Modelling agricultural changes and impacts at landscape scale: A bibliometric review

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Keywords

Water quality; water quantity; Integrated Assessment; biodiversity conservation; topic modelling

Highlights

- We performed a topic analysis on a selected ensemble of 514 publications
- Main topics were water quality, water quantity, biodiversity, Integrated Assessment
- Biodiversity was the most recent topic to emerge
- Biodiversity and water quality/quantity assessments were rarely combined
- Agricultural practices should receive more attention in landscape approaches

Abstract

Understanding the range of approaches available for assessing the impacts of agricultural changes at landscape scale is important when addressing local to global issues. Using a topic modelling approach, we reviewed the literature on impact modelling of agricultural landscapes. A search in Web of Science using the keywords model, agricultural systems and landscape yielded 1,975 hits, of which 514 papers met our selection criteria. The most salient terms fell within six groups: change, scale, pollution, biodiversity, practices and terms on biophysical/regulatory conditions. We identified four main topics: water quality, water quantity/energy crops, biodiversity and Integrated Assessment. Water management issues were more likely to be covered in North American researches, while issues related to Integrated Assessment were mainly covered in European studies. We found no relationship between topic and model type. We conclude that future integrated studies should consider the diversity of agricultural systems in governance of water and biodiversity issues.

1. Introduction

Spatial expansion and intensification of agriculture in recent decades has had tremendous environmental impacts on agricultural landscapes (Foley *et al.*, 2011). These landscapes are defined as systems in which interactions occur between farmers and their natural and social resources, including management of fields, field margins and associated semi-natural habitats (Benoit *et al.*, 2012). Modern agriculture is contributing to water degradation, increased energy use and greenhouse gas emissions, together with widespread pollution and loss of biodiversity (Foley *et al.*, 2011). These impacts take place beyond the field and farm levels, necessitating a landscape approach if they are to be addressed properly at the relevant scale(s), through relevant research disciplines and methods. Impacts resulting from spatial interactions need to be considered at larger scales than point effects. This can be watershed scale when considering water quality or quantity (e.g. Frey *et al.*, 2013; Gungor and Guncu, 2013; Fan and Shibata, 2015; Carvalho-Santos *et al.*, 2016) or landscape scale when considering spatial flows of pathogens (e.g. Hossard *et al.*, 2013), nectar-foraging species (e.g. Baveco *et al.*, 2016) etc. Many studies have examined sustainability at field or farm scale (e.g. Zahm *et al.*, 2008; Pelzer *et al.*, 2012; Craheix *et al.*, 2016), but upscaling their results to larger spatial or temporal scales may be difficult and produce uncertain conclusions (Dargaard *et al.*, 2003). However, such upscaling may be necessary to understand the impact of different land uses, crops and/or cropping techniques on landscape performance, sustainability and ecosystem services (Tscharntke *et al.*, 2005).

Because of the multiple temporal and spatial scales involved, assessment of agricultural landscapes is challenging and requires modelling approaches to study system changes and their impacts. Modelling allows the complex processes occurring to be simplified, in order to explore the impacts of possible changes (land use, crop, practices) that cannot be distinguished in the real world (e.g. Legg, 2004; Skelsey *et al.*, 2010). Different modelling approaches can be used for designing and/or assessing landscape performance in the face of change, depending on the topic studied and available knowledge. These approaches may involve empirical models (e.g. Bennett *et al.*, 2014), process-based models (e.g. Santhi *et al.*, 2014), optimisation models (e.g. Huang *et al.*, 2012), agent-based models (e.g. Brady *et al.*, 2012), statistical models (e.g. Gottschalk *et al.*, 2007) or a combination of these types of models (e.g. Schonhart *et al.*, 2016). In such studies, the objective in designing alternatives is to compare their impacts with appropriate indicators, with simulation models being used to predict values for these indicators (Clavel *et al.*, 2012).

Different methods can be used to design alternatives, ranging from simulation studies (comparable to sensitivity analyses on cropping practices and/or their proportion/location) to participatory approaches. Scenarios, which describe "possible futures that reflect different perspectives on past, present and future developments" (Van Notten, 2005), are currently used in participatory approaches. They usually include a description of the initial situation (for comparison with alternatives) and often also the drivers/causes of change (Dockerty *et al.*, 2006; Alcamo and Henrichs, 2008), which can be social, economic (e.g. policies) and/or physical or ecological (e.g. climate change). The design of alternative landscapes can be performed by the research team (e.g. Babel *et al.*, 2011) or in a participatory approach involving stakeholders (e.g. Hossard *et al.*, 2018), depending on the topic studied, the model used for assessment and the preferences of the research team.

Understanding the range of approaches available for impact modelling at landscape scale is important when exploring potential opportunities to efficiently address local to global problems. In the first instance, bibliometric analyses have been performed, without specifying scale or agriculture, on specific impacts in e.g. biodiversity research, focusing on literature growth, collaboration/citation networks and top terms (Liu *et al.*, 2011; Stork and Astrin, 2014). Such analyses were also performed looking specifically at groundwater research (Zare *et al.*, 2017) and water impacts (Niu *et al.*, 2014), to identify trends in publications, highly cited publications, keywords and associated trends. A recent review focused on global environmental assessment, highlighting "decision-theoretic approaches" (e.g. life cycle assessment, indicator selection), new methods (model, geographic information system), and hotspots (e.g. biodiversity, climate change, risk assessment) (Li and Zhao, 2015). However, such studies explore one specific impact, while not focusing on agricultural uses or on a specific (landscape) scale.

Reviews can also be performed specifically at landscape scale. However, those performed to date also focus on a specific impact, e.g. water scenario analyses (March *et al.*, 2012), on specific methods, e.g. multi-criteria assessments (Allain *et al.*, 2017), decision support systems for landscape management (Zasada *et al.*, 2017) or on synthesis and qualitative analysis of the literature on landscape approaches and their potential operationalisation (Freeman *et al.,* 2015). Thus, to our knowledge, no quantitative systematic review has been performed to date on model-based assessment of agricultural changes, to identify consistent groups of studies defining different topics. The only studies addressing the objective of group identification have focused on water scenario analyses (March *et al.*, 2012) or on biodiversity only (Chopin *et al.*, 2019), the latter using similar keywords to those used in our study. Hence, the objectives of this study were to (1) assemble a comprehensive dataset of published studies designing alternative agricultural landscapes and assessing associated changes and impacts through modelling, and (2) identify and analyse study structure, trends in knowledge and associated methods and models employed in this dataset. Thus, we focused our research on studies using models to explore the consequences of future agricultural landscape changes (i.e. design and/or assessment of new landscapes) and applied a topic modelling approach to link the type of impact with modelling approaches, in order to identify potential methodological improvements in impact analysis (Blei *et al.*, 2003). We chose to focus on agricultural landscape changes that explicitly include cropping practices or the organisation of crops/practices in the landscape. Thus, we excluded pure land cover/land use studies, where the data on agriculture are too aggregated to discriminate the diversity of cropping systems (Chopin *et al.*, 2017). Identifying trends and groups of publications sharing a similar structure can help to identify gaps in methods/topics crossing.

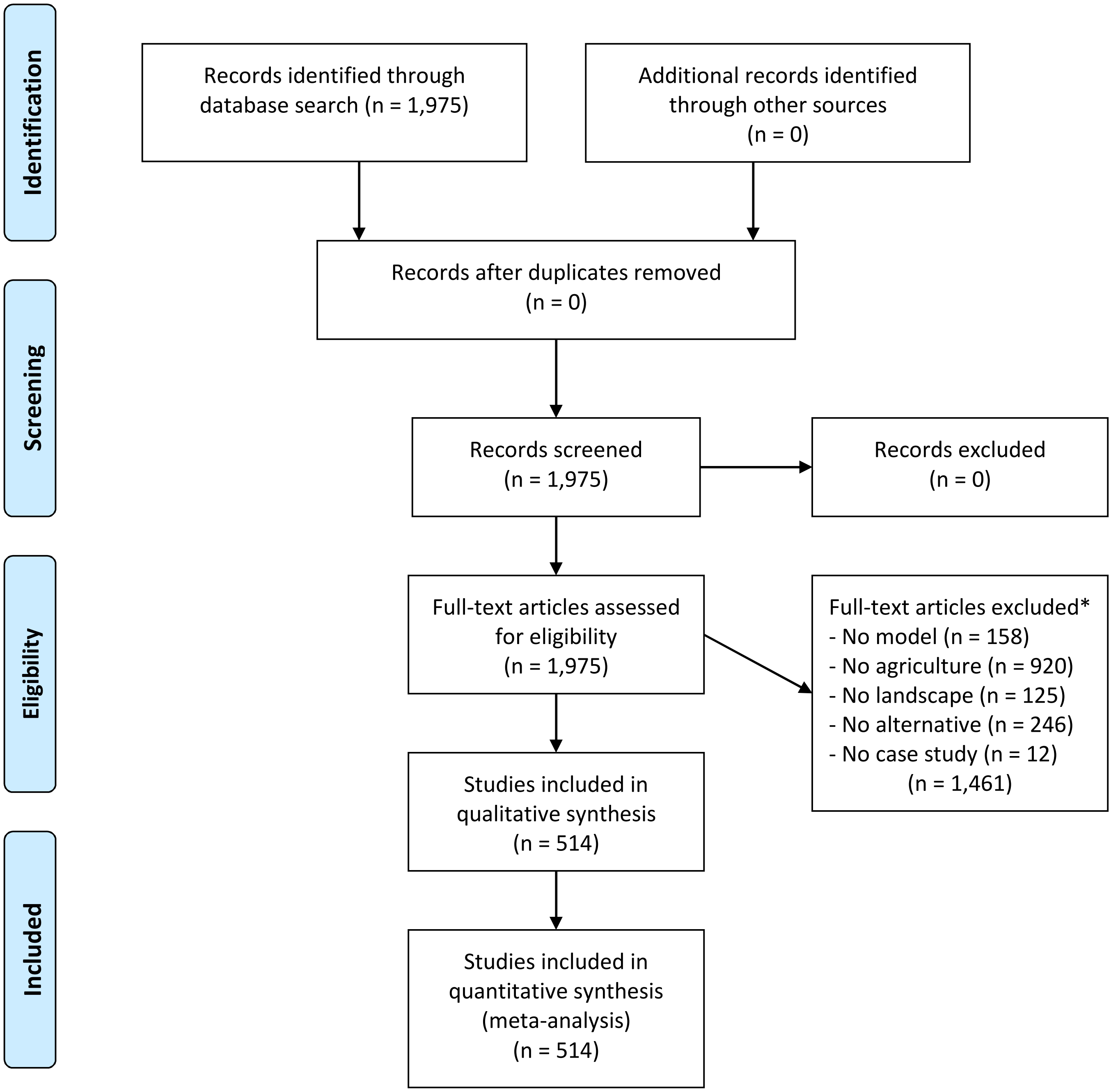
2. Methods

2.1. Literature search and study selection

The literature search was conducted in April 2017 and involved entering keywords in the Clarivate Analytics' Web of Science (formerly operated by the Institute for Scientific Information) without a time frame limitation. The search was limited to the "Article" document type and to the "English" language. For "Topics", the following search equation was used: "model* AND (agri* OR agro* OR crop* OR farm*) AND (landscape* OR watershed* OR (water NEAR catchment*)) AND (scenar* OR alternative*)". This initial search yielded 1,975 hits, spanning from 1978 to 2017. We then excluded papers based on article abstracts (1,461 studies) when they did not match our selection criteria, which were: (1) use of a model, i.e. a simplified representation of the system, as a tool to design or assess future agricultural landscape(s), (2) a focus on agricultural systems (including farming practices and/or agricultural organisation, explaining why we chose not to use "land use*" as a key word), (3) resolution at landscape scale (i.e. beyond the farm level) and (4) with outcomes on alternative agricultural systems (thus excluding papers focusing only on the effects of climate change). We did not specify the type of impact (e.g. pollution, nitrates) as our objective was to gain a general overview of the literature, without focusing on a specific impact as done in previous studies (e.g. water in Zare *et al.*, 2017; biodiversity in Liu *et al.*, 2011). Since our focus was on agricultural landscape changes explicitly including cropping practices, or their organisation in the landscape, we excluded pure land cover/land use studies that provide limited descriptions of agricultural practices, by (1) our search equation with specific agricultural terms and (2) excluding remaining studies (920) in the initial 1,975 paper dataset (eligibility step, excluded as "No agriculture") (Figure 1).

We then manually excluded general papers lacking a case study application, e.g. reviews without a case study (12 papers) (Figure 1). Our final dataset thus comprised 514 individual papers, which were all read by the research team. The list and references of the 514 papers are available online, together with the LDA R code and the groups' results (https://doi.org/10.15454/CNYTLQ).

PRISMA 2009 Flow Diagram



From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic Reviews
*M*eta-*A*nalyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

For more information, visit www.prisma-statement.org.

Figure 1. PRISMA flow diagram showing selection of papers for the final dataset (n = 514). *Exclusion reasons are shown hierarchically according to our criteria, although most papers failed to meet more than one exclusion criterion (e.g. 300 papers without agriculture and without alternative landscapes)

2.2. Overview of bibliometric analysis and topic modelling

Records of the 514 papers were manually downloaded from Web of Science into Zotero (BibTeX format). The dataset was then exported from Zotero (www.zotero.org) as a JSON file (http://www.json.org/) for analysis with R software version 3.3.3 (R Core Team, 2017) using "jsonlite" R package (Ooms, 2014). Metadata, including journal name, year of publication and main author country, were analysed to determine trends in publication with regard to time periods, journals and geographical distribution (related to author country, not case study country).

In addition to metadata analyses, publication abstracts were analysed using a topic modelling approach. Topic models, proposed in the late 1990s (Hofman, 1999; Papadimitriou *et al.*, 2000), are models used to assess the frequency of occurrence of terms in a dataset of papers from the literature (Grün and Hornik, 2011). The Latent Dirichlet Allocation (LDA) model (Blei *et al.*, 2003) is designed for topic modelling. It is a probabilistic model based on the hypothesis that each article is characterised by one or more topics, and that each topic is characterised by a unique multinomial distribution of terms (D'Amato *et al.*, 2017; Weinshall *et al.*, 2013; Yau et al., 2014). The LDA model thus allows identification of topics reflecting relevant information on the relations and similarities in structure between papers in a dataset (Weinshall *et al.*, 2013). Topics are assumed to be uncorrelated in the LDA model (Grün and Hornik, 2011) and it allows journal articles to contain more than one topic (Blei *et al.*, 2003). As a Bayesian model, LDA requires information on the *a priori* distribution of model parameters, called "prior distribution", which can be informative or non-informative, depending on the modeller choice. Using the Bayes' theorem, the prior distribution is updated to obtain the "posterior distribution" (a probability distribution), which is based on both the prior distribution and the information gathered in the data. Thus, the posterior distribution is conditional on the data used.

2.3. LDA procedure for main dataset topics

Three main steps have to be performed before estimating the LDA of a dataset (Grün and Hornik, 2011). The first step is to pre-process data with tokenisation and stemming to build a dataset dictionary, in order to ensure relevant analyses (Grün and Hornik, 2011). Tokenisation is applied to separate so-called "tokens" (e.g. words), by removing punctuation characters, numbers, converting to lower-case and removing stop words, using the "tm" R package (Feinerer and Hornik, 2017). Stemming is applied to reduce each word to its root grammatical form, in order to increase inter-paper comparability (i.e. homogeneity of terms), e.g. "chang" would be the root for changes, change, changing, etc (Appendix A). In addition, in our LDA analysis we deleted the term "model" from the dictionary, as it was the only mandatory term in our search equation (see section 2.1.). We then analysed the resulting dictionary, to further homogenise tokens by merging redundant terms (e.g. "plough" and "plow"; "tillage" and "till"; "actor" and "stakeholder"; see Appendix A for the entire list). Potentially misleading terms were manually checked in each paper to avoid unintentional mergers (e.g. catchment relating to non-water applications). Very infrequent words, i.e. terms occurring less than five times, were also removed from the analysis (as in D'Amato *et al.*, 2017).

In the second step, the number of topics (k) included in the dataset has to be chosen before running LDA. This number is often set *a priori* by the user, based on assumptions on the dataset structure (e.g. on research fields in Kane *et al.*, 2016). In the present study, we hypothesised that topics would correspond to the main sustainability issues (environmental, economic, social), but that these could be further split into sub-issues (e.g. water quality and water quantity both consider the environmental aspect of sustainability) or according to scientific discipline (e.g. economics, agronomy, hydrology etc.). Given this uncertainty, we opted not to specify the number of topics *a priori*, but to set it according to the estimation strategy proposed by Taddy (2012). This method finds the "best" number of topics within the minimum and maximum user-defined number of topics. The "best" number of topics is that maximising the Bayes factor computed with marginal likelihood calculations (Taddy, 2012), i.e. maximising the posterior distribution over the possible instances of topics over words (Uto *et al.*, 2017). To analyse our dataset of 514 papers, we set the possible number of topics between 2 and 51 (where 51 corresponded to mean number of 10 papers per topic), using the "topics" function in the "maptpx" R package (Taddy, 2012).

The third step to be performed before LDA estimation concerns the (paper) sampling method and thus the value specification for the parameters of the prior distributions (Grün and Hornik, 2011). We used a collapsed Gibbs sampler (e.g. D'Amato *et al.*, 2017) and set the distribution parameters as suggested in Taddy (2012). Gibbs sampling is a Markov Chain Monte Carlo algorithm used to obtain a sequence of observations based on a multivariate probability distribution, which is particularly useful for calculating the posterior distribution of a Bayesian network (Geman and Geman, 1984).

The LDA model for main topics was then fitted using the "lda.collapsed.gibbs.sampler" of the "lda" R package (Chang, 2015) using 2500 iterations (as in D'Amato *et al.*, 2017). This LDA-Gibbs approach provides estimates of posterior probability of association between journal articles and topic, and terms and topic. It thus provides the probability for (1) allocation of the journal articles to each topic and (2) allocation of individual terms to each topic ('topic keywords'). Topic keywords can be either generic to the entire dataset or specific to one (or a few) topic(s). Keyword specificity to one topic is measured based on computation of the "relevance" of a given term to a given topic (Sievert and Shirley, 2014). Sievert and Shirley (2014) define the relevance of a term *w* to a topic *t* as a function of a weight parameter lambda (λ) ranging between 0 and 1. λ determines the (user-defined) weight given to the probability of a term *w* under topic *k* relative to its lift: $relevance(term\ w \mid topic\ t) = \lambda * (p(w|t) + (1-\lambda)*(p(w|t)/p(w)$ (Sievert and Shirley, 2014). A high value of λ results in keywords common to the entire dataset, while a low value results in topic-specific keywords (Sievert and Shirley, 2014). λ is chosen *a priori* by the user. In this study, we mainly used a value of λ = 0.6, as recommended by Sievert and Shirley (2014), although lower values of λ were also employed (0.1 step) to look for specificities of methods and models, especially for highly specific terms (λ = 0). Topic results are available online for further exploration (http://shin-r.innovation.inra.fr/review_LH_PC/), with the possibility of choosing different λ values and visualising relevant terms according to the chosen λ value.

In addition, our analyses included a list of salient terms in the whole dataset. The saliency of a term refers to the frequency of keywords in the dataset, using word distinctiveness (Chuang *et al*., 2012). The analyses of salient and topic-specific keywords were performed using the "LDAvis" R package (Sievert and Shirley, 2015), which also calculates the distance between topics using Jensen-Shannon divergence (Sievert and Shirley, 2014). This inter-topic distance approximates the between-topic semantic relationship, using multidimensional scaling.

2.4. Characterising the main topics in the dataset

We sought to examine the potential range of models and methods within the main dataset topics identified by the general LDA model constructed above. To this end, we built a new LDA model for each topic in the whole dataset independently, by dividing the main dataset into groups of papers corresponding to the k dataset topics. As each paper could cover more than one topic (Blei *et al.*, 2003), we considered only papers where one topic was dominant. To define topic dominance for a paper, we considered the number of times words (Sw) in the paper were assigned to each of the k topics. We assigned a paper to a specific topic k_a if the related word count was at least 15% larger than the word count for any other topic k_b (i.e. $(Sw_{k_a} - Sw_{k_b})/Sw_{k_a} \geq 0.15$). Other values were tested to determine the sensitivity of our results to this 0.15 threshold (see Appendix B for tests using values of 0.05, 0.10, 0.20 and 0.25). The LDA procedure followed for sub-topic building was identical to that used for the main topics (see section 2.3), with k ranging between 2 and one-tenth of the number of selected papers. Most diagrams were built with the “ggplot2” R package (Wickham, 2009). Maps to reveal spatial trends in publications were drawn with the “rworldmap” R package (South, 2011) and Venn diagrams crossing topics were created with the “VennDiagram” R package (Chen, 2016).

3. Results

3.1. Bibliometric analysis

Based on our search equation, the first journal articles to focus on modelling impacts of agricultural landscape changes were published in 1992. Among the 514 publications included in our analysis, the vast majority (329 papers) were published after 2009 (up to April 2017, the date of our search) (Figure 2A). The 514 articles were published in 150 journals in total, with the majority of these journals (87 journals, or 57.33%) publishing only one article during the whole period and only 19% (30 journals) publishing more than five articles (Figure 2B).

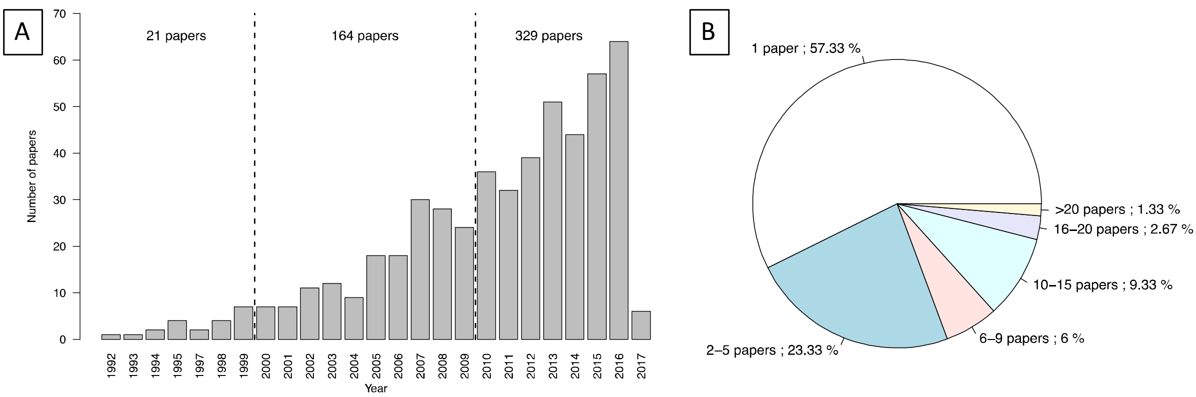


Figure 2. Overview of the global dataset regarding (A) the temporal distribution of publications and (B) the proportions (%) of journals publishing different numbers of papers (1 paper, 2-5 papers, 6-9 papers, 10-15 papers, 16-20 papers, >20 papers).

The period 1992-1999 yielded 21 publications from eight countries, the period 2000-2009 yielded 164 papers from 28 countries, and the most recent period yielded 329 papers from 36 countries (Figure 2A, Table 1). Over the whole period, USA, Germany and France were the countries publishing the most, with the USA producing about three times as many papers as the other two top countries (165 papers in USA, compared with 53 and 40 in Germany and France, respectively) (Table 1). The European continent published the largest numbers of papers in the two more recent periods (81 papers in 2000-2009 and 154 in 2010-2017).

Table 1. Publication trends in the countries publishing most papers in the study period

Period	Number of papers	Number of countries	Top three countries (number of papers)
1992-1999	21	8	USA (10); Canada (3); Italy and Netherlands* (2)
2000-2009	164	28	USA (52); Germany (21); France (9)
2010-2017	329	36	USA (103); Germany (32); France (31)
1992-2017	514	41	USA (165); Germany (53); France (40)

*Equal third place.

The top journals publishing papers on modelling the impacts of agricultural landscape changes were mainly oriented towards the environment, management, modelling and agriculture (Figure 3). The most productive outlet was *Journal of Environmental Management*, with 5% of all publications, followed by *Agricultural Water Management* and *Agriculture, Ecosystems & Environment* (about 4% each). All of the top 10 journals were launched before 1992 except *Environmental Modelling & Software* (launched in 1997). Most landscape studies published in the journals assessed environmental impacts, while economic and social impacts were in second place.

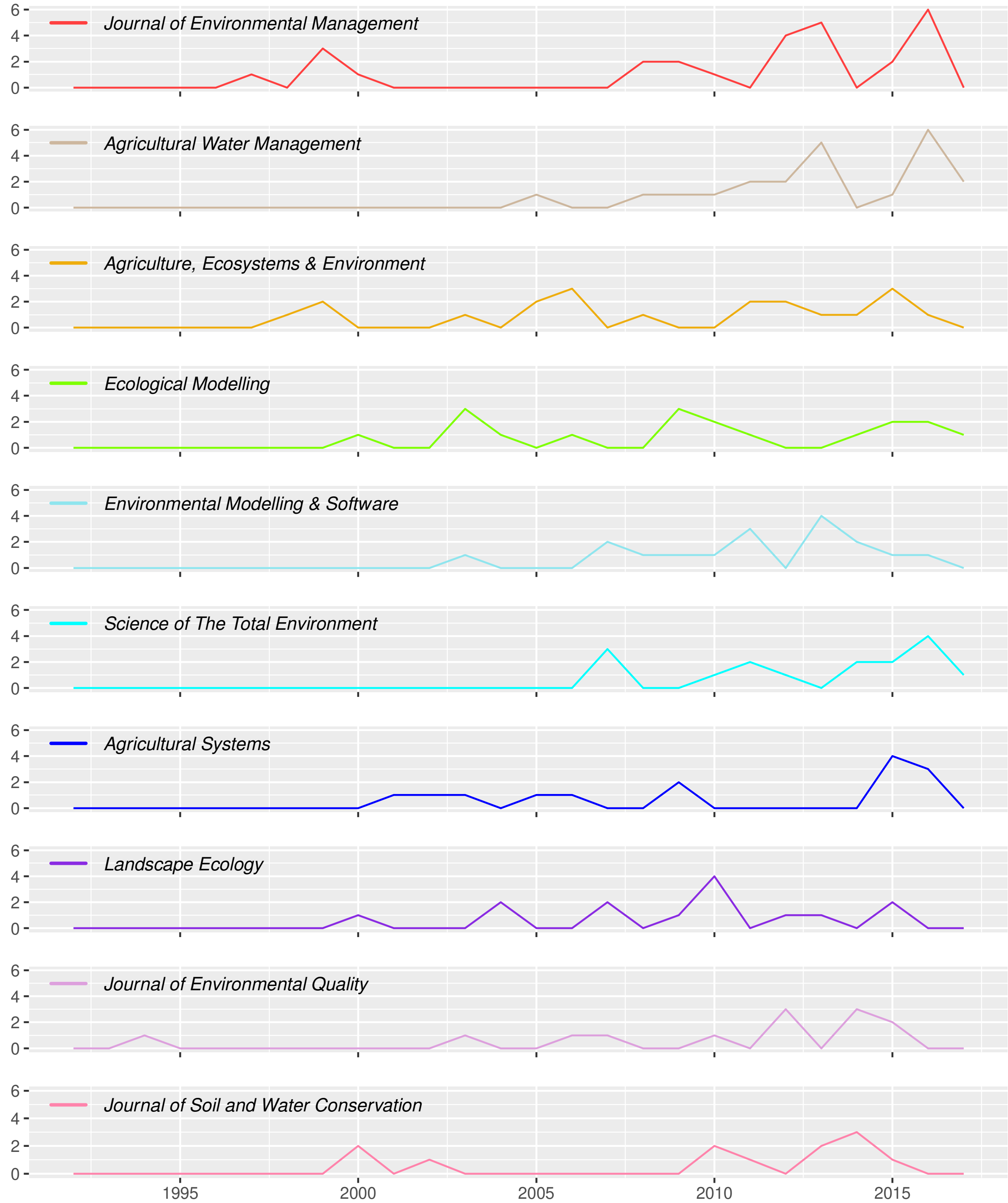


Figure 3. Publication trends in the 10 journals publishing most papers.

3.2. Characteristics of the main topics

3.2.1. Salient terms and description of topics

The five most salient terms in the entire dataset were “water”, “chang”, “land”, “watersh” (i.e. corresponding to watershed(s)), and “crop” (Figure 4). The top 30 most salient terms fell within six broad groups: (1) change trend; (2) spatial scale; (3) pollution; (4) biodiversity; (5) agricultural practices; and (6) terms related to biophysical and regulatory conditions for agricultural production (Figure 4). Four of these top 30 most salient terms were in our search equation (water, watershed, crop and landscape), but all those related to change, pollution and biodiversity were original themes not explicitly specified by our search.

Table 2. Themes covered by the top 30 most salient terms

	Theme 1	Theme 2	Theme 3	Theme 4	Theme 5	Theme 6
Name	Change trend	Scale	Pollution	Biodiversity	Agricultural practices	Biophysical and regulatory conditions
Top terms	Increase	Watershed	Sediment	Species	Practice	Climate
	Predict	Landscape	Load	Habitat	Irrigation	Soil
	Effect	Spatial	Pollution	Conservation	BMP*	Land
	Reduction	Field	Nutrient	Biodiversity	Crop	Water
	Change		Source	Population		Policy

*Best (Beneficial) Management Practice.

By maximising the Bayes factor when fitting LDA on our set of 514 papers, we identified four main topics (Figure 4, Table 3). Two of these concerned water, focusing on quality and quantity management (Topic 1 and 3, respectively). The others were Integrated Assessment and biodiversity (Topic 2 and 4, respectively).

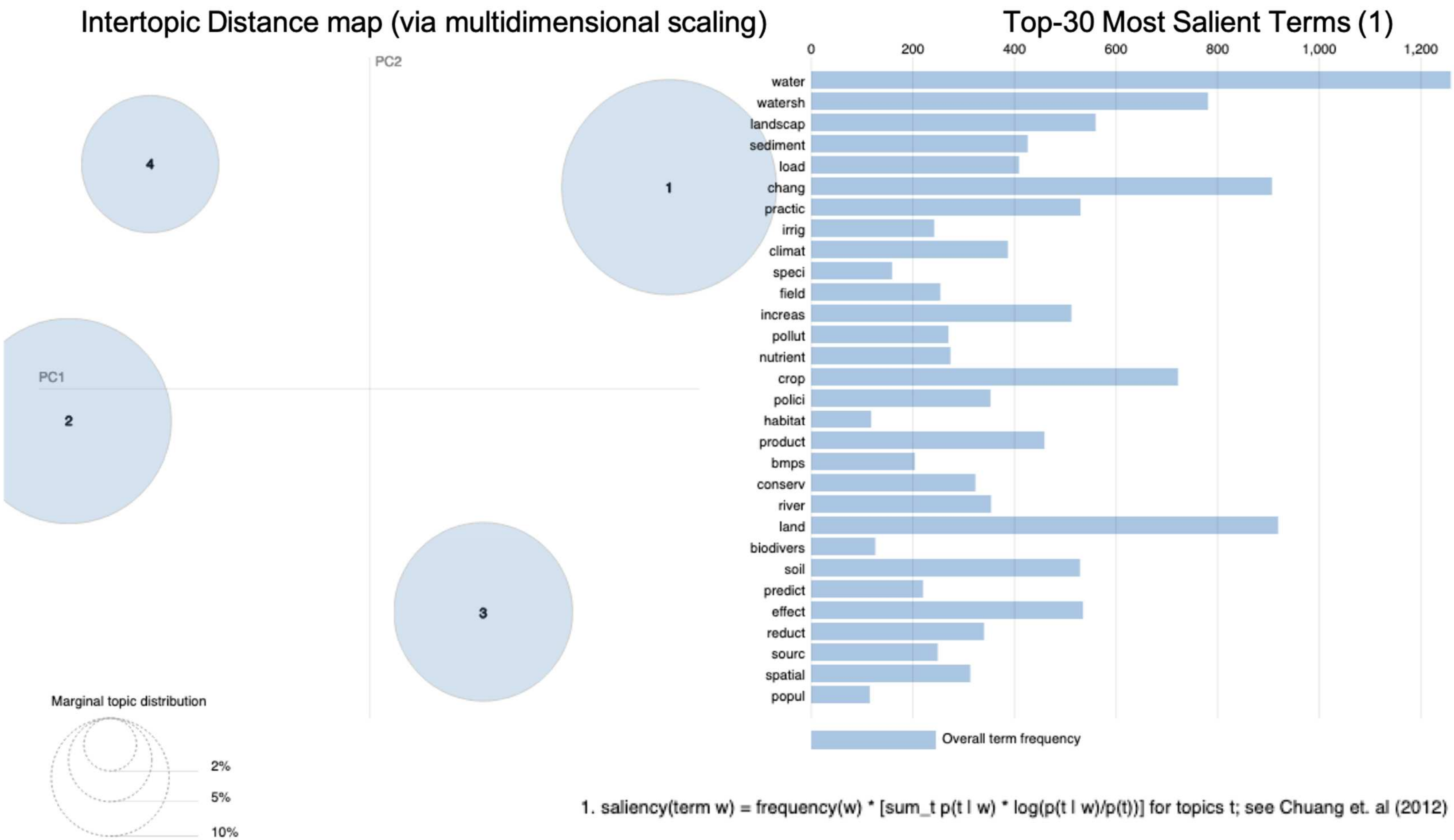


Figure 4. Top 30 salient keywords in the 514 papers in the final dataset and inter-topic distance. Saliency refers to the frequency of keywords in the dataset, and the inter-topic distance approximates the between-topic semantic relationship using Jensen-Shannon divergence. Topic 1: Water quality; Topic 2: Integrated Assessment of agricultural systems; Topic 3: Water quantity/energy crops; Topic 4: Biodiversity.

Water (Topics 1 and 3)

The first topic (Topic 1) was associated with the highest number of tokens (Figure 4), and was covered by 177 papers. This topic concerned water quality (sediment load) associated with various agricultural practices at watershed scale (see top terms in Table 3). Relevant terms (λ = 0.6) for this topic also concerned "runoff", "erosion", "fertilisation" (nitrogen, nitrate, phosphorus, fertility) and agricultural practices ("BMPs", "tillage", "practice", "management") (see http://shin-r.innovation.inra.fr/review_LH_PC/). The only relevant terms (λ = 0.6) related to methods or models were "simulation" and "SWAT" (Soil and Water Assessment Tool), which is a watershed modelling tool developed by USDA in the 1990s to predict the pollution impacts of agricultural practices in large basins (Gassman *et al.*, 2007). For Topic 1, the main purpose of modelling alternative agricultural landscapes was to simulate, at watershed scale, the (mitigating) effect of best management practices (e.g. tillage) on erosion, runoff, and/or water pollution (nutrient, nitrate and phosphorus losses), and associated yield, with a number of the studies on this topic using SWAT. Looking at very specific terms (λ = 0), two models appeared, namely "AGNPS" (Agricultural Non-Point Source) and "AnnAGNPS" (Annualised Agricultural Non-Point Source), the second model being an extension of the first. These are distributed environmental models developed to study the response of watershed hydrological and water quality problems to alternative agricultural management practices (e.g. fertilisation, best management practices (BMPs)) (e.g. Sugiharto *et al.*, 1994; Yuan *et al.*, 2003). For λ = 0 (i.e. highly topic-specific), model-related terms, namely "coefficient" and "algorithm", were among the top 30 most relevant terms. Other model-oriented terms for Topic 1 were "calibration" (λ = 0.1, 0.2 and 0.3), "validation" (λ = 0.2) and "simulation" (λ = 0.4, 0.5 and 0.6), with the latter being less specific to this topic, as indicated by the higher λ values. No temporal scale was found for Topic 1 for any λ.

Topic 3 was more related to water quantity aspects in management of groundwater resources, especially linked with irrigation practices and climate, together with bioenergy crops. This topic was dominant in 95 papers (Table 3). It included relevant terms (λ = 0.6) related to bioenergy crops ("corn", "biofuel", "bioenergy") and their hydrological aspects ("water", "change", "irrigation"). Based on λ = 0.6, the main purpose for Topic 3 of modelling alternative agricultural landscapes was to study the impact of climate change, future bioenergy/biofuel crop production (e.g. corn) or irrigation on water demand and potential yields, mainly at regional, seasonal and annual scale. Temporal scales were highlighted ("season", "annual", "year"), while terms on spatial scale included "region", "river" and "basin". The term "carbon" was also among the 30 most relevant terms for this topic (λ = 0.6), as were some terms related to scenarios and impacts ("supply", "demand", "balance", with λ values between 0.2 and 0.5) (see online diagrams). In the water resource sector, Zare *et al.* (2017) performed a bibliometric analysis of trends, without distinguishing themes related to quantity or quality in their search equation. Niu *et al.* (2014) performed a similar analysis focusing on groundwater and identified more terms related to quality in the most frequent keywords: "water quality", "nitrate/nitrogen", "pesticide", "contamination", compared with "irrigation" for quantity-related terms. The dominance in our study of the water quality topic (Topic 1) over water quantity (Topic 3) is in line with this. Top terms in the study by Zare *et al.* (2017) also included "quality", but not more specific terms related to pollution, and "irrigation" was not identified. However, "climate change", identified as a top term for the water quantity topic identifier in this study (Topic 3), was among the top 13 terms in the study by Zare *et al.* (2017), suggesting that their dataset included studies on water quantity management. No term specifically relating to agriculture was identified in the two previous analyses, but Zare *et al.* (2017) identified terms related to socio-economic terms (e.g. “policy”, “economic”, “stakeholder”), which were absent from the two water-related topics (Topics 1 and 3) in the present analysis. No journal related to agriculture was among the most active identified by Niu *et al.* (2014). The only common journal between our results and those by Zare *et al.* (2017) was *Environmental Modelling & Software* (Figure 3), although not specific to agriculture. The two journals identified in our dataset of 514 papers that specifically relate to water (i.e. *Agricultural Water Management* and *Journal of Soil and Water Conservation*) were not among the most active journals identified by Niu *et al.* (2014) and Zare *et al.* (2017).

Table 3. Top 10 terms in the four topics identified by the first LDA model in our whole dataset (n = 514 papers), with a threshold of 0.15 used for topic dominance (see section 2.4). *Best (Beneficial) Management Practices

	Topic 1: Water quality	Topic 2: Integrated Assessment	Topic 3: Water quantity/ energy crops	Topic 4: Biodiversity	No dominant topic
Number of associated papers	177	137	95	54	51
Top- 10 terms	Watershed, Load, Sediment, Water, Practice, Pollution, Nutrient, BMPs*, River, Source	Landscape, Policy, Change, Decision, Approach, Integrated, Economy, Farmer, Framework, Stakeholder	Water, Irrigation, Change, Climate, Groundwater, Production, Increase, River, Biofuel, Hydrology	Species, Landscape, Habitat, Bird, Field, Biodiversity, Population, Richness, Farmland, Predict	-

Integrated Assessment (Topic 2)

The second most important topic (Topic 2) identified by the LDA model applied on the whole dataset of 514 papers was related to Integrated Assessment approaches studying the effects of policies on landscape change and stakeholder decisions (Table 3). Using λ

= 0.6, the main purpose of modelling alternative agricultural landscapes in this topic was thus to assess the effects of (environmental) policy scenarios on farmers' decisions, farm/regional production and/or ecosystem services, using an Integrated Assessment approach (stakeholder participation). Relevant terms (λ = 0.6) for this topic included words related to the approach used: "Integrated Assessment framework", "system", "process" and "economy". These terms are descriptors of methods related to Integrated Assessment and Modelling (IAM) (Parker *et al.*, 2002) of agricultural systems with stakeholders to evaluate policy options (van Ittersum *et al.*, 2008), also called Participatory Modelling Assessment (Tol and Vellinga, 1998). "Support" was also included in the top 30 relevant terms. Scale terms (i.e. "farm", "local" (both specific to this topic) and "region") were among the 30 most relevant terms. The term "ecosystem services" was also specific to this topic. The terms "stakeholder" and "farmer" were among the 30 most relevant terms. This topic was dominant in 137 papers out of the 514 included in the dataset (Table 3). It appeared to be oriented more towards real-world applications, with method-oriented highly specific terms (λ = 0) like "participatory," "software", "DSS" (Decision Support System) and "trade-off". "Design" was also included in the top 30 most relevant terms for Topic 2, with a λ value of 0.2 (see online diagrams). No terms were related to temporal scale. Some keywords for this topic corresponded to those identified as "socio-economic" in the review by Zare *et al.* (2017). That review focused on Integrated Water Assessment, i.e. using an integrated approach in the water resource sector, e.g. "DSS", "economic", "policy", "stakeholder" etc., which appeared later than overarching and bio-physical keywords (Zare *et al.*, 2017). This indicates some fluidity in different topics/terms.

<u>Biodiversity (Topic 4)</u>

The fourth topic (Topic 4) was related to ecological issues. Top words were "species", "habitat" and "bird", while two top words related to scales, "landscape" and "field", the last appearing as a most relevant term only for this topic. A total of 54 papers had this as a dominant topic (Table 3). Some of the most relevant terms ($\lambda = 0.6$) were biodiversity-oriented ("biodiversity", "population", "abundance", "conservation", "diversity", "density", "dispersal"). The terms "GM" (genetically modified) crops, "weed", "payment" and "grassland" were also among the 30 most relevant terms. The only relevant term related to method or models was "predict" ($\lambda = 0.6$). Thus, the main purpose of modelling alternative agricultural landscapes in this topic was to predict the effect of GM development, payment or land use change in farmland (specifying crops or practices) on species habitat, conservation, diversity, abundance/density, population (e.g. bird) and biodiversity, with particular focus on field scale. With decreasing λ value, the only relevant highly specific term for this topic was "mechanist" ($\lambda = 0$) (see online diagrams). "Patch" and "distance" appeared as specific terms only in this topic ($\lambda = 0.2$, and $\lambda = 0$ to 0.3, respectively). No terms were related to temporal scale. The "biodiversity" topic has been reviewed in the past (e.g. Hendricks *et al.*, 2008; Liu *et al.*, 2011; Stork and Astrin, 2014), although with a wider scope than our focus on agricultural landscapes. These thematic reviews used biodiversity as the main search word (although others, e.g. genetic, ecosystem, etc., were used in Liu *et al.,* 2011). In those studies, the top terms concerned biodiversity: "conservation", "species", "forests", "communities", "ecology" and "ecosystems" (Liu *et al.*, 2011; Stork and Astrin, 2014). Although the subject category "agronomy" was raised, it was not among the most frequently cited (Liu *et al.*, 2011), and agriculture-related terms were not among the top 10 terms, ranking only 38th in Stork and Astrin (2014). A small number of agriculture-specific journals were included in these reviews, e.g. *Agricultural Ecosystems &*

Environment ranked 13th in Stork and Astrin (2008) and 23rd in Liu *et al.* (2011), but was not identified in Hendricks and Duarte (2008). It ranked 3rd in our analysis considering the complete dataset of 514 papers.

3.2.2. Temporal and geographical distribution of topics

Topic 1 (Water quality) was the main topic in the early 1990s and the number of articles on this steadily increased after 2005 (Figure 5), which is consistent with findings by Niu *et al.* (2014) and Zare *et al.* (2017), although they identified more papers due to the difference in search equations. Topic 2 (Integrated Assessment) and Topic 3 (Water quantity/energy crops) appeared in the mid-1990s. The number of articles related to Topic 2 then grew from the early 2000s, while the number of articles on Topic 3 stayed low until 2004, and increased from 2008-2009 to comprise more than a quarter of the total in 2015-2016 (Figure 5). Topic 4 (Biodiversity) was the last to appear (2001) and began to expand strongly in 2006, to comprise 13-16% of the total in 2015-2016. For the biodiversity topic, Hendricks *et al.* (2008), Liu *et al.* (2011) and Stork and Astrin (2014) showed exponential growth over time, which differed from our result focusing on agricultural landscape (Figure 5). Similarly, while we show that publication on this topic began in the early 2000s, they report that it began in the early 1990s (Hendricks and Duarte, 2008; Liu *et al.*, 2011; Stork and Astrin, 2014). This shows that studies on biodiversity in alternative agricultural landscapes came later than studies focusing on biodiversity conservation, highlighted as a main theme in Liu *et al.* (2011) and Stork and Astrin (2014).

Finally, the share of topics changed between the periods 1990-1999, 2000-2009 and 2010-2017, with Topic 1 being less represented in recent periods, although still dominant.

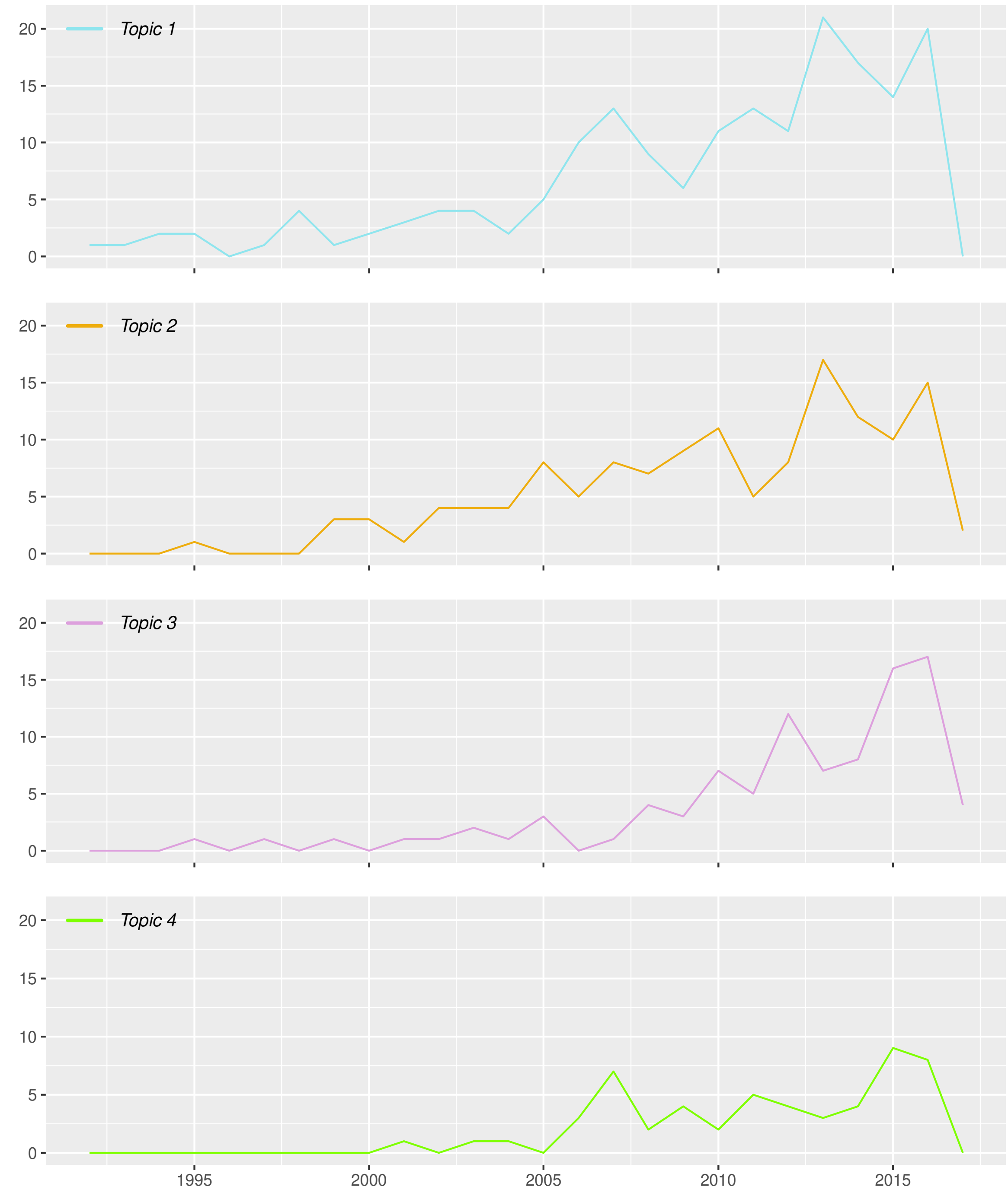


Figure 5. Count of journal articles assigned by the LDA model applied to the whole dataset to each of Topics 1-4. Topic 1: Water quality; Topic 2: Integrated Assessment of agricultural systems; Topic 3: Water quantity/energy crops; Topic 4: Biodiversity.

The trend in the top 10 terms in Topic 1 (Table 3) showed a decrease over time in the occurrence of “sediment”, while the term “pollution” became more frequently used (Appendix B). The term “BMPs” also tended to decrease in use, while “practice” increased. For Topic 2, use of the term “policy” increased, while “decision” and “farmer” first increased and then tended to decrease in recent years. Use of “stakeholder” varied greatly over time, although it became more frequent in recent years. For Topic 3, use of the terms "climate" and "change" largely increased since 2010, while the term "groundwater" was less often used. For Topic 4, the term "landscape" was frequently used since 2007, more than the term "field" (Appendix B). The word "population" gained in popularity over time, while use of "richness" declined. Finally, the term "prediction" was more frequently used in very recent years (since 2015).

The four topics were common in North American literature (USA and Canada), especially topics related to water quality (Topic 1; 48% of papers), and water quantity/energy crops (Topic 3; 51% of papers) (Figure 6). European countries also published on the four topics, but in contrast produced more on Topic 2 (Integrated Assessment; 71% of papers) and Topic 4 (Biodiversity; 78% of papers). Germany, the Netherlands, France and UK were the European leaders on Topic 2 (19, 18, 14 and 14 papers, respectively, out of 97 in Europe), while Germany clearly dominated the literature on Topic 4 among European countries (19 papers out of 42 in Europe). Australia contributed to all topics, China to all except Topic 4 (Biodiversity) and African researchers to all except Topic 2 (Integrated Assessment), while South American countries (only Brazil) contributed only to Topic 3 (Water quantity/energy crops) (Figure 6).

Identification of North America and, to a lesser extent, Europe as leaders of Topics 1 and 3 was consistent with findings by Niu *et al.* (2014) and Zare *et al.* (2017), who focused their reviews on groundwater and integrated water assessment, respectively. They also identified China, India, and Australia among the most active countries (Niu *et al.,* 2014; Zare *et al.*, 2017). While our results are in accordance with the ranking of Asian countries, they underestimate publications by Oceanic countries on water issues.

The dominance of USA and Europe on the biodiversity topic (Topic 4) is in accordance with findings in biodiversity-specific reviews (Hendricks and Duarte, 2008; Liu *et al.*, 2011). However, our geographical analysis was based on the country of the first author only and did not consider the study site country. This gave different results, e.g. for biodiversity Stork and Astrin (2014) found a strong focus on Asia and South America.

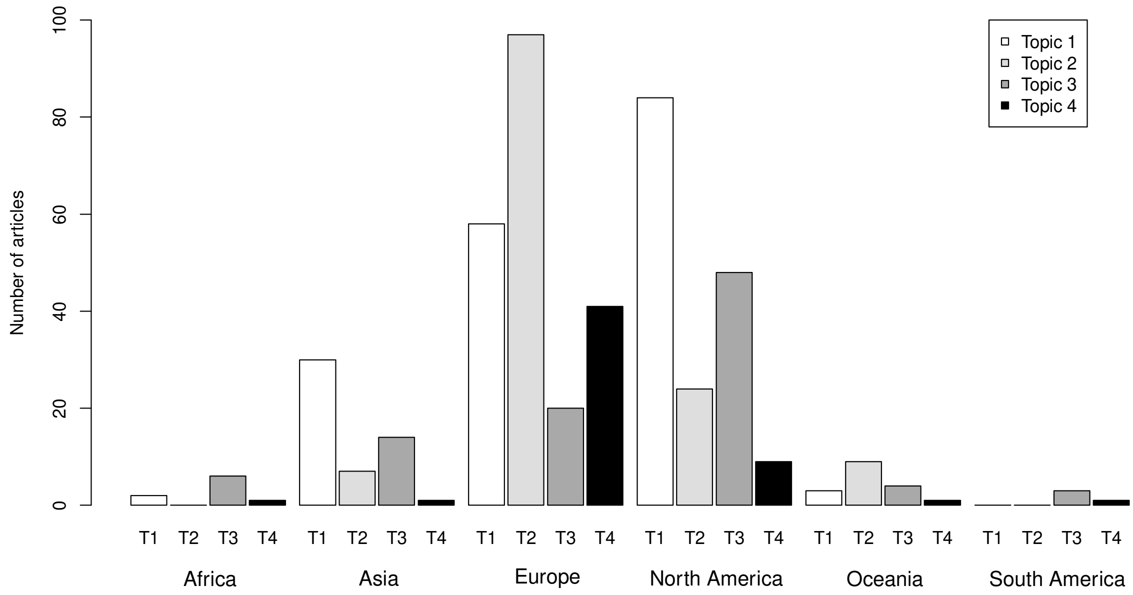


Figure 6. Continental distribution of the journal articles assigned by the LDA model applied to the whole dataset to Topics 1-4. Topic 1: Water quality; Topic 2: Integrated Assessment of agricultural systems; Topic 3: Water quantity/energy crops; Topic 4: Biodiversity.

3.3. Multiple topics

At a topic dominance threshold of 0.15, 463 papers related to only one topic (Figure 7). No article displayed a large frequency of terms corresponding to more than two topics (Figure 7). Such articles appeared only for higher dominance thresholds, with one paper showing a large number of terms related to Topics 1, 2 and 4 (threshold of 0.20 and higher), and one article related to Topics 2, 3 and 4 (threshold of 0.25) (Appendix C).

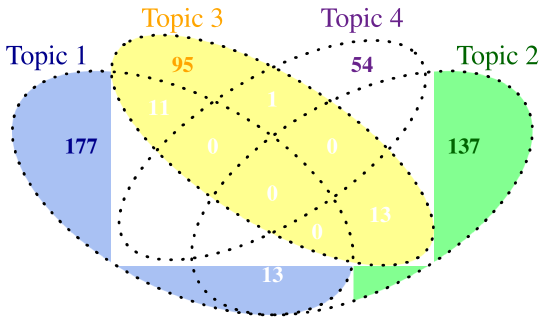


Figure 7. Venn diagram of Topics 1-4 highlighted by the LDA model applied to the whole dataset. Note that topic combinations here are based on a 0.15 dominance threshold (see section 2.4 for definition and Appendix C for threshold sensitivity analysis). Topic 1: Water quality; Topic 2: Integrated Assessment of agricultural systems; Topic 3: Water quantity/energy crops; Topic 4: Biodiversity.

A higher number of articles used terms relevant to two topics (51 papers), except for Topics 1 and 4 combined (i.e. Water quality and Biodiversity) and Topics 3 and 4 combined (i.e. Water quantity/energy crops and Biodiversity), with only one article each at the 0.15 threshold (Figure 7). The article combining Topics 3 and 4 was published in 2011 by a UK team and assessed potential regional carbon stocks according to different scenarios, among which were a bioenergy crop scenario (Topic 3) and a biodiversity scenario (Topic 4) (Cantarello *et al.*, 2011). Combinations of Topics 1 and 4, and Topics 3 and 4, were rare whatever the threshold tested (Appendix C).

At the 0.15 threshold, the number of articles sharing two topics was similar as regards Topics 1 and 2, 1 and 3, 2 and 3, and 2 and 4 (11 to 13 articles in each case; see Figure 7). Combinations of Topics 1 and 3 and of Topics 2 and 3 were more sensitive to the threshold value, with 10-fold more papers at a threshold of 0.25 than at a threshold of 0.05 (Appendix C). The number of articles covering Topic 3 was the most sensitive to threshold value, with almost 19% fewer articles at a threshold of 0.05 compared with 0.25. Comparing these two thresholds, 20 Topic 3 papers (Water quantity/energy crops) appeared to share terms with Topic 2 (12 papers), Topic 1 (7 papers), and Topic 4 (1 paper). This shows that those studies on water quantity/energy crops mostly included an Integrated Assessment framework, or aspects on water quality, which is consistent with the research trend on Integrated water Assessment and modelling (Zare *et al.*, 2017). No time trend of mixed topics in the relevant papers was found for any dominant topic (Appendix D).

This shows some 'fluidity' between topics, with varying impacts studied, e.g. the impact on birds of developing bioenergy crops (Engel *et al.*, 2012; Everaars *et al.*, 2014) or the impact of policy on bird conservation or field habitat (Drum *et al.*, 2015; Bredemeier *et al.*, 2015), although the paper was allocated to one specific topic (Topic 4 for the examples cited).

For the 51 papers for which no dominant topic was found at a threshold of 0.15, no time trend was identified regarding an increase in mixing topics (Appendix D). Overall, 29% of these papers performed an Integrated Assessment including water quality (Topics 1 and 2), 25% made an Integrated Assessment including water quantity or energy crops (Topics 2 and 3), 22% studied biodiversity with an Integrated Assessment Approach (Topics 4 and 2) and 20% of the 51 papers studied both water quality and water quantity/energy crops (Topics 1 and 3). Less frequent topic combinations were studies of water quality together with biodiversity (Topics 1 and 4) and studies of biodiversity and water quantity/energy crops (Topics 4 and 3), with one paper each.

4. Discussion

In this review, we assessed published studies in which a modelling approach was used to design and assess the performance of alternative agricultural landscapes. Our aim was to identify the structure of existing research and the range of associated methods and models employed.

4.1. Main topics identified, potential reasons and limits

Our analysis of the selected literature identified four main topics: Water quality (Topic 1), Water quantity/energy crops (Topic 3), Biodiversity (and GM) (Topic 4), and a "multi-issue" topic considering Integrated Assessment, i.e. policies and stakeholder decisions for landscape simulation (Topic 2). These topics were each linked to a scientific discipline: hydrology for Topics 1 and 3, ecology for Topic 4 and economics/policy study for Topic 2. Terms related to cropping practices (i.e. agronomic terms) were associated to each topic, although with a lower number of terms for Topic 4. Topic 3 was associated with one specific cropping practice ("irrigation") and type of crop ("biofuel", "corn") and their proportions within the landscapes. Topic 1 was associated with "BMPs", with a specification (options of "tillage", "fertilisation"), showing a certain homogeneity and simplification in the range of agronomic options tested. BMPs constituted a positive list of agronomic practices (regarding soil, water, nutrients, integrated pest and landscape management; Schenpf and Cox, 2007). The term "BMPs" appeared to be mainly used by North American researchers; this term arose in the USA in guidelines to address Non-Point Source pollution for water quality protection, through the 1972 Federal Water Pollution Control Act (Phillips and Blinn, 2004). This is consistent with the specific terms related to models in Topic 1, with the names of models developed in the North America (e.g. SWAT; see Gassman *et al.*, 2007) being the leader for water management topics (Topics 1 and 3). This could be linked to the type of agriculture practised in North America, i.e. highly irrigated (FAO, 2014), intensive and specialised (e.g. monocropping in the Corn Belt), leading to both water quality and quantity issues and related research.

Europe was the leader for the topic Integrated Assessment (Topic 2), characterised by the more general term “Decision Support System” or “DSS”. The dominance of Europe on the topic Integrated Assessment (including stakeholder participation and decision support systems), within the specific context of “alternative agricultural landscape modelling”, can be attributed to the fact that it emerged in the Netherlands in the late 1990s (Rotmans and van Asselt, 1996) and had grown into a booming field by the early 2000s (Hisschemöller *et al.*, 2001). Integrated Assessment was initially defined by two main characteristics: i) building upon research in different disciplines and ii) providing information for decision makers (Rotmans and van Asselt, 1996). However, we focused on agricultural landscapes, which could explain the geographical bias observed for this topic. For instance, Integrated Assessment methods are used by North American researchers, but their focus is not on agriculture (e.g. flood resilience in Allen *et al.*, 2019).

Topic 1 showed greater homogeneity in methods for the water quality topic, which makes comparisons easier but could also indicate less originality in the methods applied, in contrast to Integrated Assessment and water quantity/energy crops (Topics 2 and 3). The topic on biodiversity (Topic 4) was the only one highlighting different spatial scales (“patch”, “field”, “landscape”), thus tending to have a spatially explicit approach. The topic on Integrated Assessment included the term “farm”, which is more related to a decision level. Water quality studies used mostly SWAT, which is a distributed spatially explicit model. Water quantity/energy crop studies looked more at aggregated values on e.g. water demand or total production, although they sometimes considered spatial scale for implementation of a crop/practice change. The spatial scale was thus determined by the issue. However, alternative landscapes are the result of multiple drivers that take place at different scales (e.g. biodiversity at patch scale, decision and economic consequences at field and farm scale, aggregated effects at landscape scale), thus calling for multi-scale studies.

4.2. Potential gaps and future works

The impact of agricultural landscapes on biodiversity (Topic 4, the last to emerge in our dataset) was studied equally in North America and Europe. This is consistent with findings in a more general review (i.e. not specific to agricultural landscapes) by Di Marco *et al.* (2017) that there is a geographical bias (Europe, North America, Central America) in studies of conservation science. Surprisingly, the term "ecosystem services" was associated with Integrated Assessment of agricultural landscapes (Topic 2), and not biodiversity (Topic 4). The relative absence of ecosystem services in the biodiversity topic is consistent with previous findings in a review by Egoh *et al.* (2007) that a very low number of conservation assessments include ecosystem services. This could be explained by the way in which the concept of ecosystem services was promoted in Millennium Ecosystem Assessment (MA, 2005), i.e. as a policy tool aiming at sustainable use of natural resources (Seppelt *et al.*, 2011), thus corresponding more to our topic Integrated Assessment. However, the ecosystem services concept was also developed to demonstrate the value of nature (Walz and Syrbe, *in press*) and is closely related to biodiversity preservation (European Commission, 2011). This could indicate that biodiversity studies need to align more tightly to political context and governance alternatives (e.g. Velten *et al.*, 2018), with inclusion of biodiversity aspects in DSS, more stakeholder interactions and greater inclusion of ecology researchers on ecosystem services, which is becoming a hot topic. In particular, integrating the relationships between biodiversity and ecosystem services (e.g. birds feeding on weed seeds; Gaba *et al.*, 2014) in agricultural landscape modelling could help provide a framework for future policies combining biodiversity and agriculture. While we identified a few papers studying the impacts of policy on birds or habitats, those did not include a bottom-up approach involving local stakeholders to co-design possible actions and their translation into local policies (e.g. Bredemeier *et al.*, 2015), or used a simplified vision of agricultural practices (e.g. Drum *et al.*, 2015). This calls for more inclusive biodiversity-based studies involving the participation of local stakeholders (farmers, but also local authorities and nature NGOs) to develop local policies for alternative landscapes combining biodiversity preservation and agricultural production, with explicit and detailed consideration of the constraints of these two sectors. Unlike current policy developments, those studies would be based on a bottom-up approach, combining detailed knowledge of current agricultural practices, biodiversity issues and potential win-win or compromise situations identified e.g. in participatory workshops. The benefits of this type of research would be both scientific (transdisciplinary research, with cross-fertilisation between different disciplines, e.g. ecology, agronomy, economics) and oriented towards local action through the promotion of practices and policies developed locally. It follows that the design of agricultural landscapes will require joint work by scientists and stakeholders to identify the desired ecosystem services and design the necessary landscape modifications (Landis, 2017). As biodiversity and nature are becoming a hot topic with recent reports of species decreases and extinctions (Diaz *et al.*, 2019), policy-makers are urged to promote effective actions in favour of biodiversity and ecosystem services preservation. In this work, research methods and tools could be used for both design and assessment of alternative landscapes. As claimed by Hill *et al.* (2013), participatory scenario design, together with collective visioning, urgently needs to be revised to favour policy development and foster social consensus on biodiversity conservation. Complex landscapes should be represented, with models accounting for the spatial configuration or composition in a balanced way, although development of such models is "…still in its infancy" (Langhammer *et al.,* 2019). Studies could target, for instance, natural pest control in an ecological intensification perspective, where natural enemies replace pesticides in cropping and farming systems in landscape scenarios (Bommarco *et al.*, 2013). An exploratory model-based approach is lacking at landscape level, where natural pest control is only assessed via some landscape proxies such as diversity of land cover around the perimeter to determine the potential amount of services (Mitchell *et al.*, 2013).

Most papers in our dataset were linked to one dominant topic. Less frequent topic combinations were studies of water quality together with biodiversity (Topics 1 and 4) and studies of biodiversity and water quantity/energy crops (Topics 3 and 4). Although we excluded papers focusing only on the effects of climate change, this theme emerged as a driver of scenarios in Topic 3 (Water quantity/energy crops). Thus, in our dataset, biodiversity was apparently not assessed in studies linking climate change and agricultural practices, the two main factors that actually threaten biodiversity. Different studies have assessed biodiversity responses to climate change (e.g. Bellard *et al.*, 2012), or to agriculture and their potential conflicts (e.g. Henle *et al.*, 2008). Attempts to study their joint effects appear to have focused mostly on land use change, without detailing agricultural practices. Several studies have considered habitat loss, but with less attention to spatial (e.g. fragmentation in the landscape) or practice change (e.g. management intensity) (de Chazal and Rounsevell, 2009), and with a limited number of taxa considered (Chopin *et al.*, 2019). Future studies of alternative agricultural landscapes thus would need to enlarge the vision on biodiversity, e.g. by increasing the number of taxa (Chopin *et al.*, 2019) and including detailed population characteristics and their climate drivers, together with potential agricultural practices to be applied in these futures. This will require integrated approaches, as agricultural practices are determined by a set of drivers, including (but not limited to) climate change. Participatory approaches would thus be also required for this issue.

Finally, our review did not identify hot topics and methods used in agricultural studies. For instance, “resilience” was not identified as a top word among our four topics, appearing in only five of the 514 papers in our dataset. However, resilience is gaining increasing attention in agricultural research to characterise the relationship between agricultural outputs and perturbation, the two main parameters being global warming and price volatility (Urruty *et al.*, 2016). Agronomists study agricultural resilience at farm to country scale (Urruty *et al.*, 2016). The landscape scale tends to be studied by researchers in ecology, looking at e.g. spatial resilience (location, connectivity, complexity) (Cumming, 2011), land use management and habitat (Tscharntke *et al.*, 2005), or by economists looking at land use patterns and the resilience of agricultural returns (Abson *et al.*, 2013). In those ecology-based studies, agricultural practices are often simplified, characterised as categories of land use and disregarding the level of decision, i.e. the farm. This indicates that the landscape agronomy approach called for by Benoit *et al.* (2012) has not yet fully emerged. This approach is necessary for disaggregating land use and better characterising the diversity of cropping systems and landscape diversity, as highlighted by Chopin *et al.* (2017). It is particularly important for issues requiring coordination of agriculture-related actions at the landscape scale (e.g. erosion in Souchère *et al.*, 2010), or collective governance of e.g. water resources (e.g. Murgue *et al.*, 2015) or integrated crop-livestock systems (e.g. Moraine *et al.*, 2017).

5. Conclusions

In this review, we distinguished four main topics covered by studies modelling the impacts of agricultural changes at landscape scale. These were: water quality, water quantity/energy crops, biodiversity and integrated assessment. We found very few publications on these topics in South America and Africa, despite the fact that hot topics like water scarcity in Africa are likely to increase with climate change, calling for collective governance at scales beyond field and farms. Similarly, issues like GMs and emerging weed resistance, particularly in South America, call for spatially explicit methods for coordinating actions at medium spatial scales. Finally, although we found abundant North American and European studies on modelling agricultural changes and impacts at landscape scale, hot topics like pesticides (EU) and diversification (USA) did not emerge, despite their critical impacts at landscape scale for e.g. water quality, water quantity and pest control. This indicates an urgent need for integrated studies considering the diversity of agricultural and cropping systems in governance of the collective issues of water quality, water quantity and biodiversity.

Acknowledgments

The second author received funding from SLU´s Cropping system Platform. This work was also carried out with the financial support of INRA (France). We would like to thank Mary McAfee for English editing. We thank the three anonymous reviewers for their helpful and valuable comments on an earlier draft of the manuscript.

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