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HOW CAN INTEGRATED ECOSYSTEM SERVICE VALUATION HELP UNDERSTAND AGROECOLOGICAL TRANSITION?

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Abstract

Agroecology is increasingly advocated as a solution to current challenges faced by conventional farming systems. Agroecology goes beyond the suggestion of alternative agricultural practices. It also questions the whole food systems, including the stakeholders involved and their interdependencies. By suggesting such a holistic transition, agroecology also questions current research practices. Such an approach to agriculture requires new scientific tools which allow the integration of multiple value domains, account for the system complexity and the underlying uncertainties. Integrated ecosystem service (ES) valuation claims to offer such tool. However, to date, few studies report on the implementation of integrated ES valuations to real-life contexts of agroecological transitions.

The present work aims at filling this gap by applying the concept to three real-life farm examples which are undergoing agroecological transition. Both a biophysical ES assessment, based on field measurements and a socio-cultural ES valuation, based on a focus group and questionnaires, are carried out on the sampled agroecological farms and their neighbor's conventional farms. The aim is to analyze these agroecological farming systems (AFS) through the lens of the integrated ES valuation tool and to share lessons learned in a reflexive posture. Prior to the implementation of the tool to the case studies, a literature analysis is carried out providing a state-of-the-art on (i) the concept of agroecologogy and how it questions current research processes **(Article 1)** and (ii) the tool of integrated ES valuation and how it can steer agroecological transition **(Article 2)**.

The socio-cultural valuation was then implemented to identifiy and select ES for the subsequent steps of the research. Based on consultation of 19 locals including farmers (ES providers) and local inhabitants (ES beneficiaries) organized under a focus group, a list of prioritized ES was drawn. This preliminary list was then confronted to the technical and time constraints of the research and to expert judgement who decided to add two ES. At last, 12 ES were kept for the next valuation steps.

The second part of the socio-cultural valuation consisted in photographs-based questionnaires to assess the extent to which locals (local inhabitants and farmers) viewed landscapes undergoing agricultural transitions by comparing it to 'ES experts' perceptions **(Article 3)**. Manipulated photographs simulating an agroecological landscape, a conventional agriculture landscape, and landscapes including each agroecological practice isolated were submitted to both locals and ES experts. Both profiles perceive and appreciate landscapes similarly, appreciating the agroecological landscape the most and seeing it as delivering more ES. Additionnally, the agroecological landscape was seen as a synergetic whole were negative comments formulated for isolated practices disappear once assembled into the agroecological scenario. Such results illustrate that locals perceive the feedback loop of how agricultural practices shape the landscape and how this impacts ES

flows. In the light of this observation, and considering that such interactions are highly context dependent, local knowledge and perception should be capitalized for sustainable rural land management.

Next, the biophysical assessment was carried out, which focused on the selected regulating and provisioning ES **(Article 4)**. These seven ES were assessed based on 14 indicators. The assessment was carried out in three agroecological farming systems (AFS) of the Western part of the Hainaut Province in Belgium and their adjacent conventional farming systems (CFS). Based on three years of field-scale measurements, our findings suggest that the studied AFS succeed in providing a wider array of regulating services than their neighbors CFS. More precisely, soil aggregate stability, soil respiration rates are in general more supported in AFS which also show less aphid abundance. On the other hand, CFS show higher grain production and higher performance for two out of three fodder quality indices. While this ‘productivity gap’ may be due to the still-evolving state of the studied AFS, we nuance this through the lens of a new paradigm to assess farming system performance based on multiple dimensions.

Based on the implementation of the tool of integrated ES valuation on case studies AFS, a reflexive analysis was carried out to share lessons learned and feed future research.

A thorough reflexive work was carried out on the participatory ES identifaction and selection of the present research along four other case studies. This resulted in 11 recommendations detailed in **Article 5**. The literature on participatory research evaluation used to guide our reflection demonstrated the relevance of participatory science to the field of ES.

From the biophysical ES assessment, it appeared clear that each methodological option, it being the approach (the ES tool in the present case), the selected ES, the indicator or the method used to assess them, orients the outcomes of the research. This is partly due to the fact that distinct indicators measure different ecological processes or functions underlying the delivery of the ES to be assessed. Hence, it is recommended to use multiple indicators for a single ES to inform more comprehensively on the underlying processes of ES delivery.

This influence of the researcher’s methodological choices also illustrates how each methodological decision is value-laden. To bring more transparency and legitimacy to these steps, including stakeholders in ES selection (as done in the present work), but also in the selection of indicators and assessment methods is a solution often put forward. Stakeholder knowledge indeed showed to represent seen as a complementary source of information to scientific knowledge.

The integration of the two value domains, i.e. the biophysical and the socio-cultural remained a challenge, as it is the case for many other examples of integrated ES valuation. As aggregation of outcomes into a single value or score is not the pursued objective, applying scenario comparison within commensurable value categories is adviced (**Article 6** – Appendix 1). Again, stakeholder inclusive deliverative approach is one way to overcome the challenge. Inteed, such approaches allow implementing iterative research processes bridging between the two value domains.

The ES tool applied as done in the present work produces knowledge which represents a first step and a subset of the bulk of information needed by farmers envisioning transition. Within the framework of Dendoncker et al. (2018a), the present work only applies the first step, i.e. the ‘building of a common *understanding* of the current situation’. To bring the ES valuation to action and *steer* agroecological transition, the biophysical assessment and socio-cultural valuation of the present study should be embedded within a wider framework which also includes the identification of plausible evolutions of the system (step 2 of the framework). To consider different options, the approach of deliberative multicriteria analysis shows some interesting potential in supporting decision making while accommodating value pluralism and structuring deliberative approaches. Rather than providing one-size-fit all solution, deliberative multicriteria analysis provides insights on the potential compromises and could thus feed steps 3 and 4 of the framework: the selection of the most acceptable pathways of change and the implementation of the selected scenario.

Carrying such transdisciplinary research allows tackling multiple valuation languages which offers a more comprehensive perspective on the analysis. However, such research approach differs from classical disciplinary research wich has long dominated in educational programmes and research institutions. These two are currently undergoing fundamental modifications, as an increasing amount of instiutions offer mutlidisciploinary field-based problem oriented educational courses or programmes, and research institutions increasingly restructure to provide interdisciplinary environment to researchers.

Résumé

L'agroécologie est de plus en plus prônée comme une solution aux défis auxquels sont confrontés les systèmes agricoles conventionnels. L'agroécologie va au-delà de la suggestion de pratiques agricoles alternatives. Elle interroge également l'ensemble du système alimentaire, y compris les acteurs concernés et leurs interdépendances. En suggérant une telle transition holistique, l'agroécologie questionne aussi les pratiques actuelles de la recherche. Une telle approche de l'agriculture nécessite de nouveaux outils scientifiques qui permettent l'intégration de multiples domaines de valeur, tiennent compte de la complexité du système et des incertitudes sous-jacentes. L'évaluation intégrée des services écosystémiques (SE) prétend offrir un tel outil. Toutefois, à ce jour, peu d'études font état de la mise en œuvre d'évaluations intégrées des SE dans des contextes réels de transitions agroécologiques.

Le présent travail vise à combler cette lacune en appliquant l'outil à trois exemples concrets d'exploitations agricoles en transition agroécologique. Les fermes agroécologiques échantillonnées et les fermes conventionnelles voisines font l'objet d'une évaluation biophysique des SE, basée sur des mesures de terrain, et d'une évaluation socioculturelle des SE, basée sur un groupe de discussion et des questionnaires. L'objectif est d'analyser ces systèmes de production agroécologique (AFS) à travers les lunettes de l'outil des évaluations intégrées des SE et de partager les leçons apprises dans une posture réflexive. Avant la mise en œuvre de l'outil dans les cas d'études, une analyse bibliographique est effectuée pour faire le point sur (i) le concept d'agroécologie et la façon dont il remet en question les processus de recherche actuels (**article 1**) et (ii) l'outil de l'évaluation intégrée des SE et comment il peut orienter la transition agroécologique (**article 2**).

L'évaluation socioculturelle a ensuite été mise en œuvre pour identifier et sélectionner les SE pour les étapes ultérieures de la recherche. Sur base d'une consultation de 19 habitants locaux, comprenant des agriculteurs (fournisseurs de SE) et des habitants locaux (bénéficiaires des SE), organisée dans le cadre d'un groupe de discussion, une liste des SE prioritaires a été établie. Cette liste préliminaire a ensuite été confrontée aux contraintes techniques et temporelles de la recherche et à l'avis des experts qui ont décidé d'ajouter deux SE. Enfin, 12 ES ont été conservés pour les étapes d'évaluation suivantes.

La deuxième partie de l'évaluation socioculturelle consistait en des questionnaires photographiques pour évaluer dans quelle mesure les habitants (habitants locaux et agriculteurs) voyaient les paysages en transition agricole en les comparant aux perceptions d'experts de SE (**article 3**). Des photographies modifiées simulant un paysage agroécologique, un paysage agricole conventionnel et des paysages incluant chaque pratique agroécologique isolée ont été soumises aux acteurs locaux et aux experts des SE. Les deux profils perçoivent et apprécient les paysages de la même manière, en appréciant davantage le paysage agroécologique et en le considérant comme le plus porteur de SE. De plus, le paysage agroécologique a été considéré comme un ensemble synergique où les commentaires négatifs formulés pour des pratiques isolées disparaissent une fois assemblés dans le scénario agroécologique. Ces résultats montrent que les populations locales perçoivent la boucle de rétroaction sur la façon dont les pratiques agricoles façonnent le paysage et sur l'impact de ces pratiques sur les flux des SE. A la lumière de ce constat, et compte tenu du fait que ces interactions dépendent fortement du contexte, les connaissances et les perceptions locales devraient être capitalisées pour une gestion durable des terres rurales.

Ensuite, l'évaluation biophysique a évalué les septs SE de régulation et d’approvisonnement sur base de 14 indicateurs (**article 4**). L'évaluation a été réalisée dans trois systèmes de production agroécologiques (AFS) situés dans l’Ouest de la province du Hainaut en Belgique, et dans les systèmes de production conventionnels adjacents (CFS). Sur base de trois années de mesures sur le terrain, nos résultats suggèrent que les AFS étudiés réussissent à fournir un plus large éventail de services de régulation que leurs voisins CFS. Plus précisément, la stabilité des agrégats du sol et les taux de respiration du sol sont en général plus soutenus dans les AFS qui montrent également moins d'abondance de pucerons. D'autre part, les CFS affichent une production de grains de céréales plus élevée et une meilleure performance pour deux indices de qualité fourragère sur trois. Bien que cet "écart de productivité " puisse être attribuable au statut toujours en évolution des AFS étudiés, nous nuançons cette situation à l'aide d'un nouveau paradigme pour évaluer la performance du système agricole en intégrant une approche multi-dimensionnelle.

Par la mise en pratique de l'outil de l'évaluation intégrée des SE sur des cas d’études AFS, une analyse réflexive a été réalisée pour partager les leçons apprises et alimenter la recherche future.

Un travail de réflexif a été mené sur l'identification et la sélection participative des SE de la présente recherche, ainsi que sur celle de quatre autres cas d’études. Sur base de ces cinq expériences, 11 recommandations ont été formulées et détaillées dans **l'article 5**. La littérature sur l'évaluation de la recherche participative utilisée pour guider notre réflexion a démontré la pertinence de la science participative dans le domaine des SE.

D'après l'évaluation biophysique des SE, il est apparu clairement que chaque option méthodologique, qu'il s'agisse du choix l'approche (l'outil des SE dans le cas présent), de la selection des SE, du choix des indicateurs ou de la méthode utilisée pour les évaluer, oriente les résultats de la recherche. Cela s'explique en partie par le fait que des indicateurs distincts mesurent différents processus ou fonctions écologiques qui sous-tendent la fourniture des SE. Par conséquent, il est recommandé d'utiliser plusieurs indicateurs pour un même SE afin d'obtenir des informations plus complètes sur les processus sous-jacents à la fourniture des SE.

Cette influence des choix méthodologiques du chercheur illustre également comment chaque décision méthodologique est porteuse de valeurs. Apporter plus de transparence à ces étapes, en incluant les parties prenantes dans la sélection des SE (comme c'est le cas dans le présent travail), mais aussi dans le choix des indicateurs

et des méthodes d'évaluation, est une solution souvent proposée. Les connaissances des parties prenantes se sont en effet révélées être une source d'information complémentaire aux connaissances scientifiques.

L'intégration des deux domaines de valeur, du domaine biophysique et du domaine socioculturel, est demeurée un défi, comme c'est le cas pour de nombreux autres exemples d'évaluation intégrée des SE. Comme l'agrégation des résultats en une seule valeur ou score n'est pas l'objectif poursuivi, il est conseillé d'appliquer la comparaison de scénarios à des catégories de valeurs commensurables (**article 6 -** annexe 1). Encore une fois, inclure les parties prenantes est une façon de surmonter ce défi. Intégrées, ces approches permettent de mettre en œuvre des processus de recherche itératifs faisant le pont entre les deux domaines de valeur.

L'outil des SE comme appliqué dans le présent travail produit des connaissances qui représentent une première étape et un sous-ensemble de la masse d'informations dont les agriculteurs ont besoin pour envisager la transition. Dans le cadre proposé par Dendoncker et al (2018a), le présent travail n'applique que la première étape, à savoir "la construction d'une compréhension commune de la situation actuelle". Pour mettre en pratique l'évaluation des SE et *orienter et accélérer* la transition agroécologique, l'évaluation biophysique et l'évaluation socioculturelle de la présente étude doivent s'inscrire dans un cadre plus large qui inclut également l'identification des évolutions plausibles du système (étape 2 du cadre). Pour envisager différentes options, l'approche délibérative des analyses multicritères montre un potentiel intéressant pour soutenir la prise de décision tout en tenant compte du pluralisme des valeurs. Plutôt que de fournir une solution unique pour tous, l'analyse multicritères délibérative donne un aperçu des compromis potentiels et pourrait donc alimenter les étapes 3 et 4 du cadre de Dendoncker et al. (2018a): le choix des voies de changement les plus acceptables et la mise en œuvre du scénario choisi.

Cette recherche permet d’aborder divers langages d'évaluation, ce qui offre une perspective plus complète de l'analyse de système agricoles en transition. Cette approche de recherche diffère de la recherche disciplinaire classique qui a longtemps dominé les programmes éducatifs et les institutions de recherche. Ceux-ci subissent actuellement des modifications fondamentales, car un nombre croissant d'établissements offrent des cours ou des programmes éducatifs pluridisciplinaires orientés vers la résolution de problèmes sur le terrain, et les institutions de recherche se restructurent de plus en plus pour offrir un environnement interdisciplinaire aux chercheurs.

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List of acronyms

AFS : Agroecological farming systems

CFS : conventional farming systems

ES: ecosystem services

GRQ: general research question

SRQ: sub-research question

Chapter III – section 2

AE: Agroecological

CV: conventional

AF: Agroforestry

WS: Wildflower strip

IC: Intercropping

CL: Cattle-livestock association

Preface

This section introduces the approach of the present PhD dissertation, in which I have used scientific postures and views of both qualitative and quantitative scientific arenas. The reason behind this hybrid posture is closely linked to the way the research evolved throughout the PhD.

Ecologist as background and carrying this thesis within a university department of agriculture, the origin of the present work had a very ‘natural science’ prism. Indeed, the initial thesis title, ‘contribution of agroecological farming systems (AFS) to the delivery of ecosystem services (ES)’, focused mainly on biophysical field measurements and quantitative analyses. Yet, inspired by the literature about agroecology and ‘integrated’ ES valuations, the ambition to also include a social component to the analysis was present from the start. It was thus decided to carry out, along the biophysical ES assessment, a socio-cultural ES valuation. It was also planned to set up a ‘field committee’, composed of farmers and local inhabitants, in order to create a ‘co-creation’ atmosphere, where I would learn from them and they would learn from the research outcomes and from interacting with each other.

By integrating this participatory aspect, and by grounding my research into a real-life context, I quickly realized that I was dealing with complex and dynamic challenges, high stakes and strong societal and scientific uncertainties (Barnaud and Antona 2014, Hatt et al. 2016a). In the light of this observation, I became concerned that outcomes my research could be considered as complete and ready-made solutions. I felt there was a plurality of legitimate perspectives and answers to my research question and I felt the need to step back and to shift to a post-normal scientific posture, which associates different forms of knowledge, combines social and ecological systems and adopts a reflexive attitude (Funtowicz and Ravetz 1994, Francis and Goodman 2010, Raymond et al. 2010).

A reflexive posture is encouraged to shed light on the researchers’ mental framework and value-system which may influence the outcomes of the research (Barnaud and Antona 2014). A reflexive posture raises the researcher’s awareness about his background assumptions, his normative orientations, and how these shapes his methodological decisions and influence how the knowledge is produced and used (Jacobs et al. 2016). The importance of questioning our role as researchers in the research process is increasingly acknowledged in sustainability and transdisciplinary scientific communities (Stige et al. 2009, Jahn and Keil 2015, Popa et al. 2015). Hence, the focus of my research shifted to a more meta-level, one that aims to reflect on the implementation of the tool of integrated ES valuation, and how this latter one help understand agroecological farming systems in transition.

The first step of a reflexive process is to be explicit on our attitude regarding knowledge production and use. Due to the evolution of my research focus, and of my research posture, the present dissertation suggests a rather hybrid approach. To answer the general aim of my PhD, as to which extent the tool of integrated ES valuation generate knowledge about transitioning AFS, I adopt a reflexive posture.

This posture is endorsed within Chapter 5 which presents a reflexive analysis on how the use of the integrated ES valuation tool helped answering my sub-research questions. Such a reflexive posture entails writing standards closer to qualitative research, one that endorses subjectivity and provides a more personal interpretation (Holliday 2007). To answer this objective, this PhD relies on a literature analysis (Chapter II) and on case studies where the tool of integrated ES assessment is applied to farming systems undergoing agroecological transition. A biophysical and a socio-cultural ES valuations are applied to these AFS case studies, presented in Chapter III and IV respectively. Within these three chapters, I adopt a posture closer to normal science and follow standard approaches of quantitative research (Holliday 2007). In brief, while Chapter II, III and IV tend to provide ‘photographs’, assuming objectivity, Chapter V tends more towards a ‘painting’, a representation of my own impressions, accepting subjectivity.

Chapter I

INTRODUCTION

Agroecology and the tool of integrated ecosystem service valuation

1. Agriculture's challenges: the need for value pluralism

1.1. Facing the limits of the conventional farming system

The human species is currently exploiting the earth resources to a point that several planetary boundaries are being transgressed (Steffen et al. 2015). Some suggest we are now shifting from the relatively stable conditions of the Holocene to a new period pinpointed as the 'Anthropocene'; a period characterized by a significant human influence on ecological, geological and social processes (Waters et al. 2016). As a direct consequence, we are increasingly facing socio-ecological challenges all over the world, including severe impacts on the environment and biodiversity (IPBES 2018a), affected human wellbeing (Cardinale et al. 2012) and increasing social conflicts (Martinez-Alier 2003).

Agriculture undeniably shares a large responsibility in these alterations. In the context of post-World War, reaching self-sufficiency of agricultural production was a matter of priority. The European Common Agricultural Policy (CAP) through subsidies mechanisms supporting yield maximization, along with the globalization of agricultural commodity markets were the two major incentives to intensification of agriculture (van Zanten et al. 2014a). The benefits of these developments represent some of the greatest achievements (IPES FOOD 2016), with agricultural yields quintupling thanks to moto-mechanization, mineral fertilizing, crop selection and food system specialization (Mazoyer and Roudart 2002). Belgium has been particularly successful in reaching unprecedent yields. In terms of cereals, for instance, it is one of the most productive countries of Europe (6985kg/ha and 5172 kg/ha respectively in 2016, The World Bank Data 2018), but also the most demanding in terms of inorganic fertilizers with a consumption per hectare almost twice as important as the average of European countries (140kg/ha and 75kg/ha respectively in 2009, Eurostats 2018).

However, this came at the cost of several environmental and social repercussions. Farm expansion, landscape homogenization and simplification, increasing use of chemicals are the main consequences of this increase in production efficiency (van Zanten et al. 2014a). These contributed to a continuous decline in biodiversity and many ecological processes (IPBES 2018a) as well as jeopardized farmers and consumers' health (Costa et al. 2014, Kunde et al. 2017). Together with climate change, this ecosystem degradation is predicted to affect crop yield itself by an average of 10 to 50 per cent depending on the region (IPBES 2018b). As agriculture accounts for about 50% of the global land surface (FAO 2011), the challenge to maintain high agricultural productivity while sustaining the environment and its functions is crucial.

Facing these well documented negative impacts of industrial agriculture, also referred to as 'conventional' farming systems (CFS), it is now required to develop more sustainable forms of agriculture. That is to say, an agricultural system which is less dependent on chemical and petrol-based inputs, efficient in resource use, generating low environmental impacts, resilient and producing healthy food accessible to all (IPES FOOD 2016).

1.2. Agroecology suggested as a solution

The challenge to develop such agricultural systems which remain productive yet ensure social and environmental sustainability is today a societal and political affaire. Since 1992, the reforms of the Common Agricultural Policy have aimed to progressively reduce the pressure of agriculture on the environment, developing several tools for farmers to mitigate the environmental impact of agriuclure, among which the ‘Agri-Environment Scheme’, which provides financial support for Member States to design and implement agri-environment measures. In 2013, the reform went further and developed ‘the greening’ of the Common Agricultural Policy. implemented ‘green payments’ to support adoption or maintaining of farming practices that help meeting environment and climate goals. Among these actions are diversifying crops, maintaining permanent grasslands and dedicating 5% of arable land to ‘ecologically beneficial elements’. Despite an effectiveness much debated among the scientific community (Prager et al. 2012), Europe has seen its share of agricultural land doing organic farming or enrolled in agri-environmental measures significantly increase through time (Eurostat, 2018). In addtition to this European frame, the urge to develop sustainable food systems for all is present in several global political initiatives, such as the Sustainable Development Goals (SDG 2 ‘Zero Hunger’) of the United Nations or the Aichi Targets (Goal B, Target 7) of the Convention on Biological Diversity.

Within this political context, a multitude of alternative farming systems emerge and pretend answering this call (Kremen et al. 2012): multifunctional agriculture (Hodbod et al. 2016), organic agriculture (Sandhu et al. 2010), ecological intensive agriculture (Doré et al. 2011), conservation agriculture (Kassam et al. 2009), etc. To clarify this diversity of alternatives, Horlings and Marsden (2011) suggest classifying them along a gradient of ‘ecologization’, from weak to strong ecological modernization. Weak ecological modernization represents a ‘technocentric approach’ of agriculture, i.e. an approach which locates technological innovation as the core of the solution. This includes, for instance, precision-agriculture (Lindblom et al. 2017) or the use of genetically modified cultivars (Qaim and Zilberman 2003). On the other hand, strong ecological modernization refers to a more ‘ecocentric approach’, i.e. an approach diversifying farming practices and relying on ecological interactions between biophysical system components that promote natural cycles and functions supporting crop growth (e.g. natural soil fertility and pest control) (Kremen et al. 2012, Duru et al. 2015). These two approaches are not mutually exclusive, i.e. an ecocentric approach may still rely on some technological innovations and vice versa.

In the same vein of work, Wezel et al. (2013) distinguishes between three ‘levels’ of agroecological transition: efficiency increase, substitution and redesign. Efficiency increase refers to systems reducing their input consumption and resource use, by for instance, the application of technological innovation. Substitution refers to systems replacing inputs or a practice (e.g. chemical pesticides by natural pesticides). At last, the ‘redesign level’ refers to systems transitioning the whole farming system.

Agroecology is a concept laying at the strong extremity of the weak-strong gradient of ecological modernization and offers a whole system redesign (Wezel et al. 2013, Altieri et al. 2017). The concept is increasingly endorsed and is now advocated by the International Panel of Experts on Sustainable Food Systems (IPES FOOD 2016), the Food and Agriculture Organization of the United Nations (De Schutter 2014) and a wide body of scientific literature (e.g. Gliessman 2011, Altieri et al. 2015, Hatt et al. 2016aa). The term ‘agroecology’ first emerged as the application of ecological study to agricultural systems (Gliessman 1998) and then evolved to include social and economic dimensions of food systems (Francis et al. 2003). Today, the definition of agroecology remains polysemic and can refer to a science, a movement and/or a practice (Wezel et al. 2011). We refer to ‘agroecological farming systems’ (AFS) as systems combining multiple agricultural practices which rely on ecological processes to support crop production (Wezel et al. 2013) and re-think the food system and the stakeholders involved (Francis et al. 2003) to increase environmental and social sustainability, responsibility, resilience and viability (Hatt et al. 2016aa, Nicholls and Altieri 2018). Within this broad definition of agroecology, the present work focus on the ‘practice’ side of agreoecology, in which the concept aims at mobilizing functional agro-biodiversity and ecological processes to support food production. Agroecological practices embrace a wide range of practices such as integrating natural and semi-natural landscape elements, implementing cover crops, using green manure, relying on intercropping or agroforestry, etc. (Wezel et al. 2013, Hatt et al. 2016a).

1.3. How agroecology challenges current research

Seeing the strong interlinkages between social, natural and agricultural sciences that agroecology implies, accompanying agroecological transition challenges current research practices (Hatt et al. 2016a, Dendoncker et al. 2018a, Nicholls and Altieri 2018). CFS are the result of disciplinary research approaches generating standard outcomes that are applied to a variety of pedo-climatic conditions (Bawden 2010). Agroecology, in contrast, calls for decentralized and more holistic research which combines multiple disciplines with locally relevant empirical knowledge (Duru et al. 2015, Hatt et al. 2016a).

Iterative research processes (also referred to as ‘adaptive management’) are suggested where stakeholders and scientists learn from the outcomes of on-farm experiments, from which management practices are continuously redesigned based on the knowledge co-generated (Duru et al. 2015, Dendoncker et al. 2018a). Such research process starts by reaching a common understanding of the current system. This involves assessing the current biophysical (e.g. soil composition and structure) as well as the social (identifying stakeholders involved, the related stakes, values and mental frameworks) states of the agroecosystem. Based on this knowledge, potential alternatives can be co-generated and explored (Dendoncker et al. 2018a). Such transdisciplinary research thus integrates various knowledge systems and values. This enables the contextual socio-ecological complexity to be taken into account, integrates the diverse values, and develops tailor-made innovations which are 'user-inspired' and 'user-useful'(Biggs et al. 2011, Doré et al. 2011, Hatt et al. 2016a).

Despite the encouraging potential of agroecology and of its new research paradigm, few studies actually endorse the challenge and the 'top-down' single indicator-based (i.e. yield) research approach of conventional agricultural research prevails (Bommarco et al. 2013, Lescourret et al. 2015, Holt et al. 2016, Nicholls and Altieri 2018). While this conventional approach to agriculture has allowed reaching unprecedented yields, it now requires adapting to the social, economic and environmental challenges. Agroecology calls for site-specific, holistic and decentralized scientific approaches to design practices adapted to each socio-ecological system (Dale and Polasky 2007, Méndez et al. 2013, Bommarco et al. 2013, Andersson et al. 2015, Ponisio and Kremen 2016). Researchers need tools and guidance to carry out such inter – and transdisciplinary research. A more fundamental and methodological type of research is needed, one that develops and tests methodologies that are readily applicable for future applied agricultural research (Doré et al. 2011, Hatt et al. 2016a).

During the last decades, significant progress has been made with respect to the development of approaches and frameworks to investigate the multi-dimensions of agriculture and its sustainability (Schader et al. 2014) (Figure I-1). For instance, life cycle assessment (LCA) tools quantitatively address social or environmental impacts of the whole food system for a specific output unit (Brentrup et al. 2004, Benoît et al. 2010). Multi-criteria analyses (MCA) aim at assisting decision-making by ranking options or alternatives based on multiple and often conflicting criteria (Sadok et al. 2008, Alrøe et al. 2016). In fact, the amount of methods and approaches to apprehend the complexity of sustainable food systems is growing, as attested by recent reviews (van der Werf et al. 2009, Binder et al. 2013, Schader et al. 2014). Among these tools, the tool of 'integrated ES valuation' has raised considerable interest in recent years (Boeraeve et al. 2015 – Appendix 1, Jacobs et al. 2016) (Figure I-1), but remains weakly applied to agricultural contexts (Figure I-2). The present PhD Thesis contributes to this vein of work by analyzing the potential of this increasingly advocated tool for decision support in transition contexts, the tool of 'integrated ES valuations', by applying it to agroecological contexts.

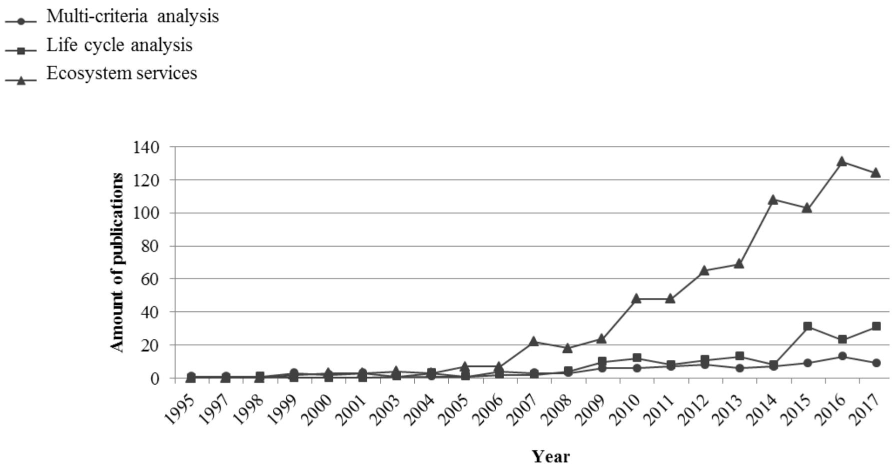

Figure I-1 : Amount of published studies inventoried by Scopus through the key-word search: 'sustainable', 'agricullture' and 'multi-criteria' or 'multicriteria analysis'(with round icons), 'life cycle analysis' (square) or 'ecosystem services' (triangle).

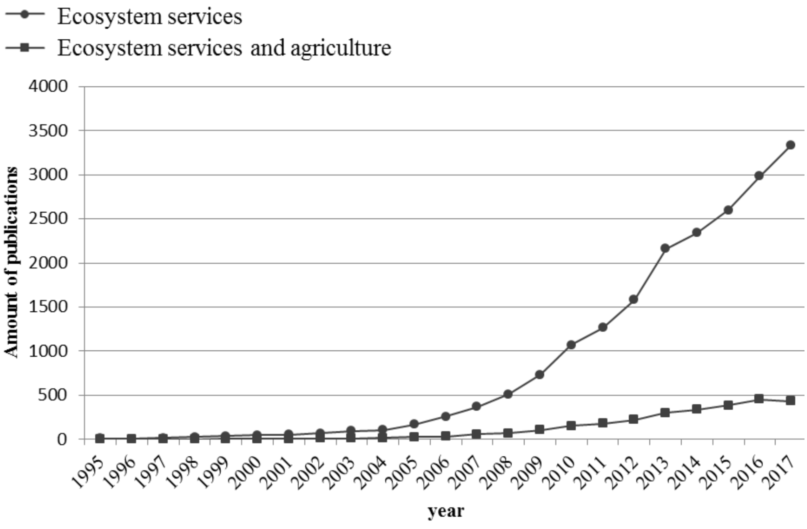

Figure I-2 : Amount of published studies inventoried by Scopus through the key-word search: 'ecosystem services' (round) and agriculture (square).

2. Integrated ES valuation as a tool to study agroecological transition

'Ecosystem services' (ES) are suggested as a conceptual tool disentangling yet embracing the complexity of agricultural systems by combining socio-ecological components (Zhang et al. 2007, Power 2010, Lescourret et al. 2015). The present section presents theoretical foundations of the ES concept and definitions. It then explains how to assess and value ES and their related value domains, and how this led to the recent advances on 'integrated ES valuations'. At last, it presents how the concept frames agriculture and agricultural management.

2.1. A concept at the interface of human and nature: theoretical background

The most commonly cited definition of ES is provided by the Millenium Ecosystem Assessment (2005):'ES are the benefits people obtain from ecosystems'. Despite the existence of a variety of definitions and debates about distinction between terms like 'services', 'goods', 'benefits' (Potschin and Haines-Young 2016) or 'nature contribution to people' (Díaz et al. 2015, Pascual et al. 2017, Peterson et al. 2018), there is a consensus that the concept offers an interface between ecological structure and processes at one end and people wellbeing and values at the other. Formely represented by the 'ES cascade' (Haines-Young and Potschin 2010), it has evolved to include societal processes (Spangenberg et al. 2014) and interactions between the social and ecological processes (Costanza et al. 2017). The latest update is suggested by the Intergovernemental Platform for Biodiversity and Ecosystem Services (IPBES), offering a 'rosetta' framework to contrast with the cascade where ES seem to flow effortlessy from ecosystems to beneficiaries (Díaz et al. 2015). This latter framework acknowledges that people value and/or manage ES which in turn influences ecological structures and processes and impacts ES flows. It acknowledges that people hold different 'worldviews' and values, which is partly influenced by the governance system and institution to which they belong.

Considering this diversity of approaches proposed to conceptualize ES, a myriad of definitions and terms exist to depict the different facets of the concept (Mouchet et al. 2014). Within the present work, we distinghish the different terms as follows:

- ❖ **ES flow**: flow between the source ecosystem and the actual users of biomass, water, regulatory/ mitigating work and information, we consider this term to be synonymous to **ES delivery**, **ES provision** and **ES *actual* flow**;
- ❖ **ES capacity**: the long term potential of ecosystems to provide services appreciated by humans in a sustainable way, under the current management. Within this manuscript, ES capacity are considered as **ES stock** and **ES *potential* flow**;
- ❖ **ES demand**: the amount of a service required or desired by individuals or groups within the society;
- ❖ **ES bundle**: a set of ES that appear together either positively associated (**ES synergy**) or negatively (**ES tradeoff**). The associations can rise from common underpinning processes or as a response to common pressures.

ES are usually classified in three categories (based on CICES 2018):

- ❖ **Provisioning ES**: all material and energetic outputs from ecosystems; they are tangible things that can be exchanged or traded, as well as consumed or used directly by people.

- **Regulating ES**: all the ways in which ecosystems control or modify biotic or abiotic parameters that define the environment of people, i.e. all aspects of the 'ambient' environment; these are ecosystem outputs that are not consumed but affect the performance of individuals, ecological communities and populations, and their activities.
- **Cultural ES**: all non-material, intangible, ecosystem outputs that have symbolic, cultural or intellectual significance

A fourth category of '**supporting ES**' has been suggested by several authors (MEA 2005, Potschin and Haines-Young 2016) to account for underlying structures and processes that characterize ecosystems. However, in the present work, we concur with authors who do not consider these as services but rather as 'ecosytem processes' or 'functions' (De Groot et al. 2010, Braat and de Groot 2012).

2.2. Valuing ecosystem services: integrating various value domains

Measuring ES flow can be done in various ways. Provisioning ES are often tangible flows (e.g. flows of biomass) and can thus be assessed from direct measurements (Balmford et al. 2008). Regulating ES can be measured by assessing changes in the related benefits (e.g. quality of air) or 'avoided changes' (e.g. disease regulation). Regulating ES are also often assessed by measuring the underlying ecological processes or functions (e.g. soil aggregate stability for the ES soil erosion regulation) (Balmford et al. 2008). Cultural ES can be estimated from the presence and structure of landscape elements known to be appreciated or inspirational (e.g. hedgerows and reliefs). However, as cultural ES are often intangible and involve subjective judgement, many cultural ES assessments enquire people of their perceived cultural benefits (e.g. inspiration, education, aesthetics) (Hernández-Morcillo et al. 2013).

As it can be noticed, we measure either the ES from the ecological system, often referring to an ES potential flow, or from the social system, referring to the ES demand (Martín-López et al. 2014). For ES potential flows, measurements are biophysical and imply measuring the ecosystem structure or ecological processes and functions as proxy. Such measurement does not measure ES flow, but gives an estimation of the ecosystem potential to deliver it. Such assessment is also referred to as '**biophysical ES assessment**'. On the social side, measurements usually involve socio-cultural or economic values referring to '**socio-cultural'** and **'economic ES valuations'** respectively. The former one assesses the importance or perception people assign to ES, while the later assesses ES for economic purposes, which can be expressed in qualitative or quantitative (i.e. monetary) terms (Iniesta-Arandia et al. 2014, Scholte et al. 2015). Each assessment or valuation method thus reveals a distinct 'value domain'.

Previous work has demonstrated that different types of valuation generate different information outputs (Andersson et al. 2015). Martín-López et al. (2014) compared the information obtained from biophysical, socio-cultural and economic ES valuations and found that different ES trade-offs came into view depending on the value domain investigated. Within each value domain, the method used to elicit the value actually also defines it. Assigning values to ES does not only ‘uncover’ values, but also ‘construct’ them, making the ES concept a ‘value-articulating’ institution (Vatn, 2005). Considering that the technique used for ES assessment determines the result, ES assessment should combine different methods which entail the distinct value domains (Jacobs et al. 2018).

In the light of these observations, the concept of ‘integrated ES valuation’ emerged. Integrated valuations combine ecological, socio-cultural, and economic valuation as methods used in a participatory way to elicit the plurality of values related to ES, as well as the tradeoffs and synergies among them (Boeraeve et al. 2015 – Appendix 1, Díaz et al. 2015, Kelemen et al. 2015, Jacobs et al. 2016).

This recognition of the need to integrate social, ecological and economic aspects of ES values in decision-making is nothing new. Among others, the World Commission on Environment and Development (1983-1987) and the United Conference on Environment and Development (UNCED) of Rio 1992, and later, of Rio+20, have stressed this need and have demanded pluralistic value frameworks. This was echoed by a wide body of academic literature (Martinez-Alier 2003, Dendoncker et al. 2013, Kallis et al. 2013, Boeraeve et al. 2015- Appendix 1) and several international ES initiatives like the Millennium Ecosystem assessment (MEA 2005), the Economics of Ecosystem Services and Biodiversity (TEEB 2010) and, more recently, the Intergovernmental Platform for Biodiversity (IPBES 2015).

While monetary ES valuation has long dominated has the valuation practice for policy and planning (Costanza et al. 1997, de Groot et al. 2012, e.g. Boerema et al. 2014), which has triggered bustling criticism (Daily et al. 2000, Gómez-Baggethun and Ruiz-Pérez 2011, Boeraeve et al. 2015- Appendix 1), the dust is now settling on the valuation debate (Jacobs et al. 2016). The question is no longer whether to integrate values or not, but on operationalizing the framework to respond to the urgency of sustainability challenges (Dendoncker et al. 2018b).

More specifically, the concept of integrated ES valuation is seen as potentially helpful to tackle the ‘wicked problem’ of agricultural transition presented in section 1. This could indeed answer the call on the urgent need to integrate nature’s diverse values in our land management decisions and actions (IPBES 2018a), and the need of agroecology to develop a thorough understanding of the socio-ecological system to co-design tailor-made practices.

2.3. The tool of ecosystem services to disentangle the complexity of agricultural systems

A large body of literature investigates how the ES concept can be used in agricultural contexts, offering a wide array of conceptual frameworks (Zhang et al. 2007, Power 2010, e.g. Lescourret et al. 2015). Our framework is depicted in Figure I-3. Agroecosystems are semi-natural ecosystems, greatly influenced and shaped by human management (arrow (a)) as depicted in most work (Dale and Polasky 2007, Power 2010, Lescourret et al. 2015). Agroecosystem management shapes the ‘ecological structure’ composed of physical, geochemical and biological components. Ecological structures in turn influence the biotic and abiotic interactions producing ‘ecosystem processes and functions’. These become ‘ecosystem services’ (ES) (arrow (b)) once generating benefits, valued and demanded by people (arrow (c)). People use, perceive and value these ES which generate benefits when they satisfy needs and wants, determining their wellbeing. The social system comprises multiple ‘worldviews’, i.e. different people can attribute different values to a same ES (Pascual et al. 2017). The social agroecosystem includes multiple ES providers (e.g. farmers) and multiple ES beneficiaries (local inhabitants, consumers and farmers). The extent to which farmers value and perceive ES and the structural and functional state of the agroecosystem, as well as the political context and globalized market in which they take part all influence their decisions on how to manage their land (arrow (d)).

In the context of this framework, the approach of agroecology suggests to manage the agroecosystem in such a way that ecological processes and functions provide ES delivery beneficial to the farmers or the society. Agroecology capitalizes on the understanding of the structural state of the agroecosystem to mobilize local ecological processes instead of external chemical or mechanical inputs. This approach thus requires detailed monitoring of the main ecological processes and functions to provide a thorough understanding of the agro-ecosystem, and allow the design of tailor-made practices. Such strategy contrasts with the one of CFS and their standardized agricultural practices.

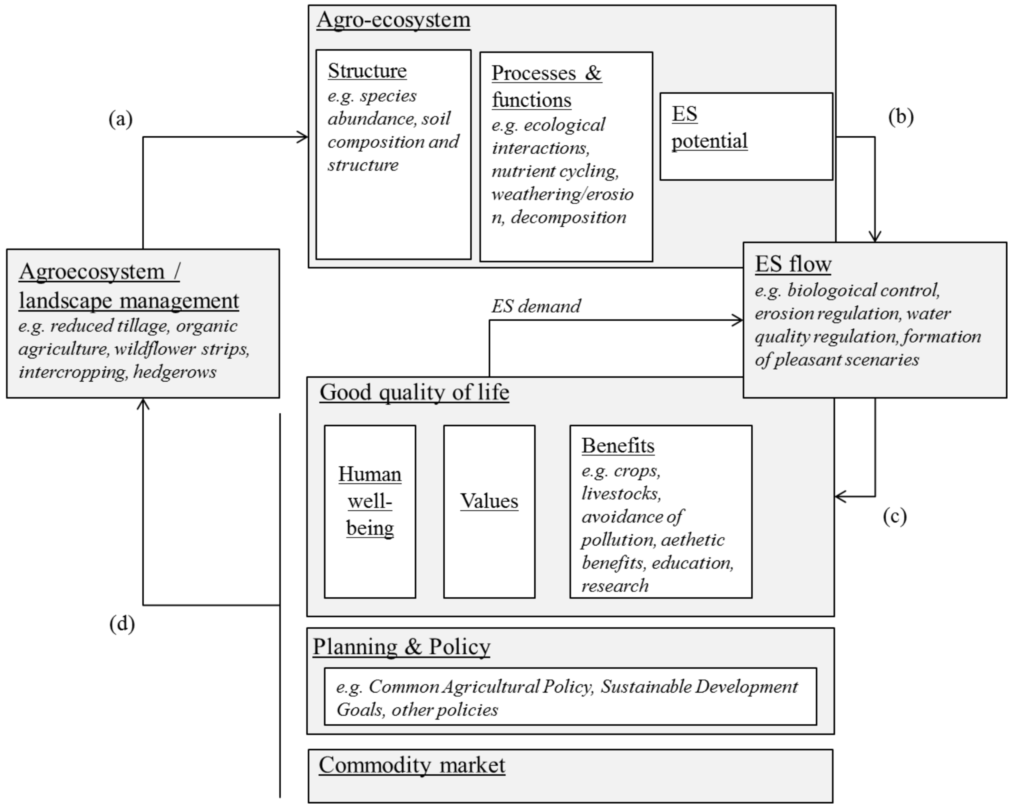

Figure I-3: Analytical framework addressing the relationship between agroecosystem structure and composition, the supply and demand of ecosystem services and the interrelation between the policy context, the globalized market, the values held by the different stakedholders and the management decisisons shaping agro-ecosystems. Arrows (a) to (d) are described in the text.

The use of the ES framework to analyze, understand and potentially re-design agricultural systems presents an opportunity to consider the agroecosystem as a complex entity composed of natural and social elements, to account for the multiple services flowing to and from the agriculture (Zhang et al. 2007, Power 2010), as well as the multiple values stakeholders attribute to them (Poppy et al. 2014). To achieve the design of innovative multifunctional productive agroecological systems, we require a thorough understanding of the relationships between ecological processes, functions and services, both under current conditions and after transitioning (Dale and Polasky 2007, Dendoncker et al. 2018a). A large range of indicators is needed to provide the required information to understand the agroecosystem and adapt it to its socio-ecological context. Farming systems represent complex entities with interacting synergizing or offsetting processes and practices. Hence, research aiming at disentangling this complexity requires system-based and multidimensional approaches (Kremen et al. 2012, Robertson et al. 2014, Ponisio et al. 2014).

However, to date, few ES work has addressed agricultural transition with an integrated approach. Most agricultural studies are based on specific agricultural practices and single services, such as, for instance, reduced-tillage and nitrogen utilization (Drakopoulos et al. 2015) or wild flower strips and pest control (Hatt et al. 2016b). So far, agricultural research assessing multiple services have been based on mapping approaches and land use indices (e.g. Maes et al. 2012), models (e.g. Lerouge et al. 2016) or literature reviews and meta-analyses (Kremen and Miles 2012, Barral et al. 2015, Rapidel et al. 2015, Garbach et al. 2016). ES responses to alternative agricultural practices vary across these studies, leading to the conclusion that farm-scale assessments of multiple ES are required to generate context-specific knowledge (Ponisio and Kremen 2016, Landis 2017). Some rare exceptions exists of field-based farm-scale assessments of multiple ES (Porter et al. 2009, Sandhu et al. 2010, Syswerda and Robertson 2014), but these fail to assess interactions between services and practices (Seppelt et al. 2011, Landis 2017). To the best of our knowledge, no research addresses agroecological systems comprising multiple agroecological practices, by analyzing multiple ES delivery and the underlying synergies and tradeoffs.

The present PhD thesis contributes to filling this research gap by providing an analysis of the implementation of the tool of 'integrated ES valuation' to farms that have undertaken an agroecological transition in mobilizing multiple agroecological practices.

3. Research questions and structure of the thesis

3.1. Objectives and research questions

Agroecology is increasingly advocated as a solution to current challenges faced by CFS. Agroecology goes beyond the suggestion of alternative agricultural practices. It also questions the whole food systems, including the stakeholders involved and their interdependencies. By suggesting such a holistic transition, agroecology also questions current research practices. Such an approach to agriculture requires new scientific tools, which allow the integration of multiple values-domains, account for the system's complexity and the underlying uncertainties. Integrated ES valuations pretend to offer such tool. However, to date, few studies report on the implementation of integrated ES valuations to real-life contexts of agroecological transitions. The present work contributes to filling this gap by applying the concept of integrated ES valuation to three real-life farm examples which have encompassed an agroecological transition. The aim is to **analyze these agroecological farming systems (AFS) through the lens of the integrated ES valuation tool and to share lessons learned in a reflexive posture**. This objective is translated into a general research question (GRQ):

GRQ: 'How can the tool of integrated ES valuation help understand agroecological transition?'

Which will test the hypothesis that the tool of integrated ES reflects the various value domains (social and environmental) involved in agroecological farming systems and thus support better understanding of these transitioning systems.

Although the selected agroecological farms also aim to rethink the socio-ecological system as a whole, the scope of this thesis is limited to the changes in agricultural practices. From the implementation of the tool to the selected AFS, I will test the hypothesis that AFS offer higher ES synergies and thus responding better to local stakeholder needs (Bacon et al. 2012, Kremen et al. 2012). To do so, I ask the following sub-research questions:

Sub-research questions applied to AFS case studies

SRQ1: What are the most valued ES by local stakeholders?

This sub-research question aims at eliciting the most valued ES by local stakeholders (i.e. ES providers: farmers and ES beneficiaries: farmers and local inhabitant) in order to guide the biophysical ES assessment towards ES which are relevant to the socio-ecological context of the studied farms. SRQ1 is addressed in Chapter III – section 1. As consumers are increasingly sensitive to multifunctional and sustainable food production (Bacon et al. 2012, de Favereau 2014), the underlying hypothesis is that local stakeholders value a wide range of ES going beyond the sole production of food.

SRQ2: How do local stakeholders perceive ES flow in AFS landscapes in comparison with CFS landscapes?

This sub-research question aims at investigating how local stakeholders regard landscapes modified by AFS by investigating their appreciation and perception of the ES delivery in AFS and CFS landscapes. SRQ2 is tackled by Chapter III section 2. As landscape perception studies have shown that complex heterogeneous landscapes are more appreciated (van Berkel and Verburg 2014, van Zanten et al. 2014b) it is hypothezised that local stakeholders appreciate AFS landscape better.

SRQ3: What is the potential ES delivery in the selected AFS in comparison with their neighbor CFS?

This sub-research question aims at understanding the potential of AFS to deliver ES bundles. In order to have a reference point, adjacent conventional farming systems ‘CFS’ are subject to the same analysis. SRQ3 is dealt with in Chapter IV. The commonly found assumption that AFS provide a wider array of ES (Hatt et al. 2016a, Kremen et al. 2012) by mobilizing ecological processes will be tested within this SRQ.

3.2. Structure of the thesis

After the introduction (Chapter I), the analysis of the present study is divided into three main parts (Figure I-4): (i) a literature analysis (Chapter II), (ii) the application of the integrated ES tool to AFS case studies (Chapter III and Chapter IV) and (ii) a reflexive analysis (Chapter V). The manuscript then provides a general d conclusion to the whole study (Chapter VI).

Chapter II develops a literature analysis of which the aim is twofold:

- Clarifying how the concept of agroecology answers current agricultural challenges and how it questions current research practices (***Article 1 - published);***
- Investigating how the concept of integrated ES valuation can steer agroecological transition and suggesting a framework for implementation (***Article 2 - published***), of which the first step is then applied to the case-studies in chapter III and IV.

Chapter III and IV deal with the three SRQ by applying the integrated ES valuation tool to the AFS case studies:

Chapter III presents the socio-cultural ES valuation of the AFS case-studies, which includes two parts:

- The participatory ES identification and selection based on stakeholders values (**SRQ1**);
- The assessment of stakeholders' perception and appreciation of AFS landscapes and their ES delivery (***Article 3 –submitted***) (**SRQ2**).

Chapter IV depicts the biophysical ES assessment of the AFS case-studies (***Article 4 – submitted***) (**SRQ3**).

Chapter V feeds back on lessons learned with a reflexive posture based on the analysis of how the tool of integrated ES valuation helped answering the sub-research questions. It includes three sections:

- A reflexive analysis on participatory ES identification and selection (***Article 5 – published***);
- A reflexive analysis on the socio-cultral ES assessment;
- A reflexive analysis of the biophysical ES assessment;
- A reflexive analysis of the implementation of the integrated ES valuation tool as a whole.

Chapter VI provides a general conclusion on the thesis study and research perspectives.

<u>Appendices</u> include among other a methodological framework of integrated ES valuation on which rely the present thesis (***Article 6 - published***).

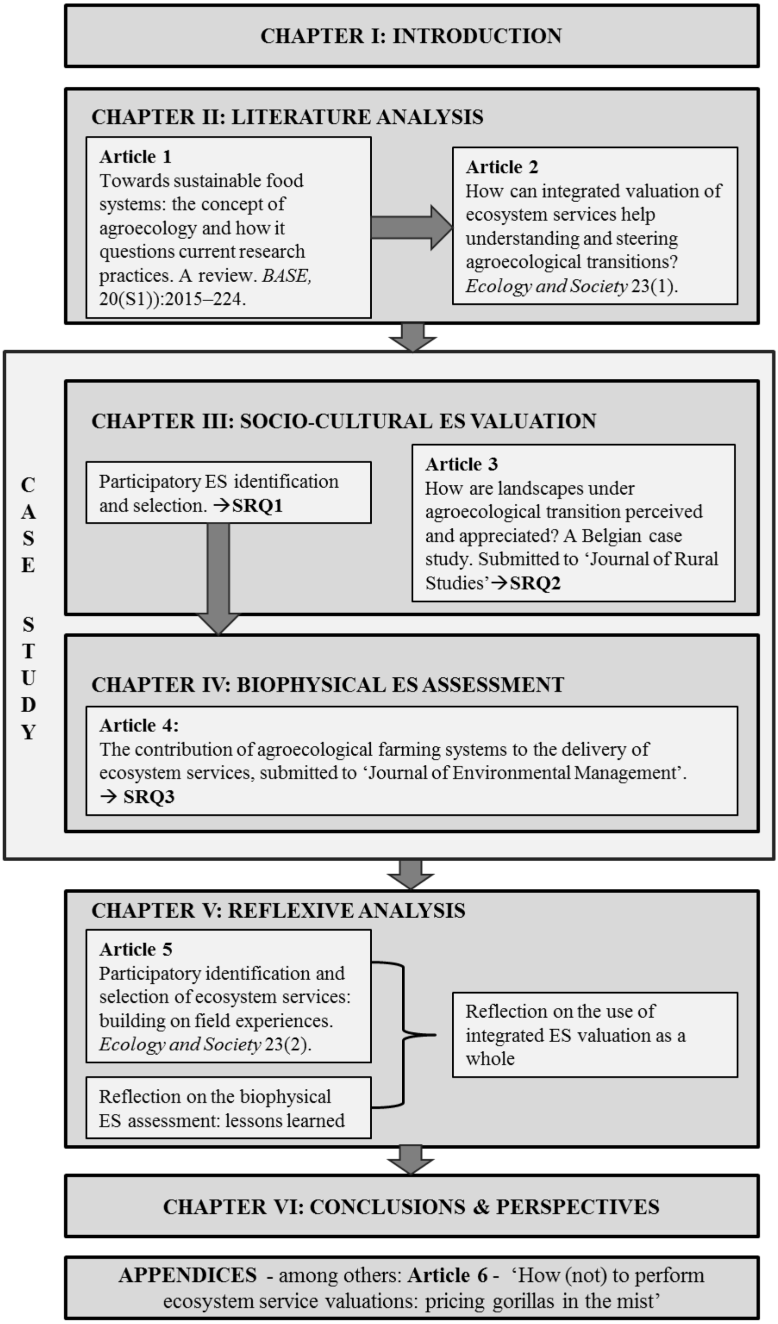

Figure I-4: Structure of the thesis.

4. Context of the selected case-studies

The studies AFS have been selected from a self-organizing network of farmers from the Western Part of the Hainaut Province in Belgium. This network gathers local farmers who increasingly experience conventional farming space as threatening their room for maneuver. They feel 'being reduced to buyers, adopters, always being guided, constrained, and taught'. To answer these constraints, farmers develop 'novelties' to ensure more autonomy, resilience and sustainability (Delobel 2013). Some change their agricultural practices (in livestock feed, soil tillage, genetic improvement, etc.), their work organization (transformation and/or on site sale of the products) or even their interconnections with other stakeholders (collaboration with restaurants, schools, consumers, etc.) (Louah et al. 2015).

As the development and implementation of these 'novelties' often trigger new challenges and questions, these farmers have created a network entitled 'The innovative farms network' (Réseau des fermes novatrices 2017). This network represents to them a 'safe learning space' where they can exchange knowledge and experiences. The network includes farmers essentially, but also scientists. The relationship between farmers and scientists proscribes top-down and unidirectional learning processes. Instead, it encourages the co-creation of knowledge, by placing farmers at the center of the research process and placing scientists as facilitators (Louah et al. 2015).

The network is organized along nine 'socio-technical aspects' all emanating from the farmers themselves. These are: soil quality improvement, social agriculture, feed autonomy, new agricultural projects, sustainable vegetable gardens, agroforestry, bread cereals, animal traction and legal protection of farming innovations (Réseau des fermes novatrices 2017). For each of them, clear objectives have been formulated, going from knowledge exchanges, the co-creation of tools or organizing conferences and debates. The work is individual at the farm level and collective throughout the network activities. A collaborative web platform facilitates the organization (Réseau des fermes novatrices 2017).

Within this network, the present study has selected three cereal farms. These have been selected because they have implemented a whole-system transition. Agricultural practices are drastically modified and the food chain adapted to shorten it and increase interactions with local stakeholders. Within this whole-system transition, the present work focuses on the change of agricultural practices, and its impacts on the environment (biophysical ES assessment) and the related values and perceptions of locals (socio-cultural ES valuation). From this 'practice' perspective, these farms are organically certified, apply reduced tillage to their soil (no-tillage or direct seeding), grow crops in association (referred to as 'intercropping' hereafter) and implement green infrastructures (grass strips, wildflower strips, hedgerows, etc.). By combining all these ecological practices, we believe these farms lay on the 'strong' end of the gradient of ecological modernization presented by Horlings and Marsden (2011) and thus respond to the definition of 'agroecological farming systems' (Altieri et al. 2017). These farms are unique examples of agroecological transition and thus not comparable to other systems. Organic or no-till farming systems, for instance, differ because they only implement one of the agroecological practices (Wezel et al. 2013) and they do not rethink the social system (Kremen et al. 2012).

The socio-cultural ES valuation relies on consultation and focus group methodologies to grasp local stakeholders perceptions and values. By stakeholders, we refer to the farmers (ES providers and beneficiaries) and the local inhabitants and consumers (ES beneficiaries). Participants are selected according to a 'purposive sampling' strategy, i.e. sampling of which the profile of participant was selected purposively in order to reach a wide variety of profiles interested in the topic rather sampling randomly in the population. The collaboration with the Parc Naturel des Plaines de l'Escaut brought an important support in the sampling process as the park already benefits from a large credibility and legitimacy among locals.

The biophysical ES assessment carries out measurements in all the cereal parcels of the three AFS in order to assess ES potential flow. As mentioned earlier, in order to have a comparison point, measurements are also carried out in adjacent CFS. All farmers from AFS and CFS have been invited to the focus-groups organized for the socio-cultural ES valuation.

Chapter II

LITERATURE ANALYSIS

New research avenues for agroecology

Abstract of Chapter II

The present chapter consists of two articles. The first article ‘towards sustainable food systems: the concept of agroecology and how it questions current research practices’ suggests a review of agroecology as an alternative to intensive industrial and conventional farming systems in order to achieve greater sustainability. First, the article introduces agroecology as a practice. Agroecological farming practices seek to optimize ecological processes, thus minimizing the need for external inputs by providing an array of ES. The article then broadens the scope by presenting how agroecology questions the entire food systems and the stakeholders involved. Agroecology is based on the assumption that agricultural practices and food systems cannot be dissociated because they belong to the same natural and socio-economic context. These redesigning of both the field and the food systems, require researchers to tackle agroecology through a prism of multi and transdisciplinarity. Hence, agroecological transition entails a transition of research practices as well. This article discusses this point, as well as how this lead to new forms of education within agricultural schools and universities.

The second article ‘How can integrated valuation of ES help understanding and steering agroecological transitions?’ echoes the call made by the first article by suggesting the tool of ‘integrated ES valuation’ to bring multiple disciplines together and collaborate with stakeholders to study and steer agroecological transition. Based on a literature review, the article suggests a four-step integrated ES valuation framework specifically targeted at understanding and steering agricultural transition. To start with (step 1), we suggest building a common understanding of the socio-ecological system in which the agricultural system is embedded by carrying a biophysical ES assessment along a socio-cultural ES valuation. Once a systemic vision of the current agricultural system is reached, plausible trajectories of change can be elaborated (step 2). In addition to evaluate what is feasible, it is necessary to make explicit what is desirable and for whom in order to provide a basis for a broadly accepted normative vision of the studied agroecosystem (step 3). The objective of the ‘last’ step is to turn into practice the options for changes discussed and selected previously, to operationalize on the ground of renewed practices, organizational structures, and management methods (step 4). This fourth step does not represent a *last* step as we suggest an interative approach. Implementing the renewed version of the system will modifiy social and ecological structures and interactions. New visions and values may emerge, potentially requiring continuous adaptations, and iterative application of the proposed framework.

Within the two broad frames suggested by these two articles, the present work narrows down the focus to specific aspects. First, while agroecology suggests a rethinking of the entire food system, the present work centers its attention to the ‘farm’ level and on the transition of agricultural practices. Within the four-step framework suggested in the second article, we locate the present work within the first step. The present work will reflect on how to the tool help *understanding* the agroecological system. The three other steps, which are more linked to a *steering* of agroecological transition, are beyond the scope of the analysis suggested by the present thesis work.

- Article 1: Published -

1. Towards sustainable food systems: the concept of agroecology and how it questions current research practices: A review

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Abstract

Multiple environmental and socio-economic indicators show that our current agriculture and the organization of the food system need to be revised. Agroecology has been proposed as a promising concept for achieving greater sustainability. This paper offers an overview and discussion of the concept based on existing literature and case studies, and explores the way it questions our current research approaches and education paradigms. In order to improve the sustainability of agriculture, the use of external and chemical inputs needs to be minimized. Agroecological farming practices seek to optimize ecological processes, thus minimizing the need for external inputs by providing an array of ecosystem services. Implementing such practices challenges the current structure of the food system, which has been criticized for its lack of social relevance and economic viability. An agroecological approach includes all stakeholders, from field to fork, in the discussion, design and development of future food systems. This inclusion of various disciplines and stakeholders raises issues about scientists and their research practices, as well as about the education of the next generation of scientists. Agroecology is based on the concept that agricultural practices and food systems cannot be dissociated because they belong to the same natural and socio-economic context. Clearly, agroecology is not a silver-bullet, but its principles can serve as avenues for rethinking the current approaches towards achieving greater sustainability. Adapting research approaches in line with indicators that promote inter- and transdisciplinary research is essential if progress is to be made.

Keywords: alternative agriculture, agrobiodiversity, ecosystem services, socioeconomic organization, marketing channels, interdisciplinary research, participatory approaches, innovation adoption

1.1. Introduction

Common practices in the food system, defined as *conventional* (Altieri 1999, Kremen et al. 2012), are coming under increasing criticism in western Europe. Historically, conventional agriculture has led to greatly increased yields and growth in agribusiness, flooding supermarkets with processed food products. Nevertheless, issues such as climate change, pollution, the decline in numbers of farmers and in food quality are being addressed, as reported in the International Assessment of Agricultural Knowledge (2009). Voices calling for a revision of the conventional food system in order to achieve greater sustainability have become louder. Agroecology (also sometimes written *agro-ecology*) is being promoted as a promising concept in answer to this call.

Stassart et al. (2012) retraced the historical broadening of the scope of agroecology, from a focus on ecological processes in agriculture to socio-ecological processes. Agroecology first emerged in 1928 and evolved during the 20th century as the application of ecological concepts to agricultural practices, with the primary aim of reducing the use of chemical inputs and the impact of agriculture on the environment (Altieri 1999). Agriculture is responsible for environmental pollution through, for example, greenhouse gas emissions (25 % of the total emissions worldwide; and 9 % in Wallonia, Belgium; Guns, 2008) and the use of chemicals (e.g. pesticides, growth regulators, mineral fertilizers) that are toxic to the environment (Devine and Furlong 2007) and human health (Baldi et al. 2013). Agroecological principles suggest that we should safeguard local ecological processes that underpin the delivery of ecosystem services (ES) crucial to agricultural activities (e.g. natural soil fertility, biological control), while maintaining the productive function of agriculture (Malézieux 2012).

Since the start of the 21st century, agroecology has increasingly been seen as a concept dealing with both ecological and human dimensions, thus involving all stakeholders in the food chain, from production to consumption (Francis et al. 2003), with the aim of increasing the social responsibility and economic viability of farmers' activities. In the European Union (EU), the economic viability of farms is questionable because Common Agricultural Policy subsidies account for almost all of a farmer’s net income (86 %, 97 % and 90 % on average in Wallonia in 2011, 2012 and 2013, respectively; Service Public de Wallonie, 2014a). In addition, the large number of suicides among farmers compared with the rest of the population (in France, 20-30 % higher; Bossard et al. 2013) can be seen as a worrying trend in society. There has also been a steady decline in the number of farms and farmers over recent decades (the EU lost 2.5 million farms between 2005 and 2010; Eurostat, 2015a). These facts raise questions about both the social relevance and the economic viability of the conventional food system.

In the light of these sustainability challenges, attention has started to focus on agricultural research. The conventional agricultural system is based on the results of disciplinary and reductionist research that have been applied to a large variety of pedo-climatic conditions by changing and homogenizing these systems to meet our needs (Kremen et al. 2012). The complexity of the issues involved (i.e. environmental, economic, social and health concerns) shows that holistic and decentralized scientific approaches are needed if sustainable systems are to be developed (Méndez et al. 2013, Louah et al. 2015).

The term *agroecology* is now increasingly being used in academic publications (Bellon and Guillaume 2012). There is a large body of work on the ecological principles of agroecology (Malézieux 2012, Duru et al. 2015) and the socio-economic dimensions of sustainable food systems (Francis et al. 2003, Gliessman 2011, Dumont et al. 2016). So far as we know, however, only a few papers (but see Stassart et al., 2012) have brought the two dimensions of agroecology together and discussed how they could be adapted to support agroecological innovation.

Based on the literature, this paper looks at how agroecology can help in planning and supporting the transition of conventional food systems towards more sustainable ones. In particular, it seeks to answer the following questions: What are the propositions of agroecology in efforts aimed at improving (i) farming practices and designs to increase environmental sustainability of agriculture and (ii) the organization of the food system in order to enhance the social and economic sustainability of agricultural product processing, distribution and consumption? (iii) How the transition towards agroecological systems challenges current research practices? This last aspect is drawn on the authors' experience of the practical issues, constraints and successes while working within the multidisciplinary research platform 'AgricultureIsLife.be' (University of Liège).

1.2. Agroecological practices to increase environmental sustainability

Since the Green Revolution, conventional agriculture has focused mainly on the production service (i.e. food, feed, forage, fiber and fuel products), often using practices that are highly dependent on anthropogenic external inputs (e.g. chemical fertilizers, pesticides, irrigation based on non-renewable water sources). These practices, however, override the key ecological processes (i.e. biotic and abiotic interactions) that underpin the delivery of ES crucial to the long-term performance of agriculture (e.g. natural soil fertility, biological control, water-holding capacity, resilience to extreme events) and lead instead to serious agricultural disservices (e.g. agrochemical pollution, pesticide poisoning, greenhouse gas emissions) (Zhang et al. 2007).

The ES framework developed through the Millennium Ecosystem Assessment (Reid et al. 2005) shows that a farming system not only provides *output services* (provisioning and cultural ES), but also receives and depends on *input services* (supporting and regulating ES), such as biological control, water purification and nutrient cycling. Through this framework, the development of environmentally sustainable agricultural practices focuses on optimizing the balance between input and output services (Zhang et al. 2007). Wezel et al. (2014a) noted that agroecological practices are “agricultural practices aiming to produce significant amounts of food, which valorize in the best way ecological processes and ES in integrating them as fundamental elements in the development of practices”.

Within the ES framework, biodiversity comes as a key concept when setting out agroecological practices (Altieri 1999, Kremen and Miles 2012, Wezel et al. 2014a, Duru et al. 2015). Three levels of integration can be distinguished: planned, associated and landscape (bio)diversity. *Planned biodiversity* refers to the biodiversity intentionally introduced by the farmer into the agroecosystem (Altieri 1999). This biodiversity includes the productive (e.g. cash crop, forage, timber, livestock) and non-productive (e.g. flowers) biota introduced into the system and managed at varying temporal (e.g. rotation, cover crops), spatial (e.g. intercropping, agroforestry, wildflower strips) and ecological (e.g. genetic diversity at the population, variety and species level) scales (Kremen and Miles 2012). *Associated biodiversity* refers to the biodiversity unintentionally introduced into the agroecosystem (Altieri 1999). This biodiversity relies on practices that provide favorable habitats for a diversity of above- and below-ground organisms, attracting them from the surrounding environment. It contributes indirectly to the productive function by enhancing ecological processes, which in turn can provide ES (Tscharntke et al. 2005). *Landscape diversity* level takes into account the integration of biodiversity through the structure and composition of the surrounding environment (Duru et al. 2015) and sees biodiversity as a function of its relationship with the surrounding landscape. Agroecological practices integrate these three levels of biodiversity in order to provide synergies between ecological processes and achieve multiple ES delivery within the system.

The link between the principles outlined above and the concrete implications in terms of management strategies at field, farm or landscape scale has been illustrated in detail in the literature with reference to a wide array of agroecological practices (Power 2010b, Kremen et al. 2012, Wezel et al. 2014a). For example, wildflower strips (planned biodiversity) can be sown along field margins in order to control insect pests. The flowers provide a refuge and food resources (nectar and pollen) that benefit insects (associated biodiversity) that can act as pest natural enemies (predators and parasitoids). The ecological process of biological pest control is therefore an input service benefiting farmers by enabling them to reduce their reliance on insecticides (Pfiffner et al. 2009). In terms of agricultural productivity, however, results with regard to final crop yields are still scarce (Tschumi et al. 2016), but product quality would benefit from the reduction in pesticide residues in the food supply for the consumers.

In order to ensure the delivery of these ES, the surrounding landscape needs to be taken into account. For example, the mere presence of wildflower strips might not be efficient enough for controlling pests (Pfiffner et al. 2009) because the delivery of this ES depends on the colonization of wildflower strips by insects coming from (semi-)natural habitats in the landscape (e.g. woodlots, perennial grasslands)

(Jonsson et al. 2015). The interdependence between landscape and plot scale in order to maintain ES is specific to each practice. For instance, Tamburini et al. (2016) showed that conservation tillage (defined in this paper as the non-inversion of soil, often combined with permanent vegetation cover) could be efficient for maintaining biological pest control even in simplified landscapes.

Both examples illustrate that the efficiency of a practice in the delivery of one or multiple services depends on interactions at different scales. It is therefore necessary to take account of plot management and landscape composition and the processes relevant to the different scales when planning strategies to maximize services.

Furthermore, synergies may appear between practices. It is therefore important to implement multiple agroecological practices in order to optimize ES delivery. For example, in a recent meta-analysis, Pittelkow et al. (2014) revealed that implementing no-tillage alone led to a reduction in crop yield, whereas combining no-tillage with soil cover (by crop residues or cover crops) and crop rotation could increase yield.

Finally, ES resulting from the implementation of one or multiple agroecological practices do not necessarily occur at the same scale as the practice itself or within the same time frame. For example, the implementation of agroforestry (defined as a land-use system that integrates, in the same area, woody elements with crops and/or livestock production; Torquebiau, 2000) will deliver ES at the farm scale because the deep rooting system of the tree and litterfall participates to nutrient cycling and therefore maintains soil fertility (Tsonkova et al. 2012). Other benefits arise on a wider scale through various processes; for example, research has shown that the presence of trees helps with carbon sequestration and thus contributes indirectly to climate change mitigation on a global scale (Jose and Bardhan 2012). Farmers can therefore expect an annual agricultural income from crops and/or livestock, as well as from fruits and/or nuts from the trees and, in the longer term, from the capitalization of the timber.

Despite the potential of agroecological practices in providing ES, there are still some uncertainties. As highlighted by Wezel et al. (2014a), who outlined the advantages and drawbacks of 15 agroecological practices, their effectiveness in providing ES depends greatly on the local context. Local pedoclimatic conditions affect the ecological processes and the economic and societal environments affect the final goods. Given this context-dependent efficiency, farmers' uncertainties lack of scientific knowledge about some ecological process, possible additional costs of equipment, increase in human labor, low commercialization rate of the product, new legislation and so on (Wezel et al. 2014a). Thus, farmers need to develop tailor-made practices adapted to their local context, which often entails going through a lengthy process of trial and error

1.3. Organizing the food system in order to increase social relevance and economic viability

A production system based on ecological processes instead of inputs, as described above, challenges the entire food system because it results in greater product diversity in space and time (Kremen et al. 2012). The challenge is particularly high given that the goods produced by agricultural systems are already numerous (i.e. feed, forage, fiber and fuel; Delcour et al. 2014).

With regard to food, the conventional food system, built on the model of supermarkets and controlled by a few transnational food companies, is based on logistic efficiency, product standardization and price competition (Raynolds 2004). While product standardization became possible through the use of mechanization and external chemical inputs (Marsden and Murdoch 2006), the need for logistic efficiency and price competitiveness led food companies – which drive the food system – to globalize their provisioning, creating competition between farmers and promoting short-term productivity (Kremen et al. 2012, Rosset and Martínez-Torres 2012). The significant decline in the number of farmers, however, as well as the importance of EU subsidies in farmer income, are indicators of the limits of this economic model for EU agriculture.

It is in this context that the need to design sustainable food systems arose and this issue became an integral part of agroecology. C. Francis et al. (2003) proposed involving all stakeholders in building such systems: farmers, processors, retailers, consumers, scientists and politicians. As Gliessman (2011) states: “Farmers alone cannot transform the entire food system.” The approach was clarified recently through a list of 13 principles on which sustainable food systems are based. These include: environmental equity, financial independence, partnership between producers and consumers and geographic proximity (Dumont et al. 2016).

Among the multiple stakeholders, particular attention has been given to consumers. Involving and educating consumers has been seen as essential for ‘closing the loop’ in the food system (Francis et al. 2003). In this context, Community Supported Agriculture (CSA) networks, which have existed for decades, are seen as an advanced model for sustainable food systems (Kremen et al. 2012). They are built on direct links between farmers and consumers through direct selling at the local scale. They are economically beneficial because they create jobs on farms and assure farm incomes over the longer term (compared with conventional food systems) (Wezel et al. 2014b). Farmer incomes can also increase because there are fewer intermediaries in short-supply chain marketing. In addition, consumers know more about how their food is produced and therefore request and choose food products based on sustainability criteria (Kremen et al. 2012). Finally, developing short food supply chains to reconnect producers and consumers is seen as an essential aspect of any agroecological transition (Guzmán et al. 2013) and is one of the 13 principles of sustainable food systems listed by Dumont et al. (2016). A recent criticism of the CSA model, however, is that it does not include the stakeholders in the entire food system (Lamine 2015b). By definition, it bypasses the intermediaries, whereas the transformation process should involve them.

There are other innovative models based on multiple stakeholder involvement. One is the French food cooperative Biocoop, a network of 345 organic shops (Lamine 2015a). Unlike traditional supermarkets, Biocoop brings producers, shop managers, employees and consumers together in an *ethical committee*. Its role is to establish common guidelines (e.g. prices at which products are bought to producers and processors, and sold to consumers) and to ensure that the common values are respected. Biocoop's current governance has been strengthened by addressing the criticism it faced in the 1990s, when it grew considerably and developed logistical tools and management strategies that did not appear to differ much from those of the conventional food system. This illustrates the challenge facing sustainable food system initiatives of finding a balance between remaining in a highly competitive food market while conserving core values that differ significantly from those of food companies.

The challenge also lies in informing consumers of the originality of sustainable food systems, compared with the conventional system, especially because of the confusion that can arise when food companies imply, through labeling, that their products derive from sustainable systems. As Warner (2007) highlighted, labels are used in conventional food chains to persuade consumers of product quality, because food scares have become common and face-to-face relationships no longer exist. They are even seen as "initiatives to create ethical space within the marketplace" (Barham 2002) without transforming it. *Quality* is an ambiguous term, however, its meaning changing over time (Warner 2007). Whereas food companies try to meet the quality expectations of consumers, a sustainable food system that involves all stakeholders does not need quality labels. For example, information about synthetic pesticide use, animal welfare, production location and human working conditions (i.e. the most important quality criteria for consumers, according to Howard and Allen, 2010) can be made available through face-to-face relationships in short-supply chains; in systems such as Biocoop, these criteria are discussed by the ethical committee and made available through a charter. Transparency in the production and processing steps, as well as democratic governance (two principles of sustainable food systems; Dumont et al., 2016), allow these systems to be highly responsive to stakeholder expectations in terms of quality, which itself can vary from one location to another (Zepeda et al. 2013).

Unlike the conventional food system, these cases show that sustainable food systems can be diverse. Although they adhere to common principles, the way in which they are implemented can vary (Dumont et al. 2016) and thus attract criticism from unsatisfied stakeholders. This decentralized and therefore flexible approach, however, allows a diversity of projects to develop, each of them tailor-made to their local context.

1.4. Scientific practices and agricultural innovations

As is clear from the discussion above, natural, social and agricultural sciences are intrinsically intertwined in food production systems and among the stakeholders in those systems. Accompanying agroecological transition therefore throws up new challenges and opportunities for research. Agroecology questions scientists about their research topics, the methods they use and develop, and the results they produce. Rather than saying that research in conventional agriculture using a biotechnological approach is no longer relevant, this section explores more holistic approaches that scientists could use to integrate complexity and uncertainty into their research practices. Not facing these challenges would lock scientific research into a limited range of thought and action, which in turn would hamper agroecological innovation (Vanloqueren and Baret 2009).

First, in order to foster innovation, research should draw on several disciplines, in line with the holistic and complex approach of agroecology. This movement is known as *interdisciplinary research*, which is research practice that involves several unrelated academic disciplines, each with its own contrasting research paradigm (Baveye et al. 2014). Linking together agricultural, ecological and many other disciplines leads to innovative practices that restore ecological regulating processes, which increase the flow of ES and, consequently, reduce farmers' reliance on external inputs. Adding social disciplines provides the opportunity to study the conditions and processes of learning and change, as well as the interdependencies between the diversity of stakeholders in the food system (Lamine 2015b). Such research highlights, *inter alia*, the long-term processes of change in farming practices (e.g. Chantre and Cardona, 2014) or the main reasons for a system's irreversibility, also known as the *lock-in effect* (e.g. Stassart and Jamar 2008 on the Belgian Blue commodity system and Vanloqueren and Baret 2009 on genetic engineering). These examples illustrate how this level of understanding facilitates the development of innovative food systems.

Second, the ambition of agroecology to include all stakeholders in the whole food system leads to their iterative involvement in the research process. This research movement is known as *transdisciplinary*, defined as participatory research focused on developing practical knowledge in pursuit of worthwhile human objectives (Baveye et al. 2014), whatever the origin of the science involved and the source of knowledge implied. This approach is sometimes also referred to as *action-oriented* or *participatory* research, although there are distinctions between the terms and their interpretation varies among authors (Méndez et al. 2013, Baveye et al. 2014, Scholz and Steiner 2015).

Such research practices are increasingly being acknowledged as beneficial in many ways. They create research that is relevant to a local context, which is necessary with the agroecological approach as the studied systems are highly context-dependent (Altieri 1999, Lyon et al. 2011). They also create opportunities for collective social learning by facilitating an exchange of information among stakeholders with differing values, views and mental frameworks (Duru et al. 2015, Vilsmaier et al. 2015). Above all, they address the gap between theoretical scientific questions and everyday problems faced by local stakeholders (Duru et al. 2015), which facilitates the adoption of research outcomes. This enhances the likelihood of innovations being taken up (Biggs et al. 2011, Duru et al. 2011) and empowers participants (Méndez et al. 2013). This type of research has been successful in many transitions to agroecological-based systems, including the transition from a conventional to an organic beef production chain in Wallonia that required overcoming several cognitive, logistical and commercial lock-ins (Stassart et al. 2008). Another example is illustrated by Cuéllar-Padilla and Calle-Collado (2011), who empowered farmers and supported them in the transition towards organic farming at a time when they had lost control over their marketing processes to transnational intermediaries. Transdisciplinary research is also useful in improving current management, as shown by Duru et al. (2011), who developed an assessment tool with – and for – farmers for the management of permanent grasslands that took account of the wide range of ES provided by such ecosystems. In essence, integrating various knowledge systems (i.e. scientific and practical) enables the contextual socio-ecological complexity to be taken into account while accompanying agroecological transition and developing appropriate tailor-made innovations (Cuéllar-Padilla and Calle-Collado 2011).

It should be noted that, currently, there is still a debate about the organization of agroecology as a discipline *per se* or as an inter- or transdisciplinary practice. This debate is similar to the one about sustainability sciences: Do we need to build one overarching scientific discipline that will address the whole spectrum of sustainability issues – or agroecological issues – or is a dynamic contribution through the expression of various knowledge outputs preferable (Dalgaard et al. 2003)? Beyond this epistemological issue, it is argued that, in practice, agroecology requires a variety of sources of information and therefore that inter- and transdisciplinarity practices are complementary ways of learning (Chantre and Cardona 2014). Indeed, the meta-level of analysis promoted by inter-and transdisciplinarity requires a certain level of disciplinary expertise to build upon.

Despite much evidence of the opportunities for research to adopt an inter- and transdisciplinary approach, challenges remain for scientists when applying these principles in practice. In order to ensure socially robust innovations, time needs to be invested from the outset of the research in setting common research objectives to address a commonly defined problem (Méndez et al. 2013). This time investment can differ between social and natural sciences, because they produce knowledge at different rates. True co-leadership between science and practice is required, where both knowledge systems are rendered visible and integrated in order to achieve greater symmetry between the two (Scholz and Steiner 2015). Throughout the whole project, regular feedback and discussions need to take place among all stakeholders in order to redirect research or its methodology, if necessary, so as to achieve the objectives of both scientists and practitioners (Cuéllar-Padilla and Calle-Collado

2011). In essence, communication is essential in order to learn from each other, build a climate of trust and ensure socially robust outcomes (Méndez et al. 2013).

This communication can, however, be hampered because of the variety of stakeholders involved, and hence the variety of (sometimes confronting) worldviews and knowledge systems. Each stakeholder sees a farming system from a different angle, depending on the plurality of the system's elements and context. With regard to scientists' worldviews, Bawden (1997) defined three research positions: technocentric, ecocentric and holocentric. Whereas the technocentric position promotes technical solutions, the ecocentric one seeks to manage ecological processes and the holocentric one integrates human processes and their interactions within the natural environment. Disciplines and knowledge systems also have their own traditions, methods, language and frameworks, which can prove difficult to coordinate and hamper discussions (Dalgaard et al. 2003, Vilsmaier et al. 2015). In addition, knowledge is influenced by one's experiences (referred as "grounded knowledge", Ashwood et al. 2014), which further challenges coordination.

Given the challenges of implementing inter- and trans-disciplinary research, we argue that such shift in a researcher's position needs to be supported. A more fundamental and methodological type of research is needed, one that develops methodologies that are readily applicable in inter- and transdisciplinary research, such as World Café, Delphi surveys and Citizen juries (Elliott et al. 2005). More importantly, educational programs have a role to play in fostering and conveying these new methods and training scientists in these new approaches. Some academic agroecological programs are based on learning-by-doing pedagogy (Lieblein et al. 2007, Francis et al. 2013), with the students' learning taking place *in situ* (e.g. farm, rural development organization) and being open-ended (i.e. searching for solutions not already known by professors). Theoretical and methodological approaches from natural and social sciences are progressively introduced to the students, who have to integrate demands from the stakeholders. In this way, students are trained in inter- and transdisciplinary practices to give them the ability to coordinate distinct grounded knowledge through a reflexive process. The contrast with conventional agricultural education systems is obvious: agroecological programs enable students to reconnect with actual conditions in the field, something that has been lost in agricultural academic institutions. They also focus on the system as a whole with a holistic perspective, rather than focusing on narrow segments of the food system (Louah et al. 2015). We believe that there is a need for a thorough reform in agricultural academic institutions where, currently, agroecological approaches play a minor role (DeLonge et al. 2016).

Repositioning the researcher raises further questions about current academic mindsets and institutions. The process of including stakeholders within the definition of the research issue, reflection and action, and of integrating various disciplines, is time-consuming, produces practical knowledge relevant to a specific local area (Cerf 2011) and leads to multiple research leaders, multiple data owners and multiple author articles. All this ill suits the classical scientific working climate, with its academic performance benchmarks of personal fast accumulation of publication (Daily and Ehrlich 1999, Dalgaard et al. 2003, Cowling et al. 2008). Adapting current research context in order to integrate inter- and transdisciplinary research approaches into the development of agroecological innovations is a major challenge, but one that urgently needs to be addressed.

1.5. Towards tailor-made solutions rather than recipes

The term agroecology is now widely used, but its meaning differs depending on who is using it. Too often, agroecology is presented with only one of its two major components considered: agricultural practices and food system organization. In addition, some research projects claim to use the concept of agroecology, and yet ignore the holistic approach. In this paper we argue that, within agroecology, agricultural practices and food system organization cannot be dissociated from each other because they are both needed in order to achieve sustainability from field to fork. We also argue that inter- and transdisciplinary approaches are needed in order to address the issues of sustainability.

We have shown, first, that there are practices based on ecological processes that allow the use of external inputs to be reduced and thus increase the environmental sustainability of farming. Second, we have shown that stakeholders in the food system are able to organize themselves in order to safeguard their activities and guarantee the social relevance and economic viability of the practices. It is clear, however, that challenges remain and therefore none of the existing examples should be taken as copy-paste solutions. Agroecology is not about 'one-size-fits-all' solutions or clear-cut recipes (Lyon et al. 2011). Rather, it suggests taking into account the natural and socio-economic environment where the food is produced and calls for the development of innovations within this precise context. We have shown that contextualizing innovation processes can require working across different scales, combining a variety of methods and drawing on various kinds of knowledge because the challenges are often complex. Agroecology therefore requires the involvement of multiple disciplines and stakeholders within the research process. With this research approach, researchers need to adapt the way in which they address the problem: the choice of the methods to use and the scales to work at will depend on the problem they need to address. Similarly, farmers facing problems with crops or livestock need to adapt their practices according to the specific conditions of their farming context (Lyon et al. 2011).

Overall, in order to re-organize the food system and develop innovations through research, agroecology proposes that is necessary first to step back and observe the complexity of local conditions before applying general solutions. Contextualization means there can be no silver-bullet; every problem requires a tailor-made solution adapted to its specific socio-ecological context. This is why there are numerous examples of agroecological innovations, as well as their shortcomings. These tailor-made solutions, however, are an appropriate way of achieving sustainability in agriculture and in the organization of the food system.

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2. How can integrated valuation of ecosystem services help understanding and steering agroecological transitions?

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Abstract

Agroecology has been proposed as a promising concept to foster the resilience and sustainability of agroecosystems and rural territories. Agroecological practices are based on optimizing ecosystem services (ES) at the landscape, farm, and parcel scales. Recent progress in research on designing agroecological transitions highlights the necessity for coconstructed processes that draw on various sources of knowledge based on shared concepts. But despite the sense of urgency linked to agroecological transitions, feedbacks from real-world implementation remain patchy. The ability of integrated and participatory ES assessments to support this transition remains largely underexplored, although their potential to enhance learning processes and to build a shared territorial perspective is widely recognized. The overarching question that will be asked in this paper is thus: what is the potential of the ES framework to support the understanding and steering of agroecological transitions? We argue that conducting collaborative and integrated assessments of ES bundles can (i) increase our understanding of the ecological and social drivers that support a transition toward agroecological systems, and (ii) help design agroecological systems based on ES delivery and effectively accompany transition management based on shared knowledge, codesigned future objectives, and actual on-the-ground implementation. In this paper, we discuss this question and propose a four-step integrated ES assessment framework specifically targeted at understanding and steering agricultural transitions that is generic enough to be applied in different contexts.

Keywords: agrocological transition; integrated ecosystem services valuation; transdisciplinarity

2.1. Integrated ecosystem services valuation to foster agricultural transitions

2.1.1. Ecosystem services in agroecosystems

Well-functioning and sustainable agroecosystems rely on a broad range of ES, such environments in turn provide another diverse set of ES to their beneficiaries.

For example, agroecosystems will benefit from a living soil rich in organic matter, which will help increase production, providing income to farmers and food to society (Adhikari and Hartemink 2016). The presence of crop auxiliaries can also increase agricultural productivity (Östman et al. 2003), while decreasing the financial and health costs of pesticides (Weisenburger 1993).

However, as Peeters et al. (2013) mention, since the middle of the 19th century, a large part of the ES provided by ecosystems before the Industrial Revolution has been replaced by techniques relying on a massive use of fossil fuel. For instance, the artificial synthesis of nitrogen, which requires vast amount of energy, has replaced symbiotic nitrogen fixation by legumes, crop protection by pesticides has replaced the biological control of pest and disease regulation by complex assemblages of living communities, and motorization has replaced manpower and draft animals.

Although the use of these artificial inputs and techniques has increased production, this replacement of ES, accompanied by a landscape simplification, induced negative impacts on the environment and on society (Costa et al. 2014, Tilman and Clark 2014). They provoked pollution and biodiversity losses that, in turn, decreased the supply of ES essential to farming itself and to society (Zhang et al. 2007, Dendoncker and Crouzat 2018, Landis 2017).

2.1.2. Limits of pure economic assessments of ecosystem services for agroecological transitions

In a free market economy, farmers will perceive the benefits of high yields generated by chemical fertilizers, but may not or only partially pay the so-called negative externalities, i.e., the environmental costs generated for instance by the loss of nitrogen in water tables or in the atmosphere. Conversely, externalities from agricultural activities can also be positive. For example, well-maintained grasslands store vast amounts of carbon, thus contributing to mitigating climate change (Gelfand and Robertson 2015), which benefits the broader society. As this ES is generally neither recognized nor paid (it escapes the market), it is produced in a suboptimal quantity by farmers (Robertson and Prior-Murray 2008). The free market economic logic leads “rational” farmers to maximize provisioning services (for which there is a market) at the expense of other categories of ES (for which there is no market) (Bohlen et al. 2009). At the local level, numerous attempts to internalize environmental externalities are already occurring across the planet under Payment for Environmental Services (PES) schemes, which can be considered as the main attempt to operationalize the ES concept. Agri-environmental schemes (AEM) are one example of PES in the European Union (Engel et al. 2008).

Although such instruments can play a role in improving environmental governance, they face a series of limitations. Muradian et al. (2013) argue that the design of payment schemes is susceptible to politicization, meaning that PES might get influenced by powerful pressure groups shaping their effectiveness and distributional outcomes. Payment for Environmental Services schemes can also sometimes act as incentive for perverse strategic behavior when eligibility criteria for getting the payments are not properly designed (Banerjee et al. 2013). In addition, some authors are concerned by the shift PES induce from a polluter-pays principle to a beneficiary-pays principle (Pirard et al. 2010). Most importantly, Muradian et al. (2013) argue that it is necessary now to shift the emphasis to tackling the ultimate causes of environmental degradation, deeply rooted in structural power inequalities. Thus, internalizing externalities and/or creating a market for nonprovisioning ES, a process referred to as the commodification of nature, will likely not be sufficient to ensure sustainable farming and may even reinforce current unsustainability issues such as access to resources and power asymmetries (Kallis et al. 2013, Boeraeve et al. 2015).

2.1.3. Integrated ecosystem services valuation as a transition tool

As Jacobs et al. (2013) state, the research field and concept of ES are rooted in strong sustainability thinking. The three pillars of sustainability and their subsequent values are indeed required when valuing ES: ecological values, social values, and economic values. These values are embedded into each other: economy and society are dependent upon the environment and bound to operate within safe ecological boundaries (Boeraeve et al. 2015). Conclusively, the final goal of ES valuation should be to achieve a more sustainable resource use, contributing to the well-being of every individual, now and in the future, by providing an equitable, adequate, and reliable flow of essential ES to meet the needs of a burgeoning world population (Jacobs et al. 2013).

Ecosystems are shaped by actors of agricultural landscapes and deliver a broad range of benefits. Thus, they involve many different actors: from coproducers and managers of ES (e.g., farmers, foresters) to ES beneficiaries (e.g., local inhabitants, tourists). In order to encourage sustainable landscape management, an integrated valuation framework including a broad set of values and stakeholders seems particularly relevant. As argued by Funtowicz and Ravetz (1993), in situations where scientific uncertainties or social stakes are high as is the case with ES valuations, scientists should adopt a postnormal posture in which they engage in dialog and knowledge coconstruction with decision makers and stakeholders (see also Barnaud and Antona 2014).

An integrated valuation framework is needed to reveal the diversity of values that can be attributed to ES. Assessing and valuing ES imply accounting for cognitive (what is) and normative (what should be) complexities and uncertainties. Such a framework is integrated if it offers a way to articulate different value domains (e.g., biophysical, social, economic) and inclusive if it does so by involving the broad set of stakeholders concerned with the valuation case (Dendoncker et al. 2013). This allows the assessment to be more sensitive and responsive to the needs and values harbored by stakeholders (Fontaine et al. 2013). The need to address the social component within such analysis is strong in agricultural contexts, as societal goals of today’s agriculture go beyond food production. Indeed, consumers demand quality, are increasingly guided by their ethics (Boogaard et al. 2010), and value traditional heterogeneous and complex landscapes as aesthetic and educational resources (Lindemann-Matthies et al. 2010). In return, in addition to earning a fair living, farmers call for recognition of the role they play in society (Pascual and Perrings 2007).

Over recent years, many place-based case studies have tried to value ES. Many invoke improved decision making as a vindication for their research. However, it is unclear whether these have actually led to improved landscape management (Laurans et al. 2013, Laurans and Mermet 2014). Although acknowledging the limitations they meet, integrated and inclusive ES valuation initiatives may lead to increasingly sustainable agricultural landscapes: they could improve environmental quality, reduce inequalities, and account for and maintain value plurality (Jacobs et al. 2016).

2.1.4. How can integrated ecosystem services valuation framework help in understanding and steering agroecological transitions?

Understanding how agricultural practices influence ES flows, which in turn impact agricultural productivity and society, is of great importance (Dale and Polasky 2007, Duru and Thérond 2015). This would help informing management decisions toward practices less harmful to the environment and more in line with consumer and local inhabitant expectations. To nourish this understanding, there is a need to thoroughly understand ecological functions and processes, their interlinkages, and their relationship to change in practices, but also how stakeholders perceive and value ES and react upon changes in ES flows (Landis 2017).

A review by Kremen and Miles (2012) comparing the provision of 12 ES in conventional farming systems and in agroecological farming systems concludes that "integrated whole-system studies of the influence of different farming practices on multiple ES are critically needed;" a conclusion confirmed by the few existing farm-scale ES assessments (Porter et al. 2009, Sandhu et al. 2010). This involves analyzing whether ES stand in conflicting (trade-offs) or reinforcing (synergies) relation to each other (Gomez-Baggethun et al. 2014). Furthermore, study of pairwise associations between ES should be extended to consider the consistent associations among multiple ES. These associations among multiple ES, also known as ES bundles (Raudsepp-Hearne et al. 2010), synthesize the typical set of ES associated with given subsystems. Bundles are composed by the types and magnitude of the ES supplied or demanded. They acknowledge the complexity of the social-ecological system by highlighting that all ES cannot be jointly maximized everywhere and under all management conditions and that social expectations regarding the "ideal" bundle of ES can vary. This information is necessary to provide a holistic picture of the social-ecological components of agricultural systems. As others, we argue that ES flows should be measured at several spatial scales (e.g., plot, farm, landscape, region) (Hein et al. 2006, Dale and Polasky 2007, Kremen et al. 2012) because different processes take place at different scales and because different scales will interest different stakeholders. Local-scale assessments may lead to information more useful to farmers in terms of practical management, whereas broader extents will be more relevant to decision makers for land-use planning and rural development plans.

The agroecological transition is characterized by complex interdependencies between ecological and social components as well as by multilateral and power-driven interplays of stakeholders, which challenges its comprehensive understanding. As both pathways of change and outcomes remain unsure (Caron et al. 2014), steering the agroecological transition relies on a collaborative learning process involving all actors concerned by the agricultural matrix and its evolutions. Throughout this learning process, the capacity of individuals and communities to propose joint actions is progressively strengthened to face the trade-offs inherent to the management of social-ecological (agro)ecosystems (Armitage et al. 2008, Galafassi et al. 2017). The multiple levels of transformation enabled by such social learning (Pahl-Wostl 2009) are a core strategic process of integrated ES valuations (Jacobs et al. 2016).

An increasing amount of ES research focuses on agroecosystems (e.g., Sandhu et al. 2010, Barral et al. 2015, Fan et al. 2016). Interestingly, these remain restricted to the assessment of ES delivery under distinct agricultural scenarios, but lack any discussion on how to reach them, i.e., how to implement an agroecological transition on the ground.

We believe integrated ES valuations can be used to steer agroecological transitions as they can interestingly support the establishment of effective emergence of communities of practice (Duru and Thérond 2015). Like Barnaud et al. (2018), we take a constructivist perspective considering that ES are social constructions, representing inherently subjective perceptions of human—nature relationships. By allowing divergent viewpoints to be documented and fostering shared understanding and conceptualizations of the systems, participative and multifaceted ES valuations hold several relevant attributes to successfully address wicked problems, such as the inclusion of social values, the reinforcement of mutual capacity building, or the establishment of trust among partners (Davies et al. 2015).

2.2. A four-step ecosystem services assessment framework for agroecological transitions in practice

In this section, we develop a four-step methodological framework to understand and steer an agroecological transition based on an integrated ES assessment (Figure II-1). This framework has been proposed building on ongoing related research, in particular on the “Farms for future” project led by the TERRA Research Centre (funded by the Belgian National Funds for Science Researche (FNRS), led by the TERRA research centre, Gembloux Agro-bio Tech, University of Liège (2016–2019)) that aims at understanding the impacts of agroecological farming systems on the delivery of ES as well as on ES beneficiaries. Our proposal is also rooted in sustainability analyses (e.g., Ostrom 2009, Ban et al. 2013) and builds on current work on integrated ES valuation (Jacobs et al. 2016). It echoes recent progress in the implementation of ES-based approaches to multifunctional and complex social-ecological systems (e.g., Cowling et al. 2008, Mastrangelo et al. 2014). This framework is foreseen to be trialled on forthcoming research-action projects aiming at understanding and supporting agroecological transitions in real-world situations.

We suggest an iterative framework, as ES flows are likely to follow nonlinear responses from the onset of an agroecological transition, and as learning and enhanced mutual understanding between different stakeholders may also change how some services are understood and valued. This process is by essence rooted in a science-practice partnership “that enables cogeneration of knowledge, which is both user-inspired and user-relevant” (Förtser et al. 2015). Agroecology offers a highly favorable venue for practicing science with people (Cuéllar-Padilla and Calle-Collado 2011) and in accordance, the path proposed by our framework requires a high level of participation from stakeholders. Many experiments worldwide have linked participatory action research and agroecological transitions (Levidow et al. 2014, Méndez et al. 2017). There is probably no silver bullet in the way these processes should actually be aligned and practically implemented: a necessary correlate of engaging in a coconstructed process is to tailor the methods and tools used to the local context and to the specific objectives of the stakeholders engaged (Funtowicz and Ravetz 1993). As a consequence, we do not provide in our framework a ready-made solution for practical implementation of the participatory process. However, an increasing number of methods are available for identifying and involving stakeholders as well as for combining environmental and social insights (see among others, Reed et al. 2009, Cuellar-Padilla and Calle-Collado 2011, Bagstad et al. 2013, Förster et al. 2015). As Jacobs et al. (2017) demonstrated, different valuation methods need to be combined to elicit the main value dimensions of nature (nonanthropocentric, relational, and instrumental). Biophysical modeling processes can be used to represent, e.g., through maps, the ability of landscapes to supply given ES. Field surveys and experiments might help ensure the robustness of these outputs and also comfort stakeholders regarding the feasibility of the agroecological transition. In turn, ES maps can usefully support discussions on the necessary conditions for sustaining multiple ES, in terms of management practices, landscape features, and environmental supporting conditions. Among interesting tools to articulate stakeholders’ perceptions of a complex system, participative mental models (Etienne et al. 2011, Moreno et al. 2014), influence networks (Crouzat et al. 2016), companion modeling (Etienne 2014), and social network analysis (Hicks et al. 2013) could be mobilized throughout the steps of our framework to come out with collective representations of the agroecosystems and of their futures. Although mobilizing such a spectrum of methods may seem demanding, it has been shown that performing such an integrated valuation does not necessarily entail more resources, as for every value dimension, methods with relatively low requirements are available (Jacobs et al. 2017).

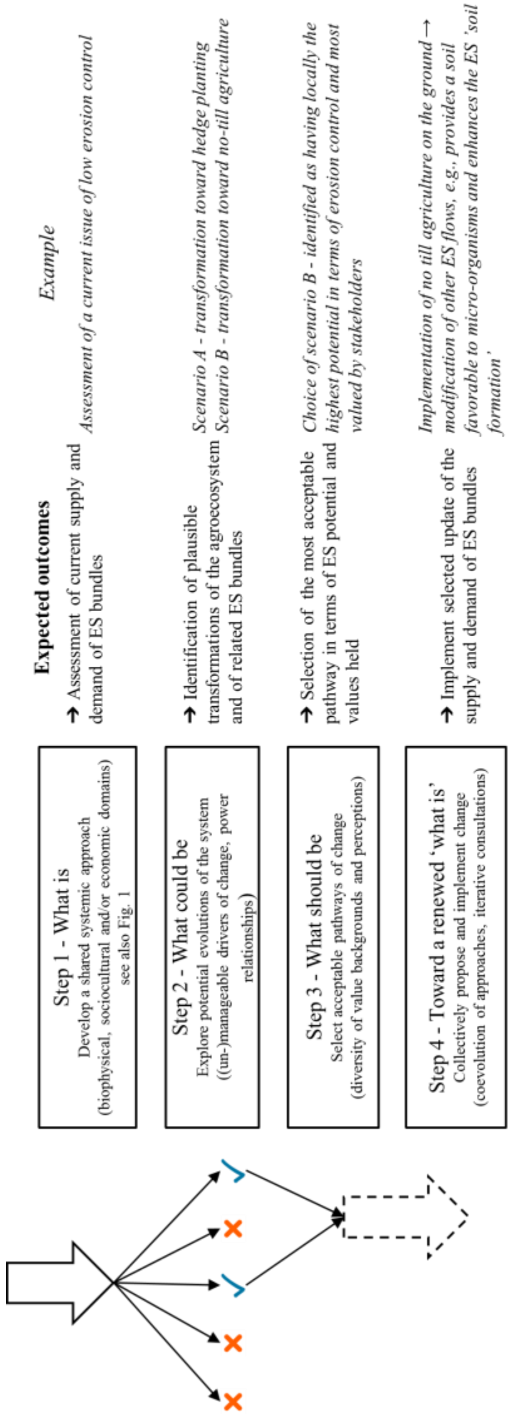

Figure II-1 : A four-step, iterative, methodological framework to steer agroecological transitions based on integrated ES assessment.

2.2.1. Step 1: Building a common understanding of the current situation ("what is")

As a first step toward steering change, reaching a common understanding or shared vision of the current system appears an essential prerequisite. Integrated ES assessments, by informing different value domains, namely biophysical, sociocultural, and/or economic domains (Martín-López et al. 2014), can help develop a common systemic approach to the agricultural matrix.

In Figure I-2, we propose a methodology to practically improve the knowledge and understanding of an agroecosystem. The objective here is for all stakeholders involved in the agroecological transition to build a shared understanding of the current state before heading toward discussions and decisions on future states of the system. This multilevel framework does not mean that levels have to be addressed following a specific order. In fact, the biophysical-oriented assessments (levels 1–5) should be embedded in the social valuation (level 6) (Dendoncker et al. 2013, Spangenberg et al. 2014, Jacobs et al. 2016). Social valuations identify stakeholders affecting or affected by ES flows, gather information on what and how stakeholders value ES ("the ES demand"), and analyze mental frameworks used when valuing ES (Fontaine et al. 2013). Stakeholders' selection is a critical aspect as it directly influences outcomes of their consultation. Carrying out a stakeholder analysis, as a preliminary step to the assessment, seems necessary to include representatives of all legitimate stakeholders (Grant and Curtis 2004, Reed et al. 2009). Identifying context-relevant ES guides ES assessments toward specific natural resource management issues. As ecological functions only become ES when someone values them or benefits from them, identifying key ES to sustain involves subjective judgments (Förster et al. 2015). To capture these judgments, it is thus critical to involve multiple knowledge sources by including stakeholders in the process of identifying and prioritizing ES (Chan et al. 2012, Spangenberg et al. 2015, Mascarenhas et al. 2016). Participatory ES identification and selection are increasingly implemented (e.g., Bryan et al. 2010, Fontaine et al. 2013), and some guidelines are starting to emerge on this specific step (Mascarenhas et al. 2016; Boeraeve et al., 2018).

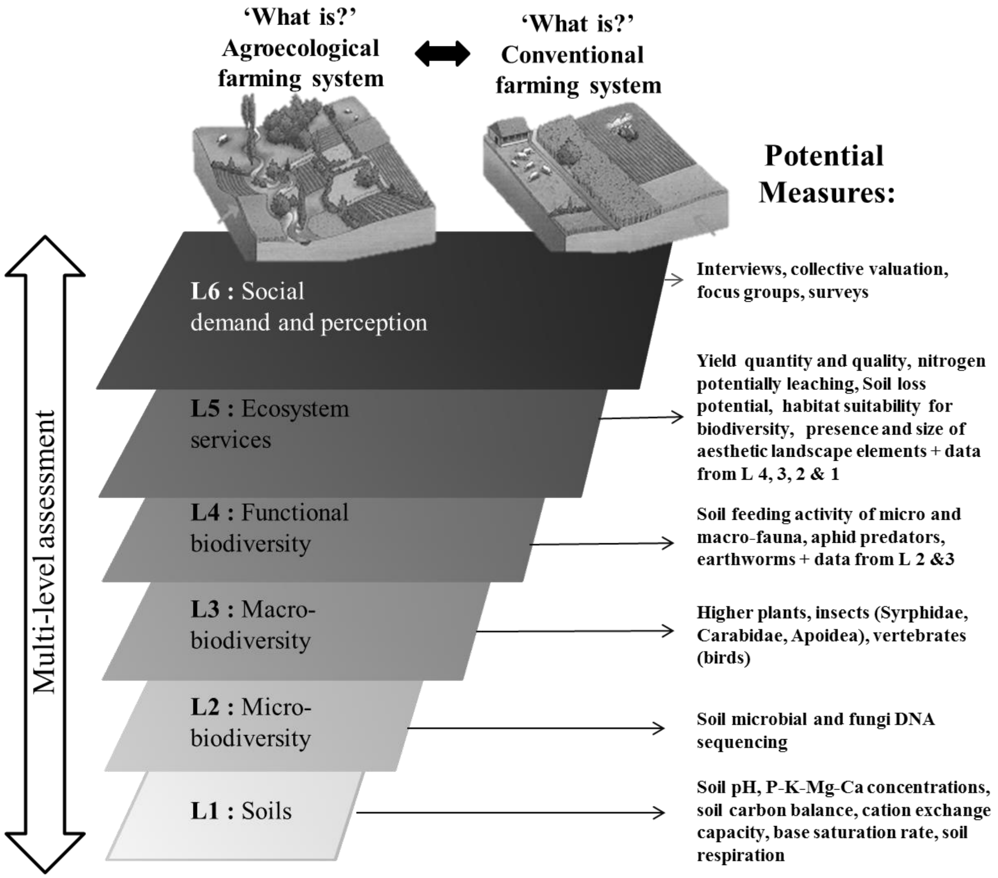

Figure II-2 : A multilevel (L) methodology to allow a better understanding of agroecological practices and their impacts on ES flows and underlying processes. Measurements can be done in agroecological parcels and conventional ones in order to have a reference point. Examples of indicators are provided on the right.

These various levels of study are all related to a set of suggested measurements. Importantly, these levels of study all relate to different spatial scales of measurement (parcel—e.g., soil data, farm—e.g., yield, and landscape scale—e.g., ES indicators of landscape connectivity, cultural ES). They feed each other by providing underlying knowledge and understanding. For example, soil data (level 1) partly explain population assemblages of soil micro- (level 2) and macrobiodiversity (level 3). Soil biodiversity in turn influences ecological processes and ES flows (level 5) such as soil structure and fertility, plant growth, and pathogen protection (Maron et al. 2011). Many macrobiodiversity groups (level 3), such as insects (Syrphidae, Carabidae, Apoidea) and vertebrates (e.g., birds) are highly sensitive to their environment and thus represent good indicators of habitat quality and its relationship to agricultural practices. From these groups, functional agrobiodiversity (level 4) can be identified, such as predators, pollinators, decomposers, etc. Additional measures can be implemented to assess functional impacts of these groups like measuring soil decomposition rates, assessing pest abundance, etc. Information gathered from the four first levels can then be translated into ES indicators (Table II-1). For instance, some soil physico–chemical properties (C balance, CEC, base saturation rate; level 1) hint at the ES "soil fertility;" or the presence of "aphid predators" (level 4) can be translated into an indicator of the ES "biological pest control." Additional indicators have to be collected specifically like "potential N leaching" to assess ES "nutrient regulation." Supplementary indicators are also gathered for cultural ES, which are assessed based on the presence of landscape elements known for being appreciated, thus harboring esthetic values (e.g., tree lines, forest patches). Information on individual ES can then be combined to characterize ES bundles typical of different management practices and ecological contexts.

At the broadest level (level 6), a social ES valuation is carried out. This provides a thorough understanding regarding socioeconomic values borne by the different stakeholders (also referred to as the "ES demand") and how they relate to the idea of an agroecological transition. Including stakeholders' values in the assessment and decision process allows accounting for power asymmetries and increases chances of equity (Felipe-Lucia et al. 2015). The method can rely on individual interviews and collective valuation (e.g., focus groups, participative workshops). Individual interviews put forward the divergence of social values among stakeholders, and the collective valuation, through deliberation, includes reciprocal and altruistic attitudes within the valuation (Sen 1995, Vatn 2005).

In theory, such assessment would ideally be carried out in the same farming systems and parcels before and after the agroecological transition to assess its impact directly. However, as such diachronic assessment is rarely feasible, assessments can be carried out concomitantly in agroecological parcels and farming systems and in conventional ones. Doing so, we have to keep in mind that comparison stricto sensu between parcels is highly sensitive to the technical history of the parcel. To avoid ignoring this, the analysis should focus on the relative distances or variances between the different elements and not on comparing means. "Compared" parcels should ideally share the same crop type, soil type, and landscape structure (which is not inherent to the practices, e.g., a nearby wood) in order to minimize potential bias, and technical itineraries of each studied parcel should be scrutinized to identify potential outliers.

As stated above, bundles of ES can be identified (Mouchet et al. 2014) to highlight the characteristic patterns of associations representative of various social-ecological subsystems (e.g., Crouzat et al. 2015). This appears of critical importance as ES are used, affected and valued differently by stakeholders, inducing the necessity to consider jointly multiple ES (Förtser et al. 2015). Overall, integrated ES valuations should be used to characterize the distinct social and ecological contexts that coexist throughout the landscape and that shape the current bundles of ES supplied and demanded.

Table II-1 : Example of how information gathered at different levels can feed integrated valuation of ES

CATEGORY	ES	INDICATOR	LEVEL
Provisioning	Commercial crop production	Yield (Harvest on a known surface)	Ecosystem services
		Quality	Ecosystem services
Regulation	Soil formation	Earthworm density, biomass, maturity and diversity	Macro-biodiversity
	Nutrient regulation	Organic matter degration by macro-organisms	Functional biodiversity
		Organic matter degration by micro-organisms	Functional biodiversity
		Nitrogen potentially leaching	Ecosystem services
	Soil fertility & C cycle	Cation exchange capacity & base saturation rate	Soils
		Total organic carbon content	
		Labile and stable Carbon Pool	
		Soil respiration	
	Pest control	Parasitism rate	Functional biodiversity
		Predation rate	Functional biodiversity
	Pollination	Pollinators density	Macro-biodiversity
		Pollinators diversity	Macro-biodiversity
	Erosion protection	Soil aggregate stability	Ecosystem services
		Soil loss potential	Ecosystem services
	Habitat quality for biodiversity	Carabid bettle density	Macro-biodiversity
		Carabid beetle diversity	Macro-biodiversity
		Micro-organisms populations (DNA sequencing)	Micro- biodiversity
		Habitat suitability and connectivity	Ecosystem services
Cultural	Physical experiences	presence of landscape elements	Ecosystem services
		size of landscape elements	Ecosystem services
	Education	farm visits (interviews)	Ecosystem services

		training sessions (interviews)	Ecosystem services

2.2.2. Step 2: Exploring a diversity of futures ("what could be")

Once a systemic vision of the current agricultural matrix is reached, plausible trajectories of change can be elaborated. Scenario approaches are an increasingly popular tool that can help span the alternative reachable futures of social-ecological systems in a collaborative way (see Oteros-Rozas et al. 2015 for a recent review). Participatory scenario making encourages complexity thinking (e.g., Waylen et al. 2015). This appears necessary to account jointly for supply and demand facets of ES assessed in Step 1 and implicated in trade-offs and synergies analyses (Mouchet et al. 2014, Crouzat et al. 2016) to thereby anticipate the implications of changes from local and global drivers of and threats to ES identified in Step 1. For instance, changes in fertilization management or in types of crops can modify the amount and temporality of nitrogen and pesticide leaching, thereby impacting the ability of landscapes to maintain water quality as well as their esthetics. Such changes in these two services can be assessed, e.g., through computer-based maps that can be closely developed and analyzed with stakeholders to identify the ways multiple ES could be affected by different management options in the future (e.g., Reed et al. 2009). Alternatively, stakeholders confronted with the will to enhance soil erosion control might propose different scenarios, including a no-till option and an increase in hedge density (Figure II-1), both of which are relevant drivers of erosion control. As bundles of ES discriminate different agricultural management trajectories, they appear to be a relevant object to trace the expected outcomes of changes in agricultural management strategies and discuss the possible evolutions of the landscape. In this step, scenarios should not only consist of proposing adaptations of current practices but should also allow major changes to be discussed, including changes in paradigm. Diachronic feedbacks from other experiments, although still too scarce (Dendoncker and Crouzat 2018), could be used to help grasp the diversity and magnitude of transformations that could be locally projected. Among necessary features to identify, manageable drivers of change should be pinpointed, as well as the existing influence relationships among actors (Felipe-Lucia et al. 2015) and their consequences on sustainability transition. Stakeholders could be invited to identify the key bottlenecks that might hinder the agroecological transition, considering among other issues knowledge, technical options, social acceptability, as well as administrative or regulatory frames. Importantly also, the influence of external economic dynamics and of internal cultural drivers such as informal institutions (Pahl-Wostl 2009) should be acknowledged to ensure the relevance of proposed alternatives.

2.2.3. Step 3: Selecting acceptable pathways of change ("what should be")

As mentioned previously, stakeholders hold varying perceptions and expectations regarding the current and ideal agricultural management(s) of their territory. Steering the agroecological transition implies managing current and emergent trade-offs among ES to orientate the system toward its expected state. In addition to evaluating what is feasible, an important effort of the integrated ES valuation should be dedicated to making explicit what is desirable and for whom (Cote and Nightingale 2012, Davies et al. 2015). In other words, it appears necessary to keep space for subjective and emotional dimensions as negotiating the agroecological transition is a highly normative political process (Wezel et al. 2009). The characterization of ES supply and demand from Step 1 will contribute to making explicit social priorities. Once the diversity of values is acknowledged, the overall legitimacy of the integrated ES valuation process is strengthened (Cash et al. 2003). The objective of this step is to identify diverse viewpoints and common ground among these that might become a basis for a broadly accepted normative vision of the studied agroecosystem. This objective can be attained by individual and collective consultation of stakeholders aimed at revealing their desired vision of the agroecosystem in the light of the information gathered in Step 2. For instance, in the objective of reinforcing the erosion control service, stakeholders might prefer turning to no-till agricultural practices rather than to increasing the density of hedges (Figure II-1). Indeed, this scenario might seem more appealing and efficient locally, regarding topographic conditions, farm equipment, or economic viability.

2.2.4. Step 4: Implementing acceptable pathways of change (towards a renewed "what is")

The objective of this step is to turn into practice the options for changes discussed and selected previously. Bluntly, Step 4 is the time for operationalization on the ground of renewed practices, organizational structures, and management methods. Steering the agroecological transition requires a "process-oriented and goal-seeking approach" to operationalize the changes projected (Duru and Thérond, 2015). Changes on targeted ES might have an influence on other ES, reinforcing the necessity to consider them jointly as bundles. For instance, changes in erosion control induced by no-till practices will probably affect, at least, the service of soil formation by inducing more favorable conditions for soil microorganisms (Figure II-1). Integrated ES valuations offer a relevant framework for identifying the necessary steps of change by including both the ecological and social aspects of the transition management. Indeed, if technical changes are to be accepted and implemented, cultural evolutions are also necessary and need to be negotiated and prepared. Feedbacks from the social system on the ecological system, including governance effects, can be adequately anticipated by the ES valuation. Differentiated approaches of change can coevolve in the territory and gather subgroups of interested stakeholders. For example, technical aspects of the agroecological transition can be discussed by some (e.g., on reduced or no-till technologies, Figure II-1), whereas others can target their efforts to structuring local distribution chains. There is probably no one-fits-all solution, so stakeholders should be stimulated by iterative coconstructed meetings to propose innovative and locally adapted solutions (Galafassi et al. 2017). Once changes are initiated, integrated ES valuations offer an interesting opportunity for monitoring the agroecological transition, as ES proxies can be tracked and social perceptions of changes in ES bundles can be iteratively assessed.

2.2.5. Ecosystem services and agroecology: limitations of the ecosystem services approach

In general, integrated valuation of ES faces a series of challenges, including fragmented policy and governance fields to target, fragmented science fields to combine for comprehensive assessments, and difficulty in accounting for equity issues in the context of power imbalances (see Jacobs et al. 2016 for a broader discussion).

The way ES assessments are designed and the specific issues they address are critical for engaging in collective transformation of agroecosystems. The ES approach, although rather holistic, may omit certain aspects, such as heritage, historic values, health, farmers' salary, local employment, human rights, etc. (Mills 2012).

Scientists must thus take a step back to grasp human well-being not only based on ES data. A quantity of ES flow may not be a good indicator of well-being as there may be no demand for it, or it may be unevenly shared among beneficiaries (Collins et al. 2010). Finally, ecological thresholds should always be as much as possible considered in such an integrated approach (Maron et al. 2017).

Even if various types of values are acknowledged, the issue of how to make the final decision remains. Valuation exercises always take place in a given institutional setting (Vatn 2005, Dendoncker et al. 2013). Because environmental resources are often common and complex goods, this institutional setting should ideally favor social rationality and communicative action, ensuring that a societal perspective is taken and that the procedure must be able to treat weakly comparable or incommensurable value dimensions (Vatn 2005, Martinez-Alier 1998). At the global level, some authors argue that new institutions and more resources devoted to environmental governance are needed (Norgaard 2010).

At the local level, however, the increase in place-based actions and public support for change raises hope. Arguably, place-based, territorial applications of transformative research could provoke local regime shifts in agriculture. Coconstructed actions between science, society, and policy may lead to greater changes. The operational potential of integrative and inclusive ES assessments to foster the transition to agroecology remains, however, to be strengthened.

2.3. Conclusion

In seeking transition of prevailing farming methods to agroecology, sustainable agricultural systems will need to be designed for autonomy, resilience, and diversity. Because it may bring together a broad range of local actors who defend disparate sets of values, integrated valuation of ES has the potential to serve as a tool for diverse actors to develop a shared knowledge base to better understand stakeholders' expectations and constraints, to recognize shared priorities, and for concerted action.

Although there are local cases where ES assessments have led to increased ES delivery and social learning, it has not been demonstrated that ES assessments could lead to more systemic changes in agroecosystems, by increasing economic efficiency, improving the environment, but also increasing equity by accounting for and dealing with power asymmetries. Moreover, at the global level, it is likely that for agroecological systems to replace the current dominant regime, wider institutional changes at larger scales are to be implemented, and many barriers to change must be overcome. However, by systematically adopting integrated and inclusive ES assessments at the local scale, crucial information on how ES delivery helps good functioning of agroecological systems and on how the latter deliver ES to local communities can be gathered and further mobilized to steer agroecological transitions for sustainability. Further research should review, gather evidence from, and communicate about stories of success and failures to draw lessons on how to accelerate these transitions.

Chapter III

SOCIO-CULTURAL ECOSYSTEM SERVICE VALUATION

Abstract of Chapter III

As introduced previously (Chapter II – section 2) ES assessments should be embedded in a socio-cultural valuation (Dendoncker et al. 2018a). Socio-cultural valuations involve numerous methods and objectives which can include: the identification and selection of stakeholders affecting or affected by ES flows (Reed 2008), the identification and selection of the ES to be included in the study (Mascarenhas et al. 2016), the evaluation of what and how stakeholders value ES (the 'ES demand' or the perception of the 'ES delivery') and the analysis of mental frameworks held by stakeholders when valuing ES (Fontaine et al. 2013, Spangenberg et al. 2014, Jacobs et al. 2016). This chapter presents the socio-cultural valuation of the study which includes i) the participatory ES identification and selection (section 1) and ii) the valuation of stakeholders' perception of ES delivery (section 2).

The first step of the valuation was organized under a focus group which took place at the start of the research, on March 19th 2015. Participants were selected according to a purposive sampling strategy, i.e. a sampling of which the profile of participant was selected purposively in order to reach a wide variety of profiles interested in the topic rather sampling randomly in the population. All farmers (agroecological and conventional) participating in the research were personally invited while the invitation was further communicated through the Parc Naturel des Plaines de l'Escaut, our local partner. The second step of the valuation relied on a questionnaire submitted to two distinct groups: local stakeholders and scientists working on ES, 'ES experts'. Local stakeholders were selected following the same communication channels as for the stakeholder selection of the first focus group (2 participants responded to both valuations). Questionnaires were submitted during a focus group (on July 4th 2016) which included also collective valuation steps not presented in the present manuscript. Questionnaires were given at the start of the focus group, before any interaction took place. It is therefore assumed that the focus group setting did not influence answers provided in the questionnaires. ES scientists were contacted by e-mail through the networking group of Belgian Ecosystems and Society (BEES).

1. Participatory ecosystem service identification and selection

1.1. Introduction

Many ES assessments select ES based on data/model availability or literature reviews. However, this bypasses the socio-cultural context in which the project takes place (Chan 2012, Malinga et al. 2013, Mascarenhas et al. 2016), leads to blind spots of potentially important ES and values, bias towards other ES and ignores the diversity of the values associated to these ES (Opdam 2013, Kenter et al. 2015). As ecological processes and functions only become ES once valued or benefited by humans, identifying relevant ES involves subjective judgement (Förster et al. 2015). To capture these judgements, it is thus critical to involve stakeholders through a process referred to as 'participatory ES identification and selection' (Malinga et al. 2013, Mascarenhas et al. 2016, Boeraeve et al. 2018).

Carrying out participatory ES identification and selection allows identifying context-relevant ES, thus guiding ES assessments towards specific needs of local communities. Embedding the ES valuation into its socio-ecological context is even more important when addressing agricultural systems which are particularly locally specific (Bell et al. 2008, Lyon et al. 2011). Agricultural systems are embedded in a socio-ecological network, being a coevolution of culture, nature, humans and landscape that cannot be separated from each other (Bacon et al. 2012, Rapidel et al. 2015).

Thus, as a first step to the integrated ES valuation, the participatory ES identification and selection is widely advocated for and increasingly implemented (e.g. Bryan 2010, Fontaine et al. 2013, Martínez-Sastre et al. 2017) with the aim to create outcomes adapted to the social and environmental contexts. However, this step is rarely explicitly detailed and is usually restricted to a mere mention in the description of the assessment's methodology (Boeraeve et al. 2018).

This section aims at presenting the participatory ES identification and selection of this research and its outcomes. Local stakeholders, including farmers (ES providers and beneficiaries) and local inhabitants (ES beneficiaries) were invited to participate in a focus group event during which they were consulted on their most valued ES. The objectives of this participatory work are to i) identify relevant ES to the socio-ecological context of the research and ii) prioritize these identified ES to guide the subsequent selection of ES to be further included in the biophysical assessments and the socio-cultural valuation. The present section first introduces the methodology followed for the implementation of the participatory ES identification and selection and the underlying theoretical background. It then presents the results of the participatory work, followed by the final selection of ES used for the biophysical ES assessment.

1.2. Methods

1.2.1. Theoretical background

Numerous methods can be used to carry out participatory ES identification and selection, most of which are inspired by the already well established background of participatory science (Kaplowitz 2000, Elliott et al. 2005). In this study, the method used relies mainly on the focus group and the Delphi approaches.

A focus group is a planned discussion among a small group of stakeholders facilitated by a moderator, designed to obtain information about (various) people's preferences and values and why these are held (Elliott et al. 2005, Gibbs 2012). The approach capitalizes on the interaction between and among participants to stimulate and refine thoughts and perspectives, thus deriving collective opinions of groups, and a range of ideas (Halcomb et al. 2007). Furthermore, focus groups are also more cost and time effective than individual interviews as multiple stakeholders are consulted at the same time (Krueger and Casey 2014).

The Delphi approach involves an iterative survey where participants complete a questionnaire and are then given feedback on their answers by other participants. With this information in hand, the respondent fills in the questionnaire again. This process is repeated to increase the mount of consensus within the group (Linstone and Turoff 2002, Elliott et al. 2005). This allows investigating individual opinions and collective values. Moreover, such design applies well when seeking selecting or ranking among several options (Kenyon et al. 2008).

1.2.2. Stakeholder selection

We distinguish, as Bertrand *et al*. (2002), between 'stakeholders' and 'local actors' (also referred to as 'locals' hereafter). Stakeholders are actors directly implicated in the studied activity such as financing members, lobbyists, etc. All these actors play an active role in decisions regarding the studied topic. On the other hand, local actors are citizens affected or affecting indirectly the studied topic. Their role is not as direct and active as the one of stakeholders, but *in fine*, they can be affected by choices made regarding the topic or can affect them indirectly (e.g. a consumer influences the market by making specific choices). Selecting stakeholders allows gathering their opinions and associated stakes according to their institutional position. Selecting locals, on the other hand, is most relevant when enquiring about citizen's viewpoints as they tend to communicate their personal positions rather than trying to represent the stake of their institution. In practice, this distinction is of course often less clear as each participant can endorse multiple roles (Lamarque et al. 2014). However, transparency about the aims of the project from the start of the exercise and being explicit on which position participants should tend for avoids confusion in that regard.

As the aim of this study was not to solve political stakes, but to generate knowledge and understanding of agricultural farming systems and their socio-ecological contexts, local actors were selected to gather personal viewpoints and opinions. Participants were selected according to a 'purposive sampling' strategy (i.e. sampling of which the profile of participant was selected purposively in order to reach a wide variety of profiles interested in the topic rather sampling randomly in the population). To reach participants, leaflets advertising the focus group event were sent to all farmers selected for the biophysical ES assessment, to local inhabitants and to mailing lists of the Parc Naturel des Plaines de l'Escaut. This selection strategy also aimed at including both ES providers (farmers) and ES beneficiaries (farmers and local inhabitants).

In total, 19 participants attended the meeting, including nine farmers (one agroecological, two practicing integrated pest management and six conventional). The rest of the participants included 2 persons directly working in the agricultural sector (one from 'Diversiferm' an association accompanying farmers to diversify their activities and one from the Parc Naturel des Plaines de l'Escaut working as agricultural project manager) and the eight local inhabitants. The aim was to consult them on which ES they find the most important to guide our subsequent ES selection for the biophysical assessment.

1.2.3. Step by step procedure of the participatory exercise

The focus group took place at the very start of the project, on March 19th 2015. Before the participatory exercise, an ES pre-identification was compiled (Figure III-1 - step 1). Based on the literature addressing ES in agriculture, assumptions were made on the ES relevant to the study context and objectives. This preliminary identification was carried out in order to avoid a lengthy list with out-of-context ES which may confuse participants. ES were also rephrased in profane terms.

On the day of the focus group, the topic was first introduced to participants (step 2). The study was presented, its specific aims and objectives were clarified. It was explained to them that the consultation would help guiding the selection of ES to be measured in AFS and CFS in a next step of the project. The necessity of the participatory activity (i.e. to adapt the study to its socio-ecological context) was exposed to participants. Through the presentation of the project, examples of how agricultural practices can influence people's views, perceptions and values were given.

After setting the scene, participants were asked to list examples of 'services provided by their (semi-)natural environment' (step 3). In this step, no ranking was required, rather, the list represented a personal brainstorming on what they can think of as services provided by their natural surroundings. This spontaneous list allows testing initial actors' knowledge and perception on their natural environment and the related services. It aims at being explicit about initial actors' knowledge and perception and let participants express themselves more spontaneously because not yet entirely framed by the concept of ES (Tadaki et al. 2015) (yet, the presentation of the project and its objectives inevitably at least partly framed their minds).

Next, the preliminary ES inventory was submitted to participants for validation (step 4). Participants were asked to react upon the ES pre-identification and were invited to bring modifications, also based on the services listed during their brainstorming in the previous step. ES could be added to the list. This allows comparing how the ES list developed from scientific theory differs from what actors perceive as relevant instinctively.

Only after this validation step was the ES concept concretely defined (step 5). Definitions and the three main categories of 'provisioning', 'regulating' and 'cultural' ES were presented in profane terms and by means of examples. Based on the validated ES list, participants were asked to rank ES individually (step 6). They were asked to select the 5 most important ES and assign them a rank of importance from 1 to 5. This ranking exercise was carried out per ES category (provisioning, regulating and cultural) and through all categories taken together.

Results of the ranking exercise were presented and discussed under the form of a focus group (step 7). The different viewpoints were put forward and participants were encouraged to present their arguments. Through discussions and viewpoint exchanges, the aim is that participants increase their understanding of each other's' reality and mental schemes.

The next step consisted in a second round of the ranking exercise (step 8), to apply the Delphi method, through which exchanges between participants increases mount of agreement. Finally, organizers concluded by highlighting the main steps and outcomes of the exercise and how these would be used within the study (step 9).

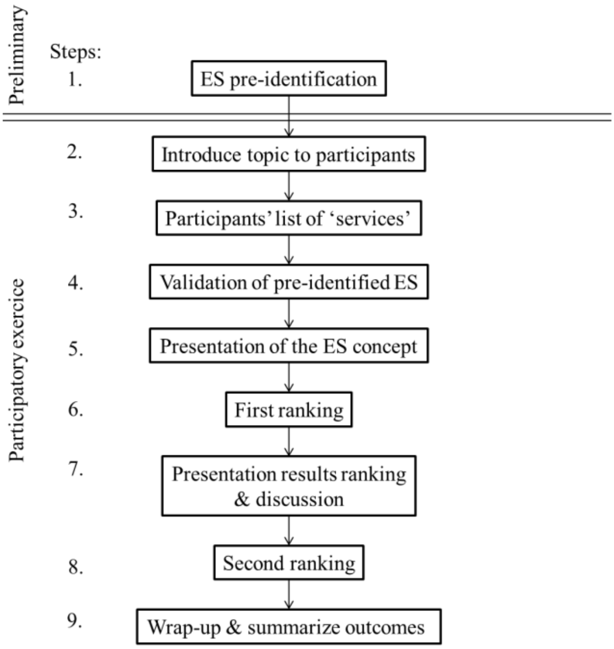

Figure III-1 : Stepwise scheme of the procedure followed for the participatory ES identification and selection.

1.3. Results

During the validation of the preliminary identified ES list (step 4), attendees wished to add two items from their spontaneous list. One was ‘farmers’ wellbeing’ (fair remuneration, no exposition to dangerous products, no pressure from lobbys, etc.), while the second one was ‘creation of local employment’. These two items identified by locals fall out of any official ES list. This is an illustration that local actors can bring complementary perception the scientific tool of ES. The ES concept does not (and could not) embrace all possible dimensions, hence the relevance to rely on a iterative approach where scientific assumptions and values are validated by local knowledge and *vice versa*.

This validation step also triggered discussions on divergences of opinions amongst participants and on which ES was important to include. These exchanges of views and opinion probably already contributed to increasing consent among the group. Hence, the second ranking exercise, as suggested by the Delphi approach, was not deemed necessary by participants. The results presented here are thus the outcomes of the first ranking session.

Both Figure III-2 and Figure III-3 show that the provision of food and regulation of human health are two very important components in the eyes of local actors. The two added ES (farmers’ wellbeing and local employment) have also been much voted for and attributed high scores (numbers above bars). Conversely, some ES gather no votes at all (Figure III-3: wood, ornamental plants, energy, protection against hazards, pest regulation, air quality, fauna/flora observation, hunting, tourism).

Apart from these ES which seem to encounter some agreements, we observe a diversity of preferences across actors. Indeed, votes are spread across a relatively wide panel of ES, coming from all categories. Some ES receive very few votes, though presenting very high scores, illustrating the diversity of viewpoints (e.g. Figure III-2: hiking, hunting, Figure III-3: climate regulation).

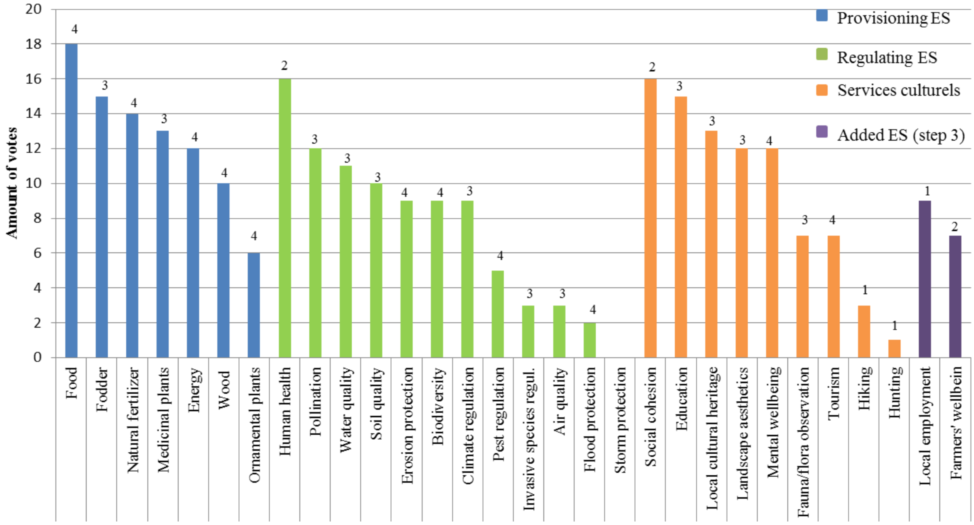

Figure III-2 Outcomes of local actors' votes regarding which ES they value the most (step 6: per category). Number of votes per ES is represented of the vertical axis while average ranks are the numbers above each bar (1: most important, 5: less important).

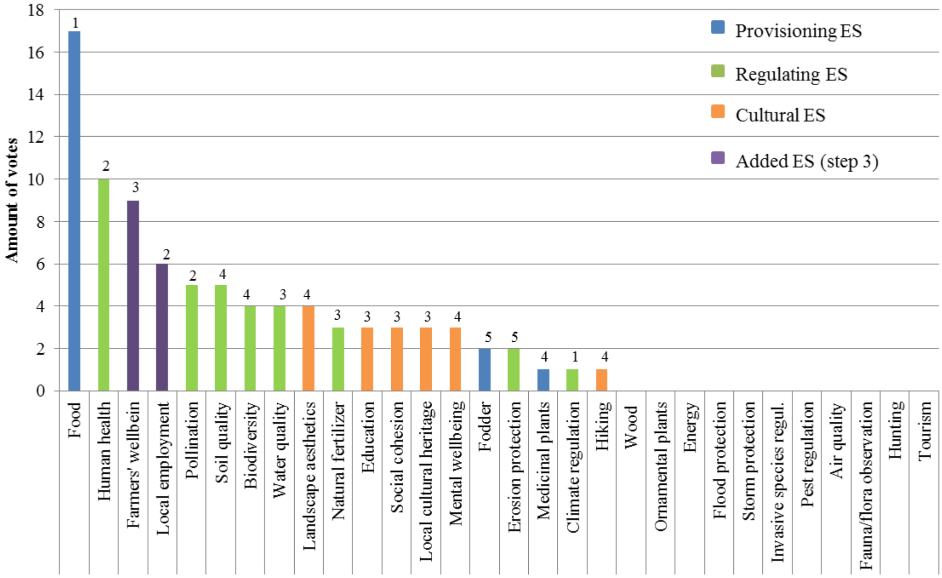

Figure III-3 : Outcomes of local actors' votes regarding which ES they value the most (step 6: across categories). Number of votes per ES is represented of the vertical axis while average ranks are the numbers above each bar (1: most important, 5: less important).

1.4. The final ecosystem service selection

After the consultation, compromises had to be found between the ES put forward by locals and the technical, expertise, time and financial constraints of the research. After carrying out the participatory ES identification and selection, several months were spent to gather literature and interview experts to find appropriate indicators and measurement methods for each prioritized ES. When a measurement method could be identified which was applicable within (i) the timeframe of the thesis, (ii) the financial constraints limiting access to specific equipment and (iii) the expertise available, the prioritized ES was kept further for the research.

Additionally, two ES were added to this list emanating from the consultation. The ES 'flood control' was added after a field visit carried out in winter showing many fields encountering flooding issues. The ES 'pest control' was also added as it is a service important to farmers and much influenced by agroecological practices, as attested by experts and literature (Bianchi et al. 2006, Balzan and Moonen 2014, Hatt et al. 2018).

The final list of ES included in the research is depicted in Table III-1. The provisioning and regulating ES are assessed both during the socio-cultural valuation (chapter III section 2) and the biophysical assessment (chapter IV). The cultural ES are valued only through the socio-cultural valuation. In total, 13 ecosystem services are included.

Table III-1 : Final list of ecosystem services selected for the present study based on the public consultation (1st column). Second column indicate the indicator(s) used for assessment/valuation, third column summarizes the reason why some ES are not kept for the subsequent steps of the study, and last column indicates which chapter assesses the service.

ES from the ranking list in order of importance	Indicator(s) used for assessment	Comments	Chapter
Food	Straw yield		III, IV
	Grain yield		III, IV
Regul. Human health	Grain quality		
Farmers wellbeing	-	Beyond available expertise	
Local employment	-	Beyond available expertise	
Pollination	-	No applicable to cereal fields	
Soil quality	Soil organic matter degradation rate Soil respiration rate		III, IV
	Available nutrients		
Biodiversity habitat	Abundance and diversity of micro-organisms	Part of a partner project	
	Abundance and diversity of carabid beetles	Part of a partner project	
Water quality	Potentially leaching nitrogen		III, IV
Landscape aethetics	Social scoring		III
Natural fertilizer	-	Beyond available expertise	
Education	Social scoring		III
Social cohesion	Social scoring		III
Local cultural heritage	Social scoring		III
Mental wellbeing	-	Beyond available expertise	

Fodder	-	Included in food production	
Erosion protection	Soil aggregate stability		III, IV
Medicinal plants	-	Beyond available expertise	
Regul. Climate	-	Beyond available expertise	
Hikes	Social scoring		III
Flood control	Soil permeability	Added upon expert consultation	III, IV
Pest control	Aphid abundance Parasitism Predation	Added upon expert consultation	III, IV

1.5. Conclusion

From the outcomes of the focus group organized for the participatory ES identification and selection, we can notice that a wide variety of ES are deemed important by locals. Expectations towards agriculture are rather diverse across actors. Although most people are perceive agriculture’s first role of providing food, a certain desire for a more multifunctional agriculture is clearly present in the studied area.

The final ES selection depends however not only on the stakeholders consultation. The research is subject to several technical, expertise, time and financial constraints which had to be taken into account. Additionally, some ES were added as deemed important after expert and literature consultation. This is more thoroughly discussed in Chapter V section 2.

- Article 3: Submitted–

2. How are landscapes under agroecological transition perceived and appreciated? A Belgian case study

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This article is submitted to the journal: 'Journal of Rural Studies'

Abstract

An increasing amount of agricultural transition initiatives are taking place, seeking for more autonomy and resilience on the farms. This undeniably reshapes the landscape and the flow of ecosystem services (ES). To date, little research includes the knowledge and perceptions of local communities on how rural landscapes in agricultural transition are perceived. Yet, farmers shape the landscape and ES flows, and local inhabitants are directly impacted. The present work aims at assessing the extent to which locals (local inhabitants and farmers) view landscapes undergoing agricultural transitions by comparing it to 'ES experts' perceptions. Manipulated photographs simulating an agroecological landscape, a conventional agriculture landscape, and landscapes including each agroecological practice isolated are submitted to both locals and ES experts (resulting in six 'scenarios'). We show that both profiles perceive and appreciate these scenarios similarly. The agroecological scenario was seen as the most appreciated and the one delivering the most ES, while the conventional one was the least appreciated and seen as the one delivering the least ES. We discuss how our results feed the call for future rural land management research to rely on co-constructed action research embedding local knowledge, perceptions and values.

2.1. Introduction

Scientific literature abounds to warn about the environmental, social and economic limitations of the current intensive agricultural model (IAASTD 2009, Tilman et al. 2011, Ponisio and Kremen 2016). In answer to these concerns, agroecology is being promoted as a promising concept (Gliessman 2006, Altieri et al. 2015). In a recent review, Hatt et al. (2016a) define agroecology as the application of ecological practices as well as the consideration of socio-economic dimensions for sustainable food systems. Agroecological practices rely on the hypothesis that modifying the agroecosystem or agro-landscape structure and processes redefines ecosystem service (ES) flows, some of which are crucial to the long-term performance of agriculture (e.g. natural pest control and natural soil fertility) (Zhang et al. 2007, Dale and Polasky 2007, Power 2010).

Agroecology is largely and increasingly embraced by the scientific community (Dalgaard et al. 2003, Wezel et al. 2013, Hatt et al. 2016a, Nicholls and Altieri 2018), but also by farmers themselves. Farmers increasingly enquire to bring changes in their practices in order to meet more resilience and autonomy (Van Der Ploeg 2008). The increasing number of farms shifting to organic farming (European Commission 2017a), implementing Agro-Environmental Measures (European Commission 2017b), putting conservation agriculture into practice (Knowler and Bradshaw 2007) and organizing short supply chains (Renting et al. 2003), are illustrative of these emerging interests.

In the Western part of the Hainaut Province in Belgium, a core group of innovating farmers spontaneously change their agricultural practices (e.g. feed autonomy, no-till agriculture, organic farming, etc.). While transitioning towards these innovative practices, the challenge for farmers lies in the numerous uncertainties related to the complex nature of agroecosystems in which ecological processes and ES form an intricate network which is often unpredictable, not fully understood (Duru et al. 2015) and specific to each production site (Bell et al. 2008, Lyon et al. 2011). To tackle the challenge, these farmers have created a network entitled the 'innovating farms network' aiming at providing a 'safe learning space' where they can exchange knowledge and experiences (Louah et al., 2015; Réseau des fermes novatrices, 2017).

As this network of farmers is gaining momentum, parts of the landscape are gradually undergoing a shift from the typical simple and homogenous landscapes of conventional agriculture in Western Europe, to a more complex and heterogeneous landscape. Rural landscapes represent the place where many people live, recreate (Vanderheyden et al. 2014) and with which they create a feeling of identity and belonging (Tengberg et al. 2012). They also represent a place creating tensions between the different users (inhabitants, farmers, industries, naturalists, etc.) (Lin and Fuller 2013).

Landscape management has become a key aspect within policy frameworks in the last decades, as attested by, among others, the Pan-European Biological and Landscape Diversity Strategy (Council of Europe 1995) and the European Landscape Convention (Council of Europe 2000). These policies emphasize the key role of human perceptions and values as the drivers of landscape changes. The European Landscape Convention defines landscapes as 'an area perceived by people, whose character is the result of the action and interaction of natural and/or human factors' (Council of Europe 2000). This definition emphasizes the necessity to integrate human perceptions and values to understand landscapes and design socially relevant agricultural landscapes.

The concept of ecosystem services (ES) offers such tool which takes a holistic system perspective accounting for the multiple perceptions, values and benefits of ES providers or beneficiaries (Schmidt et al. 2016). The tool offers a framework disentangling the complex feedback loops of how management affects ecological processes and ES flows and how in turn these ES changes are perceived (Lamarque et al. 2014). Dendoncker et al. (2018a) suggest the use of the ES tool to steer agroecological transitions. Within their proposed framework, assessing the values and perceptions of all stakeholders involved represents a first step to develop a shared understanding of the agro-landscape, to further support the co-construction of pathways of change.

While there is a growing body of scientific work being carried out on ES perceptions and values, this seems disconnected from the field of locals' perceptions of agricultural landscapes changes. Among the body of literature available regarding the perception of landscape changes (Lindemann-Matthies et al. 2010, Junge et al. 2015, Klein et al. 2015) few include the concept of ES explicitly (Bernués et al. 2016). Previous ES studies have assessed ES perception and values in other ecosystems (Hicks et al. 2013 in coral reefs, e.g. Carnol et al. 2014 in forests), across various land uses (García-Llorente et al. 2012, van Berkel and Verburg 2014, Cáceres et al. 2015, Logsdon et al. 2015) or for ES identifications and selection (Malinga et al. 2013, Mascarenhas et al. 2014, Boeraeve et al. 2018). However, few ES perception studies address specific agricultural practices and management regimes (Bernués et al. 2016). Recently, some exceptions emerge which address the perceptions of ES delivery within an agricultural context, such as Bernués et al. (2016) who focus on animal agriculture and Andersson et al (2015) who study intensive and extensive farmlands.

This paper provides a contribution to this vein of work by gaining understanding in how people perceive landscapes under agroecological transition and resulting ES flow changes. A way to better grasp local's perceptions is to compare them to the ones of 'ES experts', as suggested by Smith and Sullivan (2014). The distinction is commonly made between local and scientific knowledge and perception (Raymond et al. 2010, e.g. Carnol et al. 2014). Local knowledge refers to 'knowledge held by a specific group of people about their local ecosystems (…) derived through various experiential processes (….), reflects understanding of local phenomena'. On the other hand, scientific knowledge is 'systematic recorded knowledge (…) passed through a strict and universally accepted set or rules' (Raymond et al. 2010). In the context of agricultural management, local knowledge is held by both farmers, who manage the land, influence ES delivery; and local inhabitants, who live in the environment shaped by farmers, benefit or are impacted by the positive or negative resulting ES flows (Hicks et al. 2013).

More specifically, to examine how people perceive landscapes under agroecological transition the present research asks three questions: i) what is the perception by locals (including farmers) and experts of ES delivery in agroecological landscapes? ii) what is the appreciation of locals and experts of landscapes harboring agroecological practices? and iii) do these perception of ES delivery and appreciations differ between locals and experts?

The study focuses in the Western part of the Hainaut Province in Belgium, as parts of these landscapes are starting being modified by the aforementioned core group of 'innovating farmers'. This study does not aim at representing the global rural population as it is focused on a local specificity. Local-based approaches are relevant when addressing landscape perceptions as preferences for landscape attributes are highly context specific (Bell et al. 2008, Lyon et al. 2011, van Zanten et al. 2014b). The present study will thus provide information on how the landscapes modified by the on-going agroecological transition of the ‘innovative farm network’ are perceived and appreciated by the society. The knowledge generated by our study will allow checking the general assumption that agroecological landscapes allow reaching higher environmental, but also social sustainability.

2.2. Methods

2.2.1. Study area

The study area is located in the Western part of the Hainaut province in Belgium. This region is located in the ‘bas-plateau limoneux Hennuyers’ with a topography of plains and low-tablelands where croplands dominate. Small shrub and tree patches are scattered through the landscape, with some grasslands near habitations (CPDT 2004). The study area is representative of intensive agro-landscapes of temperate Western Europe. The climate is oceanic temperate with annual rainfall around 800mm/year and average yearly temperature around 10°C.

Within this landscape dominated by conventional intensive agriculture, a core group of innovative farmers are starting to implement new practices to ensure more autonomy, resilience and sustainability, creating more diverse and heterogeneous landscapes. Within this ‘innovative farms network’, some farmers have implemented a whole-system transition. Within these farms, agricultural practices are drastically modified as they are organically certified, apply reduced tillage to their soil (or no-tillage and direct seeding), grow crops in association (referred to as ‘intercropping’ hereafter) and implement green infrastructures (grass strips, wildflower strips, hedgerows, etc.). By combining all these ecological practices, we believe these farms lay on the ‘strong’ end of the gradient of ecological modernization presented by Horlings and Marsden (2011) and thus respond to the definition of ‘agroecological farming systems’ (Altieri et al. 2017).

2.2.2. Construction of landscape scenarios

People perceptions were studied through respondents’ evaluation of manipulated photos with Adobe Photoshop following a wide body of studies which successfully assessed people’s judgments using manipulated photos as a surrogate for the actual landscape (e.g. Junge et al. 2011, Klein et al. 2015). Scenarios were created from a baseline photograph of a simple landscape of conventional agriculture, representative of the area, but also of the intensive agro-landscapes of Western temperate Europe (Figure III-4; CV). Creating the scenarios from a baseline photograph decreases potential biases such as these potentially caused by different weather or landscape structures. The photograph was taken from a dirt road to represent an everyday scene easily experienced by local inhabitants. It was taken with a LUMIX DMC-GF7K on June 16 2016 at 11am, on a sunny and cloudless day. From this photo, landscape elements representing agroecological farming practices were added to construct the agroecological scenario (Figure III-4; AE). This scenario combines tree rows to represent agroforestry, wildflowers strips, intercropping of wheat and legumes and cattle to represent crop-livestock association systems. To further depict why people perception change between these two contrasted scenarios, the agroecology scenario was de-constructed into its different components, each leading to one scenario. Eventually, this led us to six scenarios: the two contrasted scenarios, i.e. the initial conventional landscape (CV) and the agroecological scenario combining all the aforementioned agroecological practices (AE); as well as four scenarios depicting a single agroecological practice: agroforestry (AF), wildflower strips (WF), intercropping (IC), and crop-livestock association (CL).

CV

CL

IC

AF

WF

AE

Figure III-4 : Landscape scenarios submitted to respondents for scoring of appreciation and perception of ES delivery.

2.2.3. Elicitation of appreciation and perception of ecosystem delivery across scenarios

Locals and experts were enquired about their perceptions by means of a questionnaire. The first questions relates to personal data, including sex, age, profession and the type of living environment before presenting three questions per scenario. The first question enquires about the positive and negative feelings regarding the scenario. Starting with an open question allows getting insights into participants' mental framework and offer participants the opportunity to talk without constraints or pre-defined framework imposed by scientists (Boeraeve et al. 2018). Secondly, participants are asked to rate the extent to which they believe the landscape scenario is favorable to the delivery of 13 ES (ranging from 1:not at all to 5: very favorable). The selection of ES was inspired both from a public consultation (which took place in March 2015 as an earlier step in the project). Reflections on the methodology used for this participatory ES selection are detailed in Boeraeve et al. (2018). The 13 ES included are: landscape aesthetics, biodiversity, water pollution protection, social cohesion, recreation, pest control, inspiration, heritage, food production, flood protection, erosion protection, and education. The last question of the questionnaire addressed the overall appreciation of the scenario on a 1 to 5 scale (1: I don't like at all, 5: I like a lot). Such semantic differential scale has been recommended for evaluative approaches (Lindemann-Matthies et al. 2010).

The questionnaire was submitted to locals during a focus group on July 4th 2016 taking place within a wider project including also a collective valuation not presented here. Questionnaires were given at the start of the focus group, before any interaction took place. It is therefore assumed that the focus group setting did not influence answers provided in the questionnaires. Participants were selected according to a 'purposive sampling' strategy, i.e. sampling of which the profile of participant was selected purposively in order to reach a wide variety of profiles interested in the topic rather sampling randomly in the population. The aim was to include both ES providers (farmers) and ES beneficiaries (farmers and local inhabitants).

The questionnaire was also submitted to ES experts in order to get insight into how different groups value scenarios differently. The link to the online questionnaire was sent through the spring 2017 Newsletter of the Belgian Community of Practice on Ecosystem Services (The Belgian Biodiversity Platform 2013). It was specifically mentioned that answers were expected to be the perspective of 'professionals working on ES', in order to distinguish between ES experts perceptions from personal perceptions, as a same individual can endorse several roles (Lamarque et al. 2014). The questionnaire was sent on May 22nd 2017 and was closed on June 28th 2017.

2.2.4. Statistical analyses

Statistical analyses were carried out to (i) test whether respondent's profile led to distinct perception of ES delivery or appreciations of the scenario, (ii) test within each profile (locals or experts) whether ES delivery was perceived differently across scenarios, and (iii) test within each profile, whether scenarios were appreciated differently. Since the initial focus of the research is to investigate the perception and appreciation of local stakeholders, and because the profile 'ES expert' serves as reference point, analyses of (ii) and (iii) are carried out separetly for each profile even if (i) did not show significant difference across profiles in order to provide more detailed analyses.

Analyses were performed in R software version 3.3.2 (R Core Team 2016). Data was tested for normality with Q–Q plots of the residuals. Mixed linear mixed models were applied using the package 'lme4' (Bates and Maechler 2018). The respondent's profile, the scenarios and ES were analyzed as fixed variables, while the respondent individual was analyzed as random variable. Models were constructed from the experimental variables listed above and adding interaction(s) when affecting significantly the model. This was tested by means of a Chi-square test (<0.05) using the 'anova' function. One model was constructed including all variables to test the effect of respondent's profile. One model per profile per ES was constructed to test how each ES is perceived through scenarios (see 2.3.2). Then, one model per profile was constructed to test the appreciation of the different scenarios (see 2.3.3). Multiple comparisons were carried out with the function 'glht' of the 'multcomp' package to depict differences of appreciation between scenarios (Torsten et al. 2017). Effects of the mixed linear models were tested by means of F test (<0.05) using the package 'car' (Fox et al. 2018).

2.3. Results

2.3.1. Sample characteristics

The focus group counted 13 participants, including local inhabitants (9) and local farmers (conventional (2) and agroecological (2)). The group was gender balanced (55% males, 45% females), had a majority of people living in a rural area (73%) and a majority of people aged between 40 and 65 (64%). The questionnaire was answered by 24 ES experts, two third of which were males, and 87% aged between 26 and 65. The proportion of experts inhabiting rural, urban and peri-urban areas was evenly shared among respondents (29%, 37%, 33% respectively).

2.3.2. Perception of ecosystem service delivery in agroecological landscapes

Perception of ES through the distinct scenarios do not differ between experts and locals ($F_{1,38}$=0.167, p=0.685) (Table III-2, figure III-5). Within each profile, each ES is perceived significantly different across the six scenarios with only one exception: food production in the eyes of locals ($F_{5,13}$=2.22, p=0.0665). Comparing ES delivery for the agroecological and conventional scenarios reveals that all ES are perceived as delivered differently between the two scenarios, both for experts and locals, with the exception of food production ($F_{1,24}$=2.42, p=0.126 $F_{1,13}$=0.825,p=0.375).

Table III-2 : Summary of F and p values of tests run on the different models. First section provides outcomes of the model including all variables. Underneath are the results of models per ES run through all scenarios (left) or through the agorecological scenario (AE) and the conventional one (CV) only (right) for both experts and locals.

Overall effect					
Profile		Scenario		ES	
$F_{1,38}$	Pr(>F)	$F_{5,38}$	Pr(>F)	$F_{12,38}$	Pr(>F)
0.167	0.685	32.8	<.001***	12.1	<.001***

	ES perception by profile for all scenarios				ES perception by profile for scenario AE and CV			
	Expert		Local		Expert		Local	
	$F_{5,24}$	Pr(>F)	$F_{5,13}$	Pr(>F)	$F_{1,24}$	Pr(>F)	$F_{1,13}$	Pr(>F)
Food production	4.09	0.002**	2.22	0.0665	2.42	0.126	0.825	0.375
Social cohesion	17.3	<.001***	6.01	0.00263***	34	<.001	13.3	<.001
Soil fertility	19.9	<.001***	8.21	<.001***	50.9	<.001	44.1	<.001
Aesthetic	28.6	<.001***	11.3	<.001***	72.8	<.001	43	<.001
Flood protection	17.4	<.001***	11.3	<.001***	37.1	<.001	38.4	<.001
Heritage	9.96	<.001***	8.34	<.001***	23.1	<.001	14	<.01
Erosion protection	29	<.001***	12.8	<.001***	55.7	<.001	31.2	<.001
Recreation	25.7	<.001***	12.1	<.001***	49.4	<.001	70.4	<.001
Biodiversity	38.1	<.001***	25.9	<.001***	117	<.001	128	<.001
Inspiration	21.4	<.001***	12.9	<.001***	52.7	<.001	67.2	<.001
Water pollution protection	23.9	<.001***	16.6	<.001***	52.1	<.001	24.6	<.001
Education	22.1	<.001***	11.1	<.001***	36.6	<.001	52.8	<.001
Pest control	38.9	<.001***	14.1	<.001***	122	<.001	136.1	<.001

Both locals and experts see the agroecological scenario as delivering more ES (Figure III-5; light blue) and the conventional scenario as delivering the least ES (Figure III-5; green). The intermediary scenarios follow the same trend for both profiles: the crop-livestock association is perceived as delivering less ES, followed by the intercropping scenario. Distinction between perceived ES delivery of the wildflower strip and the agroforestry scenario is less clear.

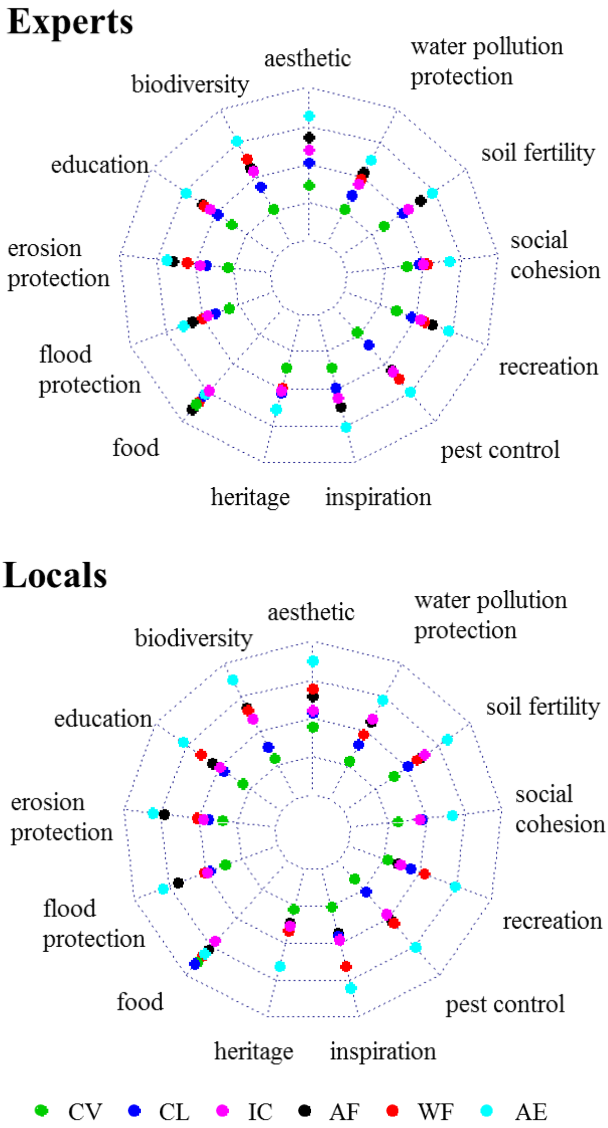

Figure III-5: Radar plot of the average perceptions of ES delivery for experts and locals. CV: conventional, CL: crop-livestock, IC: intercropping, AF: agroforestry, WF: wildflower strip, AE: agroecology.

2.3.3. Appreciation of agroecological landscapes

Outcomes of the scoring question

Experts and locals do not show significantly different appreciations of the different scenarios ($F_{1,38}$=0.434, p=0.515). Within profile models show that experts and locals both appreciate differently the distinct scenarios ($F_{5,24}$=12.9, p<.001 and $F_{5,13}$=8.5, p<.001, respectively). Both profiles show the highest appreciation for the agroecological scenario and the lowest for the conventional one (Figure III-6) (both p_{adj}<.001). Appreciations of the intermediate scenarios do not significantly differ between each other. The agroecological scenario is not significantly different from the crop-livestock association for both profile, and for locals, also from the intercropping and the agroforestry scenarios. The conventional scenario is not significantly different from the wildflower strips, and for experts also from the agroforestry scenario.

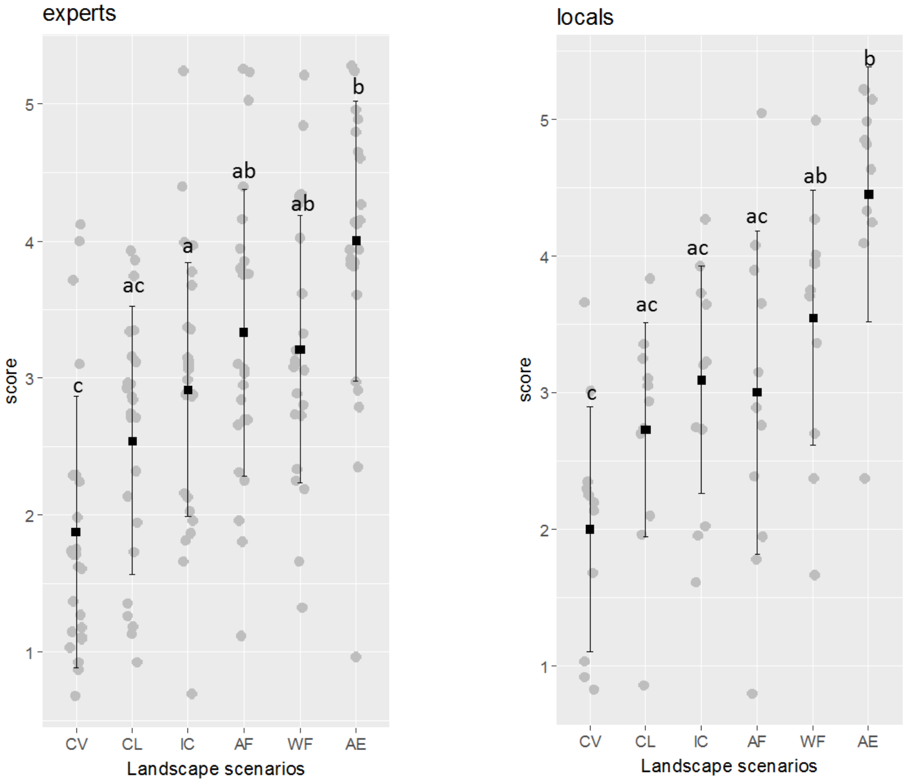

Figure III-6: Experts and locals appreciation of the six scenarios. CV: conventional, CL: crop-livestock, IC: intercropping, AF: agroforestry, WF: wildflower strip, AE: agroecology.

Outcomes of the open question about positive and negative feelings

Results from the open question enquiring about positive and negative feelings regarding scenarios showed several similarities across experts and locals. In general, few comments were directly related to ‘feelings’ as such (e.g. comments about the aesthetics or the atmosphere felt), respondents rather commented the structure or function of the agroecosystem with no value judgement (e.g. ES delivered, description of the composition of the agroecosystem). For both groups, many comments related to biodiversity and diversity in general. Each scenario received both positive (e.g. ‘environment more favorable to biodiversity’) and negative comments (e.g. ‘still not enough habitat diversity to support biodiversity’). Both groups considered all scenarios still too structured and aligned. Within both the experts and the local group, five respondents did not find any positive feeling regarding the conventional scenario, and six respondents did not find any negative feelings regarding the agroecological one.

Besides these similarities, results also showed divergences between perceptions of experts and locals. Overall, experts often mentioned the words ‘tranquility/quietness’ and ‘boring/annoying/dullness’ which was never mentioned by locals. The only comments of locals about their feelings referred to a ‘sad’ landscape, which was mentioned three times. The word ‘open’ was also thoroughly used by experts (for all scenarios except for the agroforestry and agroecological ones) and never mentioned by locals. The crop-livestock scenario gathered more negative reactions from experts (e.g. nitrogen deposition, responsible of climate change, intensive cattle production) and much more enthusiasm from locals (e.g. ‘great, cows!’, ‘nice association between crop and livestock’). However, the main positive aspect of this scenario put forward by experts (‘tradition’ or ‘typical’) was not mentioned at all by locals.

Paradoxically, both locals and experts mentioned some negative comments regarding scenarios of isolated agricultural practices which were not mentioned anymore for the agroecological scenario. In fact, all negative comments of isolated practices mentioned by locals (low profitability, poorly maintained, trees too aligned, not enough diversity, etc.) were not present in the agroecological scenario. For experts, a similar observation can be made for weeds (mentioned in all scenarios except for the agroecological one) and pesticide use (mentioned in all scenarios except for the agroecological and intercropping one). In the same vein, experts mentioned positive aspects of the conventional scenario which were also present in other scenarios (e.g. ‘no construction’, ‘no allergy’).

Appreciation of the different scenarios followed the same trends for both locals and experts, and this trend also follows the trend of ES delivery perceptions (Figure III-7).

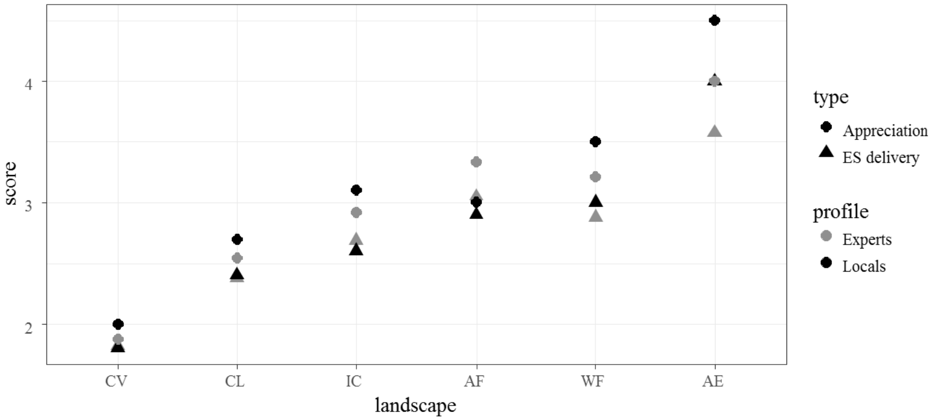

Figure III-7: average appreciation and perception of ES delivery for experts and locals. CV: conventional, CL: crop-livestock, IC: intercropping, AF: agroforestry, WF: wildflower strip, AE: agroecology.

2.4. Discussion

In spite of the limited sample size, our study presents some clear trends: from the scenario photographs, landscape changes induced by agroecological transitions are perceived positively by the local population. They are perceived as delivering more ES and are better appreciated. Only food production is not perceived differently across scenarios. Experts' perception and appreciation follow the same trend as locals, indicating a shared understanding of the complex interactions between agricultural practices, landscape modification and ES flows.

Similar landscape appreciation and perception for experts and locals

Previous research has shown similar results, where farmers' perception was similar to conservationists' (Bernués et al. 2016) or to scientific literature (Smith and Sullivan 2014). This attests that locals have some natural scientific understanding on the functioning of nature (Lewan and Söderqvist 2002). Other studies do not abound in the same direction, and depict different perceptions between rural communities and scientists or conservationists (Lamarque et al. 2014, Logsdon et al. 2015). In fact, results could possibly not be consistent across studies, as the attitude and perceptions of locals and the flows between agricultural practices and ES delivery all vary with their context (Page et al. 2015), which highlights the necessity to evaluate such relationships based on case studies (Lamarque et al. 2011).

Agroecology: greater than the sum of its parts

It is interesting to notice that food delivery was not perceived as being impacted in the agroecological scenario, it being by locals or experts. Yet, the perspective that agroecology affects productivity is widespread (Polasky et al. 2011, Smith and Sullivan 2014, Holt et al. 2016, Cramer et al. 2017). Despite this popular idea, other studies have shown that tradeoff between agricultural production and other ES delivery does not exist in the view of locals and farmers (Smith and Sullivan 2014).

In fact, recent research shows that agroecology can conciliate food provision with bundles of other ES (Kremen and Miles 2012, Robertson et al. 2014, Schipanski et al. 2014, Syswerda and Robertson 2014, Garbach et al. 2016). This asks the questions as whether the debate about bridging the yield gap in alternative and more sustainable forms of agriculture is not starting to be outdated. Rapidel et al. (2015) for instance suggest to focus on the 'service gap' rather than on the 'yield gap'. In any case, as yields of intensive agriculture come at the cost of destroying ecological processes which in turn impacts crop growth, it is of uttermost importance to include all ES in assessment of agricultural system performance (Ponisio and Kremen 2016).

In addition, the complex agroecological scenario seemed to be exempted of negative comments, even when negative comments were attributed to the single agroecological practices. Indeed, while some negative comments were made for isolated practices (e.g. 'trees too aligned', 'difficult to cultivate'), none were formulated when all these practices are combined to form the agroecological scenario. Agroecology seems to appear in locals' perception as more than the simple addition of several practices, but more as a whole, where practices interact in synergy.

Landscape appreciation follows perception of ES delivery

We also found that scenarios perceived as delivering more ES were also more appreciated. This is consistent with earlier work which highlights that multifunctional landscapes, providing a wide array of ES, are preferred (García-Llorente et al. 2012) and more linked to wellbeing (Plieninger et al. 2013). In this vein of work, previous studies have identified that more appreciated landscapes relate with landscape involving fruitful practices, fertility indicators or other symbols of sustainable human subsistence (Barrett et al. 2009, Falk and Balling 2010). In our study, the agroecological scenario was the most appreciated and seen as delivering the most ES followed by the agroforestry and the wildflower strip scenarios (without significant difference between the two), the crop-livestock association and the intercropping. The conventional scenario was the least appreciated and the one seen as delivering the least ES, except for food production.

A call for co-constructed action research for sustainable rural land management

Our results prove the locals interviewed can envision the complete feedback loop between agricultural transitions, landscape modifications and alteration in ES flows. Considering this awareness, and seeing that it is highly context-dependent, local knowledge and perception should be capitalized for sustainable rural land management (Smith and Sullivan 2014). This can be achieved by up scaling the present study to a greater and representative population sample (instead of a purposive sample as in the present study) to determine which ES are the most valued by locals and by linking agricultural practices with (perceived) ES flows (Lamarque et al. 2014). The role of locals should thus be emphasized by reconnecting ecological processes and functions to social valuation. This would support the co-design of rural landscapes relevant to its socio-ecological context, empower local communities and stimulate their identity (García-Llorente et al. 2012).

The study limitations

Some limitations are worth noting. Although our results show clear and statistically significant outcomes, the study relies on a small sample size and the locals' selection may be biased towards people sensible of the question of sustainable agriculture and landscapes. As mentioned above, similar research aiming at supporting rural landscape management should broaden the population sample to reach higher representativeness. Additionally, it is to keep in mind that appreciations and perceptions of the landscapes are based on scenarios constructed from manipulated photographs. Our results are thus to be interpreted in terms of perceptions and appreciations of *agroecological-like* scenarios. This represents thus an indirect link to real-life agroecological landscapes, or to the concept of agroecology itself (there were no explicit reference to the term 'agroecology' or 'agroecological practices'). Future work is encouraged to disentangle this distinction to clarify the actual perception of agroecology and agroecological landscapes *per se*.

2.5. Conclusion

A wide body of literature abounds in calling for research that studies agricultural transition through the prism of the concept of ES. While research studying the perception of landscape change expands, the integration of the ES concept within this vein of work remains weakly explored. Our study provides a snapshot assessment demonstrating how experts, farmers and local inhabitants, perceive landscape undergoing agricultural transition, and how this in turn affects ES flows and their wellbeing. By relying on a deconstructed agroecological scenario into its individual practices, the approach allows distinguishing between the set of components and allows putting forward that negative feelings arising for isolated practices disappear in the combined scenario of agroecology.

Being the direct 'impacted', or 'users', but also for farmers, the 'managers' and thus 'ES providers', implementing their knowledge into rural management is likely to reach high social consensus and wellbeing. Despite being locally and timely specific, we believe our results support the call for co-constructed action research for rural management, in order to design sustainable rural landscape delivering diversified ES flows. To do so, such research ought to be embedded within a wider iterative framework as suggested by Dendoncker et al. (2018a), in which the understanding of the broad set of values and perceptions of all the stakeholders involved allows co-designing and exploring potential evolutions of the agro-landscape and selecting the most acceptable, socially and environmentally sustainable pathway of change.

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We wish to thank all participants to the focus groups and the questionnaire, whitout whom the presented work could not have taken place. We thank the Parc

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Chapter IV

BIOPHYSICAL ECOSYSTEM SERVICE ASSESSMENT

- Article 4: submitted -

Contribution of agroecological farming systems to the delivery of ecosystem services

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This chapter has been submitted to the Journal of Environmental Management.

Abstract

Agroecology has been suggested as a promising concept for reconciling agricultural production and environmental sustainability by optimizing ecological processes delivering ecosystem services (ES) to replace external inputs. While this statement is widely agreed upon, there exist few assessments of real-life conditions assessing multiple ES simultaneously. This paper provides the assessment of seven ES based on 14 indicators in three agroecological farming systems (AFS) and their adjacent conventional farming systems (CFS). Based on field-scale measurements spread through three years, our findings suggest that the studied AFS succeed in providing a wider array of regulating services than their neighbors CFS. More precisely, soil aggregate stability, soil respiration rates are in general more supported in AFS which also show less aphid abundance. On the other hand, CFS show higher grain production and higher performance for two out of three fodder quality indices. While this 'productivity gap' may be due to the still-evolving state of the studied AFS, we nuance this through the lens of a new paradigm to assess farming system performance. It is now argued that we need to shift from a volume-focused production system to a system also valuing ecological processes underpinning crop production and other benefits to society. Based on our findings, we recommend future work to iterate our initiative, including several indicators per service and embedding it into a wider context of co-adaptive science-practice to further develop context-specific and user-useful research.

1 Introduction

Achieving food security is no longer a matter of producing quantity only. In less than a century, agricultural yields have quintupled thanks to moto-mechanization, mineral fertilizing, crop selection and food system specialization (Mazoyer and Roudart 2002). However, this came at the cost of damaged ecosystems (Tilman et al. 2002, Stoate et al. 2009) and threatened farmers and consumers' health (Costa et al. 2014, Kunde et al. 2017).

Today's challenge is thus to maintain agricultural productivity high while sustaining the environment and its functions (Hodbod et al. 2016, Garbach et al.

2016). The solution is no longer to rely intensively on external resources, but to restore agro-ecological functions as a mean to increase the farms' resilience and autonomy (Landis 2017, Gordon et al. 2017). Future farming systems will have to be explicitly designed to provide multifunctional and more resilient landscapes (Payraudeau and van der Werf 2005, Holt et al. 2016), and agroecology is being promoted as a promising approach to answer this call (Wezel et al. 2013, Hatt et al. 2016a, Garbach et al. 2016).

The approach of agroecology suggests safeguarding ecological processes and functions underpinning flows of ecosystem services (ES) crucial to the ES crop production (e.g. soil nutrients cycles, pest control) and other ES beneficial to society (e.g. aesthetic landscapes, healthy food) (Zhang et al. 2007, Malézieux 2012, Duru et al. 2015). The concept of agroecology also encompasses the social and economic dimensions of food systems (Francis et al. 2003) and can be defined as a science, a movement and/or a practice (Wezel et al. 2011). Within the scope of the present article, we focus on the 'practice' side of agreoecology, in which the concept aims at providing synergies to deliver multiple ES within the system. Agroecological practices embrace a wide range of practices such as integrating natural and semi-natural landscape elements, implementing cover crops, using green manure, relying on intercropping or agroforestry, etc. (Wezel et al. 2013, Hatt et al. 2016a).

To achieve the design of innovative multifunctional productive agroecological systems, we require a thorough understanding of the relationships between ecological processes, functions and services, both under current conditions and after transitioning (Dale and Polasky 2007, Dendoncker et al. 2018a). A large range of indicators is needed to provide the required information to understand the agroecosystem and adapt it to its socio-ecological context. Farming systems represent complex entities with interacting synergizing or offsetting processes and practices. Hence, research aiming at disentangling this complexity requires system-based and multidimensional approaches (Kremen et al. 2012, Robertson et al. 2014, Ponisio et al. 2014).

However, while an ever increasing body of literature acknowledges this need, little research investigates multiple ES simultaneously on transitioning or agroecological farms (Bommarco et al. 2013, Andersson et al. 2015, Holt et al. 2016). Conventional agricultural research focuses on disciplinary approaches which has led to a set of standardized practices applicable to most pedo-climatic conditions (Hatt et al. 2016a). Hence, conventional agricultural research produces knowledge on specific agricultural practices and single services (e.g. Drakopoulos et al. 2015). Most agricultural research assessing multiple services have been based on mapping approaches and land use indices (e.g. Maes et al. 2012), models (e.g. Lerouge et al. 2016) or literature reviews and meta-analyses (Kremen and Miles 2012, Barral et al. 2015, Rapidel et al. 2015, Garbach et al. 2016). Some examples exist of field-based, farm-scale assessments of multiple ES (Porter et al. 2009, Sandhu et al. 2010, Syswerda and Robertson 2014), but these fail to assess interactions between services and practices (Seppelt et al. 2011, Landis 2017), and are based on experimental farms. While research in experimental fields allows isolating factors and biases, studying real-life examples of agroecological transitions presents the advantage to study systems which had to adapt to their social and environmental constraints, thus providing holistic analyses of realistic conditions. To the best of our knowledge, no research addresses agroecological systems by analyzing multiple ES delivery and the underlying synergies and tradeoffs. Yet, agroecology calls for site-specific, holistic and decentralized scientific approaches to design practices adapted to each socio-ecological system (Dale and Polasky 2007, Méndez et al. 2013, Bommarco et al. 2013, Andersson et al. 2015, Ponisio and Kremen 2016).

This study contributes to answer this gap by pursuing an integrated ES assessment of innovative agroecological farming systems (AFS). The studied AFS are located in the Western Part of the Hainaut Province in Belgium. They take part in a self-organizing network of farmers who work together to reach more resilience and autonomy on their farms. Among these, we have selected three cereals farms which we consider as agroecological as they combine multiple ecological practices: they are organic, implement soil reduced tillage, crop intercropping and green infrastructures within the farm's landscape. While these AFS have also undertaken a transition of their entire food system, the present research focuses on the agroecosystem and agricultural practices. These AFS are unique examples of cereal cropping systems located at a relatively high level of 'agroecologization' as they combine multiple agroecological practices (Horlings and Marsden 2011, Wezel et al. 2013).

The present study carries out field-scale ES assessments in order to provide better understanding of key ecological interactions that constrain or enhance the performance of AFS in terms of ES provisioning. As a diachronic analysis of the AFS before their transition is not possible, the assessment is carried out concomitantly in adjacent conventional parcels growing cereals and sharing the same environment and soil type. Following a participatory ES identification and selection (Boeraeve et al. 2018), we assess seven regulating and provisioning ES based on 14 indicators. Our study is, to the best of our knowledge, the first attempt to assess multiple ES simultaneously based on a field-scale approach and to rely on real-life agroecological examples. Our aim is to test the theoretical hypothesis that ecological processes and interactions can substitute for external and chemical inputs of intensively managed CFS and that AFS offer greater ES synergies.

2 Material and method

2.1 Site description

The studied farms are located in the Western part of the Hainaut province in Belgium (Figure IV-1). The climate is oceanic temperate with annual rainfall around 800mm/year and average temperature around 10°C. Three AFS have been selected, sharing similar farming practices: they are certified organic, rely on reduced tillage and direct seeding, grow cereals in intercropping and implement green infrastructures (hedgerows, wildflower strips, etc.). The intercropping consists of mixes with the following: triticale, oats, rye, spelt, pea, and vetch. For location A and B intercropping mixes alternate with a winter mix (‘biomax’). This winter mix is rolled by a FACA roller before sowing the cereal mix. Location C does not make use of biomax by sowing very close to the harvest date. The selected AFS combine organic agriculture and reduced tillage since eight years and are still evolving. Agricultural practices of AFS are summarized in Table IV-1.

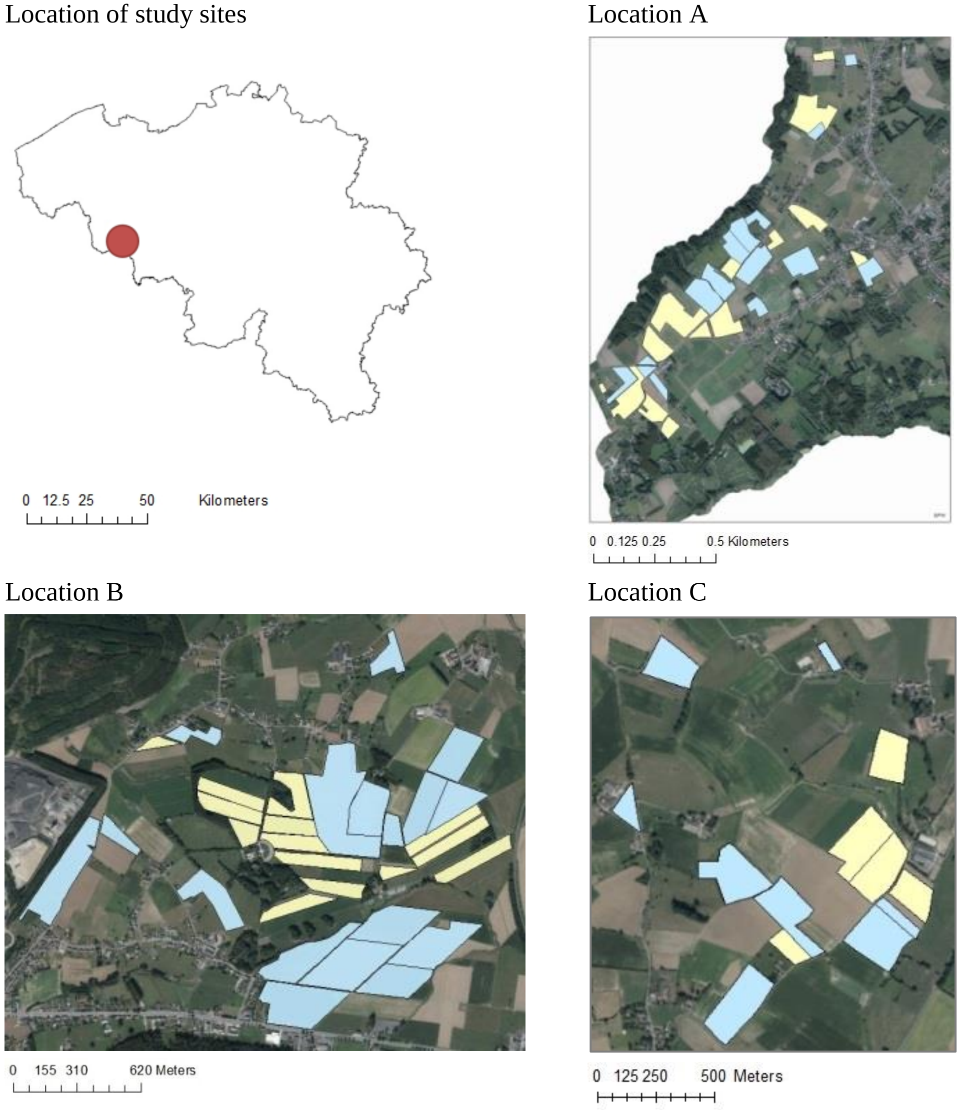


Figure IV-1 : Maps of the study sites. Belgium map indicating the position (red) of the three study locations and maps of each location (A, B, C).

Table IV-1: Description of the three agroecological farming system studied in the present research.

	AFS location A	**AFS location B**	**AFS location C**
Total surface	94	115	23
Cultivation surface	86	70	15
Permanent grasslands surface	8	10	8
Ecological structure surface and type	9ha of agri-environmental measures: wildflower strips	35ha of agri-environmental measures (hedgerows, ponds, wildflower strips)	1 parcel in agroforestry
Animal (amount, unit)	since 2015: 25 Angus cows	since 2015: 25 Angus cows	1982-1997: dairy cows 2002: 100: goats
Tillage type today	direct seeding	reduced tillage	
Year of transition to reduced tillage	1995	2013	2015 (before: only 1 ploughing / 5 years)
Year of transition to direct seeding	2010	NA	NA
Year of transition to organic farming	2011	2011	1997
Rotation	Alternation: cereal-pulse mix - biomax (winter cover) (with rarely hemp or potatoes instead of cereal mix for loc. A or favabeans for loc B)		3 years temporary grasslands - 2 years cereal-pulse mix
Approximal time of cereal-pulse mix sowing	September-October		
Composition of cereal-pulse mix	triticale, oats, rye, spelt, pea, and vetch	triticale, oats, pea, spelt	triticale, oats, rye, spelt, pea, vetch, buckwheat
Approximal time of winter cover sowing	August (after harvesting the cereal mix)		NA
Composition of winter cover	Clover, favabeans, buckwheat, flaxseed, phacelia, sunflower, oat, vetch, peas, lupin, forage radishes	Sunflower, vetch, peas, favabean, flaxseed, chinese radish, phacelia	No winter cover
Fertilization	2012: organic TMS Before potatoes: Ramial chipped wood (RCW) or manure (<1/year)	NA	Before sowing cereal-pulse mix: goat manure max 25T/ha

For each AFS parcel, a ‘reference’ parcel was selected among adjacent CFS to represent the AFS parcel before the transition. CFS parcel was paired to an AFS parcel under the condition that it was growing winter wheat (as it follows a similar cropping calendar to the intercropping mix of AFS, i.e. it is sown and harvested at the same time) and sharing a same soil type (homogenized soil texture, drainage and soil profile development). Similar soil types were first determined based on the Soil Map of Wallonia and then validated on the ground by soil scientists.

CFS are conventionally managed, i.e. applying mineral fertilizers and synthetic weed and pest controls, and using short crop rotation (typical wallonian rotation: winter wheat – beatroot – maize). Table IV-2 details the agricultural practices of the selected CFS. Selected CFS are representative of Walloon cereal farms, while selected AFS are ‘niche examples’ of cereal agroecological farms. Each AFS surrounded by its ‘reference’ CFS represent a distinct farm-set, named respectively: location A, B and C. Thus, each location is composed of one AFS and parcels from several CFS. Location A lies on a sandy loam (i.e. dominance of sand), while B and C are located on loamy sand (i.e. dominance of loam).

Table IV-2: Description of the conventional farming systems (CFS) studied in the present research. 1st column indicates the amount of parcel sampled per farm, then sufaces (total, croplands and grasslands) are provided, 3rd column lists the crops grown within the farm, 4th column provides details on the livestock of each farm, 5th column provides information on fertilizer type and frequence of use (Frequ.), 6th column gives details on phytosanitary treatments and last column describe the soil tillage type. Livestock breeds are Holstein Friesian for dairy cows and and Belgian Blue for lactating cows. *Fertilizer and phytosanitaty treatments are described for parcels of wheat only.

		Parcels	Surface			Crops	Livestock	Fertilizer*		Phytosanitary treatment*	Soil tillage type
			Tot.	Crop	Grass.			Type	Frequ.	Type and Frequ.	
Location A	CFS1	1	65	55	10	corn, wheat, beetroot	25 dairy cows	Mineral nitrogen	1	fungicide + herbicide	ploughing 25-30cm
	CFS2	1	60	45	15	corn, wheat, potatoes, temporary grasslands	100 lactating cows	TMS, mineral nitrogen	1	fungicide + herbicide	reduced tillage, ploughing on exceptions
	CFS3	4	110	64	46	corn, wheat, beetroot, alfalfa	100 dairy cows, 60 lactating cows	Urea	3	growth regulator + fungicide (2) + herbicide	ploughing or reduced tillage
	CFS4	2	60	40	20	corn, wheat, potatoes, barley	130 dairy cows	Mineral nitrogen	3	fungicide, herbicide	ploughing only for potatoes, otherwise: reduced tillage
	CFS5	4	100	98.5	1.5	corn, wheat, beetroot, potatoes, peas, beans, carrots, parsnips	10 lactating cows	Mineral nitrogen	3 or 4	growth regulator (2) + fungicide (2) + herbicides (2) + insecticide	reduced tillage

Table IV-2: (continued)

		Parcels	Surface			Crops	Livestock	Fertilizer*		Phytosanitary treatment*	Soil tillage type
			Tot.	Crop	Grass.			Type	Frequ.	Type and Frequ.	
Location B	CFS6	4	125	103	22	corn, wheat, beetroot, potatoes, barley, beans, chicory	100 dairy cows	Mineral nitrogen	NA	growth regulator (2) + fungicide +herbicide	ploughing or reduced tillage
	CFS7	3	55	35	20	corn, wheat, beetroot, alfalfa, barley	100 dairy cows (Montbéliarde)	TMF, Mineral nitrogen, Magnesium + Sulfur (Epsotop)	6	growth regulator (3) + fungicide (2)+ herbicide	ploughing 25-30cm
	CFS8	1	100	75	25	corn, wheat, beetroot	60 dairy cows, 2500 porks	Mineral nitrogen	NA	growth regulator + fungicide (2) + insecticide + herbicide	ploughing 25-30cm
	CFS9	1	65	45	20	corn, wheat, beetroot, potatoes	85 dairy cows, 60 lactating cows	Mineral nitrogen	3	growth regulator + fungicide (2) + herbicide	ploughing or reduced tillage
	CFS10	6	67	50	17	corn, wheat, beetroot, potatoes	145 lactating cows	Mineral nitrogen	1	growth regulator + fungicide (2) + herbicide	reduced tillage

Table IV-2: (continued)

		Parcels	Surface			Crops	Livestock	Fertilizer*		Phytosanitary treatment*	Soil tillage type
			Tot.	Crop	Grass.			Type	Frequ.	Type and Frequ.	
Location C	CFS11	1	35	23	12	corn, wheat, beetroot	30 lactating cows	Mineral nitrogen	2	growth regulator (1-2) + fungicide (2) + herbicide	ploughing 25-30cm
	CFS12	1	42	30	12	corn, wheat, beetroot, clover, alfalfa	80 lactating cows (Montbéliarde)	Mineral nitrogen	3	growth regulator + fungicide (2)	ploughing or reduced tillage
	CFS13	1	60	45	15	corn, wheat, beetroot, clover, alfalfa, potatoes, beans	60 lactating cows	Mineral nitrogen	NA	fungicide (0-2) + herbicide	ploughing 25-30cm
	CFS14	1	65	55	10	corn, wheat, beetroot	35 lactating cows	Mineral nitrogen	3	growth regulator + fungicide (2) + insecticide + herbicide	ploughing 25-30cm
	CFS15	1	90	75	15	corn, wheat, beetroot, potatoes	40 dairy cow	Mineral nitrogen	3	growth regulation, fungicide (1-2), herbicide (1-2)	reduced tillage
	CFS16	2	65	45	20	corn, wheat, beetroot	85 dairy cow, 60 lactating cows	Mineral nitrogen	3	growth regulator + fungicide (2) + herbicide	ploughing or reduced tillage

2.2 *Identification and selection of ES and their indicators*

As suggested by Dendoncker et al. (2018a), the biophysical ES assessment is embedded in a social valuation to guide the selection of context-relevant ES. ES were identified through a consultation with the farmers (ES providers and beneficiaries) and local inhabitants (ES beneficiaries). This was organized under the form of a focus group at the very start of the project. The procedure includes prioritization based on an individual and a collective scoring and follows a rather common methodology for participatory ES selection (Boeraeve et al. 2018). The prioritized ES were then subject to the technical constraints of the project (i.e. expertise, time, equipment and finance). The final ES list comprises seven services including two provisioning services: fodder production and quality; and five regulating services: soil quality, pest control, erosion control, flood control and water pollution control. We refer to the ES ‘fodder production and quality’ instead of ‘food’ as the cereals of the studied farms are grown for fodder purposes, as most cereal crops in Wallonia (Delcour et al. 2014b).

As many services are difficult to quantify directly, many indicators actually inform on the state of the ecosystem or ecological processes and thus on the potential ES delivery, and not on the actual ES flow. In order to offer transparency, we structure our indicators within a framework depicted in Figure IV-2 distinguishing between indicators of ecosystem state, processes or functions, services and benefits. ‘Ecosystem state’ indicators reflect the structure and composition of ecosystems, such as soil data, or abundance of specific organisms. ‘Ecosystem processes’ or ‘functions’ are the basic ecosystem functions becoming ES when benefiting humans. Following the recommendations of Andersson et al. (2015) and Lebacq et al. (2013), we use – when relevant - several indicators for the same service, to inform more comprehensively on the underlying processes to ES delivery.

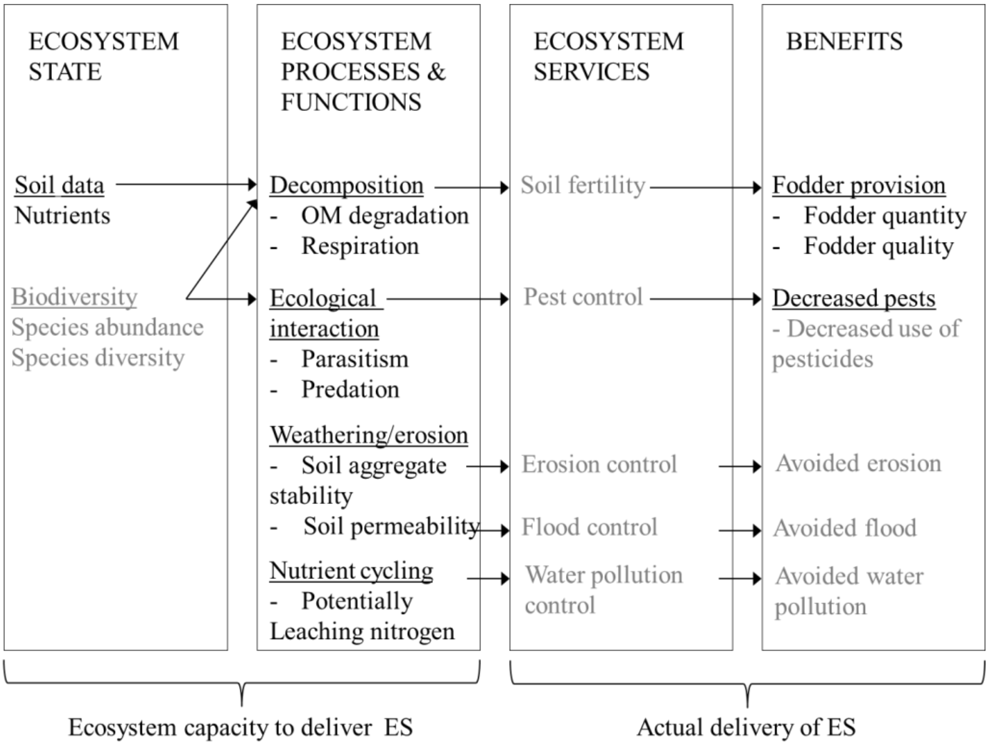


Figure IV-2 : Framework of the present study clarifying the type (i.e. whether its measures components of ecosystem state, processes or functions, services or benefits) of indicators (black) used for the biophysical ES assessment. OM= Organic Matter, ES=Ecosystem services.

2.3 Field measurements for ES assessment

The selection of measurement methods for each indicator follows the approach of the Rapid Ecosystem Function Assessment (REFA) suggesting a suite of fast, easy-to-use, repeatable and cost-efficient methods to quantify essential ecosystem components (Meyer et al. 2015). Such approach was chosen to allow spanning a larger range of ES and to allow better transmission of the results to the farmers. Table IV-3 present the measurement method selected for each indicator.

Field measurements of each indicator were carried out between spring 2015 and autumn 2017, representing three sampling seasons. Two locations were sampled at each sampling season leading to each location measurement being replicated twice, through two distinct years.

Table IV-3 : measurement method of each indictor to assess the seven selected ecosystem service.

ECOSYSTEM SERVICE	INDICATOR	ASSESSMENT METHOD
Soil erosion control	Soil aggregate stability (0-5 class)	Wet sieving
Water pollution control	Potentially leaching Nitrogen (Kg $N\text{-}NO_3$/ha)	NO_3- extraction with KCl (norm ISO 14256-1)
Soil fertility	Soil organic matter degradation rate (%)	Bait Lamina test
	Soil respiration rate (mgCO2/g)	Conductimetric determination of CO2
	Sum of nutrients (g/kg)	Atomic absorption spectroscopy/spectrophotometry
Pest control	Parasitism rate (%)	Aphids and mummies counting
	Aphid abundance	Aphid counting
	Predation rate (%)	Predation aphid cards
Flood control	Soil permeability (cm/day)	Permeameter
Fodder production	Straw yield (kg/m^2)	Dry weighting
	Grain yield (kg/4m^2)	Dry weighting
Fodder quality	Protein content (%)	Infrared quality analyses
	VEM (VEM/kg)	Infrared quality analyses
	Starch (%)	Infrared quality analyses

2.3.1 Soil physico-chemical properties

Soil data was gathered to describe the agroecosystem as soil physico–chemical properties underpin ecological processes, such as soil decomposition. Additionally, this data will allow investigating the correlation between soil parameters and ES.

Soil was sampled mid-July matching with the maturity of the cereals. In each parcel, three soil composites (500g from six sampling points) were collected by means of 0-5 cm auger at a depth of 20cm. Samples were analyzed by the Provincial Center of Agriculture and Rurality. Available nutrients (P, Mg, Ca and K) were extracted with EDTA (Ethylenediaminetetraacetic acid) (Lakanen and Ervio, 1971) and their concentrations were then assessed by means of Atomic absorption spectroscopy (Mg, Ca and K) or spectrophotometry (P). The other parameters were assessed following ISO norms: pH (water & KCl): ISO 10390 (2005); Total C and N contents: ISO10694 (1995); cation exchange capacity: ISO 23470 (2007).

2.3.2 Soil erosion protection

To assess the soil resilience to erosion, soil aggregate stability was assessed through the commonly used wet-sieving method (Herrick et al. 2001, Seybold and Herrick 2001). Nine soil aggregates was collected per parcel at the end of October, when erosion problems are usually encountered. Sieves were constructed from 1.5mm mesh screens and 2cm diameter PVC tubes. Samples were rated from one to six based on a combination of ocular observations if slacking during the first 5 minutes following immersion in distilled water, and the percent remaining after five dipping cycles at the end of the 5 minutes period. Despite manual sieving and visual rating, the method has proven to provide as valuable information as laboratory estimations (including weighting scales and mechanical sieving) (Herrick et al. 2001).

2.3.3 Water pollution protection

Agroecosystems are well known to affect water quality through nitrate leaching to streams and ground water. To assess this, we measured the remaining nitrate (NO_3-) in parcels at the end of autumn (November). This nitrate will no longer be taken up by plants and which can thus possibly leach out. Three composite samples were collected through the longest diagonals of the parcel, corresponding to three depths (0-30, 30-60 and 60-90cm). Each composite was composed of 10 sample points gathered through two crossing transects. Samples were subcontracted to the 'Water Soil Plant Exchange' Research Unit of Gembloux Agro-Bio Tech (Belgium). They extracted Nitrate from the soil sample through a reaction with potassium chloride (0.1 mol/L) in accordance to the ISO 14256-1 norm. Nitrate (kg NO_3-/ha) from the three depths were summed up and values were inverted for analyses to allow interpretation in terms of service and not dis-service.

2.3.4 Soil fertility

Soil fertility is a complex function which depends on the soil organic matter decomposition rate, the soil fauna activity and the soil nutrient content.

2.3.4.1. Soil organic matter degradation rate

Mineralization of plant nutrients was assessed by means of the bait-lamina test (Kratz 1998, Römbke 2014). Sticks were bought from Terra Protecta GmbH and consist in 16cm long PVC strips with 16 2mm holes filled with cellulose, bran flakes and active coal to mimic the material degraded by soil fauna. Nine sticks were buried in the ground vertically reaching the first 15cm of the topsoil layer. Extra control sticks were buried and checked every two days. Sticks were collected 10 to 15 days later when around 50% of the control sticks have been degraded. The degradation of the bait material is associated to the feeding activity of soil invertebrates. Soil microorganisms and invertebrates consume the 'bait,' and the number of holes that are empty gives a relative measurement of the percentage of N mineralization (Knacker et al. 2003, Porter et al. 2009, Ghaley et al. 2014).

2.3.4.2. Soil fauna activity: soil respiration

From the soil composites collected for the chimico-physical soil properties, 40g was placed into hermetically sealed jars together with a solution of NaOH (0.5M) held in a separate open container. Samples were then incubated in the dark for four months and electrical conductivity of NaOH was measured three times a week with a conductimeter (HACH sensION™ + EC71). Measurements were also performed in five jars without soil to serve as control. Electrical conductivity values of NaOH samples were used to estimate the mass of emitted CO_2 with the following formula (Rodella and Saboya 1999, Critter et al. 2004):

$$m_{CO_2} = \frac{V_{NaOH} * [NaOH] * 22 * (CE_{NaOH} - CE_t - \Delta CE_{control}) * 100}{(CE_{NaOH} - CE_{Na_2CO_3}) * Wd}$$

Where m_{CO_2} is the mass of emitted CO_2 per 100 g of dry soil C ($mgCO_2$/100g dry soil), V_{NaOH} is the volume of the NaOH solution placed in the jar, $[NaOH]$ its concentration, 22 the molar mass of CO2, CE_{NaOH} the electrical conductivity of a standard NaOH solution, CE_t the electrical conductivity of the NaOH sample, $\Delta CE_{control}$ the electrical conductivity of NaOH in the control jars, $CE_{Na_2CO_3}$ the electrical conductivity of a standard Na_2CO_3 solutions and Wd is the dry weight of the soil sample (g).

2.3.4.3. Nutrient content

Soil concentrations of the four main available nutrients for plant growth (P, Mg, Ca and K) were calculated as part of the characterization of the soil physico-chemical parameters. These were then standardized and summed up to provide one soil fertility indicator as suggested by Pankaj et al. (2011).

2.3.5 Pest control

The targeted pest of the assessment is the aphid, a common pest to cereal crops (Lopes et al. 2016, Hatt et al. 2016b). In order to better understand the mechanisms behind pest abundance, two biological control processes are assessed: parasitism and predation.

2.3.5.1. Parasitism rate and aphid abundance

Juvenile and adult aphids (winged and not winged) and their mummies (parasitized aphids) were counted on twenty randomly selected plants per parcel. Counting was performed at aphid's peak-season, occurring mid-June. No aphids were found in 2016 likely due to a rainy season. Aphid abundances were then inverted for analyses to allow interpretation in terms of service and not dis-service. Parasitism rate was calculated as the ratio between parasitized aphids and the total abundance of aphids (Roschewitz et al. 2005, Lee and Heimpel 2005, Balzan and Moonen 2014).

2.3.5.2. Predation rate

Live aphids, *Sitobion avenae*, were bought from KatzBiotech AG were glued to 5*3cm sandpaper cards with odorless solvent-free glue. Three aphids were glued per card and ten cards were placed per parcel along a transect through the longest diagonal of the parcel with a minimum distance of 10m between each other and 25m from borders. Cards were collected after 24h and remaining aphids were counted. Predation rate was calculated as the ratio between eaten aphids and the total number of aphids at the start of the experiment (Östman et al. 2001, Geiger et al. 2010).

2.3.6 Flood protection

Soil hydraulic conductivity was measured on soil sampled in 53*50mm stainless steel rings. Three samples per parcel were collected end of October, when flood risks are high du to small crop cover and regular rains. Samples were first saturated with water then placed in a permeameter (Eijkelkamp 09.02.01.05), a laboratory tool creating a difference in water pressure on both ends of the sample inducing water flow through the sample ending in a millimeter burette. Hydraulic conductivity K-factor (cm/day) was determined with the formula of the constant head method (Regalado and Muñoz-Carpena 2004, Strudley et al. 2008, Nijp et al. 2017):

$$K = \frac{V.L}{A.t.h}$$

Where V is the volume of water flowing through the sample (cm3), L is the length of the soil sample (cm), A the cross-section surface of the sample (cm2), t the time used for flow through a water volume V (day) and h is the calculated water level difference inside and outside the sample cylinder.

2.3.7 Crop production

Whole plant cereals were sampled on four quadrats of $1m^2$ per parcel to assess aboveground biomass dry matter. Plants were subdivided in grains and straw, dried (60°C for 10 days) and weighed. The final yield of grain is expressed in t/ha at 15% humidity and yield of straw as t/ha dry weight. The assessment of crop production for AFS parcels includes all the plants of the intercropping mix (triticale, oats, rye, spelt, pea, and vetch).

2.3.8 Crop quality

Protein and starch content (%) were assessed with the near-infrared reflectance spectroscopy technique (Rapid Content Analyzer, XM-1100 Series). The fodder quality index ‘VEM’ is used as an indicator for the energy supply of the cereal in a context of milk production. VEM is the commonly used indicator for fodder quality in Belgium (European Grassland Federation et al. 2008). The assessment of crop quality for AFS parcels is carried out on all the plants of the intercropping mix (triticale, oats, rye, spelt, pea, and vetch).

2.4 Statistical analysis

Two distinct types of analyses were carried out: (i) multivariate analyses to depict the correlation structure of the datasets and (ii) univariate analyses with linear mixed models to test whether farming system affects the delivery of each ES. Analyses were performed in R software version 3.3.2 (R Core Team 2016). Normality was checked and log- or square-based transformations were applied to improve the normality of some variable distributions.

To control the correlation between soil parameters and system type, we performed a principal correlation analysis (PCA) followed by a constrained ordination with a redundancy analysis (RDA) (section 3.1). A second set of PCA and RDA is applied to each location depicting the correlations between ES and system type (section 3.2). Then, the percentage of the variation of ES delivery explained by system type, soil parameters and spatial coordinates is depicted using the function ‘varpart’. To test the correlation of each of these parameters to the ES dataset, we constrained the ES dataset by each of the parameters dataset (section 3.3). ANOVA on each RDA quantifies the tested relationship by means of F tests ($p<.05$). Only soil parameters significantly correlated to ES and whiche were not used for the ‘soil fertily 3’ indicator were kept for analysis. Multivariate (PCA, RDA and variance partitioning) analyses were performed using the package ‘vegan’(Oksanen 2018).

Linear mixed models were applied using the package ‘lme4’ (Bates and Maechler 2018). The farming system (AFS and CFS) was analyzed as fixed effect, while the year, the location and the parcel pairs were analyzed as random effects. Pairs were nested within location and year, since pairs of parcel change across locations and years. For each indicator, the model was constructed from the experimental variables listed above and adding interaction(s) when it changed significantly the model. This was tested by means of a Chi-square test (<0.05) using the ‘anova’ function of the ‘lme4’ package. The effect of farming system on ES delivery was tested using a F test (<0.05) on the constructed model using the package ‘car’ (Fox et al. 2018).

3 Results

This section first presents the correlation structure of the soil parameters in order to verify the correlation between soil parameters and system type. It then presents the distinction between AFS and CFS in terms of ES delivery illustrated by means of PCA. Next, the correlation structure is depicted between ES, the system type, soil parameters and spatial data. At last, results of the mixed linear models depict whether each ES is delivered significantly differently in AFS and CFS. Descriptive statistics for each ES are provided in Appendix 2.

3.1 Parcel distribution along soil data

Figure IV-3 shows the PCA biplot of the soil parameters of all parcels sampled throughout three years of sampling. Within the soil parameters dataset, soil physico-chemical parameters (excluding soil parameters used to determine the indicator ‘soil fertility 3’: P, Mg, Ca and K) and soil texture parameters are included. The first two principal components cover 90.4% of the variability of the dataset. No clear distinction between system types can be made but a distinction can be made between location ‘A’ from the sandy loam and location B and C on the loamy sand. Constraining the soil dataset by system types by means of RDA shows that soil parameters are not significantly correlated to system types ($F= 1.0443$, $p=0.316$).

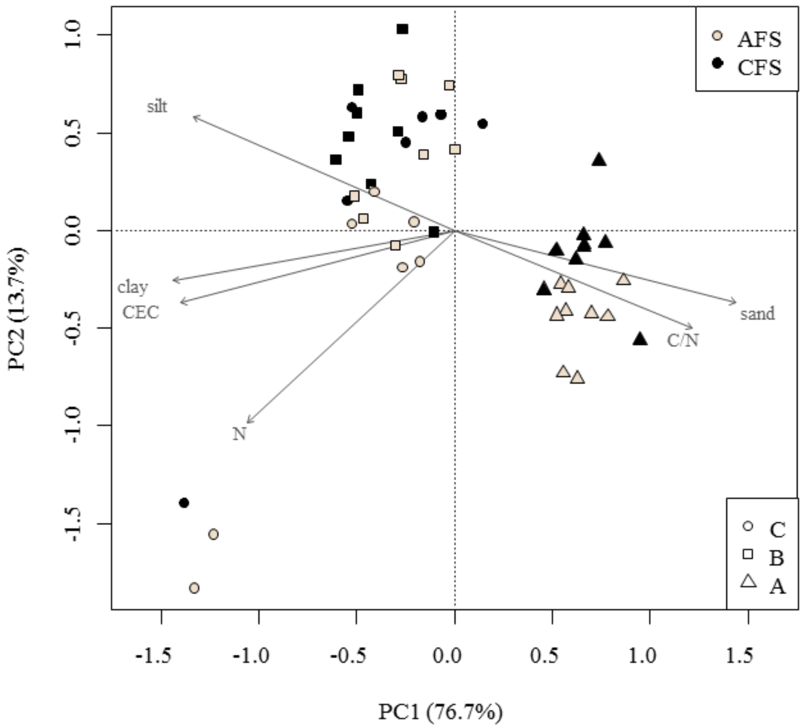


Figure IV-3 : Biplot representing sampled parcels from a PCA on soil data, physico-chemical and texture parameters. Parcels are represented according to the system they belong (white: AFS, black: CFS) and the location (A: triangle, B: square, C: circle).

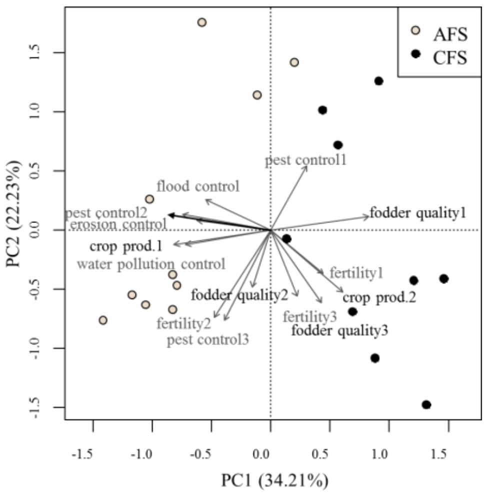
3.2 Correlation structure between ecosystem services and system types

Figure IV-4 represents the biplots of the PCAs carried out per location (A, B and C), hence integrating two years of measurements. The first two principal components of the PCA respectively explain 56.44%, 56.26% and 70.31% of the variance. PCAs distinguish, witouth being constrainted, between the two types of farming systems by their first principal component, which explain 34.21%, 39.21%, 45.56% of the variance respectively. This is confirmed by the ANOVA performed on the RDA showing significant influence of the system type (Pr>F<0.001, 0.002, <0.001 for location A, B, C respectively – Table IV-4).

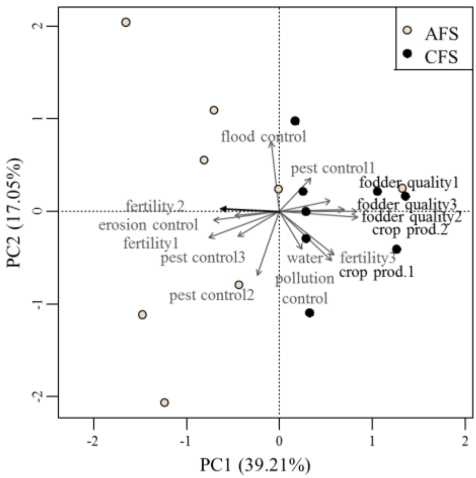
The contribution of each variable to the first axis allows detailing this main trend (Figure IV-4). AFS tend show higher regulating ES (grey) while CFS present higher provision ES (black). Two exceptions are noticed: AFS of location A performs better in terms of straw production (crop prod 1), and CFS of location B have a larger amount of soil nutrients (fertility 3). Besides this, in all locations, AFS show higher erosion control and soil respiration rates (fertility 2), while CFS always give greater grain production (crop prod 2) and protein content (fodder quality 1). In addition to these common trends, in location A, the AFS also provide more flood protection, less aphids (pest control 2), and higher protection against water pollution. In location B, the AFS provide also higher degradation of organic matter (soil fertility 1) and CFS higher straw production (crop prod.1), starch content and (fodder quality 3) VEM indices (fodder quality 2). In location C, the AFS also provides more organic matter degradation (fertility 1) while CFS perform better in starch content (fodder quality 3) and VEM indices (fodder quality 2).

The first principal component thus opposes system types and provision and regulating services illustrating a clear pattern of tradeoffs in terms of ES delivery. Grain production (crop prod.2) and protein content (fodder quality 1) are always negatively correlated to the regulating ES erosion control and soil respiration rates (fertility 2) and in location B and C, also to organic matter degradation rate (fertility 1).

A.



B.



C.

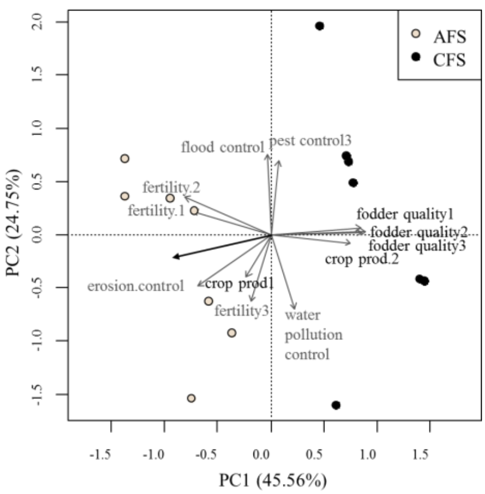


Figure IV-4 : PCA of the ES measured in location A, B and C. ES are represented as arrows (grey and black text for regulating and provisioning respectively) pointing towards the parcels (white and black dots for AFS and CFS respectively) where they reach their maximum value. The angle between the arrows is a measure for the correlation between ES, i.e. correlated ES have arrows pointing in the same direction; negatively correlated ES show arrows pointing in opposite directions; uncorrelated ES have arrows in perpendicular positions. The black arrow depicts the system variable, allowing interpretation between the ES and farming system type.

3.3 Correlation of ecosystem services with: system type, soil parameters and spatial data

RDA constraining the ES dataset with the system types shows significant correlations within the three locations (Table IV-4). RDA constraining ES with soil parameters shows significant correlation for location A and C. On the other hand, RDA constraining by the spatial coordinantes do not show significant correlation, indicating that there is no spatial correlation in the ES dataset. Proportions of the variance explained by each of these tested variables, i.e. the system type, soil parameters and spatial coordinates are summarized in Table IV-4.

Table IV-4 : Summary of proportion (%) of variance (var.) explained by the system type (syst), soil parameters and spatial coordinates (coord). Outcomes of the F tests (Pr(>F)) on the correlation of these datasets with the ES dataset for each location (A, B and C). Last four columns depict the % of variance explained by the interactions between variables.

	System (AFS - CFS)		Soil		Coordinates		syst x soil	syst x coord.	coord.x soil	syst x soil x coord.
	var. (%)	Pr(>F)	var. (%)	Pr(>F)	var. (%)	Pr(>F)	var. (%)	var. (%)	var. (%)	var. (%)
A	27.9	<.001***	27.9	0.0111 *	8.3	0.289	21.4	0	6.5	0
B	27.1	0.002 **	18.3	0.124	20.5	0.125	0	0	0	7
C	41.4	<.001***	44.4	0.0076 **	31.2	0.5	27.3	14.1	17.1	0

3.4 Effects of system types on each ecosystem service

ANOVA on the mixed linear models of each indicator details which ES is provided significantly differently between system types (Table IV-5). More precisely, soil aggregate stability, soil respiration rates are in general more supported in AFS ($F=18.3$, $p=0.043$; $F=74.5$, $p<.001$) which also show less aphid abundance ($F=25.8$, $p<.001$). On the other hand, CFS show higher grain production ($F=141.60$, $p<.001$) and higher performance for fodder two out of three quality indices: protein content and VEM ($F=125$, $p<.001$; $F=11.2$, $p<.01$).

Table IV-5 : Summary table of the F tests (column 2) applied each indicator model and its resulting p-value (column 3). Column 4 depicts whether AFS (agroeclogical farming systems) performed higher (>) or lower (<) than CFS (conventional farming systems), the amount of '>' symbol illustrating the power of the levels of significance, dark grey illustrating cases where AFS perform significantly lower than CFS and light grey when AFS perform significantly higher than CFS.

ECOSYSTEM SERVICE	INDICATOR	F	Pr(>F)	Outcomes
Erosion control	Soil aggregate stability (0-5 class)	18.3	0.0433	AFS > CFS
Water pollution control	Potentially leaching Nitrogen (Kg N-NO_3/ha)	1.34	0.258	AFS = CFS
Fertility 1	Soil organic matter degradation rate (%)	1.9	0.302	AFS = CFS
Fertility 2	Soil respiration rate (mgCO2/g)	74.5	<.001	AFS>>>CFS
Fertility 3	Sum of nutrients (g/kg)	0.004	0.9489	AFS = CFS
Pest control 1	Parasitism rate (%)	0.302	0.592	AFS = CFS
Pest control 2	Aphid abundance	25.8	<.001	AFS>>>CFS
Pest control 3	Predation rate (%)	0.12	0.731	AFS = CFS
Flood control	Soil permeability (cm/day)	0.552	0.459	AFS = CFS
Crop production 1	Straw yield (kg/m^2)	0.01	0.93	AFS = CFS
Crop production 2	Grain yield (kg/4m^2)	141	<.001	AFS<<<CFS
Fodder quality 1	Protein content (%)	125	<.001	AFS<<<CFS

Fodder quality 2	VEM (VEM/kg)	11.2	<.01	AFS<<CFS
Fodder quality 3	Starch (%)	5.8	0.138	AFS = CFS

4 Discussion

This section first discusses the hypothesis that AFS offer greater ES synergies in the light of our results. We then delineate the limitations of the present work to offer transparency on the research process. We then conclude with perspective for future work and recommendations based on our lessons learned and in regards to the limitations depicted.

4.1 The potential of AFS to deliver ES synergies

Our study shows that AFS tend to perform better in providing regulating ES while CFS deliver greater amount of provisioning ES, a result depicted by both the mixed linear models and PCA. The PCA of the three locations all showed the same pattern with the first principal component representing most of the variance and distinguishing between farming system types. Interestingly, these differences stand out despite the three different locations studied (including location A on a distinct soil type), the replication spread along three sampling years and the different technical histories of the parcels. The RDA showed that soil parameters also significantly influence the ES delivery, but the variation partitioning indicated that this variation was only partially overlapping with the variation induced by the system type. Hence, we can confidently conclude that, over the studied time period and according to the chosen indicators, our studied AFS have a clear impact on the delivery of ES, favoring regulating services while studied CFS still outperform for provisioning ES.

As cereal crops have been shown to have the greatest yield difference of all crop types between organic and conventional systems (Ponisio et al. 2014), our results are likely to depict a maximum difference in terms of yield. Moreover, the three studied AFS keep on evolving, constantly adapting, and do not represent 100% mature systems. It is possible that with time, adaptive management help bridging this yield gap (Sayer et al. 2013, Hodbod et al. 2016).

Yield and provisioning ES in general have always been the focus of agricultural work and research (Lobell et al. 2009, Ponisio et al. 2014). However, taking yield as the only measure of success is no longer pertinent as high yields come at the cost of destroying ecological processes which in turn impacts crop growth and productivity. Yield is only one factor among many others which determines the management's performance (Rapidel et al. 2015, Ponisio and Kremen 2016). The studied AFS are viable economically, and thanks to the lower amount of work required in the field (no spraying, less tillage, etc.), they 'unlock time for extra financial activities such as making transformed products, organizing school visits, etc.'(AFS farmer's personal comment).

Examples of agricultural practices successfully achieving synergies between regulating and provisioning ES exist. Robertson et al. (2014) report from 25 years of experimentation and observation of no-till, reduced input and organic systems which provide high yields and water pollution control, pest control and biodiversity support. Literature reviews of Garbach et al. (2017) and Kremen and Miles (2012c) both conclude that it is possible to design 'win-win' systems that are equally productive and that maintain or enhance other ES.

Despite these encouraging examples, we should acknowledge that it may not be possible to always achieve high levels of ES delivery everywhere. Recent work corroborates our finding by identifying tradeoffs between ES. Holt et al. (2016) show that pesticides mitigation measures may have serious impact of food production, despite enhancement of other ES. Polasky et al. (2011) identify that their scenario which maximizes the highest private returns has the lowest net social benefit. Together with these findings, our results illustrate the importance of taking ES bundles into account in land use decisions. Land-management decisions should identify potential synergies and tradeoffs across the landscape and adapt accordingly.

As agroecology is about adapting the system to its environment, prior analysis of the potential of ES delivery and synergies is a crucial preliminary step to any land-management decisions. Due to the context-specificity of agroecology, and because systems are in different evolving states of the transition, it is therefore not surprising that research reports distinct outcomes in terms of performance and ES delivery. AFS are hardly comparable: while in some locations AFS may be able to provide ES synergies, others may present tradeoffs requiring compromises in the design of agroecological farming practices (Gagic et al. 2017).

4.2 Limitations of the study

Some of the characteristics of the present study also underpin some limitations to keep in mind. The limited geographical scope hampers the extrapolation of our results to other farming systems and other regions. The three studied farms are nowhere comparable to standard, nor organic, farming systems in Belgium. These represent 'niche examples'. Studying real-life examples as done in the present research has the advantages to provide with information on systems which have adapted to their socio-environment. As agroecology is about adapting to its socio-ecological context, it is likely that what works at one place may not work somewhere else (Holt et al. 2016). Hence, local scale ES assessments of agroecosystem performance are believed to be more relevant to provide with context-specific practical guidelines (Polasky et al. 2011, Landis 2017).

between the different agricultural (organic, no till, intercropping, green infrastructures) practices implemented by the studied AFS, and it is unclear whether the outcomes of the present work are due to one specific practice or to the agroecological combination of these practices. The lower abundance of aphids in AFS, for instance, may be due to the intercopping practice as attested by the literature (known as ‘the resource concentration hypothesis’ (Root 1973, Lopes et al. 2016)(Root 1973)(Root 1973), more than to the AFS itself.

The short time frame of our assessment, and the ‘snapshot’ approach (i.e. measurements are done only once a year, through three years) also calls for precaution in the interpretation of our results. Agroecosystems involve ecological processes, functions and services which follow non-linear trends within and throughout years (Landis 2017) and some variations may have been missed within the present work. Previous work has highlighted how ecological processes can respond differently in the short and in the long term (Knapp et al. 2012, Hamilton 2015). Our snapshot approach proves already useful to highlight trends in ES delivery between AFS and CFS. However, long term repetitions would be required to develop a thorough understanding of opportunities and consequences of agroecological transitions and deliver management guidelines.

The choice of ES, indicators and measurements methods of course influence outcomes of the research. We have tempted to be as transparent as possible on the process by involving stakeholders in ES prioritization and by relying on multiple indicators per ES. In our case, the only benefits measured directly are the quantity and quality of the crops. The other indicators all refer either to the state of the ecosystem (soil data, aphid abundance) or ecological processes and functions (decomposition, ecological interaction, weathering/erosion and nutrient cycling). Our indicators are thus mostly only informing indirectly on the flow of ES and benefits, and rather inform on the ecosystem capacity to provide ES.

4.3 Perspective and recommendations

Our work suggests that having several indicators per service may provide a more nuanced estimation of the ES flow. Pest control for instance, seems to be higher in AFS when looking at aphids abundance, although this would not have been put forward if relying on parasitism or predation estimations only, as done in earlier work (e.g. Porter et al. 2009, Sandhu et al. 2010). The same applies to our estimation of soil fertility, where, soil organic matter degradation rate and the amount of available nutrients did not show any difference between system types while respiration rates were significantly different. This is even more concerning when comparing degradation with respiration as these rely on the same ecological processes. The different outcome is likely due to the degradation being assessed *in situ*, thus constrained by weather and other environmental limitations and respiration being assessed *ex situ* with controlled parameters. Hence, we support Meyer et al. (2015) and advocate that ES assessments should span a range of functions per service to represent the overall functioning and lower the risk of methodological bias. When possible, *in situ* measurements should be preferred as these represent a more direct measurement, while ex situ measurements are more likely to reflect the potential of the ecosystem to provide the assessed process, function or service.

While the choice of indicators showed to influence the outcomes of the research, it is also to keep in mind that the ES tool itself frames the prism of analysis. Despite offering a multidimensional approach, the ES tool does not, and could not, cover all aspects. In terms of system performance, the ES 'yield' should not only be combined to other ES, but also to indicators such as the economic gross margin, the workload required etc, which are indicators directly influencing the decision making of farmers. Within intercropping systems, yield indicators should be replaced by 'Land Equivalent Ratio' calculations (Mead and Willey 1980, Loïc et al. 2018) which was however impossible to implement within the present study due to a lack of data on each species yield.

While the present research offers a first snapshot of the potential of AFS to delivery ES synergies, further research is required to better understand the underlying relationships between practices, ecological processes and functions and ES flows. More collaboration should take place between multidisciplinary approach as the present study with more disciplinary studies focusing on one practice at a time an how it affects the ES cascade, as well as on how practices interact to provide associated synergies or tradeoffs.

As suggested by Dendoncker et al. (2018a), to steer agroecological transition, the assessment of supply and demand of ES must be embedded within a wider framework which also includes the identification of plausible evolutions of the system, the selection of the most acceptable pathways of change and the implementation of the selected scenario. This whole process should itself be iterative as ES follow nonlinear responses and as stakeholder needs and perceptions may vary over time (Baker et al. 2013, Dendoncker et al. 2018a). Such iterative approach would strengthen the currently limited timeframe of our study. We thus encourage further research to carry out long term and iterative monitoring of agricultural transitions.

5 Conclusion

This paper expands nascent work assessing multiple ES simultaneously in farming systems alternative to the currently dominant resource intensive system. It provides the novelty to assess multiple stakeholder-relevant ES and their interactions in real-life agroecological farming systems. It answers the call for system-based, holistic assessments of agroecological transition to provide knowledge adapted to a specific socio-ecological context.

Our studied AFS answer the expectations of meeting higher regulating ES delivery. However, they do not perform (yet) as well as CFS in terms of provisioning ES. This productivity gap is possibly due to the still evolving nature of the studied AFS. While there is a consensus on the necessity to conciliate agricultural production with ecological functions, too little evidence exists to support the design of concrete guidelines on land management. To do so, we encourage further research to iterate the work initiated by this study, relying on multiple indicators for each ES, and to embed it in a stakeholders-inclusive approach, offering farmers with a science-practice partnership that enables co-generation of solutions. As it is likely that what works at one place may not work elsewhere, such research ought to be site-specific to provide context-specific solutions. We believe that such systematic analysis of the socio-agroecosystem will be of great contribution to the striking need to reconcile environment functioning and agricultural production. In a world where many planetary boundaries have been crossed, such reconciliation is more urgent than ever.

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Chapter V

REFLEXIVE ANALYSIS

The use of integrated ES valuation to understand agroecological transition

Abstract

The tool of integrated ES valuation is attracting growing interest within the research community (Boeraeve et al. 2015, Jacobs et al. 2016, Barton et al. 2017, Dunford et al. 2018). Integrated ES assessment if defined as “the process of synthesizing relevant sources of knowledge and information to elicit the various ways in which people conceptualize and appraise ES values, resulting in different valuation frames that are the basis for informed deliberation, agreement and decision” (Gómez-Baggethun et al. 2014). By explicitly acknowledging multiple value domains and worldviews, the framework aims at societal rather than only academic impact. Despite this ambition to support decision making, the concept has primarily focused on theoretical discourses, such as the establishment of ES valuation frameworks (Haines-Young and Potschin 2010, Spangenberg et al. 2014, Díaz et al. 2015) and typologies and definitions (de Groot et al. 2002, Pascual 2017, Maes et al. 2018). Assessment of how ES valuation outcomes are used, and of the valuation process itself, is barely addressed which constraints our ability to learn from experiences of applications (McKenzie et al. 2014). Reflexivity is still a missing cornerstone in ES valuation research (Jacobds et al. 2016). Reflexivity allows the researcher to locate himself in the research process, track down how knowledge is constructed and disentangle the background assumptions and normative orientations (Jacobs et al. 2016).

This chapter aims at bringing a critical look at the research process of the present PhD thesis. As reflexive work of integrated ES valuation is little documented, the present chapter relies on the wide literature body of participatory and transdisciplinary science. Transdisciplinary science indeed shares the same objectives as integrated ES valuation (Hauck et al. 2016). The objective of transdisciplinary research, as definied by Pohl et al. (2011) indeed corroborates the ones of integrated ES valuations: (i) grasping the complexity of the issue, (ii) taking the diverse perspectives on the issue into account, (iii) linking abstract and case-specific knowledge and (iv) developing descriptive, normative, and practical knowledge that promotes what is perceived to be the common good.

This chapter first conducts a reflexive work on the participatory ES identification and selection (section 1) using mainly the literature of participatory science. It then quickly reviews the limitation of the socio-cultural valuation (section 2). Next, it explores some reflection on the biophysical ES assessment, and more specifically on the choice and use of indicators and the measurement methods (section 3). At last, section 4 undertakes a general reflection on the research process as a whole, the challenges faced and how the tool succeeded in answering the sub-research questions.

1. Refection on the participatory identification and selection of ecosystem services

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Participatory identification and selection of ecosystem services: building on field experiences

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Abstract

The concept of ecosystem services (ESs) has become a popular tool for science that aims to support decision making for sustainable management of natural resources. With the aim to integrate nature's diverse values in decisions and to reach effective actions, it is recommended that valuations begin with a participatory identification of the most relevant ESs to be included in the assessment. Despite being a crucial step directly influencing decision making, experiences of researchers with real-life applications are seldom reported. Our aim is to advance the organization and implementation of participatory ES identification and selection by providing a self-reflective description and discussion of 5 case studies (CSs). A self-evaluation workshop was organized among the researchers involved in the CSs to gather factors of success and failure encountered throughout the process. From this reflection, we suggest a list of 11 recommendations. We use a wide range of the literature on participatory research evaluation to guide our reflection and demonstrate the relevance of participatory science to the field of ESs. Reflexivity proved to be an essential aspect of sharing lessons learned and advancing methodology toward real-life impact.

Keywords: ecosystem services; integrated ecosystem service valuation; natural resource management; participatory; transdisciplinary

1.1. Introduction

The ecosystem service (ES) concept has been increasingly advocated for inclusion in decision support tools related to natural resource management (e.g., Bryan et al. 2010, Ernstson 2013, Schaefer et al. 2015). Defined as the benefits humans obtain from nature, the ES concept clarifies how ecosystems contribute to human well-being (Reyers et al. 2013, Abson et al. 2014, Spangenberg et al. 2014). Notwithstanding this assumed potential, the ES concept is scarcely documented as being implemented in decisions (Cowling et al. 2008, Laurans et al. 2013, Förster et al. 2015, Guerry et al. 2015, Polasky et al. 2015). Only a minority of ES assessments specifically report outcomes in decision-making processes (e.g., MacDonald et al. 2014, Arkema et al. 2015, Ouyang et al. 2016). Based on the analysis of several case studies (CSs), some attempts have been made to provide a framework for conducting decision-relevant ES assessments (Nahlik et al. 2012, Rosenthal et al. 2015), share lessons learned (Ruckelshaus et al. 2015), or identify factors in ES assessments that impact decision making (Carpenter et al. 2009, Posner et al. 2016, Grêt-Regamey et al. 2017).

From this emerging and growing body of literature, some conclusions arise. All agree on the importance of including stakeholders at the outset of the ES assessment to define what kind of ES information is needed. Recent work suggests the use of "integrated ES valuation" as a conceptual framework for sustainable natural resource management. Integrated valuations combine ecological, socio-cultural, and economic valuation as tools used in a participatory way to elicit the plurality of values related to ESs, including the intrinsic and relational values that go beyond strict "benefits for humans" (Díaz et al. 2015, Kelemen et al. 2015, Pascual et al. 2017). This integrated approach explicitly aims to include multiple values and worldviews in a coherent and operational framework, aiming at societal rather than only academic impact. It requires collaboration with stakeholders in on-the-ground realities to perform quantitative or qualitative assessment of these values, to increase the effectiveness and legitimacy of decision making (Dendoncker et al. 2013, Raymond et al. 2014, Spangenberg et al. 2014). In doing this, integrated valuation inevitably deals with postnormal science issues such as power relations, science-society interfaces, and the contextual and normative framing of each valuation exercise (Jacobs et al. 2016).

Within this integrated approach, the identification and selection of ESs are critical steps that directly influence the relevance to decision making. The identification and selection of ESs occur in the first ("scoping") phase of the valuation. They interact in an iterative process, where stakeholders (re)define the problem and information needs relevant to the context (Chan et al. 2012, Spangenberg et al. 2015). Identifying context-relevant ESs guides ES assessments toward specific natural resource management issues. As ecological processes only become ESs when someone values them or benefits from them, identifying ESs involves subjective judgments (Förster et al. 2015). To capture these judgments, it is thus critical to involve multiple knowledge sources by including stakeholders in the process of identifying and prioritizing ESs.

However, most of the time, researchers perform ES identification based on data/model availability or literature reviews, which ignores the socio-cultural context in which the project takes place (Chan et al. 2012, Malinga et al. 2013, Mascarenhas et al. 2016). This leads to blind spots of potentially important ESs and associated values, as well as bias toward other ESs or values, ignoring the diversity in ES benefits and information needs for stakeholders (Opdam et al. 2013, Kenter et al. 2015).

Participatory ES selections have been implemented within ES valuations (e.g., Bryan et al. 2010, Fontaine et al. 2013, Martínez-Sastre et al. 2017) but are rarely explicitly detailed and discussed (Malinga et al. 2013, Mascarenhas et al. 2016). Hence, scientists lack guidelines on how to carry out ES identification and selection (Burkhard et al. 2010). As the impact of selection on the relevance of valuation and decision outcomes is clear (Förster et al. 2015), there is a need for more reflexive research presenting organizational and personal learned lessons (Jacobs et al. 2016).

To address this, we evaluate the process of five participatory ES identification and selection processes that all fit within on-the-ground ES-based natural resource management projects in Belgium. We use existing literature on the evaluation of participatory research in general, not specifically embedded in ES assessments, to guide our evaluation. The bulk of the literature that addresses the evaluation of participatory research in the context of decision making is considerable as it includes several research fields. Among others, it includes research about transdisciplinary research in decision making (Klein 2008, Jahn and Keil 2015, Vilsmaier et al. 2015), participatory research in sustainability science or natural resource management (Blackstock et al. 2007, van der Wal et al. 2014, Wiek et al. 2014), public participation (Rowe and Frewer 2000, Grant and Curtis 2004), participatory planning processes (Hassenforder et al. 2016), collaborative management (Conley and Moote 2003), and participatory action research (Mackenzie et al. 2012). This literature provides a good basis to identify potentially relevant approaches to the evaluation of participatory ES identification and selection.

More specifically, we use the frameworks of Hassenforder et al. (2016) and Blackstock et al. (2007) to structure our work. These frameworks are designed to evaluate participatory planning projects and participatory research, respectively. The first is based on a comprehensive literature review and has been endorsed by other research (Triste et al. 2014, Jahn and Keil 2015), and the latter offers a detailed approach to frame the evaluation and a list of evaluation criteria based on a review of the literature.

We examine the CSs in a reflexive way, i.e., an explicit and structured self-evaluation. Reflexivity goes beyond the rigidity of checklists and evaluation criteria of normal science and acknowledges scientific uncertainties by allowing researchers to situate themselves in the research process and make them aware of the implicit assumptions and normative orientations that shape their decisions (Finlay 2002, Jacobs et al. 2016). Reflexive approaches are increasingly endorsed by the transdisciplinary and postnormal research communities (Stige et al. 2009, Jahn and Keil 2015, Popa et al. 2015). Following Funtowicz and Ravetz (1994), several authors suggest such postnormal posture is well adapted to the highly dynamic, complex, and unpredictable nature of social-ecological systems in which the management deals with uncertain facts, values in dispute, and high stakes (Wondolleck and Yaffee 2000, Regan et al. 2005, Barnaud and Antona 2014, Fontaine et al. 2013).

Our aim is thus twofold. First, in the *Results*, we share our experience of implementing participatory ES identification and selection. Adopting a reflexive posture, we draw recommendations from identified issues of success and barriers that facilitated or hampered effective implementation. Second, we discuss to what extent our findings corroborate existing guidelines from participatory literature. Such reflection aims to provide insights on the use of existing knowledge in participatory science in the specific case of participatory ES identification and selection. In doing so, we hope to contribute to answering the need to collect feedbacks on participatory ES identification and selection processes in a structured and reflexive way (Malinga et al. 2013, Mascarenhas et al. 2016).

1.2. Methods

To evaluate the process of participatory ES identification and selection in our five CSs, we adopt a reflexive position structured by the frameworks of Hassenforder et al. (2016) and of Blackstock et al. (2007). These are designed for the evaluation of participatory planning projects and participatory research, respectively. As Hassenforder et al. (2016) suggest, we have structured the *Methods* around the following phases:

- Description of the CSs using the descriptive variables of context, process, and outcomes.
- Framing of the evaluation, following Blackstock et al. (2007), by delineating the objective, timing, purpose, and focus of the evaluation.
- Description of the evaluation procedure.

To avoid confusion between terms, Box 1 presents some definitions of terms we have used.

Box 1: Glossary. Many terms are used interchangeably in the literature. We make explicit the meaning of the terms we have used.

<u>Ecosystem service (ES) valuation:</u> assignment of values to ESs.

<u>Participatory exercise:</u> participatory identification and selection of ESs that took place within the five case studies (CSs).

<u>Stakeholders</u>: any groups or individuals that can affect or are affected by ESs.

<u>Participants</u>: stakeholders who have been included in the participatory exercise.

<u>Project coordinator</u>: the person who initiated and is in charge of the project in which the participatory exercise took place. For CS 1, project coordinators and CS researchers are the same individuals.

<u>Self-evaluation</u>: our reflexive analysis of the five CSs.

<u>Self-evaluation workshop</u>: workshop among CS researchers to self-evaluate the organization and implementation of the participatory exercise.

<u>CS researchers:</u> researchers in charge of the organization and facilitation of the five participatory exercises we studied. CS researchers are the participants of the self-evaluation workshop and are coauthors.

1.2.4. Description of the case studies

The five CSs were identified through the Belgium Ecosystems and Society community (Belgian Biodiversity Platform 2017). A more detailed presentation of the CSs is available in Appendix 3 and is summarized in Table V-1. The selection criteria were (1) to be an ES-related project or research, (2) to have taken place in Belgium, and (3) to have implemented a participatory ES identification and selection that (4) followed a similar procedure (Table V-2) and was (5) facilitated by researchers ("CS researchers"). The procedure followed by the five CSs detailed in Table V-2 is a rather common methodology relied on for participatory ES selection. It includes an individual then a collective scoring process (Table V-2) and has the advantage of being low resource demanding and easily interpretable thanks to the scoring approach. The five CSs were run independently with no or few interactions between the CS researchers. Their selection for this self-evaluation took place after they implemented the participatory ES identification and selection.

Table V-1 : Summary of the five cases studied through the self-evaluation. CS=Case study.

CS	Title	Context	Process			Outcomes of application
			Objective and scope	Rationale for a participatory approach	Participants	
1	The contribution of agroecological farming systems to the delivery of ecosystem services	In the western part of the Hainaut Province in Belgium, a dynamic network of farmers is applying innovative agroecological practices	Use these real-life examples of 'agroecologization' to quantify the contribution of agroecological systems to the delivery of ES	participatory ES identification & selection was implemented to prioritize relevant ES for local conditions and for local actors	Local ES providers and beneficiaries: local farmers, local citizens, local environmental associations, etc., identified through snowball sampling	ES identified during the participatory exercise guided the selection of ES to be quantified during the research
2	Optimizing ES delivery through land consolidation	The new 'Walloon Code of Agriculture' requires land-consolidation plans to consider multifunctionality and therefore needs a methodology for impact assessment based on integrated ES assessment	Test and apply a participatory methodology to optimize ES provision through land consolidation	A participatory ES assessment was necessary to increase the legitimacy and saliency of the process	Local ES providers and beneficiaries: decision makers, farmers, local citizens, environmental associations, etc. all identified through a stakeholder analysis	ES identified during the participatory exercise guided the selection of ES to be quantified during the research

3	Development of an inclusive vision for multifunctional a landscape in a rural river valley	The Province of East Flanders asked researchers to assist in developing a multifunctional vision for a rural river valley currently facing issues of flooding and erosion	Inventory and value diverse uses, synergies and trade-offs by diverse stakeholders	A full overview of the issues at stake is a requirement for a vision to be legitimate, credible and acceptable	Administrations, water experts, municipality representatives, farmers, citizens, environmental associations, etc.	ES identified informed the participatory planning and vision process. The workshop also checked ES impact of landscape and infrastructure designs
4	Exploring ES potential in the river valley of Stiemerbeek	The city of Genk asked for support in the development of the river Stiemerbeek to become a strong green-blue artery which can increase the recreational and life-quality	Develop a shared vision for the Stiemerbeek valley and build up ES-related expertise for the city of Genk (capacity building)	To establish a stronger interdisciplinary approach (amongst multiple sectoral administrations)	Multiple sectoral administrations in Genk (e.g. spatial planning, sustainable development and environment, social issues, sport, tourism and cultural issues, mobility, etc.) and also some external stakeholders	Participants more familiar with the project area, the challenges the multi-functionality of the river valley. Results were appended to the Open Call for the design of a Green-Blue Public Park
5	Multi-stakeholder vision development for a mixed landscape with high natural values	The area ‘De Wijers’ in north-east Belgium and has great potential in terms of biodiversity, tourism, residential living, and business; but this potential was not fully utilized	The Provincial Government asked the Flemish Land Agency (VLM) to develop - together with all relevant stakeholders - a coherent and widely supported vision	To build a broadly-supported vision it was considered essential to organize an inclusive participatory process	Government agencies, municipalities, NGOs, private entrepreneurs, staff of the coordinating organization and researchers. It was more difficult to mobilize the industry and the social sector	ES were identified together with their rationale. Social learning, understanding and trust, and networking were enabled. The results of the workshop were synthesized

						in a vision report

Table V-2 : Steps followed by the five case studies for their participatory ecosystem service (ES) identification and selection. After defining the objective (step 1), the five case studies (CSs) carried out an ES preidentification (step 2), which was (re-) submitted to participants during the participatory exercise of ES selection for adjustment and validation (step 4). Participants were then asked to score ESs based on this commonly defined list (step 5). After a presentation of the outcomes (step 6), a second consultation was carried out to obtain consent (step 7).

STEPS		CS 1	CS 2	CS 3	CS 4	CS 5
Prior to the participatory exercise of ES selection	**1. Definition of the CS participatory exercise objectives**	Defined by CS-researchers	Co-defined by project coordinators and CS-researchers			
	2. ES pre-identification	By CS-researchers based on assumption of relevance according to the study context and objectives		Proposed jointly by participants, project coordinators and CS-researchers		Proposed by CS-researchers and project coordinators
During the participatory exercise of ES selection	**3. Presentation to participants of: the research project, its objectives and those of the participatory exercise**	By CS-researchers		By project coordinators		
	4. Adjustment and validation by participants of the pre-identified ES	Participants validated and adapted ES list				
	5. Scoring by participants of the most important ES based on the final ES identification	Assignment of a score (0-5) to the 5 most important ES		Assignment of 5 nominal scores (unimportant - essential)		Assignment of 4 scores (-1, 1, 2, 3)
	6. Presentation of the results to the whole group and discussion about the divergences and convergences of opinions	Presentation of average rank attributed to each ES		Presentation of median score and variance of each ES		Presentation of all scores in tabular form
	7. Second consultation of participants	Participants did not wish to amend their initial rank	Consent-based scoring of the 5 most important ES	Consent-based scoring of the most important and most contested ES in small groups		Consent-based hierarchy of ES per ecosystem in small groups

1.2.5. Framing our self-evaluation

A reflexive analysis is an explicit, self-aware meta-analysis (Finlay 2002) focusing on the process (Jahn and Keil 2015). As reflexive evaluation is subjective by definition (Finlay 2002), it needs to be clearly framed to be reliable, explicit, and transparent (Triste et al. 2014, Hassenforder et al. 2016). To frame our self-evaluation, we rely on the framing approach of Blackstock et al. (2007), which depicts the objective, timing, purpose, and focus of the self-evaluation:

1. The general objective of our self-evaluation is to provide a reflexive analysis of five CSs, which include participatory ES identification and selection.
2. Our self-evaluation timing fits within the Blackstock et al. (2007) category of “process evaluation” as it occurs while projects are still ongoing and focuses on the operation of the participatory exercise in order to build on strengths. Thus, we focus on how the outcome is produced rather than on the outcome itself, i.e., the selected ES for each CS.
3. Blackstock et al. (2007) identify four types of purpose for self-evaluation. We locate our self-evaluation purposes in the categories of “controlling” and “improving” as we suggest a reflection on the quality process of participatory exercises to provide guidance for future work to improve and reach their objectives.
4. The focus of a self-evaluation can either be strategic, i.e., investigates the achievement of the intended results, or operational, i.e., focuses on quality of the planned activities. The focus of our self-evaluation is operational as our aim is to provide a reflection on the process of the organization and implementation rather than on the outcomes.

1.2.6. Self-evaluation procedure

Our self-evaluation follows a qualitative approach based on a reflexive analysis. We are thus the evaluators and the researchers who took part in the organization and implementation of the participatory ES identification and selection (hereafter “CS researchers”). Each of the CS researchers was responsible for one of the five CSs. To guide the self-evaluation work, we organized a reflexive workshop among the CS researchers that took place after the implementation of the participatory exercises. We distinguish the “participatory exercises,” which are the participatory ES identification and selection that took place within the CSs, and the “self-evaluation workshop,” which is the evaluation workshop for the CS researchers that took place a posteriori (Box 1).

During the first step of the self-evaluation workshop, CS researchers gathered and wrote down personal experiences of success or barriers encountered during the preparation and implementation of their participatory exercise. In plenary, CS researchers explained and discussed their issues. We then mapped these onto the evaluation criteria for participatory research from the literature review of Blackstock et al. (2007) to structure the outcomes into larger clusters. In a second step, the CS researchers went through all the identified issues and assigned scores to indicate whether the issue also applied to their personal experience in their CSs: score 1 (true) or 0 (false). This last scoring provided an overview of the most frequently mentioned successes and barriers, which were then reformulated into recommendations.

1.3. Results

CS researchers brought up 68 different issues (of success “+” or barriers “-”, Table V-3) during the self-evaluation workshop. The issues were then mapped onto the criteria of Blackstock et al. (2007). Out of the 22 Blackstock criteria, 4 were considered redundant or nonapplicable to our CSs. The criteria framework suggested by Blackstock et al. (2007) proved to be well suited because only a minority of their criteria did not fit any of our issues. It helped us to structure our views by merging or grouping some converging issues.

The two-step procedure followed during the self-evaluation workshop distinguished between issues mentioned spontaneously and independently (Table V-3, column 3) and issues acknowledged to be applicable to other cases (Table V-3, column 4). Overall, a majority of positive experiences were reported (60% in step 1 and 70% in step 2). Only 30% of the issues raised are CS specific, whereas the other 70% are general issues relevant to several or all studies. This majority of experiences shared through 5 independent CSs highlight the importance of sharing lessons learned.

By reflexively identifying issues of success and barriers, we gathered 11 recommendations. The recommendations are listed and detailed subsequently. In brackets, we indicate how many of the 5 CSs are concerned in the issue discussed (also in Table V-3, column 4).

Table V-3 : Issues raised at the self-evaluation workshop among case study (CS) researchers (column 2) and mapped onto the Blackstock et al. (2007) criteria (column 1). The symbol in brackets indicates whether the issue refers to a success (+) or a barrier (-). Column 3 indicates how many CS researchers spontaneously considered that issue. Column 4 shows to how many CS researchers the issue applies, i.e., the number of CSs that shared the same issue (maximum = 5).

Blackstock et al. (2007) criteria	**Issues**	**Step 1**	**Step 2**
Access to Resources	Instant compilation of votes was complicated and led to some mistakes (-)	1	2
	Limited time available (-)	2	3
	Participatory exercise preparation is labor and time intensive (-)	1	3
Capacity Building	Accessibility/easiness of method and activities for participants (+)	2	4
Capacity to influence	Variable knowledge and understanding of participants (-)	4	5
	Some "powerful" participants dominated the discussions (-)	1	2
	Including everyone and making everyone express their opinion is difficult (-)	2	2

Capacity to participate	Satisfactory attendance of participants (+)	1	5
	Participants willing to discuss and negotiate, constructive atmosphere, trust (+)	1	3
	The process was considered to be a new, original way of working (+)	1	4
Champion/leadership	Project leader and facilitator was a distinct person or accompanied by an outsider (+)	1	5
	Enthusiastic engagement of some typically less engaged stakeholders (+)	1	3
	Locally trusted organization mandated the participatory exercise which added trust and increased engagement (+)	3	5
Conflict resolution	Polarization between participants due to a heterogeneous group (-)	1	2
	Increased exchanges, social learning and networking due to heterogeneous group (+)	1	5
	Participants were asked to explain their reasons and not to just agree or disagree (+)	1	5
	No conflict, overall consensus, led to acceptability of results (+)	1	5
	Participants were asked to formulate suggestions that would also benefit at least some of the other participants and not negatively affect any of the others (+)	1	2
Context	Legal context legitimizing the initiative (+)	1	1
	Opportunities for many ES synergies (+)	1	4
	Diverging initial objectives among the organizers (-)	1	2
	No political concerns addressed increased personal exchanges (+)	1	3
	Good timing with regard to the context (+)	2	4
Cost effectiveness	Low implementation costs (+)	1	4
	Setting commonly-agreed objectives in a participatory way requires sufficient time and resources for consultation and interaction (-)	1	5
Develop a shared vision and goals	False expectation of participants due to communication made by different organizers (-)	1	1
	Participants did not take part in goal setting (-)	1	3
	Difficult to share an agreed vision with stakeholders not present at the participatory exercise (-)	1	1
	Discussing in terms of desired future(s) results in a positive dialogue and is less threatening (+)	2	2
	Focusing on desired futures can make present actions less concrete (-)	1	1
	Participative exercises helped to build a common ground (+)	1	5
	The group reached agreement despite its heterogeneity (+)	1	4
	Co-design of participatory exercises by parties with different expertise improved their success rate (+)	1	4

Emergent knowledge	Outcomes of the participative exercise not directly implementable in the project (-)	4	4
	Scientific ES list and 'ES' identified by participants were complementary (+)	4	5
	Discussions next to the ranking were rich in information which is though difficult to grasp (-)	1	3
Legitimacy	Resistance to the broader project itself (-)	1	2
	Legitimacy enhanced thanks to collaboration with local partners who have already gained the credibility (+)	1	4
	Strong official mandate from upper hierarchy (+)	3	4
Opportunity to influence	Available skills for participatory process guidance (+)	1	4
	High quality facilitators of small groups compensates the power imbalance between stakeholders (+)	1	5
	Invitation to participants for a follow up of the research/project (+)	1	4
	Consultation started at the beginning of the project (+)	1	4
	Participants felt involved and useful as their prioritization was going to guide the subsequent steps of the project (+)	2	5
	Participants felt less involved as the main goal of the participatory exercise was to serve the research/project, not them directly (-)	1	1
	Working in small groups helped to reduce the effect of domination among participants (+)	1	3
	Chances to contribute to the project/research was appropriate (+)	1	5
	Organizing in the physical context/location seems a significant advantage to engage stakeholders (+)	1	5
	Stakeholders expected impact from their involvement (+)	1	5
Ownership of outcomes	Involving stakeholders to identify ES to be used for prioritization increased engagement (+)	1	5
Quality of information	The way ES are introduced/explained influences the outcomes of scoring (-)	1	5
	The use of scores sometimes restricted debates to the numbers (-)	1	1
	It was suggested that we should have started with a visit to the area (-)	1	2
	There is a trade-off between what should be done for validated scoring and what could be asked from stakeholders (-)	1	5
	Useful results serving as basis for the project/research (+)	1	4
	Attempt to reach consent rather than consensus decreased frustrations (+)	1	2
Relationships	ES concept helped to build bridges between different stakeholders (+)	3	3
	Informal time (e.g. break for food and drinks) allowed increased networking and exchanges (+)	3	5

	Positive constructive atmosphere during participative exercises (+)	1	3
Representation	Representativeness of participants not ideal (-)	2	2
	Difficult to know when representativeness among stakeholders is reached (-)	1	3
Social learning	Combination of individual votes and group discussion is of added value (+)	2	5
	Increased exchanges, social learning and networking due to heterogeneous group (+)	1	5
	Indications of social learning process were noticed (+)	1	5
Transparency	Method was explained to participants for transparency (+)	1	5
	The ES tool created some frustrations or skepticism among participants (-)	2	2
	Overlapping between ES made the scoring difficult for participants (-)	1	3
	Too many ES led to confusions (-)	1	2

Get a mandate from a locally trusted organization and organize the participatory exercise at the case study location

In our studied cases, official mandates from locally trusted organizations, e.g., farmers association (5/5); political support (4/5); or a legal context (1/5) created a trustworthy environment. "Keeping it local," by organizing the participatory exercise at the physical context/location under discussion seemed like a significant advantage to reach and engage stakeholders (5/5).

Include outsiders among the facilitator team and carefully discuss and agree on shared expectations and objectives

CS researchers, who were also facilitators of the participatory exercise, were accompanied by outsiders to avoid facilitators guiding discussions toward the project objectives (5/5). Additionally, this brought together different areas of expertise, which improved the success rate of participatory exercises (4/5) and offered the required skills for participatory process guidance (4/5). However, in two cases, this sharing of leadership between facilitators and outsiders led to diverging initial objectives between the two parties and miscommunication (2/5).

Anticipate the time load and ensure sufficient time for preparation and implementation of the participatory exercise

"Available time" was experienced as a major limiting resource (3/5), which was either determined by the project itself, because of deadlines, financial constraints, and so forth, or by the type of participants involved, e.g., farmers are typically little available because of their work constraints. This time limit hampered the setting of commonly agreed on objectives (5/5) and sometimes a proper preparation of the participatory exercise (3/5). It can also impact the process; for instance, having to rush during the participatory exercise led to mistakes and thus decreased the credibility of CS researchers (2/5). Overall, CS researchers judged participatory exercises to bear low implementation costs (4/5).

Increase participants' engagement by gathering their input at the outset of the project and involving them in goal setting and in ecosystem service identification

The timing of the participatory exercise with regard to the context was seen to be crucial (4/5). For instance, for CS 2 the participatory exercise took place within a broader project that had started a few years previously, which created resistance and a priori expectations regarding the participatory exercise. For this reason, gathering stakeholders' input at the very beginning of the project seems to be a recurrent positive experience.

To avoid "stakeholder fatigue" and ensure participants' engagement, researchers perceived it to be important that participants felt their involvement can have an impact (5/5). To do so, the goal of the participatory exercise should be relevant for the participants and society, and not only for research purposes (4/5). Involving participants at an early stage, such as in goal setting (2/5) or in identifying ESs to be selected before the prioritization and selection (5/5), was also identified to be a crucial step. In all CSs, the process of ES identification implied a combination of participants' input and ESs proposed by CS researchers based on scientific ES classifications. Despite being acknowledged to be time consuming (5/5), it helped to make topics more recognizable to participants, and they started with a shared background and understanding.

Find a good balance in the group's heterogeneity and provide informal time to increase exchanges

All CS researchers were satisfied by the attendance of participants, but not always by their representativeness. Some faced over- or underrepresentation of some sectors and had to adapt their methodologies accordingly (2/5). Some also found it difficult to know when this representativeness was reached (3/5). The heterogeneity of the group contributed to increased exchanges and mutual learning (5/5), yet too much heterogeneity within the group can generate polarization among participants (2/5). Adding informal time, such as a break for food and drinks, increased networking exchanges and contributed to a trusting environment (5/5).

Have high-quality facilitators and work in small groups to help manage group discussions

Including everyone and making them express their opinion can be difficult (2/5), and some "powerful" participants can potentially dominate the discussions (2/5). Having high-quality facilitators (5/5) or dividing participants into small groups (3/5) can help reduce the effect of dominant participants. If the project includes political issues, there is a risk that less room is left for trust and sympathy among participants (3/5).

Encourage stakeholders to explain the reasons behind their choices and discuss ecosystem services in terms of desired future

Instead of asking participants whether they agree or disagree, the emphasis was on asking participants to explain the reasons behind their choices to encourage understanding within the group (5/5). Two of the five CS researchers reported highly positive outcomes from suggesting that participants only formulate suggestions that benefit at least one other participant and do not affect any of the others negatively. In two CSs, it was also decided to discuss ESs in terms of a desired future. This resulted in more positive dialogue, as it is less threatening to discuss the future than present issues. On the other hand, in one CS, it was thought that focusing on desired futures bears the risk of not being translated into present actions.

Seek consent not consensus

In two CSs, “consent” was distinguished from “consensus” in the sense that the former does not seek common agreements on every detail but seeks an option for which nobody has fundamental objections. In a third CS, this was not done, but it was thought that it would have helped the debate.

Opt for easily accessible methods and activities

Overall, CS researchers declared positive outcomes from easily accessible methods and activities for participants (4/5). For example, one of the cases organized a field trip to bring participants with variable understanding of the area and the relevant issue to a more common level. Being transparent about the aims and the methods was also seen to be a major advantage (5/5). Similarly, the combination of individual votes and group discussion was judged to have added value (5/5).

Leave room for information that falls beyond ecosystem service scores and ecosystem service lists, being aware this may require new expertise

The use of numbers through ranking and scoring bears a small risk of restricting debates to numbers (1/5) but was mostly found to foster information-rich but sometimes difficult to grasp discussions (3/5). Participants suggested some values and services absent in scientific ES classifications, providing complementary and important information for the relevance of the project (5/5). This information was sometimes difficult to include further in the ES valuation because it fell beyond the expertise covered by the CS researchers. Involving new expertise was not always possible as the researchers were also dependent on external constraints, e.g., the funder’s deadline in CS 1.

Use the ecosystem service concept as a boundary object, keep its limitations in mind, and carefully introduce it to participants

Overall, the ES concept appeared to have contributed to building bridges between stakeholders, playing the role of “boundary object” to build a common language (3/5). The knowledge generated during the participatory exercise often formed a relevant basis for the project (4/5), although it was not always directly implementable (4/5; values expressed sometimes fell beyond the researchers’ expertise). Most CS researchers agreed that the participatory exercise helped to build a common ground for their ES valuation project (5/5). There was no open conflict nor strong divergences of opinion, overall consent was reached on the diversity of ES values raised during the exercise (5/5), and participants were willing to discuss and negotiate, in a constructive atmosphere of trust (3/5). This was noticed, for example, through indications of learning processes (5/5), enthusiastic engagement of some typically less engaged stakeholders (3/5), and feedbacks on the process from participants, who considered it to be a new, original way of working (4/5). Only one CS noted some disagreements, specifically with stakeholders who were not present at the participatory exercise.

Participants showed various levels of understanding of the concept and of ecosystem functioning (5/5). Working with too many ESs was sometimes confusing for participants (2/5), and some ESs appeared to be redundant to them (3/5). Additionally, the way the ES concept was introduced was found to influence participants (5/5).

1.4. Discussion

We examine the 11 recommendations emanating from our self-evaluation in the light of participatory literature. Such reflection aims to provide insights on the use of the existing knowledge in participatory science in the specific case of participatory ES identification and selection.

1.4.7. The support of participatory literature to participatory ecosystem service science

Some of the recommendations we propose are well-known “good practices” for participatory science. Including stakeholders from the outset of the project is a recommendation repeatedly mentioned in participatory science literature (Wondolleck and Yaffee 2000, Grant and Curtis 2004, Reed 2008, de Vente et al. 2016), and well implemented by ES researchers (Baker et al. 2013, Förster et al. 2015, Rosenthal et al. 2015). Doing this guides the research project toward objectives relevant to stakeholders and society, and not only to scientific research (Grant and Curtis 2004, Mackenzie et al. 2012). This increases participants’ feeling that their engagement can have an impact (Klein 2008, Stige et al. 2009, de Vente et al. 2016). Ultimately, it improves the implementation of the research outcomes as participants in a project take ownership of its questions and results and are thus more likely to take actions and engage with the situation later on (Biggs et al. 2011, Cuéllar-Padilla and Calle-Collado 2011, Vilsmaier et al. 2015).

Our findings also concur with previous experiences that show how reliance on accessible tools enables stakeholders to actively engage in the deliberation process (Vilsmaier et al. 2015). The process should be accessible in terms of understandability and in terms of transparency (Klein 2008). In transparent processes, the way decisions are made is explicitly explained to participants, enabling a trustworthy relationship with the researchers to be built (Rowe and Frewer 2000). This recommendation is also well acknowledged by the ES scientific community (McKenzie et al. 2014, Rosenthal et al. 2015, Ruckelshaus et al. 2015, Posner et al. 2016).

Recent studies concur with our reflections that there is a need to be familiar with the context, to gain insights on what works where (Byrne 2013), producing grounded knowledge, rather than generalizable knowledge (Ashwood et al. 2014, Popa et al. 2015). Being familiar with the context helps the project to fit within a "policy window," i.e., an opportunity for decision making, to interpret, apply, and champion the outcomes of the participatory process (Triste et al. 2014, Polasky et al. 2015, Grêt-Regamey et al. 2017). This may require mandates, facilitation, or initiation by governmental bodies. Such co-lead with an external facilitator has been suggested in previous ES work (Chan et al. 2012, Mackenzie et al. 2012, Jacobs et al. 2016). However, as shown by this previous research, and also experienced outside ES work (Mackenzie et al. 2012, de Vente et al. 2016), this bears the risk of miscommunication, diverging objectives, and a potential loss of information.

Another concern emerging from our CSs, which is also frequently expressed in the participatory literature, is the representativeness of the stakeholders involved (Rowe and Frewer 2000, Grant and Curtis 2004, de Vente et al. 2016). To fairly represent stakeholders, a large sample is required, but large groups do not function efficiently (Grant and Curtis 2004). Stakeholder analysis is believed to guide stakeholder selection toward higher representativeness (Reed et al. 2009), although generally the aim is not to reach statistical representation.

To avoid conflicting situations, two of the CS researchers suggested talking in terms of desired future, which has been reported positively in earlier work (Malinga et al. 2013, Martínez-Sastre et al. 2017). Discussions were also smoothed by asking participants to explain the reasons behind their choices, rather than just agreeing or disagreeing, a recommendation that was also formulated by Vilsmaier et al. (2015). With the same aim to facilitate group deliberation, some participatory literature has suggested the distinction between "consent" and "consensus" in the sense that the former does not seek common agreement on every detail but seeks an option for which nobody has fundamental objections (Endenburg 1998, Christian 2014). This distinction is not found in existing ES participatory recommendations, to our knowledge, although being very effective.

Finally, to apply all these recommendations, to design accessible and transparent methods, adequately select stakeholders, define commonly agreed on goals, and appropriately fit the exercise within its context, requires time, a major limiting resource as experienced in our CSs and in previous participatory work (Klein 2008, Mackenzie et al. 2012, Jahn and Keil 2015).

1.4.8. Further insight from our reflexive work

Our self-evaluation also led to recommendations not present in the ES participatory literature. For instance, we suggest to "keep it local," i.e., to organize the participatory exercise in the geographic context in which the project takes place to increase participants' feelings of legitimacy and engagement.

To decrease the chances of opposition within the group, two of the five CS researchers reported highly positive outcomes from suggesting that participants only formulate suggestions that benefit at least one other participant and do not affect any of the others negatively. In so doing, participants are encouraged to think beyond their own needs and to think about solutions beneficial to several stakeholders. This strategy has been applied outside the present work and has so far proved to be a powerful approach (Ulenaers et al. 2014). We believe this is a way to have participants aim for consent by linking self-interest with public interest. We also noticed that adding informal time, e.g., free time or a coffee break, within the exercise increases exchanges between participants and creates a trusting environment.

Most of our CSs reported relevant information emerging from the participatory exercise, but which could not always be directly implementable. Indeed, participants sometimes expressed values falling beyond the expertise covered by the researchers involved. Although similar experiences are shared in the literature (Grant and Curtis 2004, Baker et al. 2013, Chan et al. 2016, De Vreese et al. 2016), this is rarely translated into a recommendation to researchers to prepare for flexibility and adaptive postures. This is a crucial challenge, which may be hampered by institutional and academic standards (Cowling et al. 2008, Jahn and Keil 2015).

1.4.9. Opportunities and challenges for the ecosystem service concept

In our CSs, as in many others (Lewan and Söderqvist 2002, Baker et al. 2013, MacDonald et al. 2014, Mascarenhas et al. 2016), various levels of understanding of the concept and of ecosystem functioning were reported. In fact, the understanding of the concept depends on how it is introduced (Klein et al. 2016). It is well known that methods can influence outcomes of participatory exercises (Kenter et al. 2011, Malinga et al. 2013, Raymond et al. 2014). Hence, it is essential to bear in mind that the ES concept used as a tool to elicit values also shapes them (Martín-López et al. 2014). The mere choices of which stakeholder to include and which valuation method to use (Jacobs et al. 2018) are value laden, or "value articulating institutions" (Vatn 2005). What is more, although the concept definition is outwardly simple, people attribute various meanings to it (Nahlik et al. 2012, Flint et al. 2013, Barnaud and Antona 2014, Polasky et al. 2015), expanding the framing possibilities (Steger et al. 2018). The concept thus needs a stronger engagement with its normative foundations (Abson et al. 2014), and researchers using it must acknowledge that there is no single service-value relation, because multiple values can be held for one service and vice versa. Hence, no valuation method covers the whole range of values, and researchers need to consciously select complementary valuation methods (Jacobs et al. 2018).

On the other hand, in our cases the ES concept has proved to be an effective entry point for discussions between stakeholders, playing its role of "boundary object" (Abson et al. 2014, Steger et al. 2018). There was neither open conflict nor strong divergences, and issues were discussed constructively. This may have been because of multiple causes, i.e., contexts mainly offering opportunities for all, talking in terms of the future making discussions less threatening, and so forth, but was arguably favored by the positive discourse of ESs. The ES concept helps the understanding of dependencies on ecosystems, social relations, and conflicts of interest (Barnaud and Antona 2014, Steger et al. 2018). As illustrated by a participant in CS 5 who attested to "gain[ing] new insights about the functions of the valley by discussing them with other participants," the ES approach increases people's awareness of their social-ecological interdependencies and encourages collective benefits, leaving aside individual preferences.

1.5. Conclusion

We analyze five CSs that included stakeholders in the identification and selection of ESs as a first step within a broader project. This reflexive analysis provided valuable insights on the common barriers or success factors, which allowed us to formulate several recommendations. We notice that many of the recommendations we have drawn concur with the wide body of existing knowledge on participatory research. We also highlight additional specific pieces of advice that are, to our knowledge, insufficiently addressed in the current literature despite having a high potential influence on the participatory process. As most of these issues raised were shared by several CS researchers, we believe these recommendations can be of interest for future work on participatory ES identification and selection as part of integrated ES valuations.

Although we recognize that there is no "one-size-fits-all solution" and that methods should be "fit-for-purposes," we believe that feeding back experiences of participatory exercise implementation may be of great support to help future work. Our results show that reflexive analyses are valuable tools for both researchers reflecting on their own cases and for researchers willing to follow similar approaches. We hope we have opened the way to future self-evaluations of participative work to increase lessons learned and ensure future work to build on strengths. As Cowling et al. (2008:9483) state, "being mission-oriented, ES research should be stakeholder-inspired and stakeholder-useful, which will require that researchers respond to stakeholders' needs and collaborate with them."

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2. Reflection on the perception and appreciation analysis

As mentionned in Chapter III section 2, the method relied on for the analysis of agroecological landscapes perception and appreciation underpins several limitations. First, the sampling strategy of reaching participants through the Parc Naturel des Plaines de l'Escaut undeniably shaped the profile selection towards people sensitive to environmental questions. However, being an 'outsider-scientist', i.e. not coming from the studied locality and not being a farmer myself, was likely to represent a constraint to develop trusting relationship with participants or even to simply ensure their participation (Chan et al. 2017). Developing collaboration with a local partner has shown to be critical to build trust and credibility to participants (Boeraeve et al. 2018, Chapter V section 1). While this biais is thus inherent to the context of my research, it is to keep in mind while interpreting outcomes of the consultation. The non-significant differences between locals and ES experts could potentially be due to this biais. Expanding the sample of locals to an extended and random sample of local stakeholders could have provided a more sensitive analysis.

Additionally, assessment of appreciations and perceptions of the landscapes are based on scenarios constructed from manipulated photographs. Our results are thus to be interpreted in terms of perceptions and appreciations of *agroecological-like* scenarios. This represents thus an indirect link to real-life agroecological landscapes, or to the concept of agroecology itself (there were no explicit reference to the term 'agroecology' or 'agroecological practices'). The constructed landscapes indeed all show very green and 'rich' landscapes which may have influenced ES perceptions. The ES 'food provisioning', for instance, does not show significant differences across scenarios. While we interpret this as a perception of local stakeholders, this could be a consequence of the fact that all scenarios seem rather productive.

What's more, the photographs only depict agroecological practices at the parcel scale and fail to represent the whole food system transition that such transition would entail. Photographs also represent one specific season. Further studies could investigate how perceptions vary through seasons. The studied AFS and CFS indeed also differ in winter, with AFS harboring complex winter cover mixes composed of up to twelve species, including flowering plants likely appreciated by the general public (sunflowers, phacelia, etc.).

These limitations could have been better parlty lifted by means of face-to-face interviews. Interviews allow disentangling the normative backgrounds of participant's responses and provide a picture of the perspective pluralism within the interviewees.

3. Reflection on the biophysical ES assessment

Within this PhD thesis, and specifically within this step of the valuation, I opted for a holistic 'scientific worldview'. This type of worldview accepts the irreducible wholeness of nature and agroecosystems, as opposed to the reductionist and technocentric one which currently prevails in conventional agricultural research (Bawden 2010). Technocentric scientific worldviews usually focus on a couple of parameters in a controlled environment, known as 'controlled experiments' (Ford 2005).

The biophysical ES assessment applied within the present work was multi-factorial and relied on 'real farms' in which uncertainties are high and uncontrolled parameters numerous (e.g. unknown history of experimental parcels, spatial heterogeneity, weather constraints). This approach responds to the research design type of 'natural experiments' often used in ecology (Ford 2005), which is characterized by a sampling approach of existing 'real-life' settings. This implies that there was no control over all parameters thus highlighting correlations but no causal relationships. The focus was rather to depict whether variation across farming systems was higher than within a same system type. Such research design has the advantage to study processes under realistic conditions. To minimize the bias due to the uncontrolled environment, the sampling strategies for the biophysical assessment was hierarchized: several parcels of one AFS were compared to parcels of several CFS sharing similar soil type and ecological environment, and replicating this sampling pattern in three different landscapes and through three years.

As any research acquiring and interpreting data (Olsson and Jerneck 2018), biophysical ES assessments imply multiple decisions from the researchers, from the selection of ES to indicators and measurement methods to assess them. Indicators are defined as *'information that efficiently communicates the characteristics and trends of ES, helping to understand the condition, trends and rate of change in ES'* (Layke et al. 2012) or as *'an alternative when it is not possible to carry out direct measurments (...) as it stupplies information on other variables which are difficult to assess directly'*[in the present case: 'ES'] (Bockstaller et al. 1997). They are essential to track and communicate trends in the quantity and quality of ES delivered. Indicators always have received much attention from research (Namkoong et al. 1996 etc. Layke 2009, Müller and Burkhard 2012, Czúcz et al. 2018).

These choices of ES, indicators and measurements methods of course influence outcomes of the research. In the present section, we illustrate this based on examples of the present thesis in which different indicators and measurement methods yielded different results, despite addressing a single ES.

3.1. *Different indicators for a single ecosystem service*

Within the biophysical ES assessment, the ES 'pest control' was assessed through three indicators: i) aphids abundance, ii) aphid parasitism and iii) aphid predation. The first provides information on the ecosystem structure, while the two others relate to ecological functions. While aphid abundance points out to significant differences across agroecological farming systems (AFS) and conventional farming systems (CFS) ($F=25.8$, $p< .001$), the two other indicators do not distinguish between the two farming system types ($F=0.302$, $p=0.592$, $0.12=0.731$, $p=0.72$). Yet, aphid parasitism and predation are two functions explaining aphid abundance. The agroecological hypothesis is indeed that agroecological practices support pest control by providing shelter and resources to pest predators (Poveda et al. 2008, Hatt et al. 2018). The present study shows that AFS indeed host less aphids, but this does not seem to be explained by a higher parasitism or predation.

Our results corroborate with the outcomes of a recent review studying pest control in wheat-based intercropping systems, as implemented in the studied AFS (Lopes et al. 2016). This review shows that pest abundance is usually reduced in such systems as compared with pure stands such as in the studied CFS. Similarly to our results, this is not explained by an increased occurrence of their natural enemies, or their predation and parasitism rates. In fact, biological pest control can be enhanced in AFS through two main processes (Hatt et al. 2018). First, the natural enemies can be enhanced by providing non-crop areas to procure them a shelter, overwintering sites, floral resources, prey and hosts, a process known as conservation biological control. The other way is to complicate the ability of pests to locate and develop on their host plant, for instance, through intercropping, a process known as the 'resource concentration hypothesis' (Root 1973). While the first hypothesis does not seem to be confirmed in the studied AFS, the second could explain our results.

Additionally, aphid abundance is the result of many more ecological processes and biological interactions, among which parasitism and predation are only two components only partially representing the network of interactions. This illustrates the complex network of interactions taking place between the ecosystem structure, its ecological processes and functions and the resulting ES flows.

This underlines the distinction which can be made between indicators assessing the *actual* (e.g. less aphids) or the *potential* (i.e. parasitism or predation) ES flows as depicted in Figure IV-2.

3.2. *Different assessment methods for a single ecological process*

Another similar example takes place for the assessment of the ES 'soil fertility' which used two measurements methods of the same indicator which is the ecological process 'soil decomposition': the bait-lamina test, which appreciates organic matter degradation rates, and the estimation of soil respiration rates. Both measurements assess the decomposition of soil organic matter through microbial and fungal activity. Yet, the outcomes are essentially different: the bait-lamina test depicts no difference between the two treatments of AFS versus CFS ($F=1.9$, $p=0.302$) while the soil respiration assessment reveals significant higher respiration rates for AFS ($F=74.5$, $p< .001$). How could two measurements of the same ecological process lead to distinct outcomes?

One potential explanation is the difference between the *in situ* approach of the bait-lamina test and the *ex situ* measurement of the soil respiration. The sticks containing the bait organic matter are left on the field for several weeks. The sticks are thus subject to external constraints, such as weather conditions which can influence the soil humidity in turn affecting soil micro fauna activity. Indeed, out of the three years of measurement, two sampling seasons took place during a prolonged period of drought. These two dry sampling seasons coincide with the two sampling seasons leading to no significant differences between the two farming system types. Soil respiration, on the other hand, was assessed *ex situ*, outside any environmental constraints and in the controlled setting of a laboratory. Soil samples were thus not influenced by the dry weather and the micro-faunal activity took place, undisturbed.

This illustrates how assessment methods can provide a *direct* or *indirect* measure of the indicator. Bait-lamina tests, taking place on the field, measure the indicator underlying the flow of the ES soil fertility directly. On the other hand, soil respiration measurements taking place outside the field assesses only indirectly the indicator of soil decomposition. In fact, *in situ* measurements will always provide more direct measurements as *ex situ* sampling are disconnected from the field conditions and involve extraction and transport which can potentially impact samples.

Such differentiations are to keep in mind when interpreting outcomes of assessment. While direct measures are more relevant if aiming at getting insight into the on-the-ground flows of ES, the latter allows depicting impacts of agricultural system type on ecological processes which could not be put forward through the field measurements.

3.3. ES assessment or 'ES guesstimate'? The choice of indicators and measurement methods

While some results of the biophysical ES assessment may appear paradoxal because yielding distinct outcomes while assessing a single ES or indicator, they can actually be provided biological hypotheses. Yet, it remains of concern in terms of ES valuation as it illustrates how the researcher's choice of indicators and assessment methods influences outcomes and interpretations (Figure V-1).

In fact, the mere choice of using the ES tool is value-laden and orients the outcomes as it restricts the spectrum of dimensions and values addressed (Pascual et al. 2017, Díaz et al. 2018). Relying on stakeholders' consultation for the identification and selection of ES, as in the present study, is one way among others to allow widening the scope to items identified as important by stakeholders, but not recognized as 'ES' per se.

Yet, once the ES selected, two steps remain to be carried out, each involving choices which can potentially influence research outcomes (Figure V-1). First, indicators must be selected. An indicator can inform, as it is often the case for supporting ES, on the *actual* ES flow when measuring directly the ES delivery or benefits. Very often, and specifically for regulating services, indicators measure the *potential* ES delivery by addressing ecological processes and functions underlying the provision of ES. Behind each indicator, a myriad of measurement methods exist which provide more *direct* or *indirect* quantifications of the indicator.

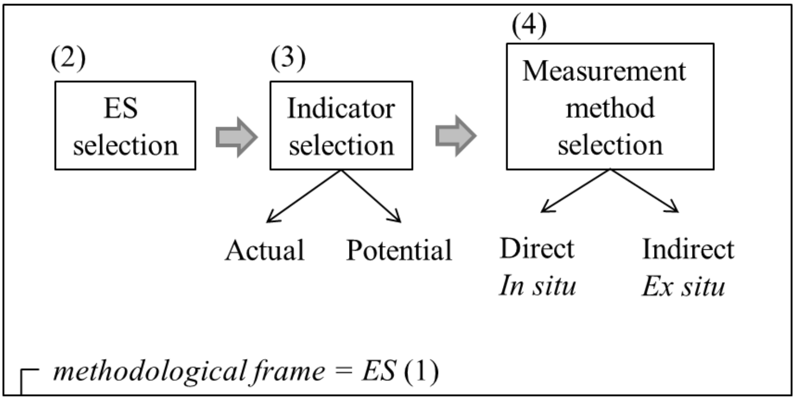

Figure V-1 : Illustration summarizing how the researcher frames the study by (1) choosing the methodological frame of ES, (2) selecting ES, (3) selecting indicators reflecting the actual or potential ES flow and (4) selecting the measurement method providing a direct or indirect estimate of the indicator.

In this thesis, the only indicators informing on the actual ES flows are the quantity and quality of the crops and the decreased aphid abundance (Figure IV-II). The other chosen indicators all refer either to the state of the ecosystem (e.g. soil data) or ecological processes or functions (decomposition, ecological interaction, weathering/erosion and nutrient cycling), thus informing on the potential ES delivery. Most of these indicators, except indicators of pest control and soil degradation rate (bait-lamina test), are assessed *ex situ*, potentially providing indirect measurements of the indicator.

In the light of this reflection, it appears clear that relying on a single indicator to assess each ES only partially depict the ES flow. Yet, when assessing multiple ES, many studies rely on one indicator per ES (e.g. Sandhu et al. 2008, Porter et al. 2009, Fan et al. 2016). We concur with previous warnings this risks to not fully and adequately characterize the diversity and complexity of the benefits provided (Layke et al. 2012, Lebacq et al. 2013). It is thus suggested to use several indicators for a single ES, to inform more comprehensively on the underlying processes to benefits and human wellbeing. Through this triangulation of different indices, measurements can better grasp the complexity and capture the often non-linear interactions within the socio-ecosystem (Norgaard 2010, Andersson et al. 2015).

3.4. To standardize or not to standardize?

As the selection of indicators and assessment methods influences the assessment outcomes, the use of different indicators and methods through distinct studies can lead to contradictory and not comparable assessments. Based on a review of 405 ES peer-reviewed research paper, Boerema et al. (2017) showed that each of the 21 ES analyzed had on average 24 different measurements methods. To overcome this lack of consensus, some authors advocate for the development of a universal and harmonized set of indicators (Boyd and Banzhaf 2007, Wallace 2007, Daily et al. 2009, Schader et al. 2014).

In opposition to this call, others argue that standardized ES frameworks can act as a ‘technology of globalization’, applying universal valuation templates to diverse local contexts, not taking into account the stakeholders and the context socio-ecological specificities (Tadaki et al. 2015).

This debate on whether to standardize indicators and methodologies is in fact echoed in many others research fields. Based on a comparison of sustainability impact assessments methods, Schader et al. (2014) call for a harmonization of indicators and assumptions. Within this context, global initiatives such as the ‘Sustainability Assessment in Food and Agriculture Systems (SAFA) Guidelines’ (FAO 2013) are presented as a helpful step toward making assessment results more comparable.

However, wariness towards a single methodology is often encountered. In transdisciplinary research, Szcheischler and Rogga (2015) state that there is a consensus within the transdisciplinary research community that one-size-fits-all solutions are not adapted to transdisciplinary issues as there is a crucial need to tailor the research to the problem and the available capacities and resources. Same goes for the research community of multicriteria analyses. As methods and tools for multicriteria analyses have developed considerably over the last 30 years, many authors have argued that there is not one ideal method and that a bundle of tools and methodologies should be applied (Sadok et al. 2008). This converges towards recently made conclusions in the field of integrated ES valuation. From their study, Jacobs et al. (2018) conclude that valuation methods have different suitabilities and that integrated ES valuation should aim at selecting complementary sets of valuation methods with the aim to cover values of all stakeholders involved.

4. Reflections on the integrated ES valuation as a whole

This section first reflects on the research posture held throughout the research process. It then presents how the tool of integrated ES valuation applied to the case studies helped answering the sub-research questions. At last, it reflects and discusses the challenges faced during the implementation of the tool.

4.1. My research posture

ES assessments are value-laden and scientists cannot expect to hold a neutral posture (Crouzat et al. 2018). Valuation spans indeed over each step of the research: the choice of types of values to elicit, the selection of stakeholders to include, the decision on which method to rely on, etc. (Jacobs et al. 2016). It is thus crucial to fully acknowledge this by being transparent on the posture held. Crouzat et al. (2018) distinguish between six scientific postures spanning possible roles at the science-policy interface. Although the present research does not link to policy *per se*, it does link to decision-making processes of farming management. Among the six postures presented by the aforementioned authors, I believe the present research falls into two categories.

First, within the PhD project as a whole, and while writing this manuscript, I respond to the scientific posture of ‘pure scientist’. This posture describes researchers motivated by scientific curiosity mainly, whose main objective is to seek knowledge outside any science-policy or decision-making processes. Indeed, the general aim of my PhD is to assess whether the tool of integrated ES valuation supports knowledge generation about transitioning agroecological farming systems. The research question and the reflections stemming out of it are thus purely epistemic.

To answer this objective, this PhD relies on a case study where the tool of integrated ES assessment is applied to farming systems undergoing agroecological transition. Within these case studies, my posture is slightly different and resembles more to the posture of ‘issue advocate’. In such posture, ‘the science and expertise are regarded as pragmatic tools for mounting convincing arguments to support certain normative actions’. My aim to use the ES tool within a context of agricultural transition is to shed lights on processes and values usually under-considered. My objective is also to use and test the ES tool as boundary object, i.e. as concept allowing discussions and negotiation to take part on a common ground (Abson et al. 2014). Within this posture, I believe that knowledge production does not only flows from the researcher to stakeholders, but that knowledge should be co-generated to allow a higher relevance of the research outcomes to the socio-ecological context and higher rates of learning processes. For this purposes, the present work was constructed including consultation processes. Despite my posture of issue advocate within the case study, the protocols used for the biophysical assessment and the socio-cultural valuation follow standard guidelines and are believed to yield similar outcomes if carried out by someone else.

It is to keep in mind that boundaries between postures are in practice less clear than in theory. In reality, my posture of ‘pure scientist’ is undeniably influenced by the posture of ‘issue advocate’ endorsed within the case study. Scientists may not expect to hold a totally neutral posture. Believing that our practice or our wolrdview is isolated from theoretical or conceptual influences has been refered to as 'naïve objectivism' (Chan 2017). The researchers' philosophical and normative beliefs always explicitely and implicitly shape their research practice. In the light of this awareness, what matters isto be transparent on both on the research posture and on the research process for which reflexivity is a key component.

4.2. Responses to the sub-research questions

This section revisits how the different steps of the valuation helped answering each sub-research question (SQR) which were applied to sampled AFS in the Hainaut Province in Belgium. This will feed the reflection on how the tool of integrated ES valuation can help understand agroecological systems.

- ✓ *SRQ1: What are the most valued ES by local stakeholders?*

This SRQ was answered within the socio-cultural valuation. A participatory ES identification and selection was first implemented in order to guide the research towards ES prioritized by local stakeholders (Chapter III – section1). The participatory ES identification and selection shed lights on the socio-ecological context influencing the relevance of ES to include in the research. While food production was perceived as the major ES in the context of agriculture, a wide variety of ES were also identified as important in the eyes of stakeholders. The resulting list of prioritized ES guided the ES selection for the biophysical assessment. However, time, financial and expertise constraints had to be considered which restricted the final list to a subset of the initial prioritized ES list. Additionally, based on experts' consultation and field visits, it was judged necessary to add two ES. Thus, the final ES list represents a compromise between stakeholders' values, technical constraints and expert opinion.

- ✓ *SRQ2: How do local stakeholders perceive ES delivery in AFS landscapes in comparison with CFS landscapes?*

This SRQ was answered in a second step of the socio-cultural valuation (Chapter III – section 2). A photograph-based questionnaire was submitted to both locals and ES experts to assess their appreciation of landscapes harboring agroecological practices and their perception of the related ES flows. The questionnaire was also submitted to ES experts in order to get insight into how different groups value landscape scenarios differently. The consultation showed that locals and experts perceive and appreciate the scenarios similarly. They appreciate the agroecological scenario better and perceive it as delivering more ES. Agroecological scenarios were not only perceived as delivering as much food as conventional landscapes, but they were also perceived as a synergetic whole where negative comments of isolated practices disappear once combined together in an agroecological scenario. Our results illustrate how locals can envision the complete feedback loop between agricultural transitions, landscape modifications and alteration in ES flows.

- ✓ *SRQ3: What is the potential ES flow in the selected AFS in comparison with their neighbor CFS?*

This SRQ was answered within the biophysical ES assessment (Chapter IV). The biophysical ES assessment provided a good picture of how agricultural management can impact ecosystem processes and functions and ES flows. Indeed, a very explicit distinction could be made between AFS and CFS. Relationships between variables were depicted by means of multivariate analyses, and synergies and tradeoffs were put forward. Our three years experimental design through three locations outlined AFS as having great potential in terms of regulating ES. A gap is still to bridge with regard to the provisioning ES, but this could be due to the still evolving stage of the studied farms. Yet, applying the ES framework to analyze farming systems allowed taking more dimensions into account than if only crop yield had been taken into account. Outcomes of such assessment however depend upon the selected ES, indicators and assessments methods. Involving stakeholders in these selection processes is one way to broaden the scientist's perspective and embrace stakeholders' values.

4.3. Challenges faced

In order to get insight into how the tool of integrated ES valuation supported the understanding of agroeclogical transition, the challenges faced during the implementation of the tool to the case studies AFS are presented and discussed.

4.3.1. The integration of distinct value domains

The biophysical ES assessment and the socio-cultural valuation of the present work revealed distinct 'value domains'. Integration means combining values and value domains to form a coherent whole. Integrated valuation does not merely consists of putting together different ES values assessed independently. Nor does it consist in aggregating values into a single unit or score (Gomez-Baggethun et al. 2014). While integration is seen within the ES field as a necessary step to deal with interconnected sustainability issues, some authors ague that integration also bears the risk to fall into 'scientific imperialism' or 'holistic reductionism' (Olsson and Jerneck 2018). While integrated ES valuation claims including value pluralism within one integrated framework, these authors argue that integrated approaches and value pluralism are not necessarily compatible. According to them, having one framework coupling social-ecological systems means incorporating more and more aspects of a problem into the analysis in an overly reductive way. To break with this cognitive distortion, they call for an approach that allows complexity and 'holistic pluralism'. The authors thus suggest treating nature and society as separate entities requiring different epistemologies, theories and methods. This lies in the same vein of thoughts as the framework suggested by Boeraeve et al. (2015 - Appendix 1). Within this article, we argue that integrated valuation should include multiple languages of valuation. In the present PhD work, I follow these guidelines stating that comparisons between scenarios can only be accomplished within value categories (Figure V-2).

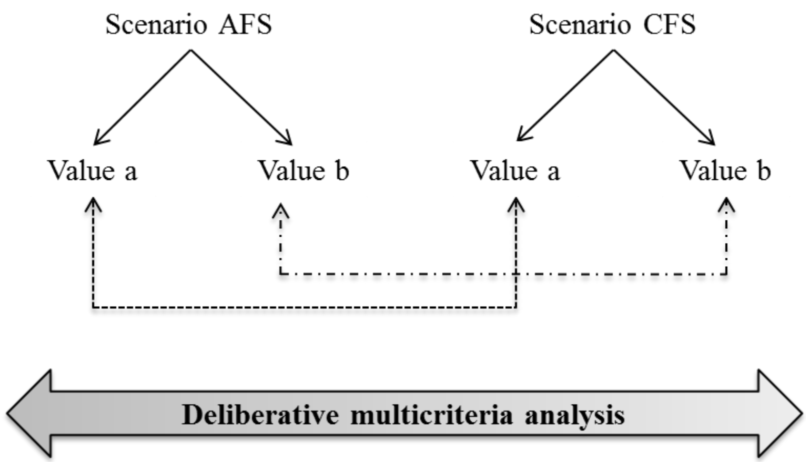

Figure V-2: ES integrated valuation framework. Unlike valuations which aggregate or sum values up, integrated ES valuation compares similar value types between scenarios (in the present case: agroecological farming systems (AFS) and conventional farming systems (CFS). Integration can for instance take the form of deliberative multicriteria analysis which structures the valuation while accounting for stakeholders' viewpoint. Adapted from Boeraeve et al. (2015 – Appendix 1).

Integrated ES valuation also aims at examining how these different values stand in relation to each another (Gómez-Baggethun et al. 2014). Analyzing relationships between ES within the biophysical assessment was made possible by means of multivariate analyses. Such analyses allowed bringing forward the tradeoff between regulating and provisioning ES. Yet, the integration of distinct value domains, in the sense of integrating outcomes from the biophysical and the socio-cultural valuations could be qualified as rather elusive.

To integrate value domains without falling into 'holistic reductionism', the initial PhD project had planned to set up a 'field thesis committee'. Just as the scientific thesis committee, composed of academics, provides a scientific and academic follow-up to the thesis work, the field thesis committee, composed of local stakeholders, would serve as lever for interactions with stakeholders and would help to fit the research within its local socio-ecological context. A final workshop was also planned to present to all stakedholders involved in the research (farmers, members of the field thesis committee, participants of the focus groups, etc.) to present and deliberate on the outcomes of the research. However, these two initiatives could eventually not be achieved within the PhD timeframe.

Deliberative approaches are indeed suggested in the literature to integrate outcomes of different valuations and assessment methods (Dunford et al. 2018). Through presentations or informal discussions, stakeholders could together draw the outputs of the different value domains assessments. This would allow reviewing and revising outcomes of valuation from both the societal perspective and the scientific practice, also enhancing chances for mutual learning (Lang et al. 2012). Overall, the use of participative and deliberative approaches is increasingly advocated for to overcome the incomparability or incommensurability of distinct value domains, a conclusion shared within the research field of multicriteria analysis (Martinez-Alier et al. 1998, Alrøe et al. 2016).

Multicriteria analysis has gained interest in the last decades. By integrating multiple qualitative and quantitative criteria and indicators, multicriteria analysis can accommodate value pluralism and incommensurability in environmental assessment (Martinez-Alier et al. 1998) and help structure deliberative approaches mentioned earlier (Munda 2004, Koschke et al. 2012). Rather than providing one-size-fit all solution, deliberative multicriteria analysis provides insights on the potential compromises (Fontana et al. 2013, Keune and Dendoncker 2014).

Deliberative multicriteria approaches thus represent an interesting approach to the second step of the framework suggested by Dendoncker et al. (2018). In parallel to developing a shared understanding of the socio-ecological system (step 1 of the framework, step applied within the present PhD thesis), a deliberative multicriteria approach could be applied to delineate the potential pathways of changes (step 2). By including stakeholders' values, perceptions and expectations into the deliberative multicriteria analysis, a picture of what is desirable for whom can be delineated (step 3) and then operationalized (step 4). Then only the work carried on could potentially be represent an integration reaching 'holistic pluralism'.

Integration of the biophysical ES assessment with the socio-cultural ES valuation represents a thorny aspect for most integrated ES valuation works, as testified by the review of 24 case studies by Dunford et al. (2018) and the research of Cáceres et al. (2015). This difficulty to articulate the social and ecological components stems from the underlying theoretical, epistemological and ontological background (Olsson and Jerneck 2018), as concluded from a comparison of 10 socio-ecological frameworks by Binder et al. (2013).

4.3.2. Bridging stakeholder knowledge and scientific knowledge

Another challenge is the gap that can exist between the stakeholders' knowledge captured during consultations and what can really be taken up in the research project. Within the present work, ES prioritized during the participatory ES identification and selection could not all be integrated within the subsequent step of research, i.e. the biophysical assessment. These restrictions were due to a lack of expertise and technical support as well as time constraints which restricted the final ES list, but also oriented the choice of indicators and assessments methods.

This tradeoff is well known: scientific research always has to find a balance between the quality/depth of the experimental design, and the financial cost (including human, technical and time costs) of the experiment (McKillup 2011, Schader et al. 2014). Hence, capturing stakeholders' knowledge to define the research objectives, or as in our case – the ES to be measured, represents an extra layer of complexity.

Implementing stakeholders' knowledge into research processes is indeed not always straightforward (Usher 2000). Several studies testify that stakeholder consultation highlighted aspects falling beyond the ES framework or the scope of the research (Grant and Curtis 2004, Baker et al. 2013, Chan et al. 2016, De Vreese et al. 2016, Bernués et al. 2016). Some transdisciplinary research mentions the potential incompatibility between the local specificity and relevance of stakeholders' knowledge and the scientific paradigm requiring generalizable findings (Briggs 2005). The same authors express some wariness about the 'apparently unproblematic union of western and indigenous soil knowledge'. In their opinion, the objectives and priorities of the two knowledge types are so divergent that there is little likelihood of meaningful dialogue taking place.

Yet, despite these warnings on the difficulty to integrate both knowledge types, many studies report on successful integration of stakeholders' knowledge within scientific work (Cuéllar-Padilla and Calle-Collado 2011, Fontaine et al. 2013, Kenter et al. 2016). Within the present study, consulting stakeholders brought forward two items falling beyond typical ES. This illustrates how consultation can represent an opportunity to broaden the scientific frame. The ES concept does not (and could not) embrace all possible dimensions (Díaz et al., 2018); hence it is relevant to rely on an iterative approach where scientific assumptions and values are validated by local knowledge and *vice versa*.

Indeed, it is to keep in mind that knowledge types integration is not uni-directional. It is also important to account for scientific and expert knowledge which accounts for important processes though invisible to the broad society. In this line of thoughts, the present work added two ES to the list of prioritized ES, based on expert opinion and field visits. Additionally, personal reports were sent to farmers summarizing outcomes of all measurements carried out on their parcels (Appendix 4). Ideally, workshops and more regular feedbacks would have been organized throughout the research between farmers and the researcher to support iterative learning processes on both sides.

Thus, involving stakeholders in the research procedure addresses the gap that can be revealed between theoretical scientists' problem and everyday life stakeholders' problem by producing responses according to local conditions and relevant to local stakeholders. In this way, it integrates contextual complexity and its inherent uncertainties to which generic solutions may not be adapted (Bell et al. 2008).

4.3.3. Trandisciplinary approaches require flexibility from the researcher

The challenge presented above of the participatory ES identification and selection leading to aspects falling beyond my expertise is representive of the importance to prepare for flexibility. Iterative learning processes as suggested in integrated ES valuation often lead to unexpected research outcomes (Lang et al. 2012, Benard and de Cock-Buning 2014, Cáceres et al. 2015, Chan 2017). The review of Dunford et al. (2018) points out that having to adapt to the research context and circumstances often influenced the method choice. Zscheischler and Rogga (2015) refer to the term 'evolving methodology' to picture the continual development of the methodology during the research process according to the research context, the knowledge acquired by stakeholders and their changing perspectives.

During my PhD research I indeed had to adapt my research questions. While I started with the research question 'What is the contribution of agroecological farming systems to the delivery of ES?', I progressively came across epistemological and methodological questions of 'how' to carry out ES assessments and valuations and 'how' these would actually (or partially?) answer my initial research question. My posture thus evolved from the rather pragmatic point of view which assumed objectivity, to a more reflexive level, embracing subjectivity. In doing so, the rarely made explicit 'Ph' of the PhD designation was brought to the front, to raise questions about the meaning of the process producing and constructing knowledge (Lynch 2014). Such reflexive work was certainly challenging for me having a natural scienfic education and experience so far. There were many occasions where I asked myself what could make my own reflection credible and valid. However, as the reflexivity especially took place during the PhD manuscript writing process, and as this process entails iterative steps of reviews and rewriting, I found myself reaching greater levels of understanding and confidence in the process each time I was revisiting the manuscript upon review. Reflexive writing represents an unfolding story in which the research gradually makes sens not only of his data, but also of his experience behind the acquisition of this data (Lynch 2014). Undeniably, reflexivity is probably an iterative and endless process of learning requiring flexibility and creativity.

4.3.4. Bringing inter- and transdisciplinarity within academia

Availability of expertise is a key factor to carry out inter or transdisciplinary research. It allows to link to the state-of-the art of each related discipline and supports the identification of adequate methods of measurement (Dunford et al. 2018), while respecting epistemological pluralism (Olsson and Jerneck 2018).

The present PhD was carried within two distinct work settings. At first, the PhD was carried out within an interdisciplinary research platform, 'AgricultureIsLife'. This research platform gathered about twenty PhD students from different disciplines, and thus affiliated to various research departments but all working on the general topic of sustainable agriculture. The platform was of great support when seeking for ES assessment methods. Many PhD students from a wide range of expertise were consulted, which helped finding measurement methods offering the tricky compromise of scientific validity and the necessity to be cost and time efficient.

Later in the research process, while collaborations with other research laboratories within the same institution were launched (to carry out experiments, borrow technical equipment, or ask for specific expertise) some wariness and reluctance were encountered. The literature acknowledges that lack of experience in transdisciplinarity in research institutions can result in a considerable amount of time being required to establish collaboration, and transcending academic disciplines

(Golde 1999, Russell 2005, Benard and de Cock-Buning 2014, Jacobs et al. 2016). The classical format of institutions organized in specialized departments which are often in competition for financial support and publication is acknowledged as ill-suited to inter and transdisciplinary research, a position shared by many other authors (Golde 1999, Wondolleck and Yaffee 2000, Reed 2008, Hall et al. 2008, Pohl 2011, Lang et al. 2012, Louah et al. 2015, Darbellay 2015, Jahn and Keil 2015). The institutional discipline-based organization hinders the establishment of knowledge dialogue beyond disciplinary boundaries. Pohl et al. (2011) coin it as follows: '*Universities have departments, the real world has problems'.*

Despite the positive experience of the present project when hosted within the interdisciplinary research platform 'AgriucltureIsLife', some argue that structures facilitating transdisciplinarity may work against it by hampering flexibility, as each problem may require new grouping and interactions (Russell 2005). Some researchers argue that the risk in creating new academic structures is to create yet another new academic field with a disciplinary mindset (Boud and Tennant 2006). In this sense, an institutional setting encouraging networking is seen as more likely to be effective. In fact, the barrier may be more cultural than institutional; hence, changing minds may be more effective (and challenging?) than changing institutions (Darbellay 2015).

Institutions suggesting interdisciplinary structures and approaches are on the rise. The Sotckholm Resilience Center aiming at '*linking ecological and social systems to make a difference for sustainable development'* (SRC 2016) is one among many examples. Many '*Unités Mixtes de Recherche*' in France also rely on various research entities to provide an interdisciplinary environment to researchers. In Belgium, universities are also starting to launch interdisciplinary research centers and approaches, such as the interdisciplinary research center TERRA of the University of Liege or the research center Transition of the University of Namur.

A change in academia culture cannot be envisioned without a shift in educational programs. In the last decades, universities have mainly offered a disciplinary education that highly encourages specialization (Golde 1999). More specifically, agricultural education programs were often disconnected from field reality (Louah et al. 2015). Recently, however, examples of (agricultural) transdisciplinary educational programs integrating contextual reality have been burgeoning. In Norway, for instance, students develop multiple potential future scenarios that could be used by stakeholders to resolves issues based on on-the-ground learning (Francis et al. 2015). Such transdisciplinary approaches to academic education is increasingly encountered (e.g. Leuphana University offering interdisciplinary education programmes, the University of Namur and Gembloux Agro-Bio Tech now suggesting interdisciplinary and inter-university masters, in Smart Ruraliy and agroecology, respectively). These examples offer great potential to open the scientific mindset towards a broad range of disciplines and towards socially relevant research.

4.3.5. Changing the paradigm of standardized quality research criteria

Beyond academic settings, a major issue lays in the research evaluation criteria. Bibliometric and citations metrics are robust and standardized, but they are not sufficient to appraise the societal impact of mutual learning from transdisciplinary research (Golde 1999, Lang et al. 2012, Jahn and Keil 2015, Jacobs et al. 2016). Such impacts often take place on long time-scales; falling beyond the time frame of the research project and the timely publication necessity (Ruckelshaus et al. 2015). The lack of quality standards in transdisciplinary research is seen simultaneously as a major criticism and as one of the least understood aspect (Klein 2008, Zscheischler and Rogga 2015). Assessing the quality of transdisciplinary research is a complex task due the high context specific, the non-linear and multiple interacting drivers of change and the high degree of uncertainty leading to unpredictable research outcomes (Lang et al. 2012, Zscheischler and Rogga 2015).

The PhD quality standards within the short time frame and often first author peer-reviewed publications requirements leaves little room for time-consuming and flexibility-demanding inter and transdisciplinary approaches (Golde 1999, 1999, Benard and de Cock-Buning 2014). By bringing together domains of the natural and the social worlds, I often felt I was fulfilling research criteria of neither of them. The traditional scientific model testing a hypothesis in a linear, objective and almost mono-paradigmatic account is probably a simplified picture of how learning takes place during a PhD research process (Hanrahan et al. 1999). Testimonies exist of PhD students having to carry out the reflexive part of their work once the doctoral work was ‘out of the way’ to be less ‘blinded by the urgency required to complete the thesis’ (Chan 2017).

Regardless of the standardized quality criteria, carrying out transdisciplinary research is rewarding on a personal stance. I feel I have learned much from the challenge, both from a theoretical and practical point of view. This gratifying feeling is shared by others as identified in a workshop bringing together postgraduate students involved in transdisciplinary research (Russell 2005).

Chapter VI

CONCLUSIONS AND PERSPECTIVES

1. The potential of agroecology

While agroecology is increasingly advocated as a solution to current socio-ecological challenges faced by conventional farming systems (CFS), researchers lack tools to integrate the multiple value domains entailed by such agricultural transition. The tool of integrated ES valuation offers such opportunities by analyzing ES from multiple value domains.

To test the applicability of such tool to agroecological transition, a biophysical ES assessment and socio-cultural ES valuation were applied to examples of farms transitioning towards agroecological farming systems (AFS), as well as to neighbor farms that have remained conventional (CFS). This section summarises insights on the potential of AFS brought by the application of the framework of integrated ES valuation. Based on the biophydisal ES assessment and the socio-cultural ES valuation, the following observations could be made:

- ✓ Food was seen as the most important ES to be delivered within food systems but a diverse range of other ES were deemed considerable by local actors (based on the participatory ES identification and selection, Chapter III – section 1);
- ✓ From landscape manipulated photographs illustrating a gradient of agroecological scenarios, the agroecological scenario including all agroecological practices was the most appreciated and seen as delivering the most ES (based on the socio-cultural ES valuation, Chapter III- section 2);
- ✓ The agroecological scenario was also seen as a synergetic whole were negative aspects of isolated agroecological practices disappear once applied simultaneously (based on the socio-cultural ES valuation, Chapter III- section 2);
- ✓ AFS showed to support higher regulating ES, but lower provisioning ES in comparison with their neighbor CFS (based on the biophysical ES assessment, Chapter IV);

Hence, **AFS seem to offer social and environmental opportunities**. Indeed, the present study shows that AFS seem to better respond to social expectations by providing a wider array of ES, as hypothetised based at the start of the thesis based on existing literature (Bacon et al. 2012, de Favereau 2014, van Berkel and Verburg 2014, van Zanten et al. 2014b, Hatt et al. 2016a, Kremen et al. 2012). Additionally, our results illustrate that agricultural farming practices impact environmental factors beyond crop yield. Focus should thus shift the paradigm of bridging the ‘yield gap’ to bridging the ‘service gap’ (including yield) to also bridge the ‘social values gap’, hence providing a holistic approach to agricultural system analysis.

2. The tool of integrated ES valuation

Agroecosystems are shaped by farmers and deliver a wide range of ES and benefits to farmers and the society. In order to encourage sustainable agroecosystem management and landscape planning, an integrated valuation framework should include a broad set of values. The mere choice of using the ES tool to study agricultural farming systems is value-laden as it does not (and could not) encapsulate the spectrum of values and dimensions that can be ascribed to nature (Pascual 2017). The ES framework itself, the selected ES, indicators and methods used to assess them, the choice of field-based measurements, questionnaires, closed-ended questions, the use of photographs, etc. are all decisions made within the present research which influence the research outcomes. In fact, each research methodological option represents a 'filter' through which an experience or a process is related, interpreted and shared. This is illustrated for the present study in Figure VI-1. Outcomes of the biophysical ES assessment are 'filtered' by the choice of the methodological framework of ES, the geographical focus (field scale), the selected ES, as well as the choice of the indicators and measurement methods chosen to represent them (a). The socio-cultural ES values are also 'filtered' by the ES framework, the geographical focus (landscape scale), the selected ES and the method applied to elicit the values (manipulated photographs) (b). These socio-cultural valus are then translated to the scientist through the approach of questionnaires and closed-ended questions (c). These pieces of informations gathered by the scientist through multiple filters is yet again interpreted through the filter of his own experiences, his 'grounded knowledge' (Ashwood et al. 2014) which construct 'his way of knowing' (d).

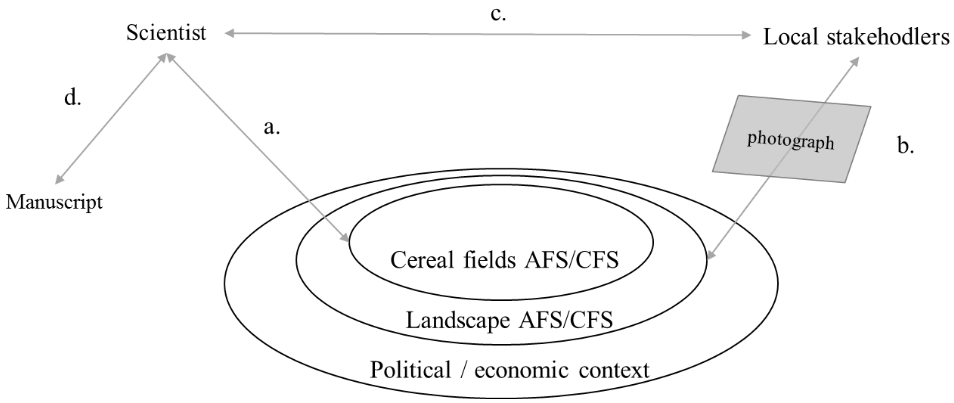

Figure VI-1: Representation of the multiple interpretation steps of the present research. Arrows (a) to (d) are detailed in the text.

Hence, scientific research outcomes are always interpreted multiple times. There is no absolute or single truth, and our practice and worldview are interwoven with our theoretical and conceptual decisions. Researchers inevitably apply their epistemological backgrounds, their assumptions, their contextual knowledge and their personal life experiences to any interpretation to unreveal the 'subjective reality' (Chan et al. 2017).

Scientists must thus take a step back to grasp human well-being or agricultural sustainability not only based on ES data. A quantity of ES flow may not be a good indicator of well-being as there may be no demand for it, or it may be unevenly shared among beneficiaries (Collins et al. 2010). As it is critical to acknowledge the diversity of values of nature and its contributions to people's good quality of, new avenues of research now advocate the shift from the ES framework to a value typology better embracing value pluralism (Pascual et al. 2017).

To embrace the inherent subjectivity of ES valuations the present work illustrated that combining stakeholder and expert knowledge brought complementary perspectives and pieces of information (e.g. for the identification and selection of ES). While stakeholders' knowledge allowed broadening the scope of the study to better embrace the values involved, expert knowledge complemented the stakeholders' perceptive to bring scientifically reknown aspects to the front which were not be visible to the broad public.

Additionally, the present work showed that relying on multiple indicators for a single ES assessment better reflected the complexity of underlying processes to ES delivery As distinct indicators measure distinct aspects of the ecological processes underlying ES flow, relying on multiple indicators for a single ES informs more comprehensively on the underlying processes to benefits and human wellbeing.

Deliberative and participative approaches applied in an iterative way are suggested to endorse the multiple perspectives. What's more, reflexivity allows the researcher to reflect in a transparent way upon his positions, involvements and subjectivities. Reflexivity is a key component in research (Gregory & Ruby, 2011; Jackson & Mazzei, 2012; Suárez-Ortega, 2013; Subedi, 2006). It involves the researcher reflecting upon and acknowledging one's positions, involvements and subjectivities in the research. Researchers are strongly implicated in the collection, analysis and theorising of data, making these processes highly subjective (Atkinson, 2007; Jackson & Mazzei, 2012). They need to be self-conscious and aware that they are also narrators during the research process (Elliott, 2005; Plummer, 2001). The role of the researcher should therefore be part of the data to be analysed (Harrison, 2009; Jackson & Mazzei, 2012; Rogers, 2004).

3. Perspectives

The ES tool applied as done in the present work produces knowledge which represents a first step and a subset of the bulk of information needed by farmers envisioning transition. To help building this commun understanding of the current situation, personal reports were sent to farmers summarizing outcomes of all measurements carried out on their parcels (Appendix 4). While this represents a first step from which they can envision potential future scenarios, it may be argued that the ES concept as such provides little management information directly useful to practicioners. Even if various types of values are acknowledged, the issue of how to make the final decision remains. Specifically, farmers could potentially and legitamy ask about the profitability of alternative options. One approach which could be interesting in that sense is the 'triple capital accounting' which accounts for social, environmental and economic capitals. 'Fermes d'avenir' in France is working on using this concept to assist agroecological transition.

Additionally, if seeking to capture the entire food system in which the agricultural system is interwoven as well as the socio-ecological impacts of the entire chain, approaches like life-cycle analyses provide good basis for investigation. The application of life cycle analysis to agricultural contexts wich also accounts for ES are only starting to emerge, but would be worth further research efforts (Zhang et al. 2010).

Within the framework of Dendoncker et al. (2018a) presented in Chapter II, the present work only applies the first step, i.e. the 'building of a common *understanding* of the current situation'. To bring the ES valuation to action and steer agroecological transition, the biophysical assessment and socio-cultural valuation of the present study should be embedded within a wider framework which also includes the identification of plausible evolutions of the system (step 2 of the framework). To consider different options, the approach of deliberative multicriteria analysis shows some interesting potential in supporting decision making while accommodating value pluralism and structuring deliberative approaches. Rather than providing one-size-fit all solution, deliberative multicriteria analysis provides insights on the potential compromises. Further research should thus investigate this research avenue in the specific case of agroecological transition, as this would feed steps 3 and 4 of the framework: the selection of the most acceptable pathways of change and the implementation of the selected scenario.

However, to envision a complete agroecological transition and provide research *steering* it, it is to keep in mind that valuation exercises, and agricultural contexts, always take place in a given institutional setting (Vatn 2005, Dendoncker et al. 2013). The multilevel perspective theory of socio-technical transitions (Geels 2002) highlights the coexistence of innovation niches, alongside with the dominant socio-technical system. Within this framework, the studied AFS are innovation niches that have emerged and developped in parallel from the dominant system, its related market and technological innovations. They represent alternative socio-technical systems functioning with different standards and institutional rules. The impediments to such transition are numerous and are subject of many scientific research (IPES-Food 2016). To name but a few: farmers' access to new knowledge forms, the technological lock-in in which they find themselves (having invested in machineries not necessarily adapted to new practices) or the food chain in which they take part and which represent a logistical constraint to transition (Meynard et al. 2018). These impediments are well and increasingly documented in the literature but were also illustrated to me through informal discussions with conventional farmers: *'I would like to change my practices, go more ecological. My daughter has many health problems, and I'd like to contribute to changing her environment. But I do not know how to do. It's not what I have learned, neither at the agricultural school, neither from my father'*, or, *'I would like to go for organic farming, but the dairy factory does not want me to, they have enough organic milk!'*

It appears thus evident that transition requires not only to modify agricultural practices, but also to adapt the socio-political context to lift cognitive, logistical, technical impediments identified (Meynard et al. 2018). Policy support mechanisms such as the Common Agricultural Policy ought thus to accelerate its ongoing 'greening' initiatives ensuring that a societal perspective is taken and treating the weakly comparable or incommensurable value dimensions (Vatn 2005, Martinez-Alier 1998). The call for developing innovative sustainable forms of agriculture encompassing the triple economic, social and environmental objectives represents a shared normative background in global decisions and agreements, as illustrated by the Sustainable Development Goals (SDG 2 'Zero Hunger') of the United Nations or the Aichi Targets (Goal B, Target 7) of the Convention on Biological Diversity, or the call made by the FAO (de Schutter 2014) or the international panel of expert IPES-Food (IPES-Food 2016), but concrete political actions remain to be taken in order for these alternatives to emerge beyond the margins.

The present research showed that the tool of ES allows disentangling (some of) the complexity of socio-agroecological systems. By integrating a biophysical with a socio-cultural valuation, it endorses different sources of knowledge. This informs on the relevance of a set of services instead of taking one variable only. All approaches have their limitations in scope and precision (Schader et al. 2014). No approach covers comprehensively all sustainability dimensions. All methods offer their own tradeoffs and compromises. The present research attempts to shed light on the underlying limitations and potential of the tool of integrated ES valuation in the context of sustainable farming systems. Being transparent on the method's boundaries indeed increases the tool's credibility and legitimacy (Pohl 2011).

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APPENDICES

Appendix 1: Boeraeve et al. 2015 How (not) to perform ecosystem service valuations: pricing gorillas in the mist

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Abstract

Monetary valuation of ecosystem services (ES) is gaining growing interest in scientific papers, policies and awareness-raising documents for its potential as a communication tool illustrating the societal importance of biodiversity. However, simultaneously, its limitations are increasingly discussed in the literature. In this paper we argue that monetary valuation of ES should be seen as representing only one component of ES valuations. We provide basic standards to ensure integrated approaches to ES valuation that can effectively contribute to preserving cultural and biological diversity by acknowledging boundaries to resource exploitation and by building on the various interests and socio-cultural values of involved stakeholders. We base our discussion on a recent study that assesses the economic value of the world-famous Virunga National Park in the Democratic Republic of Congo, home to some of the last mountain gorillas (Gorilla beringei beringei). We alert against some ES monetary valuation that narrowly frames biodiversity conservation in terms of economic calculus and argue that subjugating conservation efforts to profit logics downplays the importance of intrinsic, symbolic and other non-economic values of biodiversity. We conclude by providing principles and methodological guidelines to enhance ES valuation as a tool to promote awareness rising for biodiversity conservation through the understanding the overall importance of biodiversity for human societies.

Keywords Biodiversity conservation, Ecosystem services, Biocultural diversity, Natural resource management, Integrated valuation, Value pluralism

Introduction

Facing current challenges of increasing pressure on ecosystems and natural resources, the valuation of ecosystem services (ES) is suggested as a tool to shift from our development paradigm towards a more sustainable resource use that allows to meet the needs of present and future generations (De Groot et al. 2002; Dendoncker et al. 2013; Jacobs et al. 2014). It is nowadays a widely applied approach in sustainable development and biodiversity conservation (Bateman et al. 2013; Baveye et al. 2013; Abson et al. 2014). Particularly, monetary valuation of ES increasingly abounds in scientific papers (de Groot et al. 2012; Boerema et al. 2014), policy documents (TEEB 2010; European Commission et al. 2013) and NGO awareness-raising texts (Pinfold 2011; WWF-Dalberg 2013), including much grey literature (Adger et al. 1994; Tangerini and Soguel 2004; Brander and van Beukering 2013). In parallel to this rise, a growing body of scientific literature addresses the technical and ethical concerns with regard to valuation approaches restrained to monetary units (McCauley 2006; Spangenberg and Settele 2010; Luck et al. 2012; Kallis et al. 2013; Jax et al. 2013). Such reactions evidence a growing demand for better defining standards that secure the scientific quality and social legitimacy of environmental valuation exercises. This paper aims to serve this purpose using as a concrete illustration the recently published World Wildlife Fund (WWF) report written by the Dalberg Global Development Advisor which assesses—as its name suggests—'The Economic Value of Virunga National Park' (WWF-Dalberg 2013). The Virunga Park, located in the Democratic Republic of Congo, is known for its rich biodiversity—among which a quarter of the population of endangered mountain gorillas—and is recognized as UNESCO (United Nations Educational, Scientific and Cultural Organization) World Heritage. According to this assessment (referred to as 'Dalberg's study' hereafter), the economic value of the park currently reaches US$50 million/year but would potentially extent to US$1.1 billion/year under a sustainable development scenario. This estimation relies on the 'total economic value' (TEV) approach, frequently used to measure in economic terms the use and non-use values related to ES (Liekens et al. 2013). According to the TEV typology, a use value arises from the actual use of an ecosystem service (ES), as with the ES of crop provision or water regulation, while non-use values reflect the importance of the pure existence of biodiversity and ES and the knowledge that they provide benefits to others and future generations (Liekens et al. 2013; Davidson 2013). WWF uses monetary valuation for the honourable cause to provide arguments and raise awareness against SOCO petrol concession in the area. Whereas SOCO has recently given up its plans to not further drill or explore UNESCO sites under the pressure of the British Government, UNESCO and some highprofile individuals, (SOCO International 2014; Vidal 2014), we believe that Dalberg's report is a useful case to illustrate the limits and risks associated with narrow monetary valuations of biodiversity and ES, specially in contexts where their non-economic values can justify conservation efforts from a societal view point. With the aim of avoiding such risks, this article advances principles and methodological guidelines to align ES valuation with standards of ecological viability, social justice, and long term economic sustainability, defines conditions under which valuation could be best applied, and suggests ways of making progress towards the integration of different methods and metrics for ES valuation.

Standards for an integrated valuation of ecosystem services

The technical challenges and ethical risks of narrow approaches monetizing ES are widely acknowledged in the literature (Go´mez-Baggethun and Ruiz-Pe´rez 2011;

Kallis et al. 2013; Jax et al. 2013). Table 1 summarizes ES valuation standards found in recent literature. Before engaging in any ES assessment, the policy and socio-economic contexts need to be identified (Christie et al. 2012; de Groot et al. 2012) as well as the decision making context the valuation aims to inform (Gomez-Baggethun et al. 2014). This is key to understand potential conflicts between economic and non-economic values local people attribute to nature (Go´mez-Baggethun and Ruiz-Pe´rez 2011; Kallis et al. 2013) and to allow for the consideration of social disparities in access to ES (Jax et al. 2013). Within the complex conflict area of Democratic Republic of Congo, Dalberg's valuation assumes that 'stability and security are guaranteed' and that 'an effective law system protects the integrity of the ecosystem', likely missing critically important features with regard to the local institutional and governance context.

When applying ES valuation, transparency in the goals, calculations and underlying assumptions is essential (de Groot et al. 2012; Jax et al. 2013). A closer reading of Dalberg's non-use values estimation reveals that relying on a previous study (Hatfield and Malleret-King 2007), they misuse value definitions and misuse original data. Such misuse in definitions misled the authors to double the existence value estimated in the initial study (US$1865 million/year) using the argument that permit prices for access to gorilla areas will double, thereby overseeing that permit prices reflect a recreational use value uncoupled from the non-use value attributed to their existence. Moreover, this original estimation of non-use values refers to the whole mountain gorilla population (Hatfield and Malleret- King 2007) and as Virunga only hosts a third of the whole population, this amount ought to be adapted proportionately. A better transparency in calculations and definitions would have helped the authors avoiding this confusion.

Next to analytical flaws, consideration of multiple languages of valuation (Martinez- Alier 2003; Gomez-Baggethun et al. 2014) can be critical to address the wider societal value of ES. Throughout Dalberg's study, only monetary values are mentioned, it being for fish, tourism or gorillas' existence value, this way poorly representing cultural, spiritual, aesthetic and symbolic values related to the complex socio-cultural and ecological system studied. The three pillars of sustainability and their subsequent values are generally identified as required when valuing ES: ecological value, social value and economic value (Daily et al. 2000; Martı´n-Lo´pez et al. 2014; Jacobs et al. 2014) (Fig. 1—circles). These values are embedded into each other: economy and society are dependent upon the environment and bound to operate within safe ecological boundaries (Cato 2009; Rockstro ¨m et al. 2009; United Nations 2012). This calls for the complementarity of ES monetary valuations with other types of valuations addressing the full range of values related to ES.

Table 1: Standards for ES valuation from the perspective of value pluralism. Derived from recommendations in a.o. Baveye *et al.* (2013), Christie *et al.* (2012), Daily *et al.* (2000), Gomez-Baggethun *et al.*(2014), Jacobs *et al.*(2013), Jax *et al.* (2013), Kallis *et al.* (2013), Martin-López *et al.*(2014), Spangenberg and Settele (2010), Seppelt *et al.* (2011), TEEB (2010).

	Valuation of Ecosystem Services		
General:	Define policy and socio-economic context		
	Make transparent assumptions and calculations		
	Consider multiple values		
Values:	Ecological	Social	Economic
Aim:	Safeguard resilience and ecological integrity	Improve well-being of present and future generations	Secure economic efficiency and long-term viability
How:	Quantify biophysical properties and safety boundaries of ES	Take broad socio-cultural context into consideration	Clarify aim and scope
	Assess ecological thresholds and ecosystem non-linear response to changes	Identify sociocultural values held by stakeholders and users	Focus on value change from one situation to another and include scenario comparison
	Consider temporal and geographical scales	Apply participative approaches that involve affected stakeholders	Avoid commodification by restricting monetization to real costs of ES loss
Integration:	Multicriteria analysis		

Ecological values

Ecological values are fundamental to assess biophysical processes underlying ES, in order to understand which ecological processes are critical for long-term ES maintenance (Seppelt et al. 2011; Admiraal et al. 2013). These aspects include trade-offs among services (e.g. how enhanced supply of provisioning services can result in decreased supply of habitat and regulating services) and recognition of ecological thresholds that are relevant for ES supply (Go´mez-Baggethun et al. 2011). When systems are close to thresholds, ES valuation needs to switch from choosing among alternatives to securing the avoidance of ecosystem collapse by defining safe-minimum standards (Limburg et al. 2002; Rockstro¨m et al. 2009; Palmer and Febria 2012). Ideally, such investigations should moreover take into consideration temporal and geographical scales (de Groot et al. 2012).

Suggesting to triple fish extraction, implement hydropower plants and quadruple tourism as well as pharmaceutical prospection with no reference to data about ecological thresholds and ecological capacity, Dalberg's study risks encouraging already well-known local overfishing issues (WWF-Dalberg 2013), conflicts of fluvial alteration with local resource use (Erlewein 2013) and impacts of tourism expansion on environmental degradation (Lo et al. 2013). Consideration of ecological thresholds and of the ecological functions and process underlying the production of ES should be a fundamental component in integrated assessment and valuation of ES in order to avoid the valuation to become an incentive for unsustainable exploitation (Limburg et al. 2002; Pascual et al. 2010; Gomez-Baggethun et al. 2014).

Social values

Social values should be included as much as possible into ES valuation exercises to encompass stakeholders' point of views and socio-cultural contexts (Justus et al. 2009; Seppelt et al. 2011; Daniel et al. 2012) and in order to ensure equitable improvement of human wellbeing (Martinez-Alier 2003; Brondı´zio et al. 2010). Social values are specifically important when assessing non-use values of ES (Mace et al. 2012). Hence, the evaluation of non-use values through the sole use of money metrics following the TEV approach, as done in Dalberg's study, is likely to be misleading by failing to capture their socio-cultural importance (Chan et al. 2012). Instead, deliberative methods are proposed (Kenter et al. 2011) to include cultural and spiritual values, which can improve the accuracy and procedural quality of the assessment (Brondı´zio et al. 2010; Kenter et al. 2011; Chan et al. 2012) and can foster critical sense, responsibilities, and capacity building of local communities. The performance of such methods however depends upon many factors such as the procedural quality used in the choice of stakeholders and in the questions used in interviews and focus groups (Seppelt et al. 2011). For instance, as many studies that focus narrowly on monetary aspects of ES, Dalberg's study neglects indigenous views and the perception of local inhabitants when assessing non-use values—and bases the estimation on interviews to 27 affluent international tourists that generally are largely ignorant of local cultural and socioeconomic realities. Consequently, the final estimation of US$700 million for the non-use values (corresponding to more than 60 % of the TEV of the park) represents the value in the eyes of wealthy people and not 'the potential direct income to local communities' as pretended.

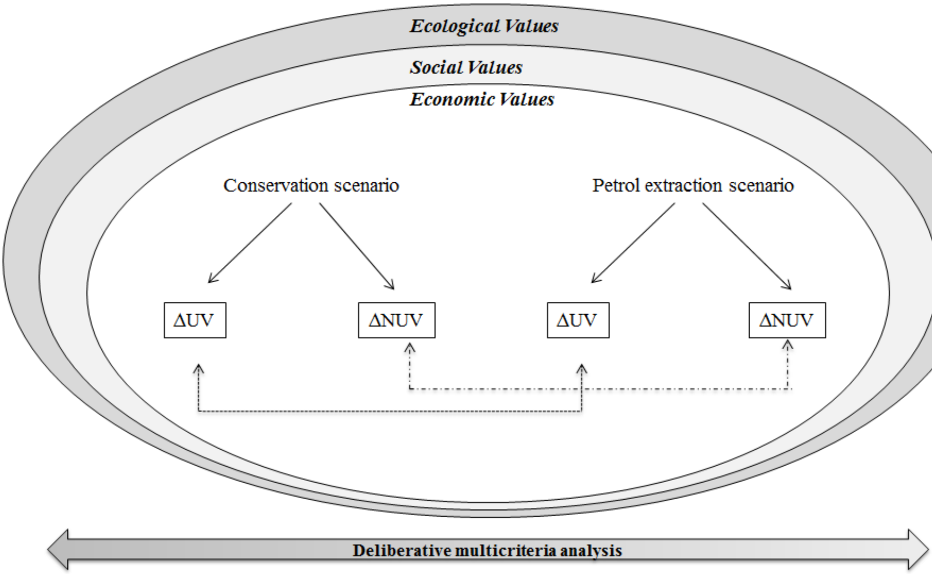

Figure 1: ES valuation framework using the TEV typology of use and non-use value. Unlike classical TEV, use values (UV) and non-use values (NUV) are not summed up. ES valuation compares use value difference between T0 and T1 (DUV) of the first scenario with the DUV of the second scenario (regular dotted arrow). Separately, the same comparison is carried out between non-use value differences (DNUV) of the two scenarios (irregular dotted arrow). Integrated ES valuation account for the fact that economy is a subset of society and that both are constrained by the environment boundaries by including ecological and social values in addition to economic ones. Deliberative MCA structures the valuation while accounting for stakeholders' viewpoint.

Economic value

Monetary valuations can be carried out for distinct purposes, ranging from awareness raising (Liu et al. 2010; Jacobs et al. 2014) to priority setting in decision making or to creating economic incentives for conservation (de Groot et al. 2012). Specifying the aim and policy context of the valuation exercise is thus crucial to avoid misuses of the valuation outcomes (Liu et al. 2010; Jax et al. 2013; Gomez-Baggethun et al. 2014). While Dalberg's study specifies to aim for awareness raising, its findings based on monetary estimates are stretched to strong political recommendations: 'Based on the findings (...), WWF urges governments, oil companies and non-governmental organizations (...) to take immediate steps to protect the park (...) and encourages all stakeholders to work together to unlock Virunga's potential as a sustainable source of direct income (...)'. Coming right after the monetary assessment of potential increased resource use (e.g. fishing could be tripled and tourism quadrupled), the assessment risks being interpreted as a 'licence for exploitation' without considering any ecological or cultural boundaries in terms of resource depletion or local perceptions on tourism congestion.

Following economic theory, monetization that aims to inform policy processes should assess value change rather than the total value of ecosystems, and more specifically, marginal change. This means that scenarios cannot be so different that the price per unit changes (e.g. a scenario leading to extreme scarcity of gorillas could rocket prices of access permits) (Daily et al. 2000). Moreover, when informing priority settings in policy decisions, values should ideally be compared between decision options (TEEB 2010; Seppelt et al. 2011). For instance, for Dalberg's case, a sustainable development scenario could have been compared to a petrol extraction scenario. In addition, comparisons between scenarios can only be accomplished within commensurable value categories (Martı´n-Lo´pez et al. 2014) (Fig. 1—dotted arrows). Therefore, the TEV approach, and its application in the Dalberg's study, are scientifically unsound by suggesting a summation of the incommensurable non-use and use values.

It must also be kept in mind that attributing monetary values to non-market ecosystem components that are not intended for sale opens the door to undesirable commodification of ES, i.e. the further inclusion of ecosystem goods into market exchanges (Go´mez-Baggethun and Ruiz-Pe´rez 2011). Commodification can increase social inequity (Liu and Yang 2013), crowd out non-economic motivations (Bowles 2008; Sandel 2012) and increase economic pressure on natural resources (McCauley 2006; Kallis et al. 2013). Cultural impacts of commodification can be especially high in the context of developing countries, where many local communities often manage resources through non-market norms (Go´mez-Baggethun et al. 2010; Christie et al. 2012). Hence, monetary valuations should be directed to ES having (in)direct commercial value or which loss bears real economic costs, but should be avoided for ES not intended for sale and which are expected to be governed by non-market norms. As much of the literature on ES valuation based on stated preferences techniques through the simulation of hypothetical markets, Dalberg's study makes thus a risky move to measure the gorillas' non-use value of existence by means of monetary metrics. Translating existence value, or any non-use value, into money is moreover highly debatable for ethical reasons (Luck et al. 2012; Jax et al. 2013; Davidson 2013) as it advances the notion that monetary equivalences for gorillas are actually feasible.

The challenge of integrating value plurality

Dalberg's failure to address what may be seen as the most critical values associated to the preservation of gorilla populations illustrates a prevailing gap in scientific knowledge: whereas many publications in the ES literature acknowledge the importance of value pluralism and integration, few provide hints on how to actually integrate values to inform decision making processes (Gomez-Baggethun et al. 2014; Martı´n-Lo´pez et al. 2014). In this context, several ES valuation frameworks have been developed, such as the Ecosystem Properties, Potentials, and Services (EPPS) framework (Bastian et al. 2013) and the assessment of ecological and economic benefits of environmental water in the Murray– Darling Basin (Jackson et al. 2010).

One approach that is gaining interest and which has already shown encouraging outcomes for integrated ES valuations is multicriteria analysis (MCA) (Justus et al. 2009; Spangenberg and Settele 2010) (Fig. 1—bottom arrow). By integrating multiple qualitative and quantitative criteria and indicators, MCA can accommodate value pluralism and incommensurability in environmental assessment (Martinez-Alier et al. 1998), and help to structure deliberative methods as mentioned above (Munda 2004; Koschke et al. 2012). MCA can also be used as decision support tools that acknowledge complexity, uncertainty and various points of view (Fontana et al. 2013). Rather than providing a one-size-fit-all solution, social MCA provide insights on the possible compromise solutions (Munda 2004; Fontana et al. 2013; Keune and Dendoncker 2014).

In such social MCA, decision support criteria, different alternatives and their respective priorities are first defined in a deliberative phase with various stakeholders. These alternatives and the criteria are then analyzed through a MCA based on a desk research and expert elicitation. These results are then discussed in a stakeholder deliberation. By acknowledging non-use values associated to the habitats of gorilla populations through an analytical deliberative MCA, elicited values may outweigh conservation scenarios against non-conservation ones. Narrow monetary valuation of ES can show that conservation is economically rational in some cases, but is unlikely to outcompete lucrative extraction activities such as oil drilling and mining.

Conclusions

Monetary valuations of ES are increasingly endorsed on the grounds of making a pragmatic case for biodiversity conservation. We are sympathetic to well-intended economic exercises by environmentalist NGO’s aimed at raising awareness about the societal importance of biodiversity and we acknowledge that monetization can be a powerful communication instrument in this respect: it can provide insights and promote informed debate concerning trade-offs between economic growth and environmental quality which are currently not endorsed by traditional economic accounting systems and prosperity measures. Yet, we contend that valuation exercises that fail to capture ecological and socio-cultural values of biodiversity can easily backfire by serving the interest of third parties which agendas have little to do with the conservation of nature. Used outside their appropriate domain and as an ultimate decision tool, monetary valuations risk being abused at the expense of the poor, future generations and—in the case of Dalberg’s study—some of the last mountain gorillas. Furthermore, monetary valuations of dubious methodological quality that use loose terminology and methodologies play against the legitimacy and long term credibility of valuation tools that otherwise can be an important component on the toolkit for ES assessments and biodiversity conservation. ES valuation should consider the lessons drawn from over 50 years of application and be mastered holistically applying standards of sound socio-economic analysis, procedural quality and value pluralism where economic, ecological and social values are seen primarily as complements and not as substitutes. We hope our contribution will trigger a constructive debate among fellow scientific communities and NGOs with shared interest of preserving the world's biological and cultural diversity.

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Appendix 2: Descriptive statistics of Chapter IV

		Erosion control			Water poll. control			Fertility 1			Fertility 2			Fertility 3		
		Aggregate stability			Pot. Leaching N			OM degradation			Soil respiration			Soil nutrient		
		0-6 class			kgN-NO_3/ha			%			mgCO2/g			g/kg		
Loc.	System	Mean	SD	Med.	Mean	SD	Med.	Mean	SD	Med.	Mean	SD	Med.	Mean	SD	Med.
A	AFS	5.95	0.06	5.95	31.70	34.16	22.79	2.80	2.80	2.80	6.1E+04	2.0E+04	6.4E+04	-2.36	0.85	-2.61
	CFS	5.10	1.40	5.44	62.44	22.24	66.28	7.00	9.40	4.20	4.3E+04	1.7E+04	5.3E+04	-1.78	1.22	-2.13
B	AFS	5.74	0.27	5.83	42.05	37.00	22.33	31.20	24.50	29.90	6.2E+04	2.3E+04	7.0E+04	0.33	2.38	0.76
	CFS	3.90	0.81	3.72	34.80	26.90	24.89	13.30	5.90	14.90	5.2E+04	2.3E+04	6.2E+04	1.29	1.45	1.64
C	AFS	5.95	0.09	6.00	43.01	31.21	36.87	3.03	13.00	29.20	8.2E+04	1.2E+04	7.9E+04	2.68	2.53	2.25
	CFS	4.05	1.13	3.44	42.57	27.53	45.46	1.17	10.90	6.90	6.3E+04	1.0E+04	6.3E+04	1.13	4.91	-0.45

		Pest control 1			Pest control 2			Pest control 3			Flood control			Crop production 1		
		Parasitism rate			Aphid abundance			Predation rate			Soil permeability			Straw yield		
		%			aphids			%			cm/day			kg/m^2		
Loc.	System	Mean	SD	Med.	Mean	SD	Med.	Mean	SD	Med.	Mean	SD	Med.	Mean	SD	Med.
A	AFS	0.093	0.167	0.000	0.75	0.64	0.49	63	26	75	6.5E+03	1.5E+04	1.4E+03	0.55	0.14	0.56
	CFS	0.057	0.033	0.053	3.09	2.12	2.80	49	27	63	6.9E+02	1.0E+03	2.5E+02	0.30	0.07	0.29
B	AFS	0.098	0.102	0.095	1.49	1.29	0.98	53	22	52	1.2E+04	2.2E+04	1.3E+03	0.41	0.17	0.44
	CFS	0.093	0.070	0.095	2.71	1.87	2.10	53	27	55	8.4E+03	1.3E+04	1.4E+03	0.50	0.07	0.51
C	AFS	0.233	0.356	0.056	0.72	0.85	0.25	26	15	27	5.5E+03	1.4E+04	3.7E+02	0.44	0.10	0.42
	CFS	0.065	0.051	0.041	2.55	0.98	2.50	44	33	30	5.5E+03	9.1E+03	1.6E+02	0.41	0.06	0.41

		Crop production 2			Fodder quality 1			Fodder quality 2			Fodder quality 3		
		Grain yield			Protein content			VEM			Starch content		
		$kg/4m^2$			%			VEM/kg			%		
Loc.	System	Mean	SD	Med.	Mean	SD	Med.	Mean	SD	Med.	Mean	SD	Med.
A	AFS	1.12	0.48	1.14	9.90	1.90	10.21	66.56	3.22	65.76	1.2E+03	1.6E+01	1.2E+03
	CFS	2.38	0.50	2.38	15.65	1.85	15.47	67.96	2.52	68.53	1.2E+03	9.5E+00	1.2E+03
B	AFS	1.26	0.99	0.85	10.31	1.43	9.85	56.94	8.03	55.22	1.1E+03	1.0E+02	1.1E+03
	CFS	3.06	0.93	2.73	13.66	0.69	13.76	70.78	1.45	70.67	1.2E+03	1.1E+01	1.2E+03
C	AFS	1.18	0.53	1.21	9.90	0.99	10.04	48.52	6.62	50.94	1.1E+03	2.7E+01	1.1E+03
	CFS	2.36	0.59	2.14	14.70	1.13	14.79	68.87	1.44	68.89	1.2E+03	1.0E+01	1.2E+03

Appendix 3: Description of case studies of chapter V

CASE STUDY 1 – The contribution of agroecological farming systems to the delivery of ecosystem services

Context

In the western part of the Hainaut Province in Belgium, a dynamic network of farmers is applying innovative agroecological practices with the purpose to reach more resilience and autonomy. While it is often attested in literature that agroecological farming practices offer greater opportunities for ES delivery, this fact is seldom quantified (e.g. Kremen et al. 2012).

Objective an scope of the project

A research project of Gembloux Agro-Bio Tech entitled 'FarmsForFuture' focuses on these real-life examples of 'agroecologization' and aims at quantifying the contribution of agroecological systems to the delivery of multiple ES.

The rationale for a participatory approach

As the research is restricted to a small locality, applying scientific lists ES may prove to be poorly relevant. Indeed, some ES, though relevant to agriculture in theory, may not be relevant for the selected farms according to the field characteristics or the values stakeholders attribute to them (Altieri 1999, Lyon et al. 2011, Plieninger et al. 2015). Hence, a local actors' consultation was intended to help prioritize relevant ES for local conditions and for local actors.

The process of the participatory exercise

To carry out this participatory selection, participants were first asked to identify ES provided within their locality. From there, participants modified the list of pre-identified ES by scientists. Next, participants ranked the five most important (from 1 to 5) ES based on the final list. The ranking methodology was inspired from the 'face-to-face Delphi' approach in which participants are given an opportunity to re-evaluate their original positions based upon discussions about each other's response (Linstone and Turoff 2002). Hence, after a first round of ranking, results were shared to the group and discussed. Participants could at last adjust their initial ranks.

Outcomes of application

The results of the ES identification and selection participatory exercise helped to focus the ES assessment towards ES relevant for the studied area and stakeholders.

The participatory ES identification added two ‘ES’ to the ES pre-identified by scientists and attributed importance to other ES than those mainly studied in scientific literature.

CASE STUDY 2 – Optimizing ES delivery through land consolidation

Context

The new ‘Walloon Code of Agriculture’ requires that land-consolidation plans consider the multifunctionality of rural landscapes. The Walloon administration called for a research project to define a methodology for impact assessment of land-consolidation plans based on an integrated ES assessment.

Objective and scope of the project

The project objective is to design a replicable methodology based on hands-on experience in a case study, located in Forville, Belgium. The methodology includes an expert-based assessment of ES supply (ES mapping and quantification) and a social ES valuation (stakeholder mapping, participatory ES selection, participatory validation of the expert-based mapped ES and participatory mapping of ES demand).

Rationale for a participatory approach

While classical impact assessment studies merely inform local stakeholders on their results, this case study moved from informing to *involving* stakeholders in developing land consolidation plans. The participatory approach was meant to raise awareness on the issues at stake, increase a sense of ownership and legitimacy of the project’s results in the eyes of the involved stakeholders, and for the research team who co-designed and implemented the collectively approved management options.

The process of the participatory exercise

To familiarize the participants with the ES notion, they were asked to individually draft a list of 10 ES, that were then briefly discussed in plenary. Subsequently, a locally adjusted CICES classification was presented to the group. Participants had the opportunity to suggest amendments to this locally adapted CICES list. Based on this list, participants individually ranked the five most important ES from 1 to 5. Afterwards, results were discussed in small sub-groups so everyone could raise concerns. One person per sub-group then shared the results in plenary.

Outcomes of application

The plenary discussion that followed led to consent on 5 ES groups, which is the final result of the participatory exercise. Only these ES were to be quantified further in the study.

CASE STUDY 3 – development of an inclusive vision for multifunctional landscape in a rural river valley

Context

The Maarkebeek is a rural river valley in the hilly region in the province of East Flanders. Low river valleys are generally used as forest and pastures, fertile hilltops are typically open cropland and villages are on the slopes. Increasing inhabitation and agriculture, combined with modifications of the streams during the last centuries, have increased flooding events and cropland erosion. Combined with increasing drought and rainfall events, climate adaptation measures are being planned in the valley.

Objective and scope of the project

The objective was to inventory the diverse values and uses of the valley, their relative importance to diverse stakeholders and interest groups, as well as potential synergies and trade-offs originating from differences in assigned values. This provided input to the detailed description for a public tender calling for a full-fledged participatory vision development and detailed design of a series of infrastructures.

Rationale for a participatory approach

As the climate adaptation measures (e.g. water storage infrastructures, erosion regulations) have direct implications on the landscape and different stakeholders (farmers, inhabitants, housing), a full overview of the issues at stake is a requirement for such a vision to be legitimate and credible. Without such credibility and legitimacy, a development vision will not be accepted and foreseen infrastructure works risk to be faced with legal, political and physical obstruction at the local scale.

The process of the participatory exercise

Based on a series of interviews, and an open citizens workshop with participatory mapping and open questions, a first list of ecosystem services was identified. This list was amended and validated in a focus group with (representatives of) all relevant stakeholders and experts from multiple disciplines involved. Consequently, an individual valuation score, a group valuation score and a trade-off analysis was conducted in this focus group.

Outcomes of application

The result of this valuation has informed the project development of the participatory planning and vision project. In close cooperation with the planning consultant and the stakeholders, the technical designs and vision for the valley are being evaluated with the ecosystem services and relative values as a benchmark, allowing for adaptive design or mitigating actions.

CASE STUDY 4 – Exploring ES in the green-blue artery of the Stiemerbeek Valley

Context

The valley of the river Stiemerbeek, in the city centre of the city of Genk, can help to reach the sustainable aim of the city council by interweaving green zones with built-up areas. The Stiemerbeek has the potential to be developed as a strong green-blue artery with a soft recreational network, which can provide links between the various strategic sites of the town and to increase the recreational and life-quality of Genk.

Objectives and scope of the project

The municipal environmental service of Genk had 4 overall goals in mind at the start of the project: (1) to search for common ground for the project in general amongst multiple sectoral administrations in Genk (e.g. spatial planning, sustainable development and environment, urban green management, social issues, sport, tourism and cultural issues, mobility, etc.); (2) to get support for the development of a shared vision for the further development of the Stiemerbeek-valley; (3) to get more concrete ES-related input (that needed to be integrated in the project definition of the "Open Call"-procedure that was initiated by the Flemish Government Architect); and (4) to start up capacity-building (in terms of increasing local knowledge regarding ES). In a first stage, these 4 goals needed to be dealt with mainly at the level of the city administrations, together with some of the major stakeholders involved, thereby hoping to establish a stronger interdisciplinary approach. In upcoming months, also the local citizens will become actively involved (during the further implementation of the next steps of the Open Call).

Rationale for a participatory approach

An ES approach was used as a guiding framework to underpin the development of a shared vision for a multi-functional river valley. In order to take into account the different needs and specific sectoral goals of the involved city administrations and other organizations, while at the same time stimulating stakeholders to think about the valley in an interdisciplinary way (which was also the overarching goal for the environmental administration of the city that initiated this initiative), a participatory approach was embedded in the process.

The process of the participatory exercise

In order to identify the most relevant ES for further discussion, a bicycle trip was organized through the valley. City administrations were invited to take part in the field trip, together with some other major stakeholders (for example NGO's as external partners in nature development). Throughout the bicycle tour, various participants were asked to explain the challenges faced or to talk about sub-projects at different halting-places. These short intermezzos were recorded and were analyzed later on by two researchers in order to identify a first list of ES. Three weeks later, a second participatory exercise was organized to prioritize these ES (with mainly the same participants). This was done in two steps. First, an individual scoring exercise took place. Based on these results, there was a second scoring exercise in small discussion groups (especially focusing the debate on those ES that had the highest variance in the individual scoring round). During this second phase, participants were also asked for their arguments. Based on these discussions and scores, the most relevant building blocks for vision-building were defined.

Outcomes of application

Most of the participants indicated that, due to both the field trip and the workshop, they became more familiar with the project area and the challenges for other stakeholders involved and that they gained insight in the multi-functionality of the river valley in particular or in other relevant topicase studies. All participants also found it important to stay actively involved in the further development of a shared vision for this project area. The results of the consultation were appended to the Open Call for the design and realization of a Green- Blue Public Park in Genk (organized in April 2015 by the Flemish Government Architect).

CASE STUDY 5 – Multi-stakeholder vision development for a mixed landscape with high natural values

Context

'De Wijers' covers 20.000 ha and is spread out over 7 municipalities in north-east Belgium. The most dominant land-uses are fish ponds, marshes, forests, heathland, grassland, residential areas and industry. The area has a big potential in terms of biodiversity, tourism, residential living, and business; but due to fragmented initiatives in the past, this potential was not fully utilized.

Objective and scope of the project

Therefore, the Provincial Government asked the Flemish Land Agency (VLM) to develop – together with all relevant stakeholders - a coherent and supported vision.

Rationale for a participatory approach

VLM (referred to as project coordinators hereunder) adopted an ES approach as a guiding framework to develop a vision for several reasons: it was felt that ES stimulate positive thinking, it was expected to enable multi-sectoral thinking, and it was considered as a suitable vehicle to achieve resilient and multi-functional landscapes. The main strategy to build a broadly-supported vision was a series of interactive participatory exercises. In total 200 people participated (mainly project partners, government agencies and NGO's). INBO was asked to support this process by providing conceptual guidance on ES and to assist in the process design.

The process of the participatory exercise

The participatory exercise was organized under the following steps: 1) Elicitation about the importance of De Wijers for the each participants, 2) based on this input, relevant ecosystems were identified by the project coordinators 3) the ES list of step 2 was compared with the CICES-Be classification (Turkelboom et al. 2014) to identify possible missing ES (by the researchers), 4) the resulting draft ES list was checked and improved with the input of project coordinators and later by the participants (during the workshop), 5) participants scored the desirability of each ES for the future (2030) for 4 different ecosystems, 6) individual scores were summarized and used as a basis for small-group discussions (esp. to find the reasons for divergent opinions), 7) a general hierarchy of ES per ecosystem was agreed upon in small groups, 8) in a second round, the hierarchy of ES per ecosystem was validated by interested participants of other groups. In a next participatory exercise, spatial plans were made based on win-win suggestions suggested by the participants.

Outcomes of application

Environmental, tourism and fishery sector were well represented among participants, whereas it was much more difficult to mobilise representatives from industry, agriculture and the social sector. From the participatory exercise, a set of priority ES for the 4 major ecosystems of De Wijers was identified together with the rational for each of these ES. The participatory exercise stimulated social learning among partners, increased understanding for other positions, enabled networking, and contributed to higher trust between stakeholders.

Appendix 4 : Example of report sent to farmers

Cover letter

Madame, Monsieur,

Comme convenu, nous revenons vers vous concernant l'étude que nous menons dans votre localité. Ce rapport regroupe les résultats obtenus durant les trois années de recherche menée par Gembloux Agro-Bio Tech en partenariat avec le Parc Naturel des Plaines de l'Escaut et l'Université de Namur. Cette recherche vise à amener des éléments de réponses quant à la faisabilité d'une réconciliation entre l'agriculture, la nature et la société dans la région de l'ouest du Hainaut. Plus précisément, cette recherche met en place une série de mesures dans des systèmes agricoles qui prétendent répondre à une telle réconciliation (dits « agroécologiques » ci-après). Afin d'avoir un point de repère, les mêmes mesures sont effectuées dans des exploitations voisines, elles restées en agriculture conventionnelle.

Cette recherche est effectuée sur trois fermes agroécologiques de la région. Pour chacune des trois exploitations une série de parcelles voisines conventionnelles sont sélectionnées, celles-ci appartenant à divers agriculteurs.

L'étude repose sur divers paramètres. La sélection de ceux-ci a reposé sur une consultation des acteurs locaux, à laquelle vous aviez été invités, qui a eu lieu le 19 mars 2015. Lors de cette consultation, nous avons discuté ensemble des paramètres qu'il serait important et intéressant de mesurer. Ceci afin de mettre en place une recherche pertinente pour la région et ses acteurs locaux.

Gembloux Agro-Bio Tech vous remercie chaleureusement pour votre importante collaboration dans le cadre de ce projet de recherche. Nous trouvons essentiel d'effectuer des mesures dans des exploitations en situation réelle en outre des expériences habituellement menées en ferme expérimentale et en conditions contrôlées. Nous espérons que le présent rapport pourra vous amener des éléments d'information intéressants. Par soucis du respect de l'anonymat des différents agriculteurs ayant participé à l'étude, ce rapport ne reprend que les données issues des mesures de votre exploitation et la moyenne des exploitations du même type que la vôtre (agroécologique ou conventionnelle).

Nous vous prions d'agréer, Madame, Monsieur, l'expression de nos sentiments les plus distingués. Nous restons à votre entière disposition si vous disposez de remarques ou questions quant aux présents résultats.

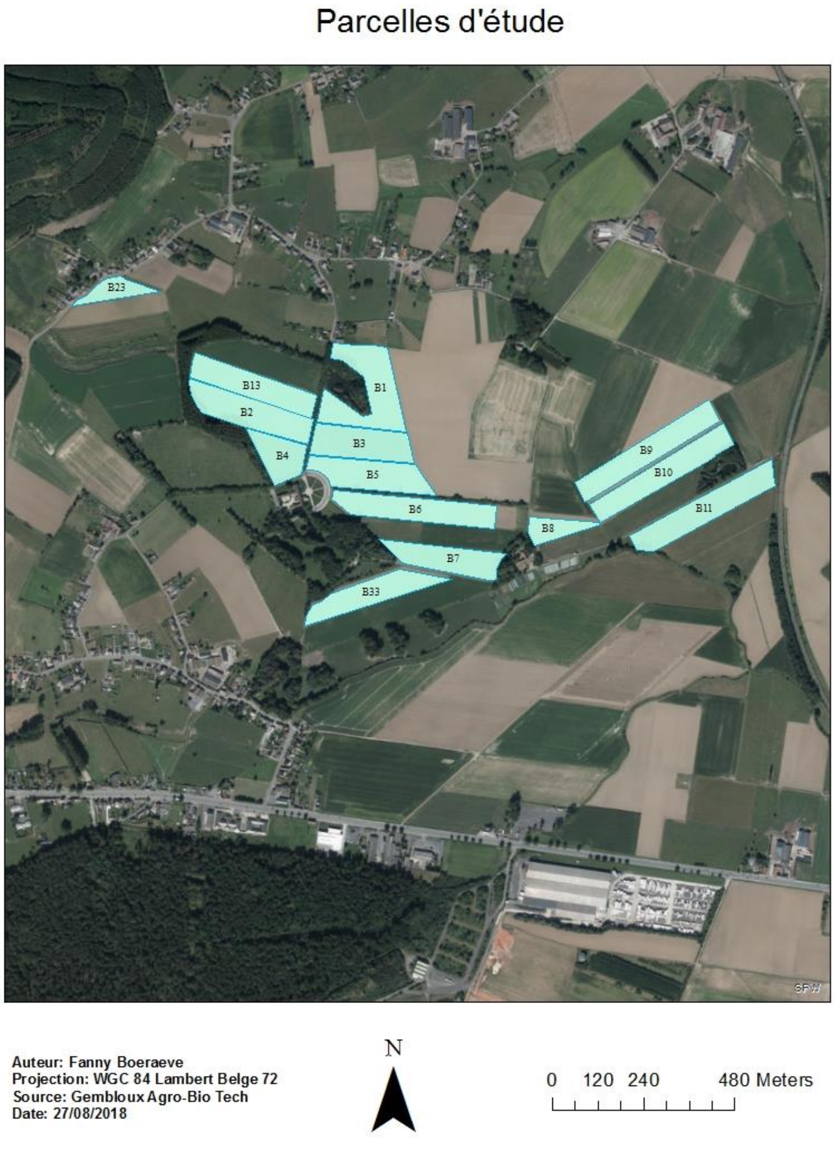
Cordialement,

Fanny Boeraeve, pour le projet « Farms4Future » de Gembloux Agro-Bio Tech

AUTEURS DU RAPPORT : FANNY BOERAEVE (DOCTORANTE ULG), MARIE-NGUYET TRAN (STAGIAIRE ULB)

RAPPORT

Ci-dessous se trouve la carte reprenant les parcelles étudiées de votre exploitation. La sélection de ces parcelles s'est basée sur 1) la culture présente (céréale) 2) son profil pédologique (profil semblable entre parcelles).



Azote potentiellement lessivable (APL)

Les nappes phréatiques et les cours d'eau sont régulièrement pollués par les reliquats azotés issus de l'agriculture. Pour évaluer le potentiel d'une parcelle agricole à contribuer à ce phénomène on mesure « l'Azote Potentiellement Lessivable ». Ceci consiste à contrôler le stock d'azote nitrique dans les 90 premiers centimètres du sol et ce, à l'automne lorsque les pluies commencent à lessiver les nitrates (Petit, 2012). Plus la réserve d'azote est grande, plus le risque de lessivage des nitrates est important, plus les eaux seront potentiellement contaminées (NitraWal, 2014).

L'APL se mesure en kg d'azote/ha. Le graphe ci-dessous reprend les résultats obtenus sur vos parcelles en 2015 et 2016.

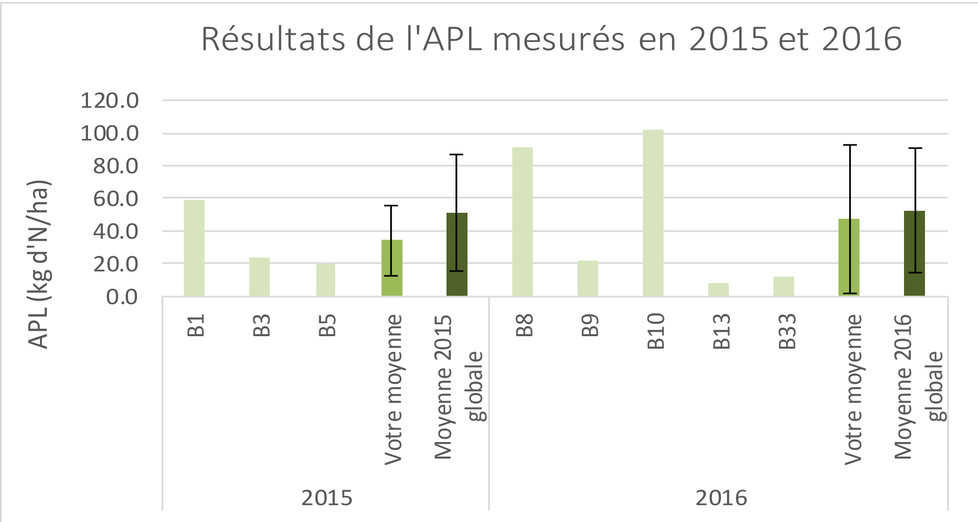


Figure 2 : Résultats de l'APL mesurés en 2015 et 2016 sur les parcelles du domaine de Graux. « Votre moyenne » est la moyenne des résultats de toutes vos parcelles. « Moyenne globale » reprend la moyenne des résultats de toutes les parcelles agroécologiques étudiées sur une année. La barre sur les bâtonnets représente la dispersion des données (écart type).

Interprétation

Avec les deux graphes ci-dessous, et sachant les prélèvements des échantillons ont été fait le 25 novembre en 2015 et le 16 novembre en 2016, nous pouvons analyser les résultats de la **Figure 1**. Lorsque le résultat d'une parcelle contrôlée figure :

sous la ligne verte (médiane) : il est qualifié de bon,

entre la ligne verte et la ligne orange (centile 66) : il est qualifié de satisfaisant,

entre la ligne orange et la ligne rouge (seuil d'intervention) : il est qualifié de « limite » ;

au-delà de la ligne rouge: il est qualifié de mauvais.

Si l'on se réfère à ces dates sur les droites ci-dessous nous constatons que la moyenne d'APL de 2015 est un résultat dit « excellent ». En effet, ce résultat (34,1 kg d'N/ha) se situe sous la droite verte de la **Figure 2** qui était à 40 kg d'N/ha au 26 novembre. Nous observons que la parcelle B1 contient davantage d'APL (58,6 kg d'N/ha). Le résultat est dit « moyen» pour cette parcelle seule. A nouveau, la moyenne d'APL pour 2016 est « excellente ». Elle se trouve bien sous la droite verte de la **Figure 3** (+/- 62 kg d'N/ha) puisqu'elle est à 46,8 kg d'N/ha. Les parcelles B8 et B10 obtiennent cependant un résultat médiocre car les résultats se situent sous le seuil d'intervention (droite rouge).

Les moyennes d'APL en 2015 et 2016 de vos parcelles sont inférieures aux moyennes de toutes les parcelles « agroécologiques » étudiées ces deux années-là (« Moyenne globale » sur la **Figure 1**) : 34,1 *vs.* 51 kg d'N/ha en 2015 et 46,8 *vs.* 52,5 kg d'N/ha en 2016. Cependant, comme l'illustre la grande taille de la barre d'erreur, ces différences sont non significatives.

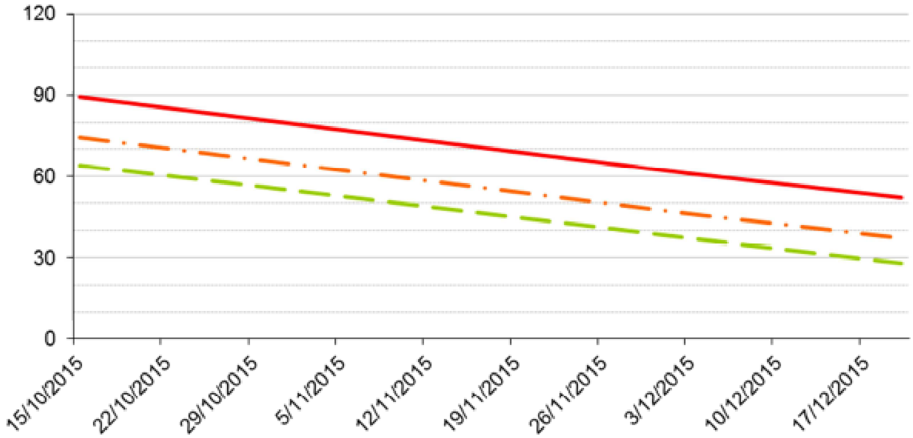


Figure 3 : Graphe de référence pour la classe A3[1] en 2015 (Vandenberghe et al., 2015). En ordonnée, le nombre de kilos d'azote par hectare.

[1] Classe A3 : obtenue par les céréales suivies d'une culture implantée en automne (froment sur froment, froment-escourgeon, froment-colza, froment-prairie temporaire (supérieur à 6mois)).

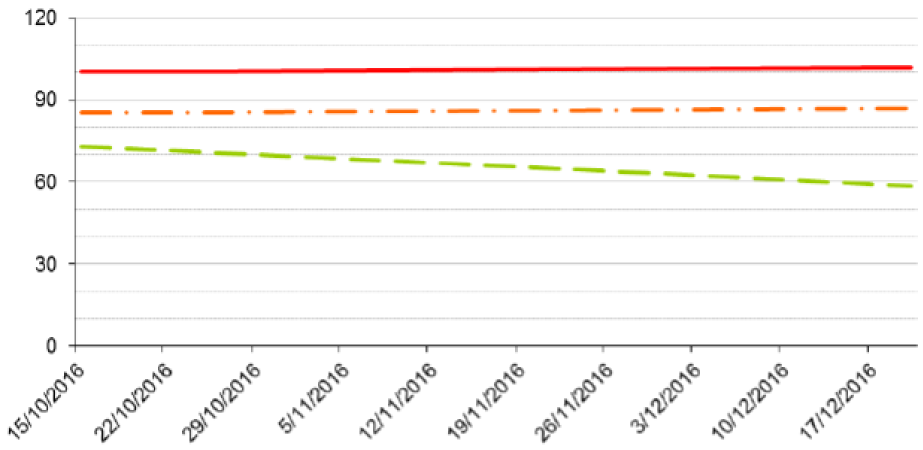


Figure 4 : Graphe de référence pour la classe A3 en 2016 (Vandenberghe et al., 2016). En ordonnée, le nombre de kilos d'azote par hectare.

Résistance du sol à l'érosion

En Wallonie, 30 % des terres agricoles sont touchées par l'érosion, avec une perte de plus de 5 tonnes de sol par hectare et par an (Service public de Wallonie, 2014). Les agrégats sont des structures formées de particules minérales (argiles et limons) et d'humus qui peuvent avoir une tendance plus ou moins importante à la désintégration sous l'effet hydrique. Une croûte de battance[2] peut alors se former et ainsi favoriser l'érosion puisque l'eau ne s'infiltrera plus de manière favorable. Pratiquement, lorsque la résistance des agrégats est faible, leur désintégration est favorisée créant plus facilement une croûte de battance favorisant l'érosion. A l'inverse, lorsque les agrégats ont une bonne cohésion interne, ils sont moins sujets à la désintégration et participent donc moins au phénomène d'érosion. L'étude menée a donc consisté à mesurer la stabilité des agrégats afin d'évaluer la sensibilité du sol à l'érosion.

Pour l'expérience, un prélèvement de 9 échantillons sur chaque parcelle a été réalisé à 0,5 centimètre de profondeur. Après les avoir séchés, les agrégats sont introduits dans un tamis. Ce dernier est ensuite immergé dans l'eau pendant 5 minutes, puis soumis à cinq mouvements d'aller-retour dans l'eau. En se rapportant au tableau 1, il est alors possible de relier la quantité de l'échantillon dissous avec une classe de stabilité de l'agrégat (de 0 à 6) (Prosensols).

[2] Croûte de battance : S'observe lorsque la surface du sol a séché après le passage d'averses éclatant les agrégats. De fines particules sont alors libérées comblant ainsi les interstices du sol.

Tableau 1 : Classes de stabilité structurale en fonction des critères de dissolution de l'échantillon (Prosensols).

Classes	Critères
0	Sol trop instable pour récolter un agrégat (tout le sol passe à travers le filtre)
1	50% de l'échantillon est dissous en 5 secondes lors de l'immersion dans l'eau
2	50% de l'échantillon est dissous entre 5 à 30 secondes après immersion
3	50% de l'échantillon est dissous entre 30 sec et 5 min après immersion ou Il reste moins de 10% de l'agrégat de départ après 5 cycles d'immersion
4	Il reste entre 10 et 25% de l'agrégat de départ après 5 cycles d'immersion
5	Il reste entre 25 et 75% de l'agrégat de départ après 5 cycles d'immersion
6	Il reste entre 75 et 100 % de l'agrégat de départ après 5 cycles d'immersion

La **Figure 5** ci-dessous, reprend les résultats des mesures effectuées sur vos parcelles en 2015 et 2016. Les résultats de la stabilité structurale sont présentés sous forme de classe : 0 signifiant un sol sensible à la battance tandis que 6 correspond à une bonne résistance du sol (Prosensols).

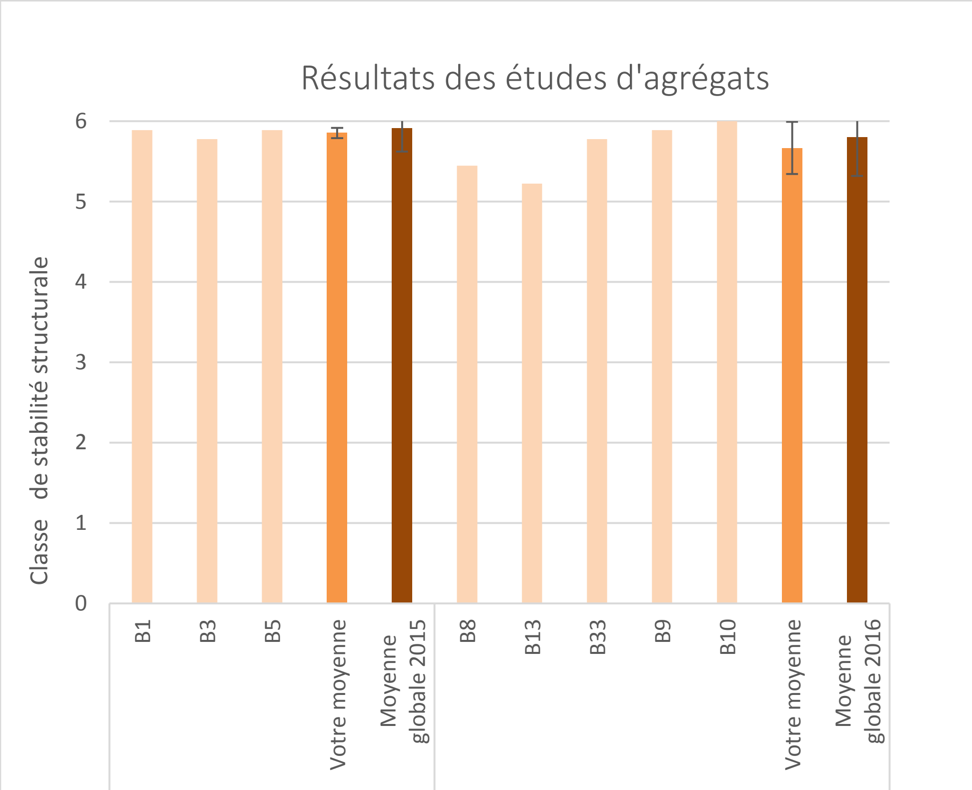


Figure 5 : Résultats de l'évaluation de la résistance des agrégats à l'érosion étudiée sur les parcelles du Domaine de Graux en 2015 et 2016. « Votre moyenne » est la moyenne des résultats de toutes vos parcelles. « Moyenne globale » reprend la moyenne des résultats de toutes les parcelles agroécologiques étudiées sur une année. La barre sur les bâtonnets représente la dispersion des données (écart type).

Interprétation

Globalement, les agrégats récoltés sur les différentes parcelles traduisent une bonne stabilité des sols qui seront alors peu sujets à l'érosion. En effet, toutes les parcelles indiquent une classe supérieure à 5. La parcelle B13 se distingue très légèrement des autres avec la classe la plus basse de 5,22. En 2015, les trois parcelles étudiées sont proches de la moyenne (5,85). En 2016, la moyenne est légèrement plus basse (5,66) et la parcelle B10 obtient la classe maximale de 6.

Les moyennes de vos parcelles en 2015 et 2016 sont inférieures aux moyennes des classes de toutes les parcelles agroécologiques étudiées ces deux années-là : 5,85 *vs.* 5,91 la première année et 5,66 *vs.* 5,80 la deuxième année.

Régulation naturelle des ravageurs de cultures

Les ravageurs de cultures peuvent causer de nombreux dégâts non négligeables. L'étude suivante se penche sur la présence plus ou moins importante d'auxiliaires indigènes pouvant éliminer naturellement les pucerons par parasitisme ou prédation.

1. Parasitisme

Le parasitisme des pucerons s'effectue notamment via les Aphidius qui pondent leurs œufs à l'intérieur du puceron. La larve se développe en se nourrissant de son hôte et en ressort en laissant derrière lui le puceron vide : une momie (**Figure 5**). Pour chaque parcelle, 20 plantes ont été prélevées afin d'en comptabiliser le nombre de pucerons sains et de momies ce qui a permis d'estimer le taux de parasitisme comme suit :

$$\frac{Nombre\ de\ momies\ sur\ la\ parcelle}{(Nombre\ de\ momies\ +Nombre\ de\ pucerons\ sains)}$$

Figure 6 : Pucerons momifiés (gros bruns) au milieu d'une colonie de pucerons sains (Pilon, 2009).

La **Figure 6** représente le nombre de pucerons sains qui ont été comptés sur les différentes parcelles étudiées. La **Figure 7**, quant à elle, montre le taux de parasitisme calculé avec la formule précédente.

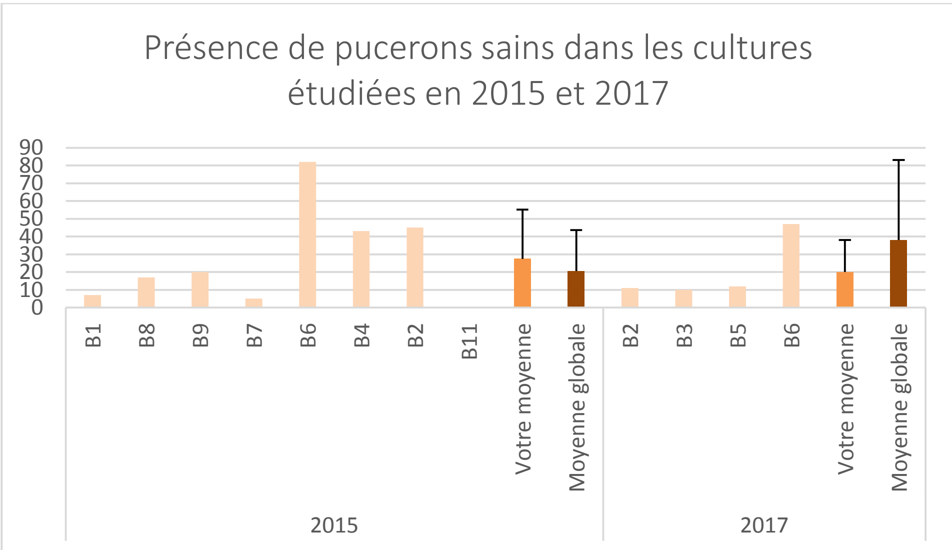


Figure 7 : Nombre de pucerons sains comptés sur 20 plantes au sein des différentes parcelles étudiées au Domaine de Graux pour les années 2015 et 2017. « Votre moyenne » est la moyenne des résultats de toutes vos parcelles. « Moyenne globale » reprend la moyenne des résultats de toutes les

parcelles agroécologiques étudiées sur une année. La barre sur les bâtonnets représente la dispersion des données (écart type).

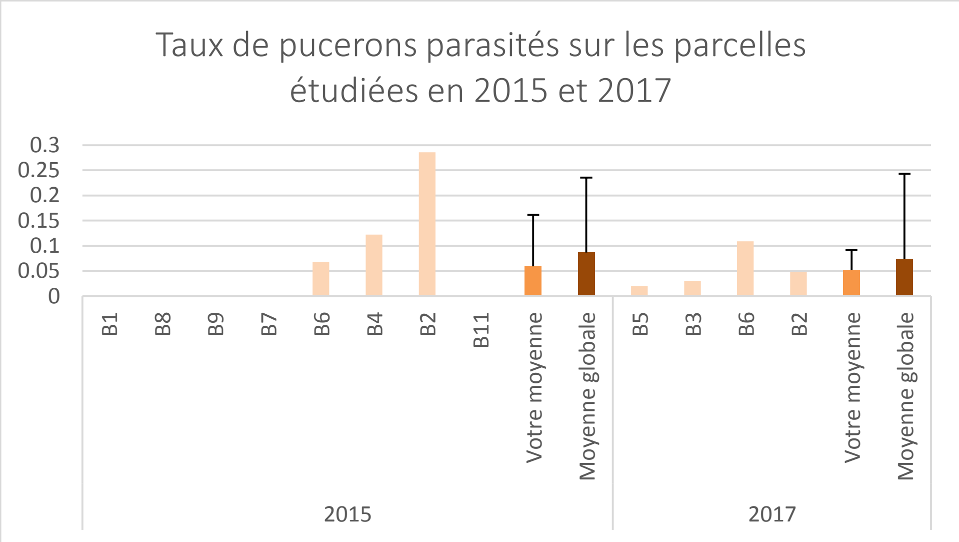


Figure 8: Taux de parasitisme calculés sur les parcelles du domaine de Graux pour les années 2015 et 2017. « Votre moyenne » est la moyenne des résultats de toutes vos parcelles. « Moyenne globale » reprend la moyenne des résultats de toutes les parcelles agroécologiques étudiées sur une année. La barre sur les bâtonnets représente la dispersion des données (écart type).

Interprétation

Globalement, peu de pucerons ont été comptabilisés sur vos parcelles, que ce soit en 2015 ou 2017. Cependant, pour les deux années la parcelle B6 semble avoir eu le nombre de pucerons plus important (82 pucerons/20plants en 2015, 47 en 2017). Aucun puceron n'a été recensé sur la parcelle B11 en 2015.

Ce faible nombre de pucerons ne semble pas être expliqué par un haut taux de parasitisme. En effet, durant les deux années d'étude, la moyenne des taux de parasitisme reste très faible : 0,05.

Au vu de la grande dispersion des données, on peut juger vos moyennes de pucerons et de parasitisme comme comparables avec les moyennes des autres parcelles agroécologiques étudiées aux mêmes années.

2. PRÉDATION

Le taux de prédation a également été calculé avec la méthode des « plaques de prédation ». Pour ce faire, trois pucerons ont été collés sur une plaque adhésive. Ces plaques ont été installées par 10 sur chaque parcelle et récupérées 24 heures plus tard. Le taux de prédation est alors calculé comme suit à l'échelle de la parcelle :

$$\frac{Nombre\ de\ pucerons\ mangés}{Nombre\ de\ pucerons\ mangés + Nombre\ de\ pucerons\ encore\ présents}$$

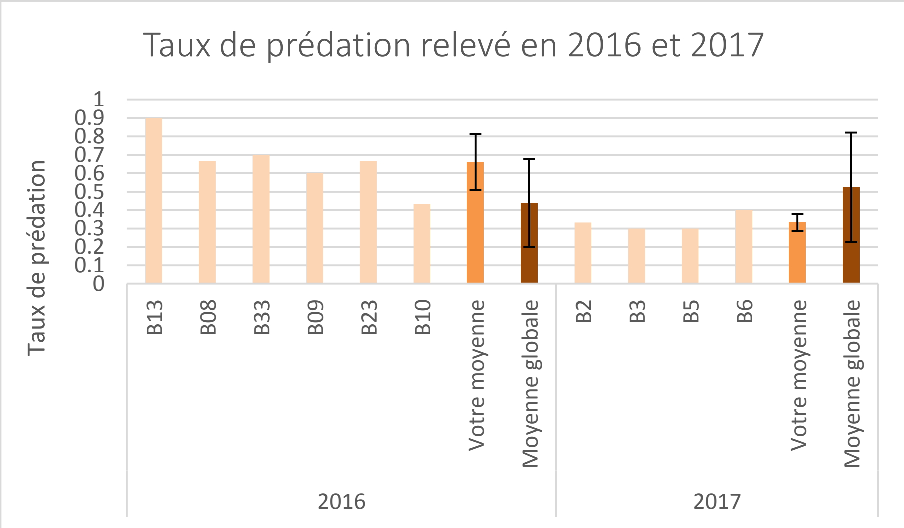


Figure 9 : Taux de prédation calculés sur les parcelles du domaine de Graux pour les années 2016 et 2017. « Votre moyenne » est la moyenne des résultats de toutes vos parcelles. « Moyenne globale » reprend la moyenne des résultats de toutes les parcelles agroécologiques étudiées sur une année. La barre sur les bâtonnets représente la dispersion des données (écart type).

Interprétation

Globalement les taux de prédation sur vos parcelles sont élevés, et ce, particulièrement en 2016 (66% en moyenne 2016 contre 33% en 2017). Ce taux élevé pourrait expliquer le faible nombre de pucerons présent sur les mêmes parcelles. Il est à noter que les données de 2016 sont à interpréter avec prudence suite à une erreur dans le protocole.

Fertilité et qualité du sol

1. Dégradation de la matière organique

La dégradation de la matière organique est importante puisque ce processus transforme des composés organiques complexes en éléments minéraux simples assimilables par les plantes et nécessaires à leur croissance (Roger-Estrade).

L'expérience a consisté à utiliser la méthode des « Bait Lamina Sticks » (Terra-Protecta, 1999). Ces « sticks » sont percés de 16 trous et remplis d'un substrat imitant le parenchyme de feuille (cellulose, flocons de son ainsi que des traces de charbon actif) (Terra-protecta, 1999). Ils sont enfoncés dans le sol à 20 centimètres et sont récupérés une dizaine de jours plus tard. Le nombre de trous vides est alors compté pour évaluer le taux de minéralisation selon la formule suivante :

$$\frac{Nombre\ de\ trous\ vides}{Nombre\ total\ de\ trous\ (16)}$$

La **Figure 9** représente ces taux de minéralisation sur les différentes parcelles étudiées en 2015 et 2016.

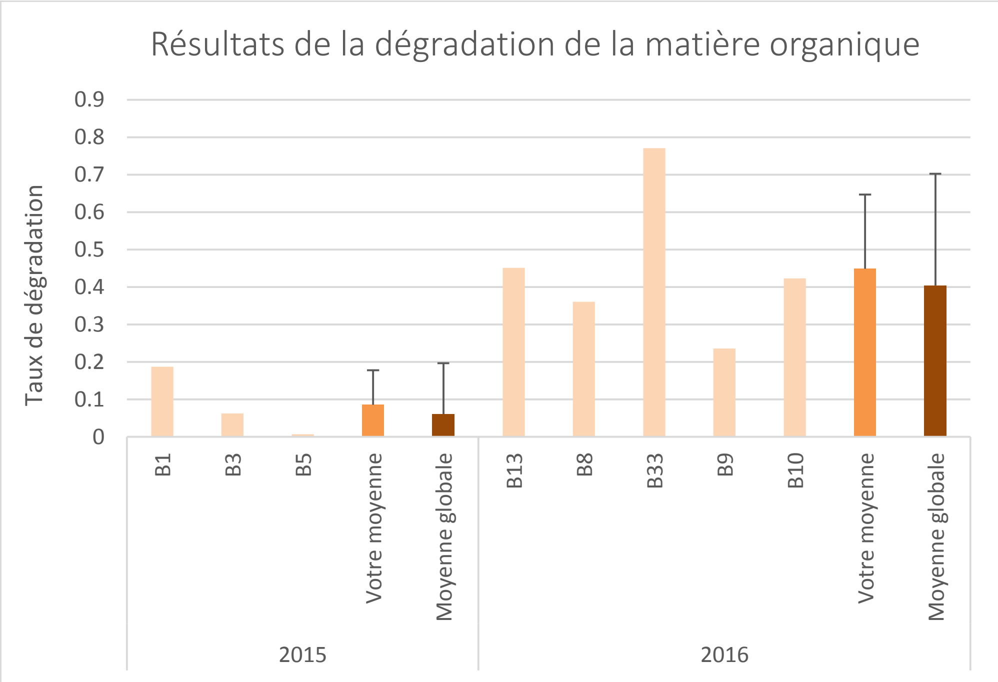


Figure 10 : Taux de dégradation de la matière organique présente dans les sols du Domaine de Graux étudiés en 2015 et 2016. « Votre moyenne » est la moyenne des résultats de toutes vos parcelles. « Moyenne globale » reprend la moyenne des résultats de toutes les parcelles agroécologiques étudiées sur une année. La barre sur les bâtonnets représente la dispersion des données (écart type).

Interprétation

Observons sur la **Figure 9** que la matière organique présente dans le sol s'est mieux dégradée en 2016 (44,9% en moyenne) qu'en 2015 (8,6 % en moyenne). Ceci peut s'expliquer par le fait que la période durant laquelle l'échantillonnage fut effectué en 2015 était une période très sèche, ce qui est connu pour ralentir les processus de dégradation dans le sol. Les résultats de 2015 sont donc à interpréter avec prudence tandis que ceux de 2016 montrent des taux de dégradation intéressants. Ceci est donc probablement indicateur d'une bonne qualité de sol pour la culture.

Vos moyennes de taux de dégradation en 2015 et 2016 sont globalement similaires à ceux des autres parcelles agroécologiques étudiées durant ces deux années.

2. PRÉSENCE DE VIE DANS LE SOL

La respiration du sol des parcelles étudiées a été mesurée afin de connaitre l'importance de l'activité microbiologique s'y trouvant. Ainsi, 40 grammes de sol d'une parcelle ont été mis dans un bocal hermétique en présence d'une solution de NaOH (**Figure 10**) dont la conductivité électrique a été mesurée au fil du temps. En effet, lorsque les microorganismes respirent, le CO_2 émis dans le bocal réagit avec le NaOH et en modifie sa conductivité électrique. La quantité de CO_2 relâché peut être connue grâce à la conductivité électrique du NaOH et du Na_2CO_3 avant de commencer l'expérience puisqu'elle se base sur la réaction suivante : $2\ NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$

Figure 11: Bocal hermétique contenant 40 grammes d'échantillon de sol ainsi qu'une solution de NaOH.

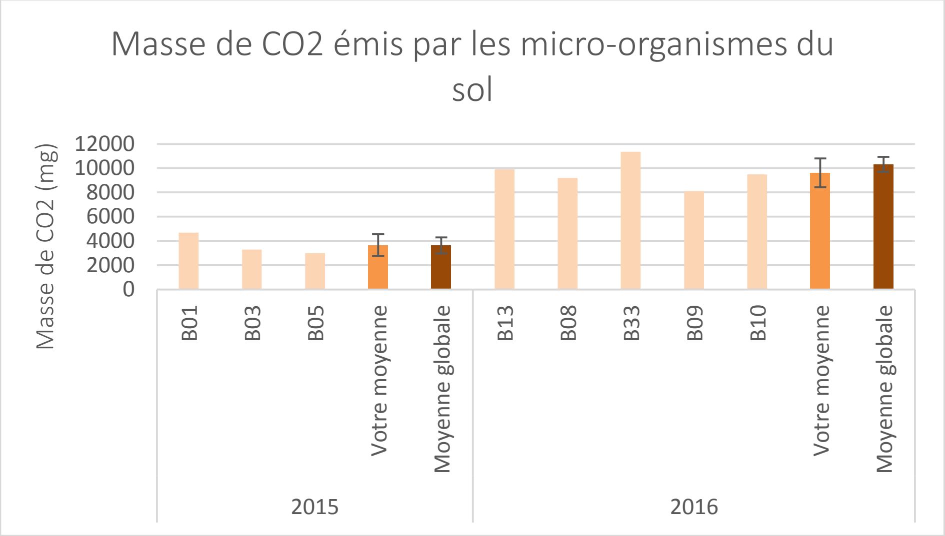


Figure 12 : Masse de CO_2 émis par les micro-organismes du sol en 2015 et 2016. « Votre moyenne » est la moyenne des résultats de toutes vos parcelles. « Moyenne globale » reprend la moyenne des résultats de toutes les parcelles agroécologiques étudiées sur une année. La barre sur les bâtonnets représente la dispersion des données (écart type).

Interprétation

La **Figure 11** révèle que plus de CO_2 a été émis par les micro-organismes en 2016 par rapport à 2015. Ceci révèlerait que davantage d'activité biologique était présente lors de la deuxième année d'étude, ce qui correspond aux résultats ci-dessus et confirme l'hypothèse que la sécheresse de 2015 pourrait expliquer une présence/activité moindre des micro-organismes dans le sol. Vos moyennes sont globalement similaires à celles des autres parcelles agroécologiques.

Rendement

Lors de ces trois dernières années, des études de rendement ont également été entrepris. Ainsi, 4 x 1m² ont été récoltés sur les parcelles analysées. L'échantillon étant très petit, ces mesures ne sont en aucun cas comparables à vos mesures de rendement. En effet, vos mesures se basent sur une autre méthode ainsi que sur un plus grand échantillon, et sont donc susceptibles d'aboutir à des résultats très divergents. Les résultats de rendement de ce rapport ne servent donc qu'à être comparés entre eux et ne fournissent pas une assez grande précision que pour être interprétés dans l'absolu. La paille et les grains ont été séparés et le graphe suivant a été obtenu en calculant le poids sec pour la paille et le poids sec à 15% d'humidité pour les grains.

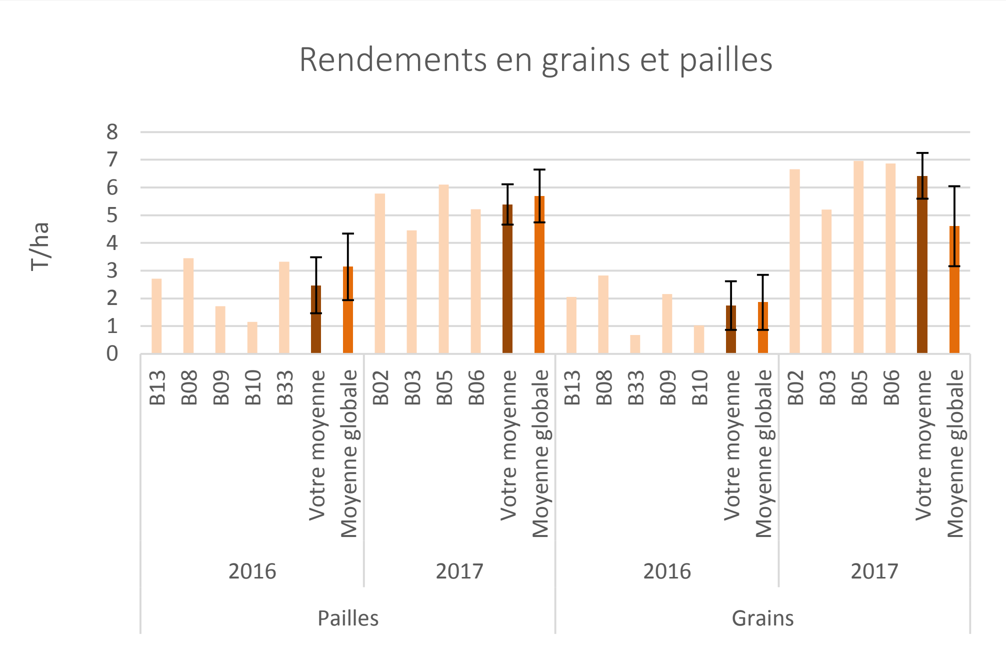


Figure 13 : Rendements en grains et pailles des parcelles du domaine de Graux étudiées en 2016. « Votre moyenne » est la moyenne des résultats de toutes vos parcelles. « Moyenne globale » reprend la moyenne des résultats de toutes les parcelles agroécologiques étudiées sur une année. La barre sur les bâtonnets représente la dispersion des données (écart type).

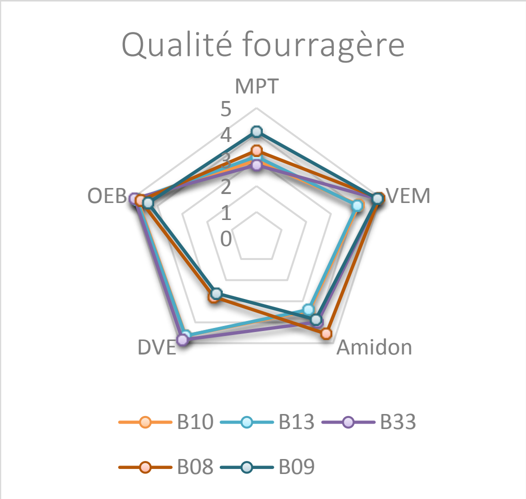
Interprétation

Nous constatons sur la **Figure 12** que la parcelle B8 obtient le meilleur rendement pour l'année 2016, et ce, pour le rendement pailles et grains. Cependant, les rendements restent relativement bas en 2016 : 2.47T/ha en moyenne pour les pailles et 1.7T/ha pour les grains. Ces rendements bas ont aussi été relevés dans les autres fermes agroécologiques de l'étude comme en témoignes les moyennes globales : 3.1T/ha pour les pailles et 1.8T/ha pour les grains. L'année a, en effet, été mauvaise comme stipulé dans le Livre Blanc « Céréales » de septembre 2016. En 2017, vos rendements sont nettement supérieurs avec 5.4T/ha pour les pailles et 6.4T/ha pour les grains.

Qualité fourragère

Les grains récoltés ont ensuite été analysés par l'asbl « Objectif Qualité » qui en ont mesuré divers indices de qualité fourragère. Le graphique en radar ci-dessous reprend cinq indicateurs intéressants à relever. Ainsi, nous avons repris les VEM (VoederEenheid Melk) qui évaluent les besoins en énergie des ruminants. La valeur alimentaire DVE représente, quant à elle, les protéines digestibles dans l'intestin grêle des ruminants. L'OEB (Bilan des protéines dégradables au niveau du rumen) indique l'équilibre entre les composés azotés et énergétiques d'une ration. Enfin, la MPT reflète la capacité qu'a un aliment à fournir des acides aminés utilisables par l'animal tandis que l'amidon est une des sources d'énergie pour l'animal. Ces deux dernières valeurs s'expriment en % MS (Decruyenaere et al., sans date).

Afin de pouvoir rendre compte de ces différents indices sur le même graphique, les données initiales ont été traduites en scores allant de 0 (mauvais) à 5 (très bon). Ces scores sont attribués de manière relative à l'ensemble des mesures effectuées dans la même année.



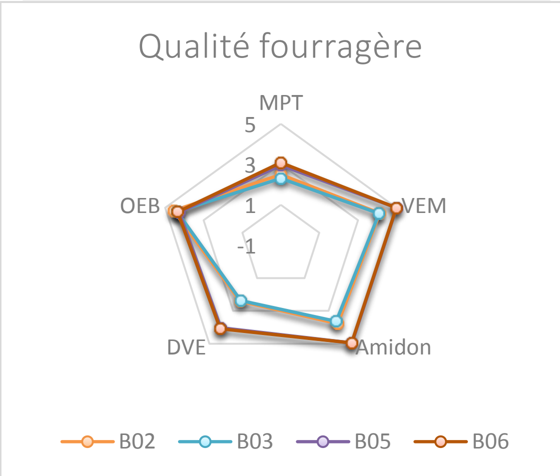


Figure 14 : Différents indices donnés aux fourrages récoltés en 2016 (gauche) et 2017 (droite) au Domaine de Graux.

Interprétation

Il ressort de la **Figure 13** que la parcelle B9 obtient le meilleur score pour tous les indices mise à part l'amidon. Voici un tableau récapitulatif avec les valeurs exactes des différents indices fourragers.

Tableau 2 : résultats des analyses qualité pour 2016 et 2017. MS=Matière sèche.

2016	Graux B8	Graux B9	Graux B33	Graux B10	Graux B13
VEM (/kg MS)	1175,81236	1158,63549	1160,24403	979,397954	964,437433
DVE (g/kg MS)	77,60	80,04	71,57	56,95	57,99

OEB (g/kg MS)	-24,95	-4,31	-36,60	-20,71	-17,84
MPT (%MS)	10,79581 98	13,15610 08	9,008165 74	9,63	10,07
Amidon (%MS)	64,96983 18	55,26631 17	56,89784 37	49,17	48,61

2017	**Graux B2**	**Graux B3**	**Graux B5**	**Graux B6**
VEM (/kg MS)	995,26387	987,859927	1205,3448 1	1203,395 74
DVE (g/kg MS)	53,8073642	52,9807314	90,440724 1	91,4958215
OEB (g/kg MS)	-18,35	-24,95	-29,09	-25,79
MPT (%MS)	9,5917263	8,8377781	11,371235	11,8077102
Amidon (%MS)	55,16427 99	53,0953789	72,313861	72,2899808

Globalement, toutes les parcelles fournissent des fourrages de qualités aux animaux tant au niveau énergétique que protéique. L'OEB négatif signifie que la ration serait un peu plus riche en énergie qu'en azote. En 2016, les parcelles B8, B9 et B33 fournissent plus de VEM/kg MS. Les acides aminés nécessaires aux animaux seront plus facilement fournis par un fourrage issu de la parcelle B9. Ceci pourrait s'expliquer par le fait qu'en plus de l'avoine, pois et triticale, la parcelle contenait également de l'épeautre. Enfin, les céréales présentes sur la parcelle B8 semblent plus riche en amidon que les autres parcelles. Remarquons que lorsque la teneur en amidon est importante, le pourcentage de MPT diminue et inversement. En 2017, les fourrages fournissaient moins d'acides aminés utilisables par l'animal.

Perméabilité du sol

L'eau doit pouvoir s'infiltrer de manière optimale sur les parcelles. C'est pourquoi, l'étude de la perméabilité du sol est essentielle. L'expérience débute par la mise en saturation de l'échantillon de sol prélevé sur le terrain. Après cette étape, l'échantillon est inséré dans un perméamètre. Cet appareil permet de calculer la vitesse avec laquelle de l'eau traverse le sol. Le coefficient K de perméabilité peut alors être calculé (Becquevort, 2013). Ils sont repris sur le graphique ci-dessous et exprimés en cm/s.

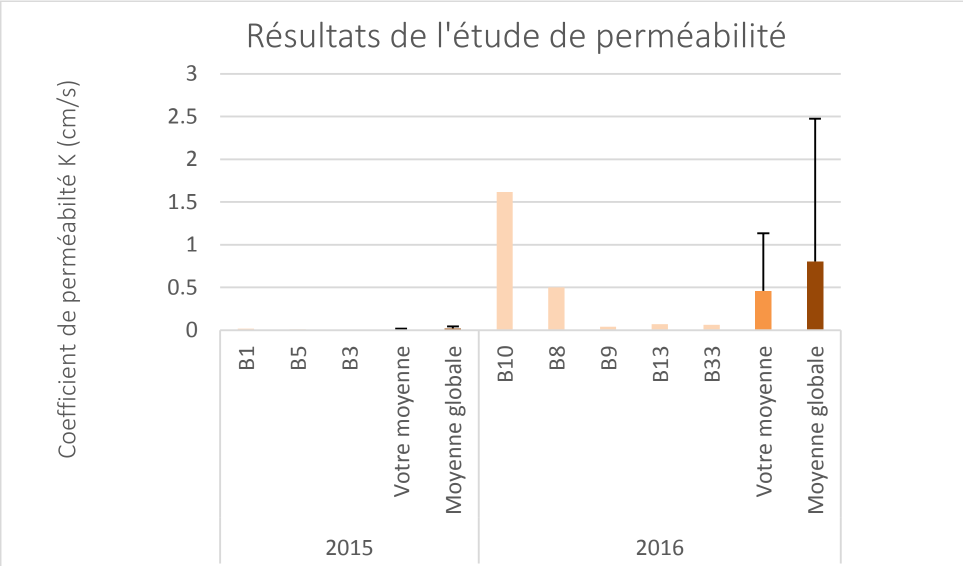


Figure 15 : Différents coefficients K de perméabilité calculés sur plusieurs parcelles en 2015 et 2016. « Votre moyenne » est la moyenne des résultats de toutes vos parcelles. « Moyenne globale » reprend la moyenne des résultats de toutes les parcelles agroécologiques étudiées sur une année. La barre sur les bâtonnets représente la dispersion des données (écart type).

Interprétation

En 2015, nous observons que la moyenne des coefficients de perméabilité est de 0,012 cm/s. Ceci correspond à un sol fortement perméable (FAO, sans date) et donc peu enclin à des problèmes d'inondation. Le drainage est alors favorable au sein des trois parcelles étudiées. En 2016, la moyenne des coefficients K est de 0,46 cm/s. Cette moyenne est élevée car la parcelle B10 semble avoir une forte perméabilité. En effet, son coefficient K est de 1,6 cm/s).

Sur les deux années, vos moyennes rejoignent les moyennes globales des autres parcelles conventionnelles.