suckler and dairy cattle breeding). The interview phase anchored this study in a local context, which also induced specific synergies and trade-offs related to this context (i.e. drainage issues, heritage landscape maintenance, Maraîchines breeding, management of reed beds). The results analysis highlighted the fact that synergies occurred mostly among regulation services and that trade-offs generally involved a production service and another category (i.e. regulation or cultural services). Considering the farmers' perspective, it seemed that farmer's personal dimensions (i.e. personal values and objectives) and their global environment (i.e. natural, economic, legal and social/societal environments) were decisive in their decisions. Overall, this farm-level study has furthered an understanding of the farmers' decision process and its impact on ecosystem services provision in terms of both the biophysical and the sociological dimensions.

Les relations entre services écosystémiques ont été explorées au niveau de l'exploitation agricole. D'abord, une synthèse bibliographique basée sur 33 articles a dessiné une vue d'ensemble des synergies, antagonismes et arbitrages entre services écosystémiques. Ensuite, des entretiens ont été menés au printemps 2018 auprès de 8 agriculteurs dans les marais littoraux atlantiques (en Charente-Maritime et Deux-Sèvres). Différents types de systèmes agricoles ont été étudiés (ex : agriculture biologique et conventionnelle ; élevage de bovins allaitants et laitiers). La phase d'entretiens a ancré cette étude dans un contexte local, ce qui a renseigné des synergies et des arbitrages spécifiques à ce contexte (problématiques de drainage, entretien d'un paysage patrimonial, élevage de Maraîchines, gestion des roselières). L'analyse des résultats a souligné que les synergies étaient les plus fréquentes entre les services de régulation et que les arbitrages impliquaient généralement un service de production et une autre catégorie (services de régulation ou culturels). Du point de vue des agriculteurs, il est ressorti que les dimensions personnelles (valeurs et objectifs personnels) et leur environnement global (contextes naturel, économique, légal, social/sociétal) étaient déterminants dans leurs décisions. Globalement, cette étude au niveau de l'exploitation agricole a permis de mieux comprendre le processus de décision des agriculteurs et son influence sur l'approvisionnement de services écosystémiques au regard des dimensions biophysiques et sociologiques.