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ABSTRACT

We performed a quantitative and qualitative analysis of the scientific literature on ecosystem services in order to help tracing a research agenda for agricultural sciences. The ecosystem services concept now lies at the heart of current developments to address global environmental change. Do agricultural sciences generate knowledge that covers this emerging theme? An analysis of scientific production allowed us to return to the ecological origins of this concept and see how little it has been appropriated by agricultural sciences until now, despite major focus on the issue of agro-ecosystems in the literature. Agricultural sciences tend to be more active in the field of environmental services, defined as services rendered by humans to ecosystems. The main studied services are those which have already been clearly identified and which act in synergy. Less attention is paid to the antagonisms between different services. These findings call for the implementation of agricultural research programmes that will consider the socio-agro-ecosystem as a whole and broaden the traditional issues addressed by agricultural sciences. We insist on three main management and operational issues that needs to be overcome if this is to be done: working at the landscape scale, increasing inter-disciplinary collaborations and take uncertainties into account.

Contents

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1. Introduction

1.1. Genealogy of the concept

The concept of ecosystem services is both a field for research and a sector for policy (Hill et al., 2013). According to Vihervaara et al. (2010) and Barnaud et al. (2011), the idea of the services rendered to humanity by ecosystems developed at the end of the 1970s. Its dissemination throughout science, expertise and public debate resulted from its institutionalisation in 1992 through the Rio “Earth Summit”, which laid the foundations for the preservation of biological diversity and protection of the environment in international law. International initiatives concerning ecosystem approaches were announced in 1996 by the United Nations in the context of implementing the Convention on Biological Diversity, but the operational use of this approach in terms of ecosystem services only took form in 2004 in the context of a UN programme led by a group of international scientific experts, designed to better identify and evaluate the importance of ecosystems to human well-being: the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2005, Chap. 1, p. 27). This report ratified a definition that had already been proposed by Daily et al. (1997): “*Ecosystem services are the benefits people obtain from ecosystems”*. Publication of the MEA was followed by a very marked rise in the number of scientific publications focused on this theme (Jeanneaux et al., 2012), and reflecting inclusion of the ecosystem service concept in numerous initiatives and international platforms such as the IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services), the SGA-Network (Sub-Global Assessment Network, operated by the United National Environment Programme, UNEP), or the implementation of evaluation and mapping programmes at a national or continental scale, such as the European MAES working group (Mapping and Assessment of Ecosystems and their Services, in support to the EU Biodiversity Strategy to 2020; European Commission, 2011; Maes et al., 2013), or several other national evaluations (e.g. Countryside Council for Wales, 2011). The development of those platforms and programmes trigger new insights, resources and subsequent organisational work for conservation sciences and strategies (Granjou et al., 2014).

In the same way that the concept of ecosystem services took some time to become a reality, the issues of agricultural biodiversity announced in 1996 under the UN process were only the subject of few working programmes during that decade, which saw the initiation of international public actions to defend biodiversity (the 2000 CBD Programme of Work). This international initiative was accompanied by regional commitments such as the Kyiv Resolution that endorsed the emerging role of the Pan-European Biological and Landscape Strategy in order to implement the CBD strategy. In the late period the concept itself is a matter of discussions crossing the boundaries of science and policy and reflecting on the weakness of some concepts and on the scope of the ecosystem services framework (Lele et al., 2013).

1.2. An opportunity for agricultural sciences

Linked to questions regarding the protection of biodiversity, the ecosystem service concept has been widely used to describe the services rendered by so-called “natural” ecosystems that are currently little impacted by human activities and frequently linked to defending natural resources or introducing sanctuaries to cover certain environments (e.g. wooded areas, natural grasslands, and wetlands). The ecosystem service concept has thus been little applied outside so-called conservationist approaches, although agriculture has tried to render its production systems more environmentally friendly – to varying degrees depending on the country – and notably relative to the issue of water pollution by nitrates or pesticides, or the contamination of soils. More recently, definitional discussion and ecosystem services classifications have included more clearly agriculture within their ontologies, including biomass resources for industrial uses (see, for example, CICES, 2013).

But agriculture could be seen as managing a large proportion of continental ecosystems, which occupy 40% of land on our planet. At this scale, the concept of the services rendered by agro-ecosystems is still only referred to implicitly in political initiatives impacting agriculture, and notably in Europe: the programme to control global warming (with an EU target of reducing net greenhouse gas emissions by 20% between now and 2020, http://ec.europa.eu/clima/policies/package/index_en.htm), or greening of the Common Agricultural Policy (upcoming reform to the first pillar, http://www.europarl.europa.eu/news/en/news-room/content/20130923IPR20606/html/CAP-reform-deal-MEPs-ensure-significant-improvements-in-future-farm-policy). At the same time, agriculture finds itself caught between maintaining or even increasing production in order to ensure global food security, an objective which often forgets the question of the solvency of demand or the quality of food supplies linked to public health targets, and the environmental nuisances it causes and that society or the ecosystems themselves can no longer withstand (erosion, eutrophication, pollution, etc.). Agriculture is therefore more than ever confronted by contradictory imperatives that could be addressed simultaneously through the ecosystem service concept, once this concept does not become a paragon for greening: to guarantee the supply of consumer goods (food, wood, drinking water, etc.), to supply new services such as the control of climate change or flooding, and to preserve the functional capacities of ecosystems, notably linked to biodiversity. This constitutes a paradigm shift in agriculture–environment relations reflected by the ecosystem service concept, from a vision of minimising the impacts linked to agriculture towards a systemic vision of managing natural resources in partnership with all stakeholders. In this context, study of the synergies, antagonisms and compromises between ecosystem services becomes a major challenge for agricultural sciences (Power, 2010; Brouwer et al., 2013). They must take account of both ecological and human processes, as testified by the emergence of the term socio-ecological systems (Gallopín et al., 1988) and thus reorient their work within an unrestricted, cross-disciplinary dialogue and form part of all the scientific communities that are focusing their efforts on the major issues of climate change and sustainability. This repositioning nevertheless implies the conceptualisation of management methods and decision-making guidelines, which at present remains a considerable challenge, notably in order to place a non-monetary value on the social and cultural characteristics of ecosystem services (Chan et al., 2012; Satz et al., 2013).

1.3. *Objective of the study*

Clark (2001) and Cash et al. (2003) highlighted the challenge faced by decision-makers in trying to render knowledge systems more consistent with the objectives of sustainable development. Evaluations and collective expert reports issued by different institutions or resulting from international initiatives have referred to the same problem. Numerous fields of technological research have thus been impacted (ICSU, 2005), including agricultural sciences, taking over from previous research and development orientations that focused on alternative farming practices (Edens et al., 1985).

Furthermore, we are currently seeing a growing trend towards the mobilisation of bibliometrics to reconstruct the epistemic and institutional trends of knowledge production regimes, resulting from a greater accessibility to the world-wide web of research available to researchers and managers (Meyer and Schroeder, 2009). Profit could be drawn from this situation to support the design and deployment of research agendas in a perspective of sustainable development. Bibliometric evaluations of the state of research on ecosystem services have already been performed (Vihervaara et al., 2010; Seppelt et al., 2011; Yang et al., 2011; Blouin et al., 2013; Laurans et al., 2013): evaluations of the number of articles published, the importance of the different services, ecosystems or geographical regions studied, etc. However, they have either focused on a country (China; Yang et al., 2011), a taxon (earthworms; Blouin et al., 2013), or a given theme (economic valuation; Laurans et al., 2013), or were performed on a limited corpus (153 publications for Seppelt et al. (2011), and 353 publications and 687 publications for Vihervaara et al. (2010)). As a result, no study has yet sought to perform a large-scale analysis of the literature on ecosystem services using a quantitative yet detailed approach. As a follow-up from Vihervaara et al. (2010), we feel that this work is important in order to identify past and present epistemic trends, and then place them in a foresight context.

We therefore propose here a quantitative and qualitative analysis of the scientific literature on ecosystem services, based on a corpus extracted from the *Web of Science*, in order to address a scientific policy issue with respect to agricultural sciences, but that could extend to other domains. Do agricultural sciences generate knowledge which covers the emerging theme of ecosystem services? In other words, is the ecosystem services turn impacting a research domain, which is at stake both in the framing of causes of environmental damages and in the present search for agroecological transition? We propose to address this issue through three questions of major importance regarding deployment of agricultural sciences: (1) are agricultural sciences and agro-ecosystems represented to a significant degree in the theme of ecosystem services? (2) Has a specific approach been identified to generate new scientific issues and fieldwork? (3) Do publications in the literature on ecosystem services consider the study of several services at the same time and the issue of trade-offs between services?

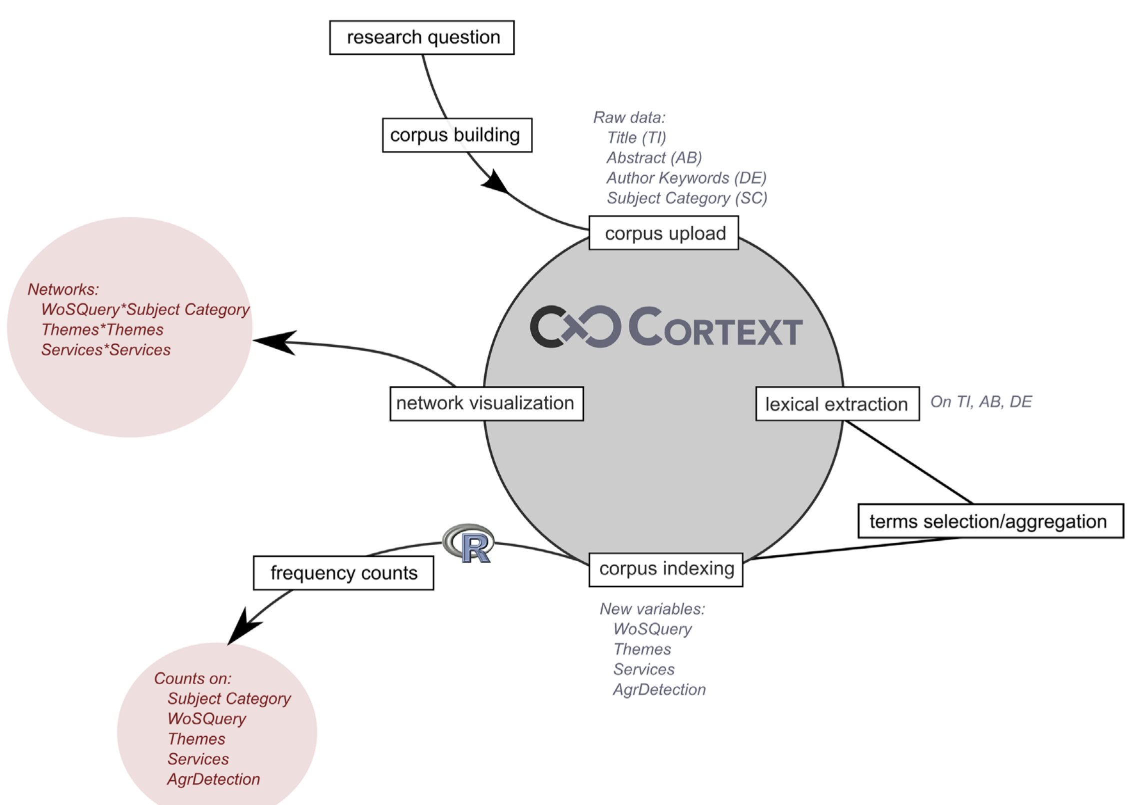

Fig. 1. Diagram of the procedure followed.

2. Material and methods

Analysing and understanding the emerging structure of major knowledge databases constitutes the epistemic project of the field of "big data" that affects all disciplines. In this context, tracing and mapping the structure and organisation of knowledge represents a major challenge for social studies of science, where an understanding of the social and cognitive dynamics of research activities is a necessary gateway (Cambrosio et al., 2004, 2006; Bourret et al., 2006; Bonaccorsi, 2008). Today, evolutions affecting the analysis of scientific dynamics are to a great extent driven by the issue of characterising the cognitive dynamics of knowledge production (Powell et al., 2005). The question of the emergence of multi- or cross-disciplinary research fields is also crucial (Lucio-Arias and Leydesdorff, 2007). Thus, the theoretical issues underlying the reconstruction of evolutions in long-range scientific fields are obstacles that need to be overcome (Chavalarias and Cointet, 2013). In this context, network analysis plays a very important role in the scientific characterisation of research fields such as ours. In order to model socio-semantic dynamics based on a corpus of texts (Cointet, 2009), it is necessary to link several instruments. A software platform called CorTexT was developed, (http://www.cortext.org) notably for that purpose, with an online interface: CorTexT Manager (http://manager.cortext.net/). Fig. 1 shows how the CorTexT Manager was used for the analyses. The R software (R Core Team, 2012) supplemented these analyses for certain types of data processing.

Scientometric analysis can be described as having different successive phases. A corpus of references relative to the ecosystem service concept was built up using a query containing several synonyms of the concept. Based on this corpus, a lexical extraction made it possible to obtain lists of terms corresponding to the themes and services studied. Categorisation and sorting by experts of the terms obtained enabled homogenisation of their denomination. An indexing phase then permitted identification of the occurrences of these terms in the corpus. While a frequential description helped us to evaluate the importance of the different synonyms employed for this concept, and the importance of agricultural sciences and the services studied in the corpus, visualisation of the network of terms permitted an analysis of the disciplinary origin of the different synonyms for "ecosystem service", and characterisation of the thematic groups and range of services studied simultaneously. The different phases of the analysis listed above are described in more detail below.

2.1. Constitution of the corpus

The resource used most in scientometrics is the Thomson-Reuters *Web of Science* portal. It provides access to databases with multidisciplinary coverage, including 12,000 journals and 148,000 reports from conferences in the different fields of science (Science Citation Index Expanded, SCIE), the social sciences (Social Sciences Citation Index, SSCI), and the arts and humanities (Arts & Humanities, A&H). We chose to use the three *Web of Science* databases. Given the existence of numerous synonyms for the concept of ecosystem services, the search term was constructed by crossing, one by one, the different synonyms existing for "service" and "ecosystem" (and variations in their spelling)

{ *ecosystem*, *agrosystem*, *environmental*, *agroenvironmental*, *ecological*, *agroecological*, *landscape*, *land*, *landuse* }	X	{ *service*, *function*, *good*, *amenity* }

Construction of the list of synonyms was based on different studies (De Groot et al., 2002; Lamarque et al., 2011; Jeanneaux et al., 2012; Le Roux et al., 2012). The precise content of the search term is shown in Appendix A. The search term used for the *Web of Science* (SCI, SSCI, A&HCI) produced 12,184 references during the period 1975–2012. Taking account of the Convention on Biological Diversity (1992) and Millennium Ecosystem Assessment (2005) publications, this total corpus could be broken down into 11,915 documents covering the period from 1993 to 2012, and 9027 applicable to the period between 2006 and 2012. Four bibliographical fields used in this were the *Title* (TI), *Author Keywords* (DE), *Abstract* (AB) and *Subject Category* (SC) fields. The SC field corresponded to one or more disciplinary keywords attributed by the *Web of Science* to each reference in its database, based on a predefined list of 151 *Research areas*: (http://images.webofknowledge.com/WOKRS510B3_1/help/WOS/hp_research_areas_). In our case, we focused in particular on the research area *Agriculture*, which groups the *Web of Science* categories *Agriculture Economics & Policy*; *Agriculture Engineering*; *Agriculture*, *Dairy & Animal Science*; *Agriculture*, *Multidisciplinary*; and *Agronomy*, *Horticulture*, *Soil Science*. The TI and SC fields appeared to be completed for all the references. The total corpus was also satisfactorily compliant regarding the AB (98%) and DE (84%) fields.

2.2. Terminological extraction of multi-terms

The lexical extraction proposed by CorTexT generates lists of normalised nominal groups (the multi-terms are grouped as a function of their root form, so that plural and singular forms of an expression only constitute a single lexical entity, etc.). This was performed on the full text of the *Abstract* and on the *Author Keywords* field. We retained all multi-terms with a minimum frequency of 8 (i.e. corresponding to 1‰ of the corpus) and then sorted their occurrence: with a number of occurrences higher than eight, 4534 terms were extracted from the AB field, and 623 keywords from the DE field. Of these, 223 terms were common to the keywords and abstracts, which gave a total of 4934 terms (6% of mono-terms, 82% of bi-terms, 12% of multi-terms with more than two terms).

2.3. Categorisation and sorting of the terms extracted

The terms obtained were sorted into eleven exhaustive categories, which emerged during the sorting process and referred to (1) services, (2) harmful effects (e.g. *biodiversity loss*, *extreme events*), (3) actors (e.g. *stakeholders*, *farms*), (4) societal issues (e.g. *economic consequences*, *poverty*), (5) the notion of management (e.g. *management*, *agricultural practices*), (6) the notion of governance (e.g. *policy*, *legislation*), (7) the notion of future (e.g. *sustainability*, *goals*), (8) ecosystems, (9) organisms, (10) geographical areas, and (11) methods. We chose not to retain the terms in categories 8–11 because their analysis did not form part of our study objectives. Several typologies have been proposed to formalise the classification of ecosystem services suggested by the MEA (e.g. De Groot et al. (2002), Boyd and Banzhaf (2007), Wallace (2007), Fisher et al. (2009), Haines-Young and Potschin (2010) and CICES (2013)). In our case, we used the definition and classification proposed by Fisher et al. in order to compile our categories of services. These authors separated the notion of ecosystem service from that of benefits obtained by humans: "*ecosystem services are the aspects of ecosystems utilised (actively or passively) to produce human well-being*" (p. 645). They then made a distinction between intermediate services (not used directly by humans) and final services that are used directly by humans: "*nutrient cycling is a process in which one outcome is clean water. Nutrient cycling is a service that humans utilise, but indirectly. Clean water provision is* *also a service that humans utilise, but directly. Clean water, when consumed for drinking, is a benefit of ecosystem services*" (p. 646). Our categorisation of services was verified by six experts working independently. New intermediate services appeared and enriched those defined by the MEA: *resilience*, *resistance*, *stability*, *recovery*, *regeneration*, *adaptation*, *habitat provisioning*, *reproduction*, *biodiversity increase*. An example of the grouping of terms is shown in Appendix B for the service *Climate regulation*. It should be noted that we chose not to consider the term *biodiversity per se* as a service but as a property of ecosystems that underpins ecosystem services (Lele et al., 2013). In total, 1305 terms were thus retained and then grouped into 152 sub-categories that complied as far as possible with the initial formulations.

2.4. Indexing of textual fields

Indexing enables the detection of articles containing the terms retained and their annotation using the terms in question. An initial indexing was able to identify the terms of the *Web of Science's* query that were present in each article (new field called WoSQuery generated from TI, DE and AB). A second indexing was then performed using the 152 sub-categories previously identified (new field called Themes, generated from DE and AB). This field was completed for 97% of the corpus, a hit rate indicative of how well this list of themes reflected the corpus. A third indexing was then made, which only retained the terms determining services (a new field called Services, generated from DE and AB, with a completion rate of 67%). A fourth and final indexing was then able to identify the documents containing motifs such as *agr** or *farm** or even *forest** in order to evaluate the importance of agricultural environments in the corpus (a new field called AgrDetection generated from TI, DE or AB, with a completion rate of 43%).

The corpus was then subjected to two types of analysis: frequential analysis on the one hand, and the visualisation of co-occurrence networks on the other. Counts were used to calculate the frequency of (1) different synonyms for "ecosystem service" (WoSQuery field), (2) the principal themes considered (Themes field) and (3) the services studied (Services field). The maps were used to analyse (1) the disciplinary origin of the different synonyms, (2) the links between the themes considered, and (3) the ranges of services studied simultaneously.

2.5. Frequential description of occurrences

The importance of the different synonyms for "ecosystem service" (Query field), the different themes studied (Themes field) and the different disciplines concerned (SC field) were measured by counting their occurrences. For example, a publication indexed under both ecology and conservation biology counted for one in each of these disciplines. The numbers obtained where then compared against the total number of publications in the corpus or the number of documents indexed, depending on the case. An example of this is shown in Fig. 2-A. These lexical analyses were performed using a script developed under R (R Core Team, 2012).

2.6. Calculation and visualisation of networks

The disciplinary origin of the different synonyms for the "ecosystem service" concept, the links between the themes considered and the ranges of services were studied using co-occurrence maps for the terms. An example is given in Fig. 3. The general procedure used to establish these maps was as follows:

- *raw data*: calculation of the frequency of occurrence of each term and each pair of terms.
- *Measuring proximities*: normalisation of these occurrence and co-occurrence measurements, in order to overcome any bias. Different measures of similarity can be found in the literature: *association strength*, *cosine*, *inclusion index*, *Jaccard index* (Boyack et al., 2005). CorTexT manager proposes various measures and we retained two: the chi-2 measure for nodes, which arose from different fields (heterogeneous graphs), and distributional measure (Weeds and Weir, 2005) for nodes,

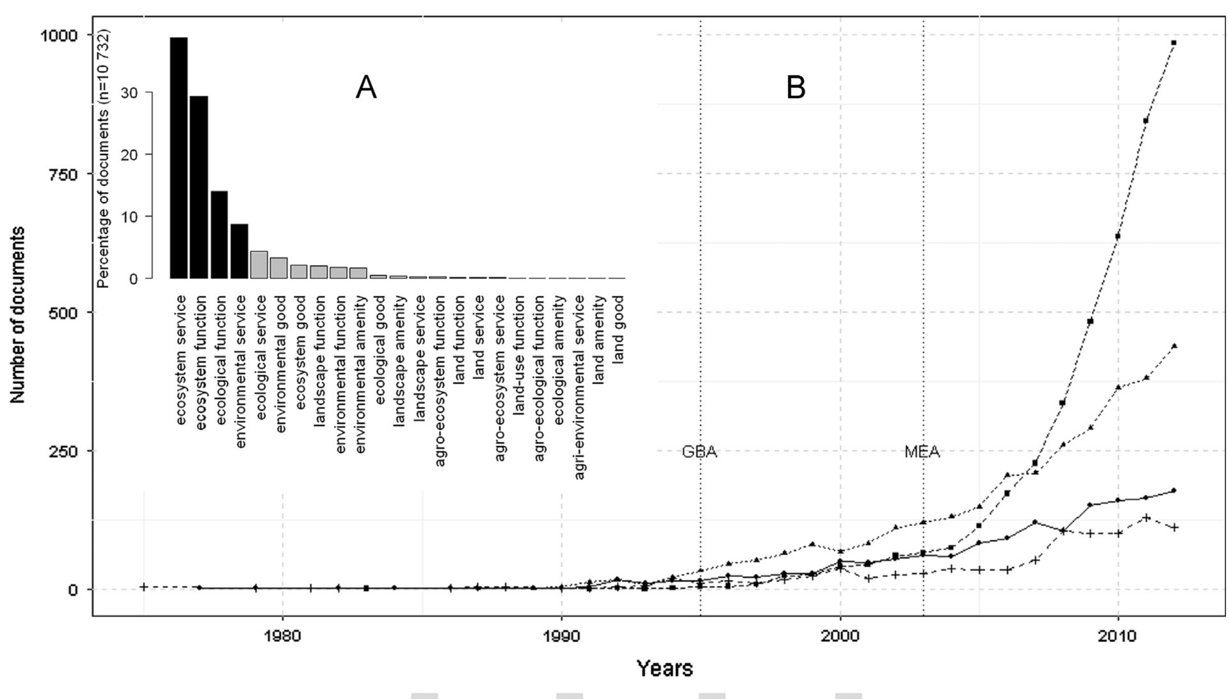

Fig. 2. (A) Relative importance of the different terms employed. (B) Distribution of references over time according to the four most commonly used terms. EcoServ-WoS Corpus 1975–2012. Fields TI, AB, DE. The total (100%) corresponds to the number of documents indexed. GBA: Global Biodiversity Assessment. MEA: Millenium Ecosystem Assessment.

Fig. 3. Map of co-occurrences of the four main terms used to designate ecosystem services and the twenty most common disciplinary fields, as defined by the *Web of Science*. (a) 1997. (b) 1998. (c) 2012. Measure: chi-2. Threshold: top-5 neighbours. EcoServ-WoS corpus. Fields: SC, TI, AB, DE.

which arose from a single field (homogeneous graphs). Chi-2 is a so-called direct or local measure. It takes account of the number of co-occurrences of each pair considered. Distributional measure is an indirect or global measure. Calculation of the similarity of two nodes was based on comparing their entire co-occurrence profile with the other terms identified.

- *Community detection*: algorithms for the structural analysis of networks enabled the identification of cohesive sub-groups in the network; i.e. sub-graphs with a very high density of internal links. For our work, we used Louvain's algorithm, which is one of the most widely used to accomplish this task (Blondel et al., 2008).

- *Mapping*: visualisation of a network in the form of a map. Because proximity networks are weighted, there is a risk that their visualisation will be rendered illegibly if all the links are preserved. It is therefore necessary to apply a filter, which can be defined in two ways: at a global level where only links with an intensity greater than a given threshold are retained, or at a local level, retaining for each node only the *n* first nodes to which it is linked. In the present case, we imposed a number of 5 neighbours. Once the network had been filtered, spatialisation algorithms inspired by classic graph visualisation methods (*Fruchterman–Reingold*) were implemented by CorTexT Manager to generate the final map. A final functionality (*heatmap*) was then able to reveal the links between our different themes or services and the Agriculture research field.

3. Results

3.1. Distribution of Query terms

The different synonyms for "ecosystem service" were used almost exclusively: 92% of references in the *Web of Science* only used one, 7% used two and 1% used more than two (a maximum of four). The terms most frequently employed were *ecosystem service* (39% of the documents indexed), then *ecosystem function* (29%), *ecological function* (14%) and *environmental service* (9%) (Fig. 2-A).

The distribution of references over time is shown in Fig. 2-B. The corpus was dominated by the term *ecosystem function* until 2007, when this was supplanted by *ecosystem service*. Exponential accelerations in production were observed in 1995 and 2003, years which saw publication of the Convention on Biological Diversity (Watson et al., 1995) and the analytical framework for the Millenium Ecosystem Assessment (Millennium Ecosystem Assessment, 2003).

3.2. How Query terms relate to disciplinary fields

Similarly to Bonin and Antona (2012) and Jeanneaux et al. (2012), we advance the hypothesis that the use of different expressions to describe similar concepts can be explained by the existence of separate research communities. In order to prove this hypothesis, we labelled each article as a function of the expression (s) in the initial search term that allowed it to be included in the corpus. The compilation of a co-occurrence map for the four most common search terms with the twenty most common subject categories in 1997 (the year before the term *ecosystem service* was formalised), in 1998 (the year during which it took on such importance) and in 2012 (a more recent period) allowed us to see that these expressions were attached to specific fields (Fig. 3).

Each node represents a term. The more a term is used in combination with other terms, the larger the point representing it. The greater the distance between two terms, the less frequently they are associated in the corpus and the thinner the line linking them. Two nodes of the same colour belong to a group of terms that are more densely linked than they are with the other terms in the network. A threshold was applied to this map, it retains only the five strongest links for each node. The term *ecosystem service* appeared significantly as from 1998: in 1997, it was not one of the four most commonly used expressions, which were *ecosystem function*, *ecological function*, *environmental service* and *environmental good*. The following were observed with respect to:

- *ecosystem function*: an agglomeration of biological disciplines with a systemic component (*forestry*, *entomology*, *agriculture*, *marine* & *freshwater biology*, etc.);
- *ecological function*: disciplines focused on the abiotic or microscopic components of ecosystems (*geography*, *physics*, *geology*, *microbiology*, *genetics* & *heredity*, etc.);
- *environmental service*: disciplines implementing actions on the environment (*engineering*, *water resources*, *biodiversity* & *conservation*, etc.);
- *environmental good*: disciplines relative to the social sciences (*government* & *law*, *business* & *economics*, etc.).

In 1998, the disappearance of the *environmental service* cluster was observed, whose disciplines were redistributed to the *ecosystem function* and *ecological function* clusters. The *ecosystem service* cluster took its place between these two clusters, and attracted several disciplines to which they had previously belonged: *evolutionary biology*, *urban studies*, *environmental sciences* & *ecology*, etc. as well as *biodiversity* & *conservation*. This term was also strongly linked to *business* & *economics*. At its origin, therefore, the concept did not federate agricultural sciences.

The landscape had changed little in 2012: the map account for ecology and conservation biology in the *ecosystem service* cluster; applied disciplines in the *environmental service* cluster (*business* & *economics*, *agriculture*, *forestry*, *engineering*); fundamental biological and physical sciences in the *ecological function* and *ecosystem function* clusters.

As a result, it appears that the existence of different terms reflected different research communities. The origins of the ecosystem service concept should therefore be attributed to ecology and conservation biology, and then to economics. As for agricultural sciences, they appear to have been little involved in these fields, on the contrary to *environmental service*.

We then tried to characterise the presence and importance of agricultural sciences and agro-ecosystems in this theme of ecosystem services. We restricted our analyses to articles published during the post-MEA period (2006–2012, $n=7707$), following the study of trends in ecosystem services research published by Vihervaara et al. (2010), and covering the period prior to the MEA. The corpus obtained was called the EcoServ-WoS corpus.

3.3. Importance of agronomy and agro-ecosystems

According to the SC field, environmental sciences and ecology dominated (60%), followed by agriculture (10%), marine and freshwater biology (9%), conservation biology (9%), economics (6%) and forestry (5%). Taken together, agriculture and forestry represented 1149 references, or 15% of the EcoServ-WoS corpus. All the other disciplines were present in fewer than 5% of documents each. If a comparison was made between the proportions obtained for agriculture and forestry via the *Subject Category* and those obtained by detecting the semantic patterns *agr**, *farm** or *forest** in abstracts or author keywords, the following results were found: 10% (SC *Agriculture*) versus 27% ([*agr** *OR farm**] pattern) and 15% ([*Agriculture OR Forestry*] SC) versus 43% ([*agr** *OR farm** *OR forest**] pattern). The figures obtained for agronomy in its strictest sense thus varied considerably with the method used, ranging from 10% (*Subject Category*) to 27% ([*agr** *OR farm**] patterns). It was found that only 20% of articles possessing the *agr** or *farm** pattern were indexed using the *Agriculture* category. As a result, there were a large number of studies that mentioned agro-ecosystems without forming part of the *Agriculture* discipline. A random sampling of 20 articles allowed us to understand the source of this disjunction between articles dealing with agro-ecosystems and those labelled as agronomy. This could mainly be explained by the existence of social sciences documents on agro-ecosystems, on the one hand, and documents focused on studies at the landscape scale, on the other. In this latter case, agro-ecosystems did not constitute a principal element in the study.

3.4. Studied themes and agronomy-related themes

Sorting of the vocabulary resulting from the lexical extraction, and subsequent indexing of the documents using the 152 categories retained, allowed us to cover 97% of the corpus. The 15 most frequent themes out of the 152 retained are shown in Fig. 4-A, and they were led by: *biodiversity*, *management*, *water provisioning*, *conservation* and *scenarios*. A note should therefore be made of the importance of “biodiversity”, “management” (*management*, *conservation*) and “forecasting” (*scenarios*) as themes. In total, 67% of documents were indexed with at least one service. Half of the corpus mentioned a harmful effect (of humans on ecosystems (pesticides) or vice versa (extreme events)) (51%), two-thirds included notions of management (68%), and a third dealt with decision-making criteria (37%) or future goals to be achieved (36%). Mentions of governance or actors were much less represented, each in 17% of documents.

A co-occurrence map of the 152 sub-categories was compiled and is presented in Fig. 4-B. In order to simplify its interpretation, this map retained only the five closest neighbours to each node, and only links with an intensity stronger than 0.3. The colour gradient enables visualisation of the preferential involvement of the *Agriculture* discipline (via the SC field) in certain themes. Six major groups can be distinguished: one dealing with social science issues (yellow and green), a second with water (pale blue), a third with climate (dark blue), a fourth with different ecosystem functions (red), a fifth with the provision of habitat (pale blue) and the sixth with agricultural themes (orange).

The first observation is that the social sciences fields (yellow and green clusters) and the natural science field (other clusters) were clearly distinct. According to the *Subject Category*, 55% of the documents in the Ecoserv-WoS corpus were single-disciplinary, 33% bi-disciplinary and 12% involved more than two disciplines. Although the rate of multidisciplinary documents was high (45%), the map showed that this multidisciplinarity principally connected the human and social sciences between each other, or natural sciences between each other.

The first cluster of social sciences (yellow) corresponded to the issue of *payment for ecosystem services* in tropical forest zones. It contained numerous allusions to social well-being terms: d*evelopment goals*, *public goods*, *property rights*, *equity*, *poverty*, *community members*, etc., characteristic of the vocabulary used in studies on socio-ecological systems (Glaser et al., 2008). It was thus in this cluster that the largest number of actors was found (*policy makers*, *land owners*, *civil society*, etc.).

The second cluster of social sciences (green) concerned management and operational issues: *assessment*, *uncertainty*, *risk*, *policy*, *economic consequences*, *economic costs*, etc. It was in this cluster that the term *trade-off* was found, linked to the terms *social benefits*, *decision makers*, *decision making*, *policy*, *economic valuation*. Terms linked to economic evaluation referred to classic economics methodologies: *contingent valuation*, *willingness to pay*, *stated preferences*, etc. These *management*, *decision making* issues were closely linked to economic terms (*economic costs*, *economic benefits*, *economic consequences*, *economic activity*). The objects and goals associated with this “management” cluster were designated using very general terms (*natural resource*, *sustainability*, *economic benefits*). The objects of this management were not solely natural; they also involved human activities such as *land settlement*, *exploitation*, *recreational activities*. The importance of traditional economics methodologies could therefore be seen (Farley, 2010), as could arguments in favour of social development used to address the management of natural resources and some human activities.

Partitioning between “biological sciences” and “social issues” highlighted the distinction made by Fisher et al. (2009) between intermediate services (ecosystem functions) and final services (resulting from the coupling of a human activity with these intermediate services). Intermediate services and their corresponding harmful effects (e.g. *habitat provisioning* and *habitat fragmentation*) were associated within the same clusters in the “biological sciences” part of the map. Final services were found in the other clusters, segregated as a function of the degree of involvement of ecosystem dynamics in the human uses made of them: use of stocks (*exploitation*, *recreational activity*), or mobilisation of their fluxes (*energy provisioning*, *water provisioning*, etc.).

As for agricultural sciences, they tended to be involved in biophysical themes linked to the health and nutrition of plants. Once again, this was far distant from an integrated vision of socio-agro-ecosystems.

3.5. Studied services: type of services and relationships

The distribution of services is presented in Fig. 5-A. In the lead was *agricultural production* (in the broadest sense of agriculture + forestry) and *primary production*. All other services were each present in fewer than 10% of documents. 49% of documents mentioned only one service, 30% mentioned two and 21% more than two. These proportions were not modified over time (see Fig. 5-B). As a result, a majority of documents only mentioned one service. Furthermore, 72% of the documents indexed using “ecosystem function” were also indexed with at least one service. Virtually the same percentage (73%) was obtained for the documents indexed with “ecosystem service”. This therefore confirmed our choice to include “ecosystem function” and other derived expressions in our initial search term.

Map C in Fig. 5 visualises the co-occurrence links between services. To simplify its interpretation, this map only retained the five closest neighbours to each node, but this did not modify the topology of the network. The colour gradient enabled visualisation of the preferential involvement of the *Agriculture* discipline (via field SC) in some services (the intensity of blue corresponding to a score for the specificity of the discipline compared with elements in the map (chi-2)). Five groups of services which tended in particular to be studied together can be seen, distinguished by the node colours of yellow, red, green, pale blue and dark blue. The yellow group concerns water-related services (*water cycle*, *water quality*, *erosion control*) or the limitation of pollution (*pollution control*, *waste treatment*, *air quality*). The red, green and dark blue clusters concern intermediate or support services: *biogeochemical cycles*, *nutrient cycling*, *soil quality*, *soil formation*, *primary production*, *resilience*, *stability*, *resistance*, *recovery*, *biodiversity increase*, *regeneration*. The pale blue group concerns services linked to agriculture: *agricultural production*, *biological control*, *pollination*, *reproduction*, *pest control*, etc. A separation can thus be seen between services linked to biological dynamics and those linked to nutrient cycles. Agricultural sciences hold a strong position in production services (*energy provisioning*, *agricultural production*) and support functions for nutrient supply (red cluster). This discipline does not focus notably on ecosystem regeneration and resistance services (green and dark blue clusters), or on water-related services or the pollution of ecosystems (yellow cluster).

4. Discussion

4.1. Methodological considerations regarding the categorisation process

Our use of a semi-automated method should not mask the fact that categorisation of the terms obtained resulted from cognitive work that could be subject to minor variations, depending on the choices made. To overcome this potential bias, an initial automated detection of services was made using the expressions specific to the MEA (e.g. *climate regulation*, *pests control*, etc.),

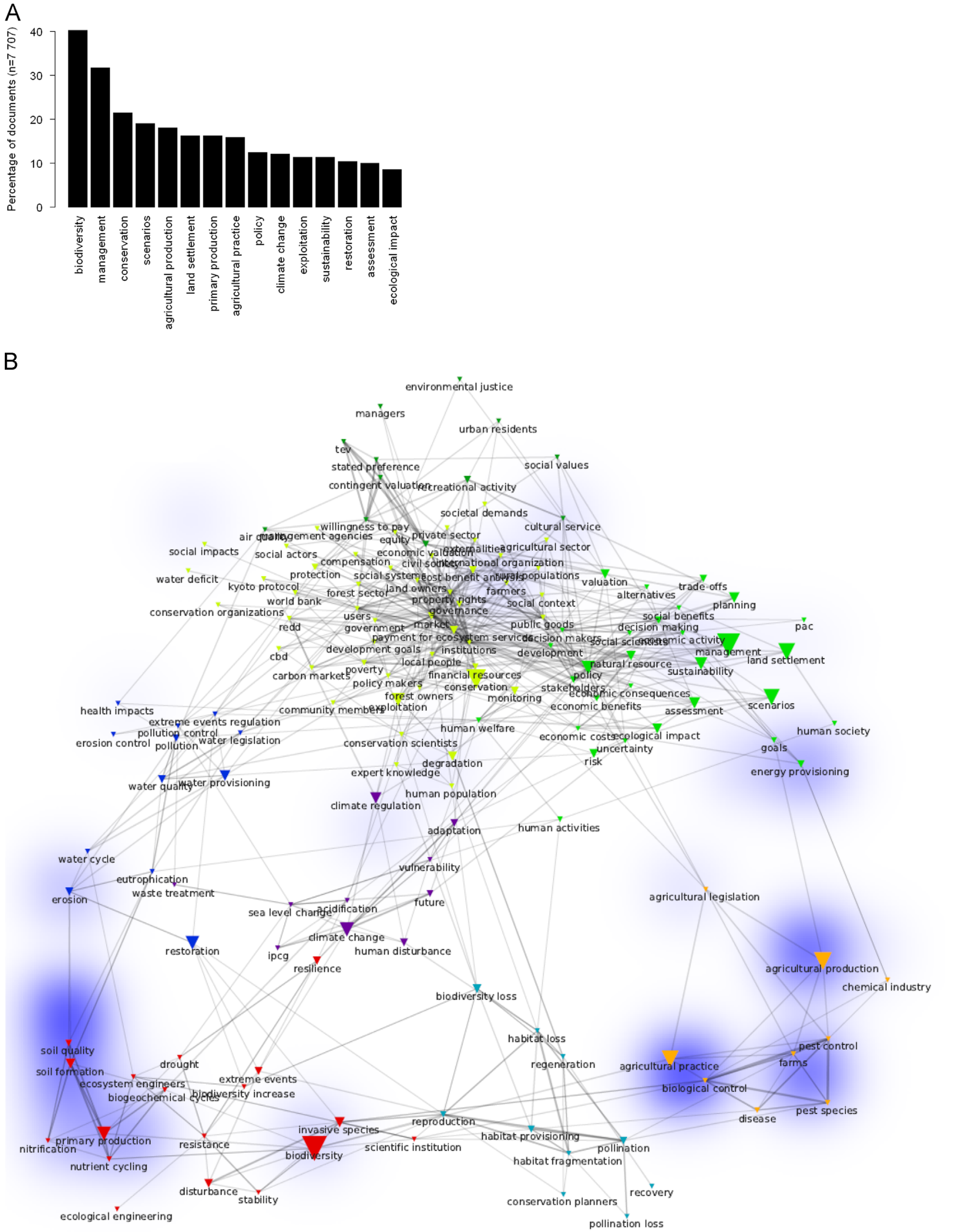

Fig. 4. A. Proportion of documents indexed using the 152 thematic sub-categories. The total (100%) corresponds to the total number of documents. B. Co-occurrence map of the 152 thematic sub-categories retained. Measure: distributional. Threshold: 0.3+top-5 neighbours. Heatmap: Subject category “Agriculture”. EcoServ-WoS corpus, fields AB and DE.

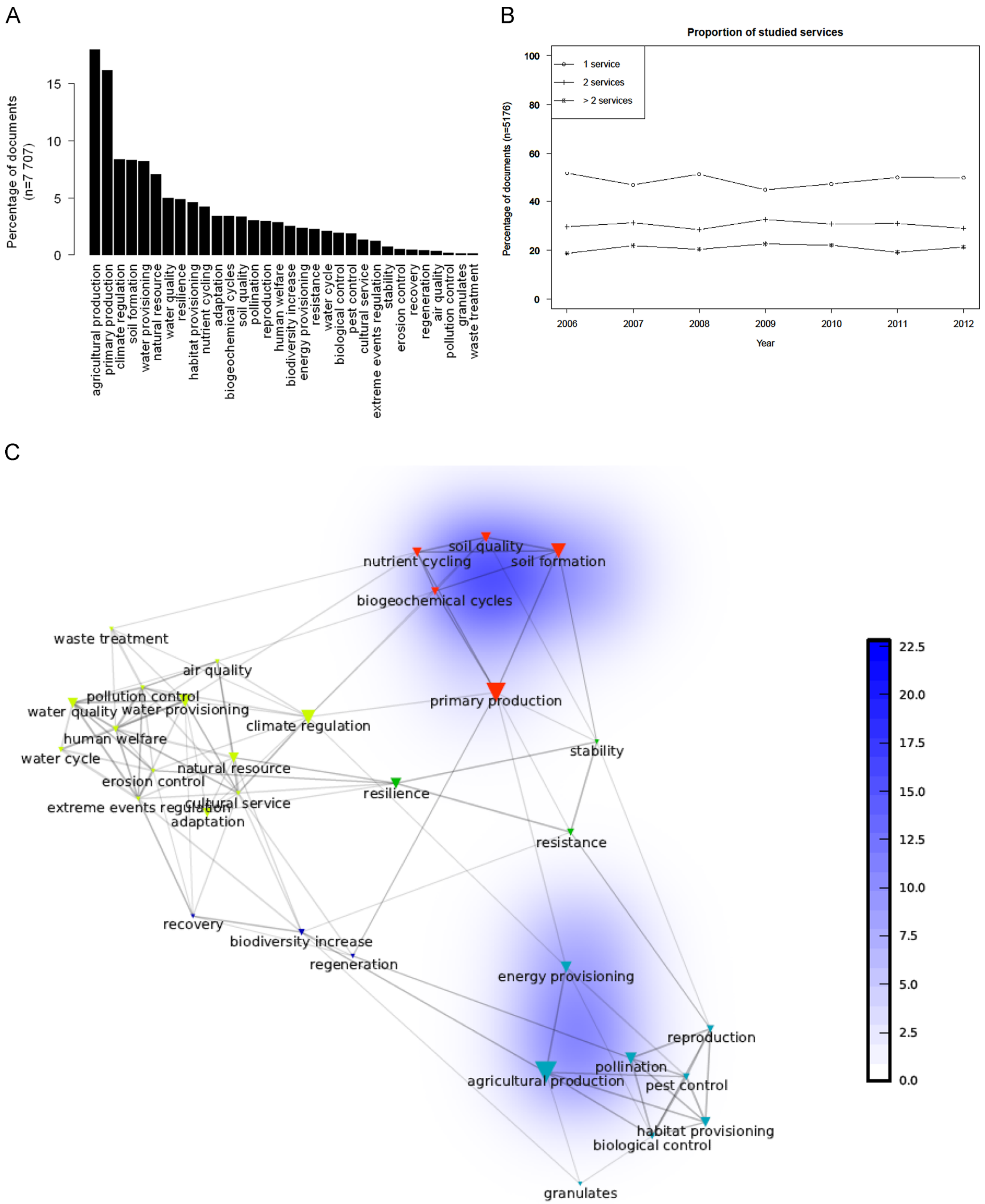

Fig. 5. A. Relative importance of services. The total (100%) corresponds to the number of documents in the corpus. B. Distribution over time of documents mentioning 1, 2 or more than 2 services. The total (100%) corresponds to the number of documents indexed with at least one service. C. Mapping of the co-occurrence of services. Measure: distributional. Threshold: top-5 neighbours. Heatmap: "Agriculture" subject category. EcoServ-WoS corpus. Fields AB and DE.

but this only enabled the re-indexing of 47% of the corpus. We then realized that a large proportion of our corpus did not use MEA-specific vocabulary, which indicated greater semantic richness. We were therefore obliged to perform a manual categorisation of the most common expressions, and to avoid any selection bias we implemented a cross-over method for validation already improved for Farming Systems Research (Barbier et al., 2012) by experts in the field ($N=6$). This gave our list a definite robustness, even though it might contain biases and be subject to debate and improvement, this being permitted by the "open data" nature of the data, the explanation of our methods and the openness of the CorTexT online platform.

4.2. "Ecosystem service": a concept that is little appropriated by agricultural sciences

Our results confirmed once again that the "ecosystem service" concept developed within several biological (evolution, environment, conservation) and social (economics) disciplines, and is still marked today by these roots. The most common theme that emerges from the mapping strategy is biodiversity, and the main discipline is ecology. The two years during which a marked rise was seen in the publication rate – 1995 and 2003 – corresponded respectively to publication of the Global Biodiversity Assessment (Watson et al., 1995) and that of the conceptual framework for the MEA (Millennium Ecosystem Assessment, 2003). In addition, 1997 saw the publication of *Nature's Services*: *Societal Dependence on Natural Ecosystems* by a conservation ecologist (Daily et al., 1997) and of the article entitled *The value of the world's ecosystem services and natural capital* by another ecologist (Costanza et al., 1997). These two articles are frequently cited by scientists as markers for the emergence of the ecosystem service concept (Bonin and Antona, 2012). The results of our study echoed other works tracing the genesis of the concept using a qualitative approach (Froger et al., 2012; Serpantié et al., 2012). The *ecosystem service* concept grew from ecology, was taken up by conservation biologists and then finally by the political sphere. Furthermore, Serpantié et al. (2012) pointed out that disciplines such as systematics, evolutionary sciences or even sociology were underrepresented when the MEA was compiled. This could explain why they were absent from the map in Fig. 2-C (case of systematics and sociology) or only linked to the most generic terms of *ecosystem function*, *ecological function* (case of evolutionary sciences).

In the landscape we have outlined here, agricultural sciences do not seem to have appropriated this concept, either at its origins or today, preferring that of "environmental services". And indeed, the concepts of "environmental services" and "ecosystem services" do not always have the same significance. For some authors, the "environmental service" concept refers to the services rendered by humans to ecosystems (e.g. the positive amenities of agriculture), or in other words services that can be regulated and remunerated (Lamarque et al., 2011; Bonin and Antona, 2012). This explains why economics, and disciplines based on the productive functions of the environment, make up the *environmental service* cluster (Fig. 3-C). In addition, the "multifunctionality" concept of agriculture might have been preferred to that of "ecosystem service" (Bonnal et al., 2012).

Nevertheless, a large number of the works in this corpus dealt with agro-ecosystems without being indexed in the *Agriculture* field by the *Web of Science*. This disjunction between articles focused on agro-ecosystems and those labelled as agronomic can mainly be explained by the existence of social science studies on agro-ecosystems, on the one hand, and work at a landscape scale on the other. There is no universal definition of such landscape approaches, which can equally refer to the "modelling of biophysical elements" and "spatial planning" (Sayer et al., 2013).

4.3. A conventional approach for agriculture

Agricultural sciences are positioned in the themes of production, biological control and ecosystem support functions (Figs. 4-B and 5-B), which are their themes of specialty (Cañas-Guerrero et al., 2013). One bias affecting these findings may result from how the *Web of Science* indexes documents in the *Agriculture* category. For example, some documents written by agronomists may have been classified by the *Web of Science* under ecology or conservation biology. However, few links were observed within our corpus between clearly agronomic themes (agricultural production, etc.) and management and conservation themes (green and yellow clusters, Fig. 4-B), even though Cañas-Guerrero et al. (2013) demonstrated a significant increase in use of the keywords *management* and *diversity* during the past 15 years in articles belonging to the *Web of Science Agriculture* category. As a result, the marked absence from our data of the *Agriculture* category regarding the management and operation themes showed that agricultural sciences address the theme of ecosystem services via their traditional issues: *yields/growth/soil/plants* (Cañas-Guerrero et al., 2013). Agricultural sciences thus deal with ecosystem services in a biophysical manner, and do not integrate the agro-socio-ecosystem as a whole. Finally, they pay little or no attention to the issue of the pollution (and restoration) of ecosystems, even though agriculture is one of the activities responsible for this pollution.

4.4. Few studies of compromises between services

The determinants for the combinations of services observed in Fig. 5-C are not known. Do they arise from the same ecological function? Are they impacted by the same management methods? Stallman (2011) theorised the different combinations of services that might be expected and their relationships (synergy, antagonism, neutrality). It appears that the range of services observed on the map in Fig. 5-C mainly link services that are acting in synergy. Consequently, it appears that antagonistic bundles of services are underrepresented. Consequently, there is no connexion between the term *trade-off* and potentially contentious pairs of services. This term is instead connected to general terms that designate either a long-term objective (social benefits, economic benefits) or decision-making (Fig. 4-B). As a result, research on antagonistic services is still necessary.

5. Conclusions

First of all, our study proposes a methodological scientometric framework, which is not specifically dedicated to the exploration of the agricultural sciences domain. It might be used in various other contexts. It relays on the use of native categories of the *Web of Science*, enriched by external dictionaries of concepts and experts' verification. But it also proposes to use the power of automatic terminological extraction, clustering based on community detection and visualisation of knowledge. The use of semi-automated methods to characterise scientific production is a helpful tool to retrospectively trace research agenda, provided it is embedded in discussions with experts, on ecosystem services and agricultural research management in our study.

This framework enables to answer the key question raised in this article: "Do agricultural sciences generate knowledge, which covers the emerging theme of ecosystem services?". As revealed by their impacts on environment, farming activities are determinant in defining the ecological status of numerous environments (groundwater resources, enclosed seas such as the Baltic, forests, soils, etc.). Our study has shown that the exponentially rising concept of ecosystem services is nevertheless little appropriated by agricultural sciences. Numerous studies on ecosystem services take account of agricultural environments, but these studies are mainly interested in landscapes at a large scale, or to the negative consequences of cultivation practices. This peculiar landscape approach has been chosen by the CBD Subsidiary Body on Scientific, Technical and Technological Advice to enable the optimum integration of agricultural production and environmental conservation: "*The landscape approach acknowledges the various trade-offs among these goods and services. It addresses them in a spatially explicit and ecosystem-driven manner that reconciles stakeholders' multiple needs, preferences, and aspirations*" (Sayer et al., 2013). This further underlines the importance for agricultural sciences to adopt the ecosystem service concept in order to become a contributor in these landscape approaches, which are currently being studied by non-agricultural disciplines. They need to harness the specificities of agro-ecosystems and cultivation practices as key elements in these approaches.

However, our study shows that whenever agricultural sciences address ecosystem services, they mainly do it through traditional, non-integrated approaches. The ecosystem service concept could be better used in agricultural research to characterise and quantify all the services rendered by agro-ecosystems, along with their synergies and antagonisms. An approach quite distinct from the study of nuisances linked to farming activities. Increasingly numerous studies have thus indicated the existence of levers for the management of agricultural environments based on an agro-ecological approach regarding practices in order to impact the numerous services that agro-ecosystems could render. There remains one major obstacle, which is the issue of the learning and collaborations that are necessary to increase the sustainability of agri-food systems (Källström and Ljung, 2005; Elzen et al., 2012). If the ecosystem service concept is to be used as a basis for a new paradigm for agriculture and the design of new farming practices, then our research shows that several changes are to be undertaken within agricultural sciences in order to focus on these complex socio-agro-ecosystems. More studies need to be designed at the landscape scale, along with the development of cross-disciplinarity – notably to study compromises between services and between actors – and the ability to take account of uncertainties. Some of our results have shown disjunctions between articles according to definitional differences but also to polysemous notions, such as landscape. Our methodology enables to explore the inherent complexity of a non-unified domain of research on ecosystem services. In the light of this general characteristic, agricultural sciences show the same type of tensions, but it appears that they have not appropriated the ecosystem services issues and underlying epistemic challenges, at least in the way scientific production is labelled.

At present, the "ecosystem service" concept is receiving growing critiques for its potential to over-commoditise nature in order to meet human needs (Higgins et al., 2012), and for its liberal origins which present freedom of choice as a fundamental principle for humanity (Millennium Ecosystem Assessment, 2005, Chap. 1, Fig. 1.1, p. 28). As a general framework, ecosystem service nevertheless has the advantage of encouraging closer links between disciplines concerned by the sustainable management of human activities and those concerned by the fate of ecosystems. Agricultural sciences have certainly a lot to bring to this debate, because of a fundamental ambiguity of their position: they have contributed to the industrialisation of agriculture with subsequent harmful effects on environment and they contribute also to many exploration of sustainable solutions based on agroecosystem approaches. Definitional controversy, a classic figure of scientific debate, should not then diminish the value of ecosystem service, which also resides in its ability to encourage dialogue between diverging approaches. At a time when the question of e.g. managing the anthropogenic components of climate change is becoming a challenge for humanity (Rockström, 2009), the conciliation of divergent approaches on ecosystems becomes essential to ensuring the coherence and consistence of a global research agenda.

Authors' contributions

Elise Tancoigne led the study under the supervision of Guy Richard and Marc Barbier, she wrote most of the text and produced maps and analysis with Guy Richard and Marc Barbier. Jean-Philippe Cointet has brought methodological guidance during the course of the project. Analysis of data was carried out in collaboration between Elise Tancoigne and Marc Barbier.

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Appendix A

Query executed on *Topic* field. Timespan=All Years. SCI-EXPANDED – 1956-present. SSCI – 1956-present. A&HCI – 1975-present. CPCI-S – 2000-present. CPCI-SSH – 2000-present. Updated 2013-03-29.

TS=("eco-system* service" OR "eco*system* service" OR "eco-system* services" OR "eco*system* services" OR "agro*system* service" OR "agro*-system* service" OR "agro-*system* service" OR "agro-*-system* service" OR "agro*system* services" OR "agro*-system* services" OR "agro-*system* services" OR "agro-*-system* services" OR "environmental service" OR "environmental services" OR "agro*environmental service" OR "agro-environmental service" OR "agri*environmental service" OR "agri-environmental service" OR "agro*environmental services" OR "agro-environmental services" OR "agri*environmental services" OR "agri-environmental services" OR "ecological service" OR "ecological services" OR "agro*ecological service" OR "agro-ecological service" OR "agro*ecological services" OR "agro-ecological services" OR "landscape service" OR "landscape services" OR "land service" OR "land services" OR "land-use service" OR "land-use services" OR "eco-system* function" OR "eco*system* function" OR "eco-system* functions" OR "eco*system* functions" OR "agro*system* function" OR "agro*-system* function" OR "agro-*system* function" OR "agro-*-system* function" OR "agro*system* functions" OR "agro*-system* functions" OR "agro-*system* functions" OR "agro-*-system* functions" OR "environmental function" OR "environmental functions" OR "agro*environmental function" OR "agro-environmental function" OR "agri*environmental function" OR "agri-environmental function" OR "agro*environmental functions" OR "agro-environmental functions" OR "agri*environmental functions" OR "agri-environmental functions" OR "ecological function" OR "ecological functions" OR "agro*ecological function" OR "agro-ecological function" OR "agro*ecological functions" OR "agro-ecological functions" OR "landscape function" OR "landscape functions" OR "land function" OR "land functions" OR "land-use function" OR "land-use functions" OR "eco-system* good" OR "eco*system* good" OR "eco-system* goods" OR "eco*system* goods" OR "agro*system* good" OR "agro*-system* good" OR "agro-*system* good" OR "agro-*-system* good" OR "agro*system* goods" OR "agro*-system* goods" OR "agro-*system* goods" OR "agro-*-system* goods" OR "environmental good" OR "environmental goods" OR "agro*environmental good" OR "agro-environmental good" OR "agri*environmental good" OR "agri-environmental good" OR "agro*environmental goods" OR "agro-environmental goods" OR "agri*environmental goods" OR "agri-environmental goods" OR "ecological good" OR "ecological goods" OR "agro*ecological good" OR "agro-ecological good" OR "agro*ecological goods" OR "agro-ecological goods" OR "landscape good" OR "landscape goods" OR "land good" OR "land goods" OR "land-use good" OR "land-use goods" OR "eco-system* amenity" OR "eco*system* amenity" OR "eco-system* amenities" OR "eco*system* amenities" OR "agro*system* amenity" OR "agro*-system* amenity" OR "agro-*system* amenity" OR "agro-*-system* amenity" OR "agro*system* amenities" OR "agro*-system* amenities" OR "agro-*system* amenities" OR "agro-*-system* amenities" OR "environmental amenity" OR "environmental amenities" OR "agro*environmental amenity" OR "agro-environmental amenity" OR "agri*environmental amenity" OR "agri-environmental amenity" OR "agro*environmental amenities" OR "agro-environmental amenities" OR "agri*environmental amenities" OR "agri-environmental amenities" OR "ecological amenity" OR "ecological amenities" OR "agro*ecological amenity" OR "agro-ecological amenity" OR "agro*ecological amenities" OR "agro-ecological amenities" OR "landscape amenity" OR "landscape amenities" OR "land amenity" OR "land amenities" OR "land-use amenity" OR "land-use amenities")

Appendix B

List of terms extracted from the *Abstract* (AB) *and Author Keywords* (DE) fields and gathered under the *Climate regulation* label:

carbon accumulation|&|carbon accumulating|&|climate change adaptation|&|Climate Change Adaptation|&|adaption for climate change|&|climate change mitigation and adaptation|&|climate change adaptation and mitigation|&|C sequestration|&|C sequestrations|&|sequestration of C|&|Sequestration of C|&|soil C sequestration|&|Soil C sequestration|&|C sequestration in soil|&| sequestration of C in soils|&|Sequestration of C in soil|&|C sequestration in soils|&|soil C storage|&|C storage in soils|&|C storage|&| carbon fixation|&|Carbon fixation|&|CARBON FIXATION|&|including carbon sequestration|&|increase carbon sequestration|&|increased carbon sequestration|&|increases in carbon sequestration|&| increasing carbon sequestration|&|increase in carbon sequestration|&|carbon mineralization|&|carbonate minerals|&|carbonate mineral|&|sequester carbon|&|sequestering carbon|&|sequestered carbon|&|carbon sequester|&|sequesters carbon|&|carbon sequestration|&|Carbon sequestration|&|sequestration of carbon|&|soil carbon sequestration|&|soil carbon storage|&|soil and carbon storage|&|Carbon storage in soils|&|carbon stocks|&|carbon stock|&| Carbon stocks|&|Stocks of carbon|&|carbon storage|&|Carbon storage|&|storage of carbon|&|carbon stores|&|carbon store|&|store carbon|&|stored carbon|&|storing carbon|&|carbon stored|&|carbon uptake|&|climate change mitigation|&|mitigation of climate change|&|mitigating climate change|&|mitigation of climatic change|&|climate control|&|Climate controls|&|climatic control|&| control climate|&|Climate controlled|&|climatic controls|&|climate mitigation|&|mitigating climate|&|climate regulation|&|climatic regulation|&|regulating climate|&|reducing emissions from deforestation|&|Reducing Emissions from Deforestation|&|Reduced Emissions from Deforestation|&|reduced emissions from deforestation|&|Reducing emissions from deforestation|&|Reduced Emissions From Deforestation|&|reducing emissions|&|Reducing Emissions|&|reduced emissions|&|Reduced Emissions|&|Reducing emissions|&|reduced emission|&|emission reductions|&|emissions reductions|&|emission reduction|&|emissions reduction|&|reduction in emission|&|reductions in emissions|&|reduction in emissions

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