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

2

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12 Keywords

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

15

16 Highlights

17 - We performed a topic analysis on a selected ensemble of 514 publications

18 - Main topics were water quality, water quantity, biodiversity, Integrated Assessment

19 - Biodiversity was the most recent topic to emerge

20 - Biodiversity and water quality/quantity assessments were rarely combined

21 - Agricultural practices should receive more attention in landscape approaches

22

23

24 Abstract

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

38 1. Introduction

39 Spatial expansion and intensification of agriculture in recent decades has had
40 tremendous environmental impacts on agricultural landscapes (Foley *et al.*, 2011).
41 These landscapes are defined as systems in which interactions occur between farmers
42 and their natural and social resources, including management of fields, field margins and
43 associated semi-natural habitats (Benoit *et al.*, 2012). Modern agriculture is contributing
44 to water degradation, increased energy use and greenhouse gas emissions, together
45 with widespread pollution and loss of biodiversity (Foley *et al.*, 2011). These impacts
46 take place beyond the field and farm levels, necessitating a landscape approach if they
47 are to be addressed properly at the relevant scale(s), through relevant research
48 disciplines and methods. Impacts resulting from spatial interactions need to be
49 considered at larger scales than point effects. This can be watershed scale when
50 considering water quality or quantity (e.g. Frey *et al.*, 2013; Gungor and Guncu, 2013;
51 Fan and Shibata, 2015; Carvalho-Santos *et al.*, 2016) or landscape scale when
52 considering spatial flows of pathogens (e.g. Hossard *et al.*, 2013), nectar-foraging species
53 (e.g. Baveco *et al.*, 2016) etc. Many studies have examined sustainability at field or farm
54 scale (e.g. Zahm *et al.*, 2008; Pelzer *et al.*, 2012; Craheix *et al.*, 2016), but upscaling their
55 results to larger spatial or temporal scales may be difficult and produce uncertain
56 conclusions (Dargaard *et al.*, 2003). However, such upscaling may be necessary to
57 understand the impact of different land uses, crops and/or cropping techniques on
58 landscape performance, sustainability and ecosystem services (Tscharntke *et al.*, 2005).
59 Because of the multiple temporal and spatial scales involved, assessment of agricultural
60 landscapes is challenging and requires modelling approaches to study system changes
61 and their impacts. Modelling allows the complex processes occurring to be simplified, in
62 order to explore the impacts of possible changes (land use, crop, practices) that cannot

63 be distinguished in the real world (e.g. Legg, 2004; Skelsey *et al.*, 2010). Different
64 modelling approaches can be used for designing and/or assessing landscape
65 performance in the face of change, depending on the topic studied and available
66 knowledge. These approaches may involve empirical models (e.g. Bennett *et al.*, 2014),
67 process-based models (e.g. Santhi *et al.*, 2014), optimisation models (e.g. Huang *et al.*,
68 2012), agent-based models (e.g. Brady *et al.*, 2012), statistical models (e.g. Gottschalk *et*
69 *al.*, 2007) or a combination of these types of models (e.g. Schonhart *et al.*, 2016). In such
70 studies, the objective in designing alternatives is to compare their impacts with
71 appropriate indicators, with simulation models being used to predict values for these
72 indicators (Clavel *et al.*, 2012).

73 Different methods can be used to design alternatives, ranging from simulation studies
74 (comparable to sensitivity analyses on cropping practices and/or their
75 proportion/location) to participatory approaches. Scenarios, which describe “possible
76 futures that reflect different perspectives on past, present and future developments”
77 (Van Notten, 2005), are currently used in participatory approaches. They usually include
78 a description of the initial situation (for comparison with alternatives) and often also the
79 drivers/causes of change (Dockerty *et al.*, 2006; Alcamo and Henrichs, 2008), which can
80 be social, economic (e.g. policies) and/or physical or ecological (e.g. climate change). The
81 design of alternative landscapes can be performed by the research team (e.g. Babel *et al.*,
82 2011) or in a participatory approach involving stakeholders (e.g. Hossard *et al.*, 2018),
83 depending on the topic studied, the model used for assessment and the preferences of
84 the research team.

85 Understanding the range of approaches available for impact modelling at landscape
86 scale is important when exploring potential opportunities to efficiently address local to
87 global problems. In the first instance, bibliometric analyses have been performed,

88 without specifying scale or agriculture, on specific impacts in e.g. biodiversity research,
89 focusing on literature growth, collaboration/citation networks and top terms (Liu *et al.*,
90 2011; Stork and Astrin, 2014). Such analyses were also performed looking specifically at
91 groundwater research (Zare *et al.*, 2017) and water impacts (Niu *et al.*, 2014), to identify
92 trends in publications, highly cited publications, keywords and associated trends. A
93 recent review focused on global environmental assessment, highlighting “decision-
94 theoretic approaches” (e.g. life cycle assessment, indicator selection), new methods
95 (model, geographic information system), and hotspots (e.g. biodiversity, climate change,
96 risk assessment) (Li and Zhao, 2015). However, such studies explore one specific
97 impact, while not focusing on agricultural uses or on a specific (landscape) scale.

98 Reviews can also be performed specifically at landscape scale. However, those
99 performed to date also focus on a specific impact, e.g. water scenario analyses (March *et*
100 *al.*, 2012), on specific methods, e.g. multi-criteria assessments (Allain *et al.*, 2017),
101 decision support systems for landscape management (Zasada *et al.*, 2017) or on
102 synthesis and qualitative analysis of the literature on landscape approaches and their
103 potential operationalisation (Freeman *et al.*, 2015). Thus, to our knowledge, no
104 quantitative systematic review has been performed to date on model-based assessment
105 of agricultural changes, to identify consistent groups of studies defining different topics.

106 The only studies addressing the objective of group identification have focused on water
107 scenario analyses (March *et al.*, 2012) or on biodiversity only (Chopin *et al.*, 2019), the
108 latter using similar keywords to those used in our study. Hence, the objectives of this
109 study were to (1) assemble a comprehensive dataset of published studies designing
110 alternative agricultural landscapes and assessing associated changes and impacts
111 through modelling, and (2) identify and analyse study structure, trends in knowledge
112 and associated methods and models employed in this dataset. Thus, we focused our

113 research on studies using models to explore the consequences of future agricultural
114 landscape changes (i.e. design and/or assessment of new landscapes) and applied a
115 topic modelling approach to link the type of impact with modelling approaches, in order
116 to identify potential methodological improvements in impact analysis (Blei *et al.*, 2003).
117 We chose to focus on agricultural landscape changes that explicitly include cropping
118 practices or the organisation of crops/practices in the landscape. Thus, we excluded
119 pure land cover/land use studies, where the data on agriculture are too aggregated to
120 discriminate the diversity of cropping systems (Chopin *et al.*, 2017). Identifying trends
121 and groups of publications sharing a similar structure can help to identify gaps in
122 methods/topics crossing.

123 2. Methods

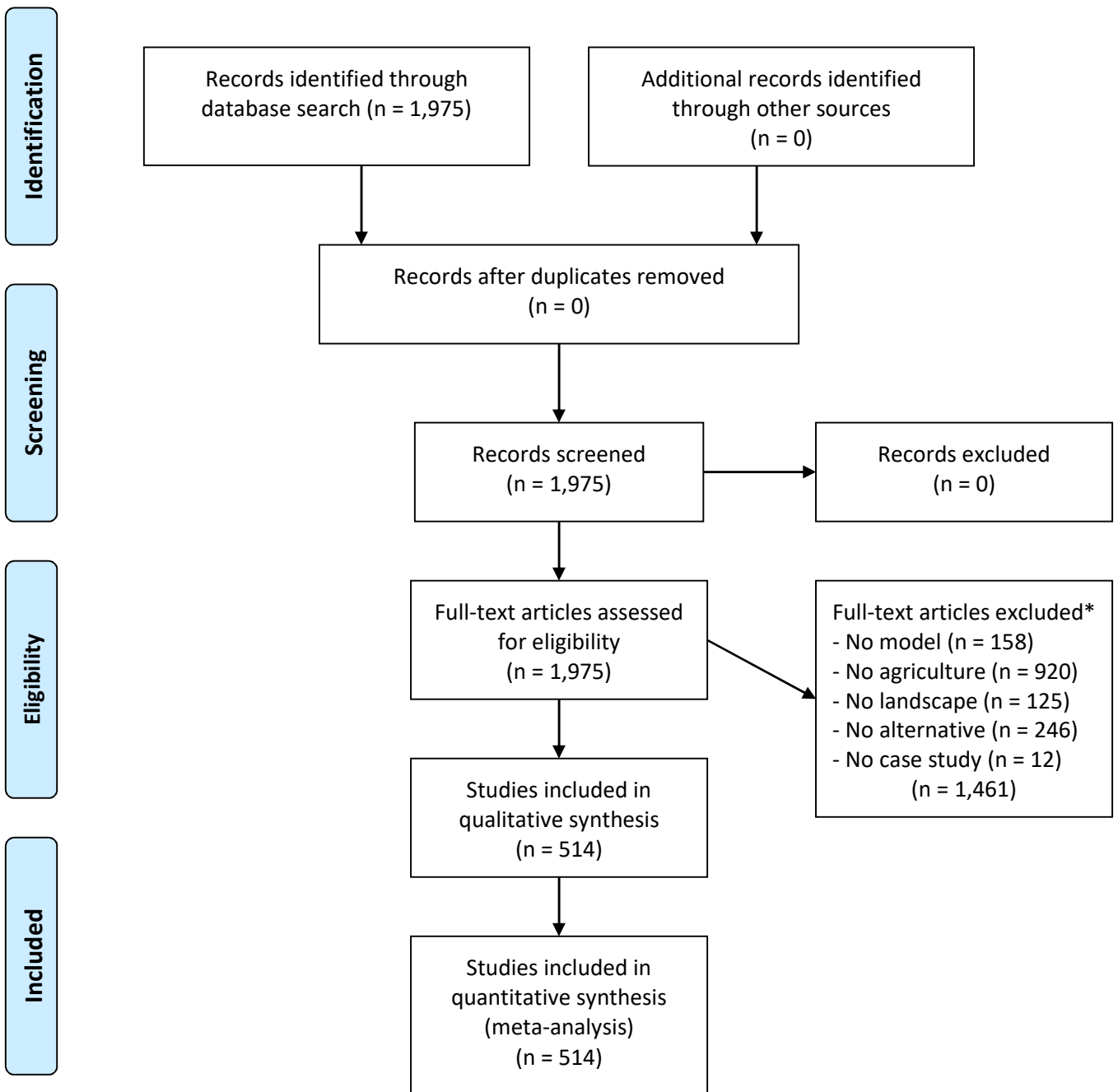
124 2.1. Literature search and study selection

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

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



PRISMA 2009 Flow Diagram



From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews : Meta-Analyses: 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)

153 2.2. Overview of bibliometric analysis and topic modelling

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

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

177 distribution and the information gathered in the data. Thus, the posterior distribution is
178 conditional on the data used.

179

180 2.3. LDA procedure for main dataset topics

181 Three main steps have to be performed before estimating the LDA of a dataset (Grün
182 and Hornik, 2011). The first step is to pre-process data with tokenisation and stemming
183 to build a dataset dictionary, in order to ensure relevant analyses (Grün and Hornik,
184 2011). Tokenisation is applied to separate so-called “tokens” (e.g. words), by removing
185 punctuation characters, numbers, converting to lower-case and removing stop words,
186 using the “tm” R package (Feinerer and Hornik, 2017). Stemming is applied to reduce
187 each word to its root grammatical form, in order to increase inter-paper comparability
188 (i.e. homogeneity of terms), e.g. “chang” would be the root for changes, change, changing,
189 etc (Appendix A). In addition, in our LDA analysis we deleted the term “model” from the
190 dictionary, as it was the only mandatory term in our search equation (see section 2.1.).
191 We then analysed the resulting dictionary, to further homogenise tokens by merging
192 redundant terms (e.g. “plough” and “plow”; “tillage” and “till”; “actor” and “stakeholder”;
193 see Appendix A for the entire list). Potentially misleading terms were manually checked
194 in each paper to avoid unintentional mergers (e.g. catchment relating to non-water
195 applications). Very infrequent words, i.e. terms occurring less than five times, were also
196 removed from the analysis (as in D’Amato *et al.*, 2017).

197 In the second step, the number of topics (k) included in the dataset has to be chosen
198 before running LDA. This number is often set *a priori* by the user, based on assumptions
199 on the dataset structure (e.g. on research fields in Kane *et al.*, 2016). In the present
200 study, we hypothesised that topics would correspond to the main sustainability issues
201 (environmental, economic, social), but that these could be further split into sub-issues

202 (e.g. water quality and water quantity both consider the environmental aspect of
203 sustainability) or according to scientific discipline (e.g. economics, agronomy, hydrology
204 etc.). Given this uncertainty, we opted not to specify the number of topics *a priori*, but to
205 set it according to the estimation strategy proposed by Taddy (2012). This method finds
206 the “best” number of topics within the minimum and maximum user-defined number of
207 topics. The “best” number of topics is that maximising the Bayes factor computed with
208 marginal likelihood calculations (Taddy, 2012), i.e. maximising the posterior
209 distribution over the possible instances of topics over words (Uto *et al.*, 2017). To
210 analyse our dataset of 514 papers, we set the possible number of topics between 2 and
211 51 (where 51 corresponded to mean number of 10 papers per topic), using the “topics”
212 function in the “maptpx” R package (Taddy, 2012).

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

220 The LDA model for main topics was then fitted using the “lda.collapsed.gibbs.sampler” of
221 the “lda” R package (Chang, 2015) using 2500 iterations (as in D’Amato *et al.*, 2017).
222 This LDA-Gibbs approach provides estimates of posterior probability of association
223 between journal articles and topic, and terms and topic. It thus provides the probability
224 for (1) allocation of the journal articles to each topic and (2) allocation of individual
225 terms to each topic (‘topic keywords’). Topic keywords can be either generic to the
226 entire dataset or specific to one (or a few) topic(s). Keyword specificity to one topic is

227 measured based on computation of the “relevance” of a given term to a given topic
228 (Sievert and Shirley, 2014). Sievert and Shirley (2014) define the relevance of a term w
229 to a topic t as a function of a weight parameter lambda (λ) ranging between 0 and 1. λ
230 determines the (user-defined) weight given to the probability of a term w under topic k
231 relative to its lift: $\text{relevance}(\text{term } w \mid \text{topic } t) = \lambda * (p(w|t) + (1 - \lambda) * (p(w|t)/p(w))$ (Sievert
232 and Shirley, 2014). A high value of λ results in keywords common to the entire dataset,
233 while a low value results in topic-specific keywords (Sievert and Shirley, 2014). λ is
234 chosen *a priori* by the user. In this study, we mainly used a value of $\lambda = 0.6$, as
235 recommended by Sievert and Shirley (2014), although lower values of λ were also
236 employed (0.1 step) to look for specificities of methods and models, especially for highly
237 specific terms ($\lambda = 0$). Topic results are available online for further exploration
238 (http://shin-r.innovation.inra.fr/review_LH_PC/), with the possibility of choosing
239 different λ values and visualising relevant terms according to the chosen λ value.
240 In addition, our analyses included a list of salient terms in the whole dataset. The
241 saliency of a term refers to the frequency of keywords in the dataset, using word
242 distinctiveness (Chuang *et al.*, 2012). The analyses of salient and topic-specific keywords
243 were performed using the “LDAvis” R package (Sievert and Shirley, 2015), which also
244 calculates the distance between topics using Jensen-Shannon divergence (Sievert and
245 Shirley, 2014). This inter-topic distance approximates the between-topic semantic
246 relationship, using multidimensional scaling.

247

248 2.4. Characterising the main topics in the dataset

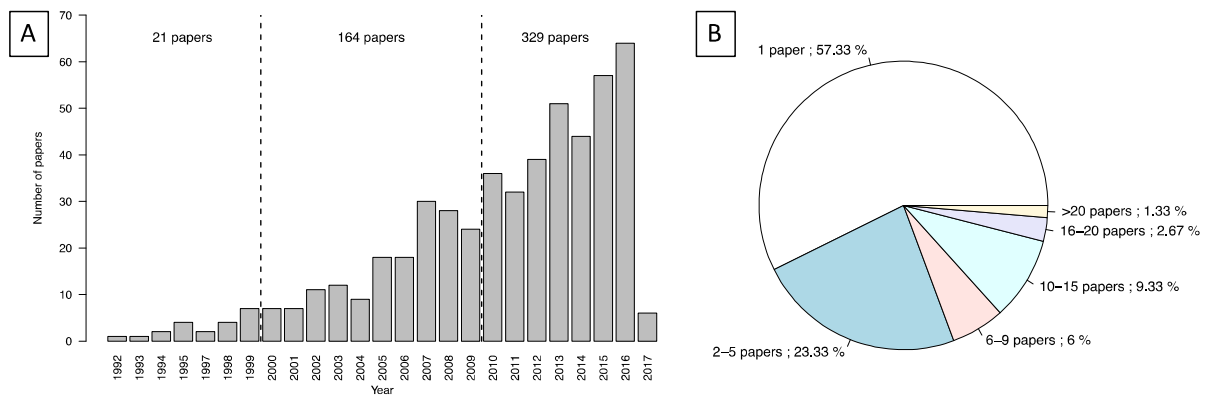
249 We sought to examine the potential range of models and methods within the main
250 dataset topics identified by the general LDA model constructed above. To this end, we
251 built a new LDA model for each topic in the whole dataset independently, by dividing the

252 main dataset into groups of papers corresponding to the k dataset topics. As each paper
253 could cover more than one topic (Blei *et al.*, 2003), we considered only papers where
254 one topic was dominant. To define topic dominance for a paper, we considered the
255 number of times words (Sw) in the paper were assigned to each of the k topics. We
256 assigned a paper to a specific topic k_a if the related word count was at least 15% larger
257 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
258 values were tested to determine the sensitivity of our results to this 0.15 threshold (see
259 Appendix B for tests using values of 0.05, 0.10, 0.20 and 0.25). The LDA procedure
260 followed for sub-topic building was identical to that used for the main topics (see
261 section 2.3), with k ranging between 2 and one-tenth of the number of selected papers.
262 Most diagrams were built with the “ggplot2” R package (Wickham, 2009). Maps to reveal
263 spatial trends in publications were drawn with the “rworldmap” R package (South,
264 2011) and Venn diagrams crossing topics were created with the “VennDiagram” R
265 package (Chen, 2016).

266 3. Results

267 3.1. Bibliometric analysis

268 Based on our search equation, the first journal articles to focus on modelling impacts of
269 agricultural landscape changes were published in 1992. Among the 514 publications
270 included in our analysis, the vast majority (329 papers) were published after 2009 (up
271 to April 2017, the date of our search) (Figure 2A). The 514 articles were published in
272 150 journals in total, with the majority of these journals (87 journals, or 57.33%)
273 publishing only one article during the whole period and only 19% (30 journals)
274 publishing more than five articles (Figure 2B).



275

276 Figure 2. Overview of the global dataset regarding (A) the temporal distribution of
277 publications and (B) the proportions (%) of journals publishing different numbers of
278 papers (1 paper, 2-5 papers, 6-9 papers, 10-15 papers, 16-20 papers, >20 papers).
279

280 The period 1992-1999 yielded 21 publications from eight countries, the period 2000-
281 2009 yielded 164 papers from 28 countries, and the most recent period yielded 329
282 papers from 36 countries (Figure 2A, Table 1). Over the whole period, USA, Germany
283 and France were the countries publishing the most, with the USA producing about three
284 times as many papers as the other two top countries (165 papers in USA, compared with
285 53 and 40 in Germany and France, respectively) (Table 1). The European continent

286 published the largest numbers of papers in the two more recent periods (81 papers in
 287 2000-2009 and 154 in 2010-2017).

288

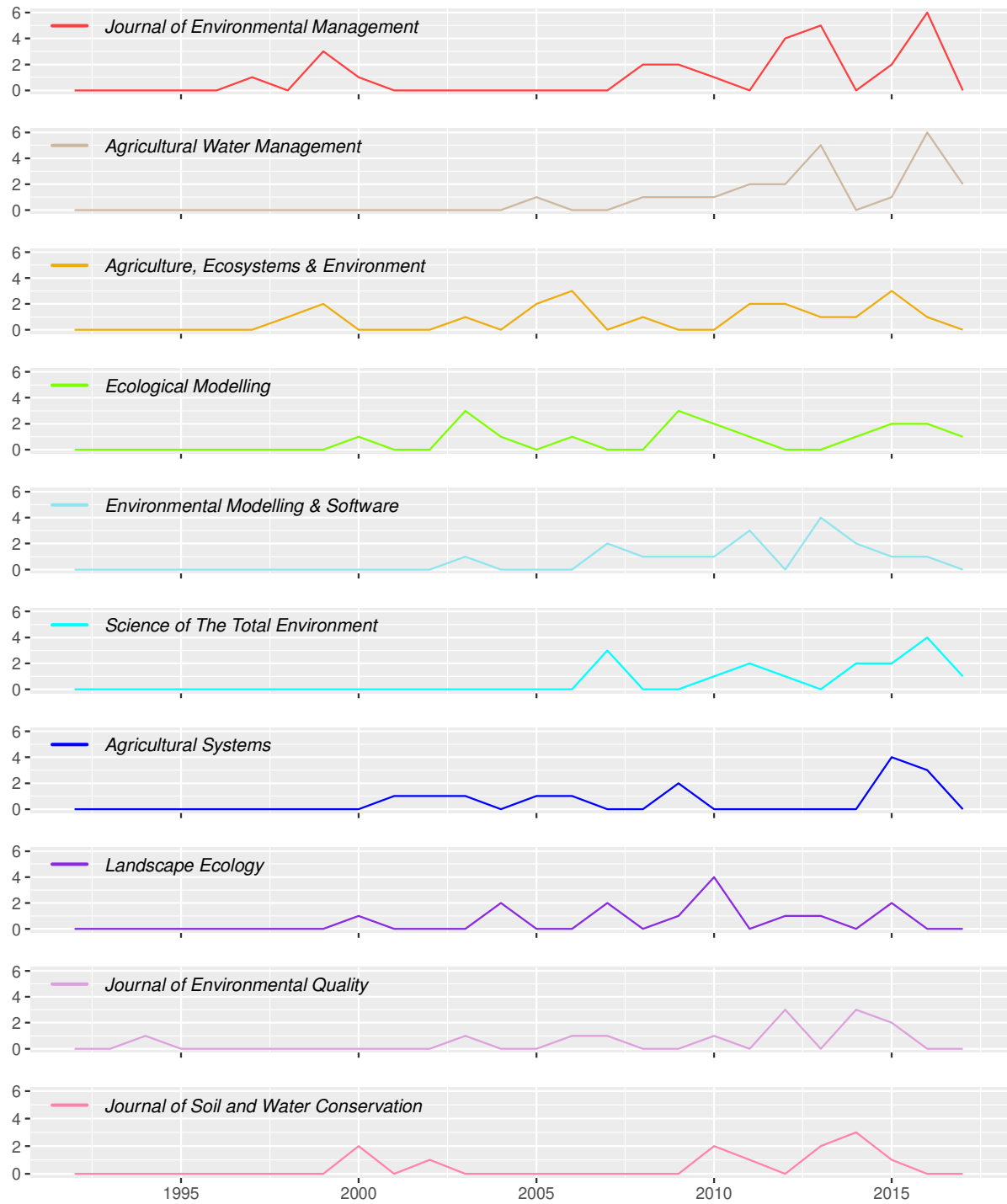
289 Table 1. Publication trends in the countries publishing most papers in the study period

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)

290 *Equal third place.

291

292 The top journals publishing papers on modelling the impacts of agricultural landscape
 293 changes were mainly oriented towards the environment, management, modelling and
 294 agriculture (Figure 3). The most productive outlet was *Journal of Environmental*
 295 *Management*, with 5% of all publications, followed by *Agricultural Water Management*
 296 and *Agriculture, Ecosystems & Environment* (about 4% each). All of the top 10 journals
 297 were launched before 1992 except *Environmental Modelling & Software* (launched in
 298 1997). Most landscape studies published in the journals assessed environmental
 299 impacts, while economic and social impacts were in second place.



300
301 Figure 3. Publication trends in the 10 journals publishing most papers.
302
303

304 3.2. Characteristics of the main topics

305 3.2.1. Salient terms and description of topics

306 The five most salient terms in the entire dataset were “water”, “chang”, “land”, “watersh”
307 (i.e. corresponding to watershed(s)), and “crop” (Figure 4). The top 30 most salient

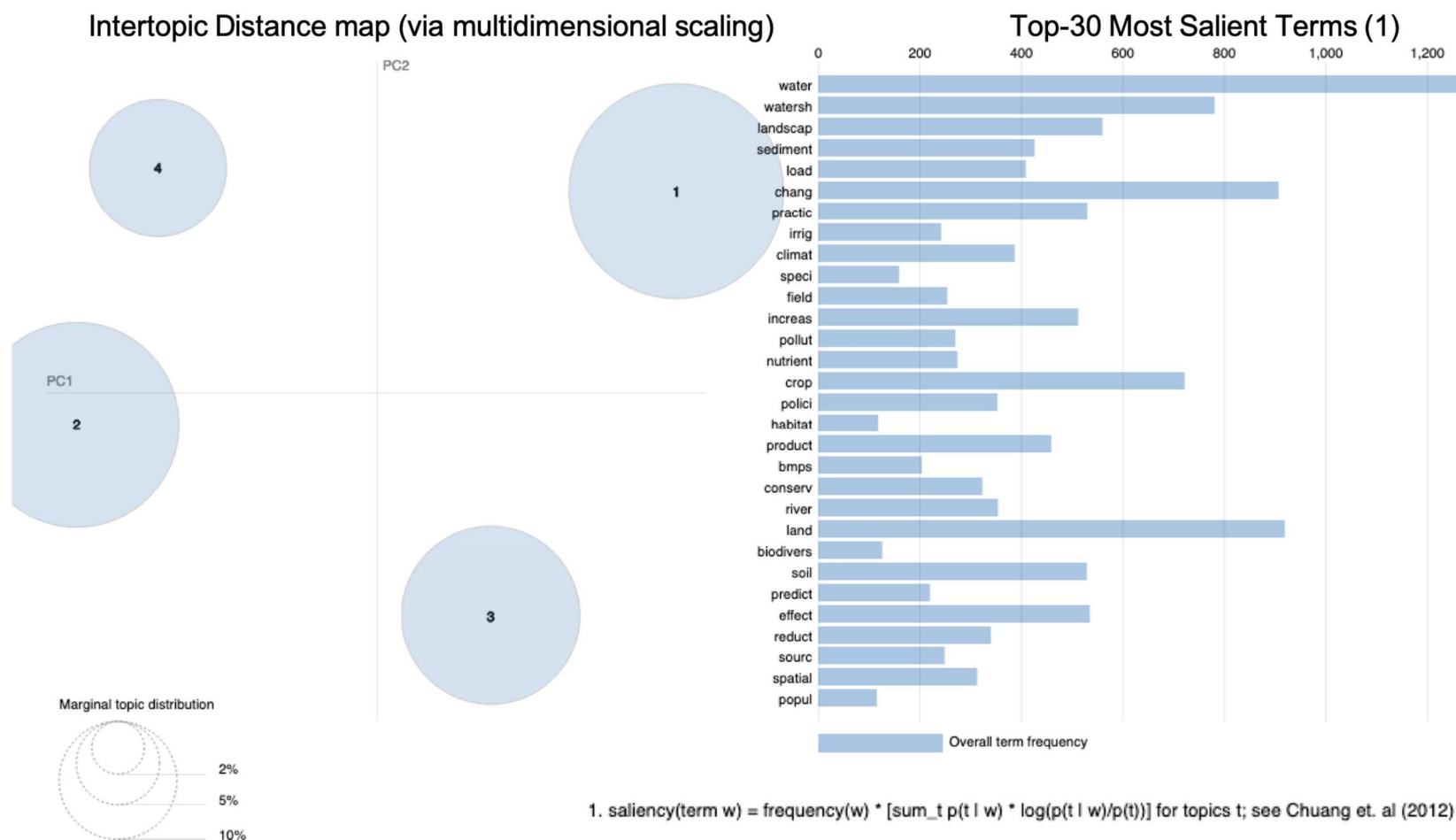
308 terms fell within six broad groups: (1) change trend; (2) spatial scale; (3) pollution; (4)
 309 biodiversity; (5) agricultural practices; and (6) terms related to biophysical and
 310 regulatory conditions for agricultural production (Figure 4). Four of these top 30 most
 311 salient terms were in our search equation (water, watershed, crop and landscape), but
 312 all those related to change, pollution and biodiversity were original themes not explicitly
 313 specified by our search.

314 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 Predict Effect Reduction Change	Watershed Landscape Spatial Field	Sediment Load Pollution Nutrient Source	Species Habitat Conservation Biodiversity Population	Practice Irrigation BMP* Crop	Climate Soil Land Water Policy

315 *Best (Beneficial) Management Practice.

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



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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.

326 Water (Topics 1 and 3)

327 The first topic (Topic 1) was associated with the highest number of tokens (Figure 4),
328 and was covered by 177 papers. This topic concerned water quality (sediment load)
329 associated with various agricultural practices at watershed scale (see top terms in Table
330 3). Relevant terms ($\lambda = 0.6$) for this topic also concerned “runoff”, “erosion”,
331 “fertilisation” (nitrogen, nitrate, phosphorus, fertility) and agricultural practices
332 (“BMPs”, “tillage”, “practice”, “management”) (see [http://shin-](http://shin-r.innovation.inra.fr/review_LH_PC/)
333 [r.innovation.inra.fr/review_LH_PC/](http://shin-r.innovation.inra.fr/review_LH_PC/)). The only relevant terms ($\lambda = 0.6$) related to
334 methods or models were “simulation” and “SWAT” (Soil and Water Assessment Tool),
335 which is a watershed modelling tool developed by USDA in the 1990s to predict the
336 pollution impacts of agricultural practices in large basins (Gassman *et al.*, 2007). For
337 Topic 1, the main purpose of modelling alternative agricultural landscapes was to
338 simulate, at watershed scale, the (mitigating) effect of best management practices (e.g.
339 tillage) on erosion, runoff, and/or water pollution (nutrient, nitrate and phosphorus
340 losses), and associated yield, with a number of the studies on this topic using SWAT.
341 Looking at very specific terms ($\lambda = 0$), two models appeared, namely “AGNPS”
342 (Agricultural Non-Point Source) and “AnnAGNPS” (Annualised Agricultural Non-Point
343 Source), the second model being an extension of the first. These are distributed
344 environmental models developed to study the response of watershed hydrological and
345 water quality problems to alternative agricultural management practices (e.g.
346 fertilisation, best management practices (BMPs)) (e.g. Sugiharto *et al.*, 1994; Yuan *et al.*,
347 2003). For $\lambda = 0$ (i.e. highly topic-specific), model-related terms, namely “coefficient” and
348 “algorithm”, were among the top 30 most relevant terms. Other model-oriented terms
349 for Topic 1 were “calibration” ($\lambda = 0.1, 0.2$ and 0.3), “validation” ($\lambda = 0.2$) and

350 “simulation” ($\lambda = 0.4, 0.5$ and 0.6), with the latter being less specific to this topic, as
351 indicated by the higher λ values. No temporal scale was found for Topic 1 for any λ .

352 Topic 3 was more related to water quantity aspects in management of groundwater
353 resources, especially linked with irrigation practices and climate, together with
354 bioenergy crops. This topic was dominant in 95 papers (Table 3). It included relevant
355 terms ($\lambda = 0.6$) related to bioenergy crops (“corn”, “biofuel”, “bioenergy”) and their
356 hydrological aspects (“water”, “change”, “irrigation”). Based on $\lambda = 0.6$, the main purpose
357 for Topic 3 of modelling alternative agricultural landscapes was to study the impact of
358 climate change, future bioenergy/biofuel crop production (e.g. corn) or irrigation on
359 water demand and potential yields, mainly at regional, seasonal and annual scale.

360 Temporal scales were highlighted (“season”, “annual”, “year”), while terms on spatial
361 scale included “region”, “river” and “basin”. The term “carbon” was also among the 30
362 most relevant terms for this topic ($\lambda = 0.6$), as were some terms related to scenarios and
363 impacts (“supply”, “demand”, “balance”, with λ values between 0.2 and 0.5) (see online
364 diagrams). In the water resource sector, Zare *et al.* (2017) performed a bibliometric
365 analysis of trends, without distinguishing themes related to quantity or quality in their
366 search equation. Niu *et al.* (2014) performed a similar analysis focusing on groundwater
367 and identified more terms related to quality in the most frequent keywords: “water
368 quality”, “nitrate/nitrogen”, “pesticide”, “contamination”, compared with “irrigation” for
369 quantity-related terms. The dominance in our study of the water quality topic (Topic 1)
370 over water quantity (Topic 3) is in line with this. Top terms in the study by Zare *et al.*
371 (2017) also included “quality”, but not more specific terms related to pollution, and
372 “irrigation” was not identified. However, “climate change”, identified as a top term for
373 the water quantity topic identifier in this study (Topic 3), was among the top 13 terms in
374 the study by Zare *et al.* (2017), suggesting that their dataset included studies on water

375 quantity management. No term specifically relating to agriculture was identified in the
 376 two previous analyses, but Zare *et al.* (2017) identified terms related to socio-economic
 377 terms (e.g. “policy”, “economic”, “stakeholder”), which were absent from the two water-
 378 related topics (Topics 1 and 3) in the present analysis. No journal related to agriculture
 379 was among the most active identified by Niu *et al.* (2014). The only common journal
 380 between our results and those by Zare *et al.* (2017) was *Environmental Modelling &*
 381 *Software* (Figure 3), although not specific to agriculture. The two journals identified in
 382 our dataset of 514 papers that specifically relate to water (i.e. *Agricultural Water*
 383 *Management* and *Journal of Soil and Water Conservation*) were not among the most
 384 active journals identified by Niu *et al.* (2014) and Zare *et al.* (2017).

385 Table 3. Top 10 terms in the four topics identified by the first LDA model in our whole
 386 dataset (n = 514 papers), with a threshold of 0.15 used for topic dominance (see section
 387 2.4). *Best (Beneficial) Management Practices
 388

	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	-

389
 390 Integrated Assessment (Topic 2)

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

394 = 0.6, the main purpose of modelling alternative agricultural landscapes in this topic was
395 thus to assess the effects of (environmental) policy scenarios on farmers' decisions,
396 farm/regional production and/or ecosystem services, using an Integrated Assessment
397 approach (stakeholder participation). Relevant terms ($\lambda = 0.6$) for this topic included
398 words related to the approach used: "Integrated Assessment framework", "system",
399 "process" and "economy". These terms are descriptors of methods related to Integrated
400 Assessment and Modelling (IAM) (Parker *et al.*, 2002) of agricultural systems with
401 stakeholders to evaluate policy options (van Ittersum *et al.*, 2008), also called
402 Participatory Modelling Assessment (Tol and Vellinga, 1998). "Support" was also
403 included in the top 30 relevant terms. Scale terms (i.e. "farm", "local" (both specific to
404 this topic) and "region") were among the 30 most relevant terms. The term "ecosystem
405 services" was also specific to this topic. The terms "stakeholder" and "farmer" were
406 among the 30 most relevant terms. This topic was dominant in 137 papers out of the
407 514 included in the dataset (Table 3). It appeared to be oriented more towards real-
408 world applications, with method-oriented highly specific terms ($\lambda = 0$) like
409 "participatory," "software", "DSS" (Decision Support System) and "trade-off". "Design"
410 was also included in the top 30 most relevant terms for Topic 2, with a λ value of 0.2
411 (see online diagrams). No terms were related to temporal scale. Some keywords for this
412 topic corresponded to those identified as "socio-economic" in the review by Zare *et al.*
413 (2017). That review focused on Integrated Water Assessment, i.e. using an integrated
414 approach in the water resource sector, e.g. "DSS", "economic", "policy", "stakeholder"
415 etc., which appeared later than overarching and bio-physical keywords (Zare *et al.*,
416 2017). This indicates some fluidity in different topics/terms.

417

418 Biodiversity (Topic 4)

419 The fourth topic (Topic 4) was related to ecological issues. Top words were “species”,
420 “habitat” and “bird”, while two top words related to scales, “landscape” and “field”, the
421 last appearing as a most relevant term only for this topic. A total of 54 papers had this as
422 a dominant topic (Table 3). Some of the most relevant terms ($\lambda = 0.6$) were biodiversity-
423 oriented (“biodiversity”, “population”, “abundance”, “conservation”, “diversity”,
424 “density”, “dispersal”). The terms “GM” (genetically modified) crops, “weed”, “payment”
425 and “grassland” were also among the 30 most relevant terms. The only relevant term
426 related to method or models was “predict” ($\lambda = 0.6$). Thus, the main purpose of
427 modelling alternative agricultural landscapes in this topic was to predict the effect of GM
428 development, payment or land use change in farmland (specifying crops or practices) on
429 species habitat, conservation, diversity, abundance/density, population (e.g. bird) and
430 biodiversity, with particular focus on field scale. With decreasing λ value, the only
431 relevant highly specific term for this topic was “mechanist” ($\lambda = 0$) (see online
432 diagrams). “Patch” and “distance” appeared as specific terms only in this topic ($\lambda = 0.2$,
433 and $\lambda = 0$ to 0.3, respectively). No terms were related to temporal scale. The
434 “biodiversity” topic has been reviewed in the past (e.g. Hendricks *et al.*, 2008; Liu *et al.*,
435 2011; Stork and Astrin, 2014), although with a wider scope than our focus on
436 agricultural landscapes. These thematic reviews used biodiversity as the main search
437 word (although others, e.g. genetic, ecosystem, etc., were used in Liu *et al.*, 2011). In
438 those studies, the top terms concerned biodiversity: “conservation”, “species”, “forests”,
439 “communities”, “ecology” and “ecosystems” (Liu *et al.*, 2011; Stork and Astrin, 2014).
440 Although the subject category “agronomy” was raised, it was not among the most
441 frequently cited (Liu *et al.*, 2011), and agriculture-related terms were not among the top
442 10 terms, ranking only 38th in Stork and Astrin (2014). A small number of agriculture-
443 specific journals were included in these reviews, e.g. *Agricultural Ecosystems &*

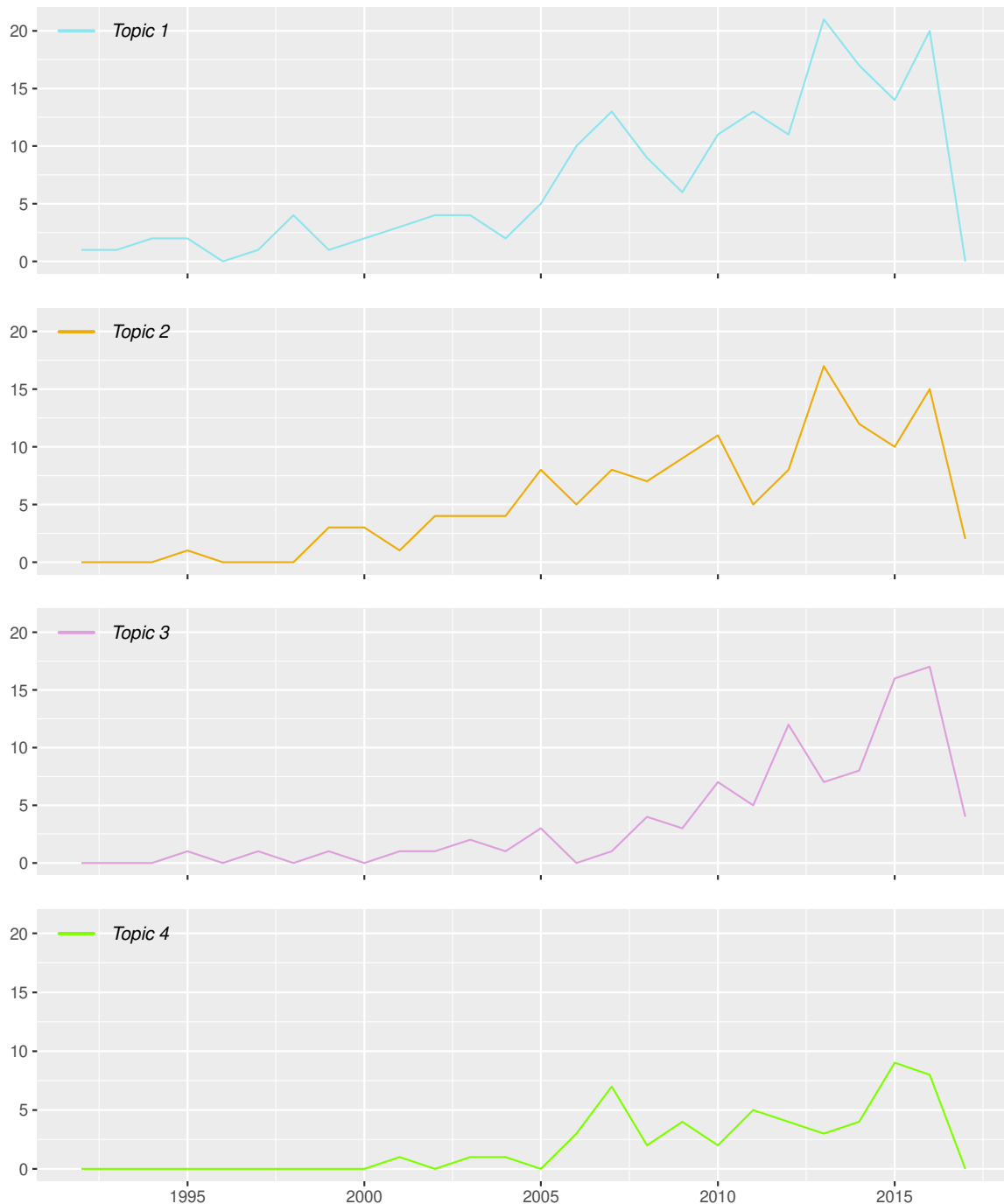
444 *Environment* ranked 13th in Stork and Astrin (2008) and 23rd in Liu *et al.* (2011), but was
445 not identified in Hendricks and Duarte (2008). It ranked 3rd in our analysis considering
446 the complete dataset of 514 papers.

447

448 3.2.2. Temporal and geographical distribution of topics

449 Topic 1 (Water quality) was the main topic in the early 1990s and the number of articles
450 on this steadily increased after 2005 (Figure 5), which is consistent with findings by Niu
451 *et al.* (2014) and Zare *et al.* (2017), although they identified more papers due to the
452 difference in search equations. Topic 2 (Integrated Assessment) and Topic 3 (Water
453 quantity/energy crops) appeared in the mid-1990s. The number of articles related to
454 Topic 2 then grew from the early 2000s, while the number of articles on Topic 3 stayed
455 low until 2004, and increased from 2008-2009 to comprise more than a quarter of the
456 total in 2015-2016 (Figure 5). Topic 4 (Biodiversity) was the last to appear (2001) and
457 began to expand strongly in 2006, to comprise 13-16% of the total in 2015-2016. For
458 the biodiversity topic, Hendricks *et al.* (2008), Liu *et al.* (2011) and Stork and Astrin
459 (2014) showed exponential growth over time, which differed from our result focusing
460 on agricultural landscape (Figure 5). Similarly, while we show that publication on this
461 topic began in the early 2000s, they report that it began in the early 1990s (Hendricks
462 and Duarte, 2008; Liu *et al.*, 2011; Stork and Astrin, 2014). This shows that studies on
463 biodiversity in alternative agricultural landscapes came later than studies focusing on
464 biodiversity conservation, highlighted as a main theme in Liu *et al.* (2011) and Stork and
465 Astrin (2014).

466 Finally, the share of topics changed between the periods 1990-1999, 2000-2009 and
467 2010-2017, with Topic 1 being less represented in recent periods, although still
468 dominant.



469
 470 Figure 5. Count of journal articles assigned by the LDA model applied to the whole
 471 dataset to each of Topics 1-4. Topic 1: Water quality; Topic 2: Integrated Assessment of
 472 agricultural systems; Topic 3: Water quantity/energy crops; Topic 4: Biodiversity.

473
 474 The trend in the top 10 terms in Topic 1 (Table 3) showed a decrease over time in the
 475 occurrence of “sediment”, while the term “pollution” became more frequently used
 476 (Appendix B). The term “BMPs” also tended to decrease in use, while “practice”
 477 increased. For Topic 2, use of the term “policy” increased, while “decision” and “farmer”
 478 first increased and then tended to decrease in recent years. Use of “stakeholder” varied

479 greatly over time, although it became more frequent in recent years. For Topic 3, use of
480 the terms “climate” and “change” largely increased since 2010, while the term
481 “groundwater” was less often used. For Topic 4, the term “landscape” was frequently
482 used since 2007, more than the term “field” (Appendix B). The word “population” gained
483 in popularity over time, while use of “richness” declined. Finally, the term “prediction”
484 was more frequently used in very recent years (since 2015).

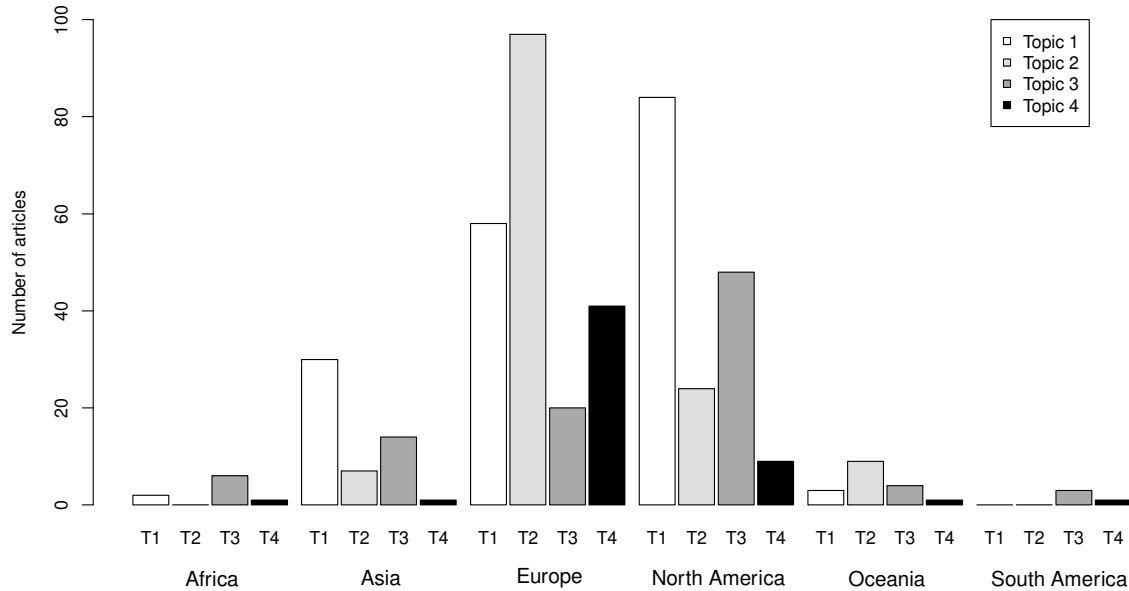
485 The four topics were common in North American literature (USA and Canada), especially
486 topics related to water quality (Topic 1; 48% of papers), and water quantity/energy
487 crops (Topic 3; 51% of papers) (Figure 6). European countries also published on the
488 four topics, but in contrast produced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

496 Identification of North America and, to a lesser extent, Europe as leaders of Topics 1 and
497 3 was consistent with findings by Niu *et al.* (2014) and Zare *et al.* (2017), who focused
498 their reviews on groundwater and integrated water assessment, respectively. They also
499 identified China, India, and Australia among the most active countries (Niu *et al.*, 2014;
500 Zare *et al.*, 2017). While our results are in accordance with the ranking of Asian
501 countries, they underestimate publications by Oceanic countries on water issues.

502 The dominance of USA and Europe on the biodiversity topic (Topic 4) is in accordance
503 with findings in biodiversity-specific reviews (Hendricks and Duarte, 2008; Liu *et al.*,

504 2011). However, our geographical analysis was based on the country of the first author
 505 only and did not consider the study site country. This gave different results, e.g. for
 506 biodiversity Stork and Astrin (2014) found a strong focus on Asia and South America.

507



508

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

513

514 3.3. Multiple topics

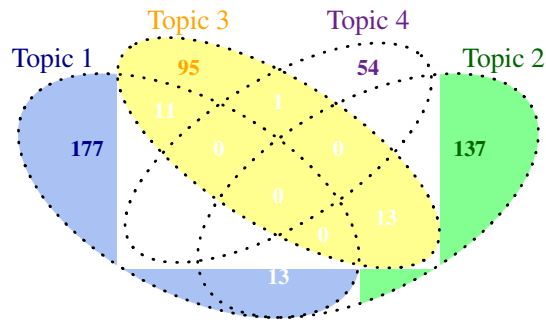
515 At a topic dominance threshold of 0.15, 463 papers related to only one topic (Figure 7).

516 No article displayed a large frequency of terms corresponding to more than two topics

517 (Figure 7). Such articles appeared only for higher dominance thresholds, with one paper

518 showing a large number of terms related to Topics 1, 2 and 4 (threshold of 0.20 and

519 higher), and one article related to Topics 2, 3 and 4 (threshold of 0.25) (Appendix C).



520
 521 Figure 7. Venn diagram of Topics 1-4 highlighted by the LDA model applied to the whole
 522 dataset. Note that topic combinations here are based on a 0.15 dominance threshold
 523 (see section 2.4 for definition and Appendix C for threshold sensitivity analysis). Topic 1:
 524 Water quality; Topic 2: Integrated Assessment of agricultural systems; Topic 3: Water
 525 quantity/energy crops; Topic 4: Biodiversity.
 526

527 A higher number of articles used terms relevant to two topics (51 papers), except for
 528 Topics 1 and 4 combined (i.e. Water quality and Biodiversity) and Topics 3 and 4
 529 combined (i.e. Water quantity/energy crops and Biodiversity), with only one article each
 530 at the 0.15 threshold (Figure 7). The article combining Topics 3 and 4 was published in
 531 2011 by a UK team and assessed potential regional carbon stocks according to different
 532 scenarios, among which were a bioenergy crop scenario (Topic 3) and a biodiversity
 533 scenario (Topic 4) (Cantarello *et al.*, 2011). Combinations of Topics 1 and 4, and Topics 3
 534 and 4, were rare whatever the threshold tested (Appendix C).

535 At the 0.15 threshold, the number of articles sharing two topics was similar as regards
 536 Topics 1 and 2, 1 and 3, 2 and 3, and 2 and 4 (11 to 13 articles in each case; see Figure
 537 7). Combinations of Topics 1 and 3 and of Topics 2 and 3 were more sensitive to the
 538 threshold value, with 10-fold more papers at a threshold of 0.25 than at a threshold of
 539 0.05 (Appendix C). The number of articles covering Topic 3 was the most sensitive to
 540 threshold value, with almost 19% fewer articles at a threshold of 0.05 compared with
 541 0.25. Comparing these two thresholds, 20 Topic 3 papers (Water quantity/energy crops)
 542 appeared to share terms with Topic 2 (12 papers), Topic 1 (7 papers), and Topic 4 (1

543 paper). This shows that those studies on water quantity/energy crops mostly included
544 an Integrated Assessment framework, or aspects on water quality, which is consistent
545 with the research trend on Integrated water Assessment and modelling (Zare *et al.*,
546 2017). No time trend of mixed topics in the relevant papers was found for any dominant
547 topic (Appendix D).

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

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

562

563 4. Discussion

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

568

569 4.1. Main topics identified, potential reasons and limits

570 Our analysis of the selected literature identified four main topics: Water quality (Topic
571 1), Water quantity/energy crops (Topic 3), Biodiversity (and GM) (Topic 4), and a
572 “multi-issue” topic considering Integrated Assessment, i.e. policies and stakeholder
573 decisions for landscape simulation (Topic 2). These topics were each linked to a
574 scientific discipline: hydrology for Topics 1 and 3, ecology for Topic 4 and
575 economics/policy study for Topic 2. Terms related to cropping practices (i.e. agronomic
576 terms) were associated to each topic, although with a lower number of terms for Topic
577 4. Topic 3 was associated with one specific cropping practice (“irrigation”) and type of
578 crop (“biofuel”, “corn”) and their proportions within the landscapes. Topic 1 was
579 associated with “BMPs”, with a specification (options of “tillage”, “fertilisation”),
580 showing a certain homogeneity and simplification in the range of agronomic options
581 tested. BMPs constituted a positive list of agronomic practices (regarding soil, water,
582 nutrients, integrated pest and landscape management; Schenpf and Cox, 2007). The
583 term “BMPs” appeared to be mainly used by North American researchers; this term
584 arose in the USA in guidelines to address Non-Point Source pollution for water quality
585 protection, through the 1972 Federal Water Pollution Control Act (Phillips and Blinn,
586 2004). This is consistent with the specific terms related to models in Topic 1, with the
587 names of models developed in the North America (e.g. SWAT; see Gassman *et al.*, 2007)

588 being the leader for water management topics (Topics 1 and 3). This could be linked to
589 the type of agriculture practised in North America, i.e. highly irrigated (FAO, 2014),
590 intensive and specialised (e.g. monocropping in the Corn Belt), leading to both water
591 quality and quantity issues and related research.

592 Europe was the leader for the topic Integrated Assessment (Topic 2), characterised by
593 the more general term “Decision Support System” or “DSS”. The dominance of Europe on
594 the topic Integrated Assessment (including stakeholder participation and decision
595 support systems), within the specific context of “alternative agricultural landscape
596 modelling”, can be attributed to the fact that it emerged in the Netherlands in the late
597 1990s (Rotmans and van Asselt, 1996) and had grown into a booming field by the early
598 2000s (Hisschemöller *et al.*, 2001). Integrated Assessment was initially defined by two
599 main characteristics: i) building upon research in different disciplines and ii) providing
600 information for decision makers (Rotmans and van Asselt, 1996). However, we focused
601 on agricultural landscapes, which could explain the geographical bias observed for this
602 topic. For instance, Integrated Assessment methods are used by North American
603 researchers, but their focus is not on agriculture (e.g. flood resilience in Allen *et al.*,
604 2019).

605 Topic 1 showed greater homogeneity in methods for the water quality topic, which
606 makes comparisons easier but could also indicate less originality in the methods
607 applied, in contrast to Integrated Assessment and water quantity/energy crops (Topics
608 2 and 3). The topic on biodiversity (Topic 4) was the only one highlighting different
609 spatial scales (“patch”, “field”, “landscape”), thus tending to have a spatially explicit
610 approach. The topic on Integrated Assessment included the term “farm”, which is more
611 related to a decision level. Water quality studies used mostly SWAT, which is a
612 distributed spatially explicit model. Water quantity/energy crop studies looked more at

613 aggregated values on e.g. water demand or total production, although they sometimes
614 considered spatial scale for implementation of a crop/practice change. The spatial scale
615 was thus determined by the issue. However, alternative landscapes are the result of
616 multiple drivers that take place at different scales (e.g. biodiversity at patch scale,
617 decision and economic consequences at field and farm scale, aggregated effects at
618 landscape scale), thus calling for multi-scale studies.

619

620 4.2. Potential gaps and future works

621 The impact of agricultural landscapes on biodiversity (Topic 4, the last to emerge in our
622 dataset) was studied equally in North America and Europe. This is consistent with
623 findings in a more general review (i.e. not specific to agricultural landscapes) by Di
624 Marco *et al.* (2017) that there is a geographical bias (Europe, North America, Central
625 America) in studies of conservation science. Surprisingly, the term “ecosystem services”
626 was associated with Integrated Assessment of agricultural landscapes (Topic 2), and not
627 biodiversity (Topic 4). The relative absence of ecosystem services in the biodiversity
628 topic is consistent with previous findings in a review by Egoh *et al.* (2007) that a very
629 low number of conservation assessments include ecosystem services. This could be
630 explained by the way in which the concept of ecosystem services was promoted in
631 Millennium Ecosystem Assessment (MA, 2005), i.e. as a policy tool aiming at sustainable
632 use of natural resources (Seppelt *et al.*, 2011), thus corresponding more to our topic
633 Integrated Assessment. However, the ecosystem services concept was also developed to
634 demonstrate the value of nature (Walz and Syrbe, *in press*) and is closely related to
635 biodiversity preservation (European Commission, 2011). This could indicate that
636 biodiversity studies need to align more tightly to political context and governance
637 alternatives (e.g. Velten *et al.*, 2018), with inclusion of biodiversity aspects in DSS, more

638 stakeholder interactions and greater inclusion of ecology researchers on ecosystem
639 services, which is becoming a hot topic. In particular, integrating the relationships
640 between biodiversity and ecosystem services (e.g. birds feeding on weed seeds; Gaba *et*
641 *al.*, 2014) in agricultural landscape modelling could help provide a framework for future
642 policies combining biodiversity and agriculture. While we identified a few papers
643 studying the impacts of policy on birds or habitats, those did not include a bottom-up
644 approach involving local stakeholders to co-design possible actions and their translation
645 into local policies (e.g. Bredemeier *et al.*, 2015), or used a simplified vision of
646 agricultural practices (e.g. Drum *et al.*, 2015). This calls for more inclusive biodiversity-
647 based studies involving the participation of local stakeholders (farmers, but also local
648 authorities and nature NGOs) to develop local policies for alternative landscapes
649 combining biodiversity preservation and agricultural production, with explicit and
650 detailed consideration of the constraints of these two sectors. Unlike current policy
651 developments, those studies would be based on a bottom-up approach, combining
652 detailed knowledge of current agricultural practices, biodiversity issues and potential
653 win-win or compromise situations identified e.g. in participatory workshops. The
654 benefits of this type of research would be both scientific (transdisciplinary research,
655 with cross-fertilisation between different disciplines, e.g. ecology, agronomy, economics)
656 and oriented towards local action through the promotion of practices and policies
657 developed locally. It follows that the design of agricultural landscapes will require joint
658 work by scientists and stakeholders to identify the desired ecosystem services and
659 design the necessary landscape modifications (Landis, 2017). As biodiversity and nature
660 are becoming a hot topic with recent reports of species decreases and extinctions (Diaz
661 *et al.*, 2019), policy-makers are urged to promote effective actions in favour of
662 biodiversity and ecosystem services preservation. In this work, research methods and

663 tools could be used for both design and assessment of alternative landscapes. As claimed
664 by Hill *et al.* (2013), participatory scenario design, together with collective visioning,
665 urgently needs to be revised to favour policy development and foster social consensus
666 on biodiversity conservation. Complex landscapes should be represented, with models
667 accounting for the spatial configuration or composition in a balanced way, although
668 development of such models is “...still in its infancy” (Langhammer *et al.*, 2019). Studies
669 could target, for instance, natural pest control in an ecological intensification
670 perspective, where natural enemies replace pesticides in cropping and farming systems
671 in landscape scenarios (Bommarco *et al.*, 2013). An exploratory model-based approach
672 is lacking at landscape level, where natural pest control is only assessed via some
673 landscape proxies such as diversity of land cover around the perimeter to determine the
674 potential amount of services (Mitchell *et al.*, 2013).

675 Most papers in our dataset were linked to one dominant topic. Less frequent topic
676 combinations were studies of water quality together with biodiversity (Topics 1 and 4)
677 and studies of biodiversity and water quantity/energy crops (Topics 3 and 4). Although
678 we excluded papers focusing only on the effects of climate change, this theme emerged
679 as a driver of scenarios in Topic 3 (Water quantity/energy crops). Thus, in our dataset,
680 biodiversity was apparently not assessed in studies linking climate change and
681 agricultural practices, the two main factors that actually threaten biodiversity. Different
682 studies have assessed biodiversity responses to climate change (e.g. Bellard *et al.*, 2012),
683 or to agriculture and their potential conflicts (e.g. Henle *et al.*, 2008). Attempts to study
684 their joint effects appear to have focused mostly on land use change, without detailing
685 agricultural practices. Several studies have considered habitat loss, but with less
686 attention to spatial (e.g. fragmentation in the landscape) or practice change (e.g.
687 management intensity) (de Chazal and Rounsevell, 2009), and with a limited number of

688 taxa considered (Chopin *et al.*, 2019). Future studies of alternative agricultural
689 landscapes thus would need to enlarge the vision on biodiversity, e.g. by increasing the
690 number of taxa (Chopin *et al.*, 2019) and including detailed population characteristics
691 and their climate drivers, together with potential agricultural practices to be applied in
692 these futures. This will require integrated approaches, as agricultural practices are
693 determined by a set of drivers, including (but not limited to) climate change.
694 Participatory approaches would thus be also required for this issue.

695 Finally, our review did not identify hot topics and methods used in agricultural studies.
696 For instance, “resilience” was not identified as a top word among our four topics,
697 appearing in only five of the 514 papers in our dataset. However, resilience is gaining
698 increasing attention in agricultural research to characterise the relationship between
699 agricultural outputs and perturbation, the two main parameters being global warming
700 and price volatility (Urruty *et al.*, 2016). Agronomists study agricultural resilience at
701 farm to country scale (Urruty *et al.*, 2016). The landscape scale tends to be studied by
702 researchers in ecology, looking at e.g. spatial resilience (location, connectivity,
703 complexity) (Cumming, 2011), land use management and habitat (Tscharntke *et al.*,
704 2005), or by economists looking at land use patterns and the resilience of agricultural
705 returns (Abson *et al.*, 2013). In those ecology-based studies, agricultural practices are
706 often simplified, characterised as categories of land use and disregarding the level of
707 decision, i.e. the farm. This indicates that the landscape agronomy approach called for by
708 Benoit *et al.* (2012) has not yet fully emerged. This approach is necessary for
709 disaggregating land use and better characterising the diversity of cropping systems and
710 landscape diversity, as highlighted by Chopin *et al.* (2017). It is particularly important
711 for issues requiring coordination of agriculture-related actions at the landscape scale
712 (e.g. erosion in Souchère *et al.*, 2010), or collective governance of e.g. water resources

713 (e.g. Murgue *et al.*, 2015) or integrated crop-livestock systems (e.g. Moraine *et al.*, 2017).

714

715 5. Conclusions

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

730

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