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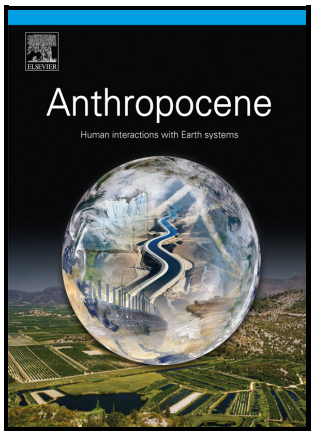

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Publications reveal how socio-ecological research is implemented: lessons from the Rhône Long Term Socio-Ecological Research platform

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ABSTRACT

Socio-ecological research enlists inter- and transdisciplinarity to address complex environmental issues. Yet the "socio-ecological system" concept can be interpreted in many different ways. A characterization of the diverse practices in socio-ecological research could facilitate dialogue between researchers about the possible conceptual and ethical approaches. In this study, we investigated if a detailed analysis of scientific articles would reveal the nature and course of a socio-ecological research network, and the research angle of its members. The example we used was the Rhône River Long-Term Socio-Ecological Research (LTSER) platform in France. We combined a multivariate analysis of a reading grid of publications by Rhône River LTSER researchers and a textual analysis of the scientific narratives. The publications were from a 10-year period and corresponded to those used in a recent international comparative analysis of LTSER platforms. The analysis revealed that the research was dominated by a biophysical approach, with a progressive increase in social aspects. The emergence of a transdisciplinary approach, co-constructed with operational partners, was also shown. The research conducted by the Rhône River LTSER was grounded in the context of managing a river with strong anthropic influences and interests, and the scientific approach aimed to provide knowledge for guiding decisions. Little reference was made in the publications to socio-ecological conceptual frameworks. Beyond the example of this LTSER platform, we identified indicators for describing the degree of inter- and transdisciplinarity and the different perceptions of socio-ecological systems. The narrative analysis revealed the angle of the research approach; this method could be used in future studies for a comparison of the diverse approaches of multiple research groups.

KEYWORDS

Transdisciplinarity; interdisciplinarity; scientific narrative; Rhône River; socio-ecological system; environmental ethics

1.INTRODUCTION

In the context of rapid global change and the urgent environmental challenges we face, effective action requires transdisciplinary knowledge of complex human–nature interactions. This will rely on improving dialogue between the academic and operational sectors (Holzer et al., 2018b). Transdisciplinary studies differ from multi- and interdisciplinary research by going beyond simply coordinating several disciplines to involve multiple fields as well as non-academic stakeholders to create new approaches to complex problems (Holzer et al., 2018b; Lawrence and Despres, 2004; Renn, 2021). One response has been socio-ecological research, which views human and natural spheres as an integrated system. This is the approach adopted by the international network of Long-Term Socio-Ecological Research (LTSER), which enlists transdisciplinarity by jointly studying natural and human systems in long-term data-sharing projects designed in collaboration with stakeholders (Holzer et al., 2018b).

LTSER platforms are hosting place-based socio-ecological research, within the International Long-Term Ecological Research (ILTER) network. The latter originated in the LTER network, which was created in the United States by the National Science Foundation in the 1980s. The aim was to produce

long-term ecological knowledge based on multiple sites and spatial scales that would enable data comparability and provide information for decision-making (Dick et al., 2018; Holzer et al., 2018b; Mauz et al., 2012). The international network ILTER was created in 1993; in the late 1990s, voices were raised about the need to better integrate social studies in ecological research (Dick et al., 2018; Redman et al., 2004). Due to the magnitude of human-induced global changes, an "S" for "social" (LTSER) was added to the LTER acronym in the 2000s (Mauz et al., 2012); the need to better consider interactions between human and natural systems to solve environmental problems had become evident (Dick et al., 2018).

Redman et al. (2004) created the conceptual basis for the integration of social sciences in LTER, arguing that researchers needed to consider a complex "socio-ecological system" that combines human and natural systems. This approach takes into account the complexity of human systems (e.g. institutions, social cycles, cultural patterns, economic dynamics), including interactions and feedback loops, in study of ecosystem dynamics, traditionally based simply on biophysical and human drivers. This socio-ecological conceptual framework was further developed by Haberl et al. (2006), who defined "meta-principles" for consistency and comparability to guide the development of specific LTSER models at a local scale. Haberl et al. (2006) identified key themes that required interdisciplinary approaches and compared LTER and LTSER; in particular, in these authors' definition, LTSER considers human communities as engaged in an interactive system with nature, rather than simply as populations that disturb ecosystems. Inter- and transdisciplinary LTSER research does not position itself as an external observer of natural phenomena – it is aware of its involvement in what it studies as a social process (Haberl et al., 2006). Collins et al. (2011) also contributed to build the foundations of the socio-ecological framework by creating an integrative model guiding transdisciplinary research.

Beyond the theory, in practice socio-ecological research has resulted in a wide variety of research approaches, influenced by local circumstances such as the characteristics of the research group/platform, the different disciplines involved, the types of funders and stakeholders. A research group's original motivations for joining the LTSER network have also led to different ways of moving from purely ecological research to socio-ecological research (Dick et al., 2018).

This variety of practices has also resulted from a range of conceptual frameworks associated with socio-ecological research. The "socio-ecological system" (SES) concept has developed beyond the context of the LTSER network and the proposals of Redman et al. (2004) and Haberl et al. (2006), giving rise to varied conceptual perspectives and practical approaches from a vast network of interconnected researchers. For example, Gallopín (2006) identifies vulnerability, resilience and adaptive capacity as key concepts of the socio-ecological approach. Liu et al. (2007) refer to "coupled human and natural systems" and describe organizational, spatial and temporal couplings in these complex systems. In their review of SES literature, Colding and Barthel (2019) highlight the importance of the conceptual frameworks of Berkes and Folke (1998), Anderies et al. (2004) and Ostrom (2007) in the history of the SES concept.

In different ways, these three frameworks orient socio-ecological research towards resource management efforts. Berkes and Folke (1998) seek to connect institutions to ecosystems through the perspective of resilience. Anderies et al. (2004) analyse what affects the "robustness" of a socio-ecological system in institutional arrangements, with "robustness" depending on preventing an ecological system from changing in a way that can no longer support a human population or that causes its long-term suffering. The work of E. Ostrom (2007, 2009) gave rise to the Social-Ecological Systems Framework (SESF), which seeks to enable interdisciplinary scholars and policymakers to interact on resource management issues, by identifying components and relationships within socio-ecological systems (McGinnis and Ostrom, 2014). In their review, Colding and Barthel (2019) observe that the concept of socio- or socio-ecological system is often used without clear definition; indeed, they argue that the diverse definitions could reduce the concept's utility and create confusion.

It could equally be seen as an asset that the SES concept enables many perspectives on human–nature relationships. In that perspective, the characterization of diverse approaches is important. Without this clarification, the ethical challenges of these varied perspectives could be underestimated; in the context of the environmental crisis, it is particularly important to consider what is at stake in the direction research takes with regard to human–nature relationships. Different ethical foundations for human–nature relationships are another cause of variability in socio-ecological research, and should not be

underestimated. For example, Rozzi et al. (2012) note the high prevalence of economic perspectives in the social component of socio-ecological research, and advocate for filling the conceptual gap concerning ethical aspects in LTSER by integrating ecological sciences and environmental ethics.

In the context of the LTSER network, a recent comparative analysis of 25 international LTSER research groups showed the diversity of SES platforms, and indicated that a combination of top-down harmonization and bottom-up self-definition of these at the local level was needed for socio-ecological research to progress (Dick et al., 2018). Such a joint effort is necessary to meet the challenge of simultaneously addressing local expectations and international obligations (Dick et al., 2018; Holzer et al., 2018a). Although methods have been developed to assess LTSER transdisciplinary goals (e.g. Holzer et al., 2018b), an in-depth characterization of the various socio-ecological approaches is essential in order to facilitate dialogue and comparisons between research groups of their methods and objectives. This methodological gap was illustrated by the difficulties Dick et al. (2018) encountered in their comparative analysis; for example, they reported that different research groups differently interpret questions such as the consideration of "human wellbeing" in their publications.

This study sought to address the lack of methods for characterizing socio-ecological approaches, beyond the context of the LTSER network alone. How can publication analysis help to clarify the position of any socio-ecological research network? An important aim of such a method is to facilitate dialogue with other research groups, within and beyond the socio-ecological sphere, and foster inter- and transdisciplinarity, for which there is an urgent necessity. Using the LTSER network as an example, and building on the international comparative analysis conducted by Dick et al. (2018), we investigated if a more detailed analysis of scientific publications would reveal the nature and course of a specific socio-ecological research network. To do this, we analysed 10 years of publications (2006–2016) from one of the largest European socio-ecological research platforms: the Rhône River LTSER. We first performed a multivariate analysis of the detailed characteristics of publications (e.g. research focus, disciplines involved, funding sources; all encoded in a reading grid), as well as their temporal dynamics. We then analysed the scientific narrative of publications (lexical worlds and co-occurrences) to characterize in more detail research themes and the approach of the publication authors. We discuss how such analyses

of publications can help to clarify the "socio-ecological system" concept in practice and foster dialogue between groups about different approaches in socio-ecological research and forms of inter- and transdisciplinarity.

2. MATERIALS AND METHODS

2.1. The Rhône River LTSER platform and its publications

The Rhône River Long-Term Socio-Ecological Research (LTSER) platform (in French, *Zone Atelier du Bassin du Rhône*: ZABR) belongs to the LTSER_France network, which is itself part of the European eLTER network and the international network ILTER (Mirtl et al., 2018). The Rhône platform is one of the largest LTSER groups in Europe in terms of publications (Dick et al., 2018). In the LTSER landscape, it has a median position concerning several aspects, including the degree of involvement of social elements (Dick et al., 2018). The platform brings together some 300 researchers from a number of research centres and disciplines; they interact closely with diverse operational stakeholders (e.g. public water agencies, regional and local authorities, NGOs, private companies). The research is mostly related to nine field sites in the Rhône River basin (98,500 km², with 90,500 km² in France), with the objective of addressing societal issues at a local scale and producing an interdisciplinary and long-term understanding of the Rhône Basin. The Rhône is an anthropized river impacted by various human activities: it has been controlled for flood protection, navigation and hydropower purposes since the mid-19th century. The river provides water for irrigation and drinking (Olivier et al., 2022) and cools four nuclear power plants. Since the 1990s, the Rhône River has been the subject of major ecological restoration measures in France, e.g. to increase minimum flow and to reconnect floodplain channels to the main channel in bypassed, dammed river reaches (Lamouroux et al., 2015). The Rhône research group was labelled as an LTER platform in 2001, but its research history dates back to 1979, following a French interdisciplinary environmental research programme (PIREN Rhône; Bouleau, 2014).

For our publication analysis, we used a corpus containing 97 full-text peer-reviewed articles published by members of the Rhône LTSER group between 2006 and 2016 and publicly accessible: 71 were written in English and 26 in French. These articles, archived in the Rhône LTSER database, were those considered by Dick et al. (2018) for the Rhône LTSER in their comparative European analysis of a number of LTSER plaforms. We used the same corpus and thus the same time frame as Dick et al. (2018) in order to develop a complementary method based on the same study object and extend its conclusions. Of the full list of articles listed by the research group in activity reports over the studied

period (n=1279), including disciplinary and interdisciplinary studies, the selected articles relate to the Rhône River: that is, one of the nine LTSER field sites. The corpus from the Rhône LTSER used by Dick et al. (2018) included 125 articles, books and reports. We excluded the 23 books and reports for consistency in the application of the analysis tools. Of the 102 articles concerning the Rhône, we removed 5 articles whose relation with the river was marginal, so our final corpus was 97 articles.

2.2. Multivariate analysis of the publication characteristics

We described each of the 97 publications using a reading grid that we defined and filled in. As the co-authors of this study represent different disciplines and research units involved in the Rhône River LTSER platform, we considered our experience relevant for this task. We defined the reading grid during a dedicated workshop, listing ten publication characteristics, each with between two and eleven binary categories (i.e. a value of "0" or "1"; see full description of categories in Table 1). For each publication, the reading grid characterized the research focus (i.e. location, study object [e.g. fish, chemicals], object type [e.g. aquatic, terrestrial]), the type of research (i.e. duration, fieldwork involvement), the degree of inter- and transdisciplinarity (i.e. scientific disciplines, contracts, funders) and the research position (i.e. river perception by the researchers [e.g. ecosystem, resource], keywords mentioned).

We used a multivariate fuzzy correspondence analysis (FCA) (Chevenet et al., 2006) of the reading grid to provide a summarized view of the publication contents. The FCA was performed with the ade4 library (Thioulouse et al., 2018) in R (R Core Team, 2022). It was designed for the ordination of objects (here, the 97 publications) that can be associated with several categories of each variable. Like other ordination techniques, FCA creates factorial axes that are combinations of the variable categories (here, the characteristics). These axes ordinate the articles according to the similarity of their respective sets of characteristics. We used factorial maps combining the two first FCA axes to investigate how each individual characteristic and their categories influenced the ordination of articles. In addition, the different publication years, as well as the language, were projected on the factorial maps as supplementary variables, in order to infer potential temporal trends over the period considered (2006–2016) as well as linguistic effects.

2.3. Analysis of the scientific narrative of publications

The narrative analysis was performed on the 71 articles in English, as a joint analysis of two languages was not possible. We used IRaMuTeQ© open-source software to perform a statistical analysis on the text corpus.[2] We converted the 71 PDF articles into text files (.txt format) and encoded them in UTF-8. We eliminated figures, tables, legends, bibliographies, authors and affiliations, article formatting (e.g. page number, journal name) and as many errors due to the file conversion as we could identify (e.g. misspelled words, extra spaces). This manual cleaning was necessary to allow the software to run effectively and focus on text content only. We then created a single text file containing all articles encoded in UTF-8, to facilitate the import of the corpus into IRaMuTeQ.

The software IRaMuTeQ (Ratinaud and Déjean, 2009) performs statistical analysis of textual data (Lebart et al., 1998; Lebart et al., 2019). It uses R software (R Core Team, 2022) and the Python language and identifies lexical classes based on a top-down hierarchical classification (Reinert, 1983). This classification follows several stages during which analysable forms (e.g. nouns, verbs) are crossed with text segments (40 words by default) to classify text segments into classes, or clusters (Cottet et al., 2015). The aim of clustering is to identify "lexical worlds" (Rouré and Reinert, 1993) across the whole corpus. The graphical representation, a dendrogram, shows the relationships between classes. We kept the main default parameters for simple clustering of text segments; this included lemmatization and an indexation dictionary. Lemmatization refers to the grouping of forms of the same dictionary entry (e.g. flood, flooding, flooded, floods). Verbs are reduced to the infinitive, nouns to the singular (and in French, adjectives to the masculine singular). This procedure makes it possible to reduce lexical diversity. Indexing refers to the use of the internal dictionary to identify words and phrases in a language. Although most of the default settings were retained, we changed the number of terminal classes on phase 1, adjusting this from 10 to 15 to create a more complex dendrogram than obtained by the basic settings.

We also produced similarity analyses with IRaMuTeQ for the main classes of the dendrogram. A similarity graph shows the relationships between the forms associated with a class during the descending

[2] See http://www.iramuteq.org/ accessed on 21/11/2022

hierarchical classification. The size of lexical forms (i.e. the terms) on the graph shows their frequency, and the thickness of the line between two forms indicates their co-occurrence (Cottet et al., 2015). We excluded proper nouns, measurement units, and non-meaningful forms (e.g. “al”) from classes before drawing similarity graphs, and only kept the most frequent lexical forms to obtain readable graphs. We kept default settings except for the aesthetic parameters of the graph (e.g. size of the image, line colours). These graphs reveal information on the meaning keywords adopt within lexical worlds, depending on the way authors link them together, making them interesting tools to characterize the publication narrative.

THEMES **Characteristics**	Categories: codes	%	Categories: details
RESEARCH FOCUS			
Location: Location of the study More than one answer was possible.	Switzerland	1	Geographic sections along the Rhône River, from the source in Switzerland to the delta (see map in supplementary materials, S.1)
	Léman	4	
	Upper Rhône	31	
	Sault-Miribel	18	
	Lyon	11	
	P.Bénite-Bourg.Val	15	
	Bourg.Val-Donzère	8	
	Donzère-Arles	6	
	Delta	4	
	NA	2	
Study object: Main focus of the study.	Chemicals	10	Main physicochemical, biological or social focus of the study
	Water	17	

More than one answer was possible.	Sediments	13	
	Hydromorphology	13	
	Fish	7	
	Invertebrates	14	
	Plants	11	
	Society	11	
	Other objects	3	
Type of object: Categorization of study objects. More than one answer was possible.	Aquatic	76	
	Terrestrial	17	
	Other types	7	
TYPE OF RESEARCH			
Duration: Studied period	X0–1	26	0–1 year
	X1–10	31	1–10 years
	X10–30	17	10–30 years
	X30–100	10	30–100 years
	X100 more	16	>100 years
Field: Indicates if authors conducted fieldwork	Field	79	
	No field	21	
INTER- AND TRANSDISCIPLINARITY			
	Sociological pole	4	Studies about human societies and people
	Socio (eco)	8	Sociological dominance, ecology in context

Scientific disciplines: Degree of interdisciplinarity. More than one answer was possible for uncertain assignments.	Interaction	4	Balanced studies involving ecological and sociological interactions
	Eco (socio)	23	Ecological dominance, sociological aspects in context
	Ecological pole	45	Studies about the biophysical system (biology, physics, chemistry)
	NA	17	
Contracts: Contracts related to the study. More than one answer was possible. These contracts generally involved multiple research centres of the Rhône LTSER and multiple funders.	RhônEco	22	Large project on ecological restoration (>1998)
	OSR	3	Large project on sediment/pollutant fluxes (>2009)
	OTHU	3	Projects linked to an urban observatory (>1999)
	Agency - LTSER	11	LTSER + water agency agreement (>2006)
	OHM	4	Short contracts (Human–Environment Observatory > 2011)
	Other Rhône Plan	2	Other projects - Rhône management plan (>2009).
	Other contracts	39	
	NA	16	
Funders: Main funder(s) of the study. More than one answer was possible.	CNR	7	Hydropower company managing the Rhône
	EDF	5	National electricity company
	Regions	10	Regional public authorities
	Water Agency	18	Rhône Basin agency (coord. basin plans)
	Europe	5	
	ANR	6	National Research Agency
	OHM	4	Research funds from a Human–Environment Observatory > 2011)

	Other funders	42	
	NA	2	
POSITIONING OF RESEARCH			
River perception: Describes how the river is perceived by the authors in the publication (e.g. "the river is perceived as a risk factor"). More than one answer was possible, but the objective was to highlight the core characteristic(s).	Ecosystem_bio	22	An ecosystem characterized by biology
	Ecosystem_phy	29	An ecosystem characterized by physics
	Ecosystem_chem	4	An ecosystem characterized by chemistry
	Opportunity	19	A scientific opportunity (e.g. for testing methods)
	Resource	4	A resource (e.g. energy production, natural resources)
	Risk_env	6	An environmental risk (e.g. pollution)
	Risk_soc	9	A societal risk (e.g. water quality, flooding)
	Tourism	< 1	A touristic territory
	Context	4	A context for human leisure (e.g. a landscape)
	Human habitat	3	A human habitat (for living, identity and heritage)
Keywords mentioned: Occurrence of keywords selected by workshop participants for exploratory, non-exhaustive purposes in the full-text article. Keywords targeted explicit references to conceptual	SES	0	Socio-ecological system
	SER	0	Socio-ecological research
	TRANS	6	Multi-/inter-/transdisciplinar(it)y
	INTEG	8	Integrated approach
	SERVICE	3	Ecosystem services
	SD	3	Sustainable development
	TIPPING	< 1	Tipping point

frameworks for transdisciplinary studies of human–nature relationships. More than one answer was possible.	RESILIENCE	9	Resilience
Keywords were searched with the “Find” command in French or in English depending on the article.	NA	71	

Table 1: Characteristics of publications documented in the reading grid according to categories. The % column indicates the frequency of each category within the corpus of 97 articles. Acronyms for contracts and funders are defined on first occurrence in the main text, except for OTHU: Observatoire de Terrain en Hydrologie Urbaine (Field Observatory of Urban Hydrology), ANR: Agence Nationale de la Recherche (National Research Agency), and OSR: Observatoire des Sédiments du Rhône (Observatory of Rhône Sediments).

3. RESULTS

3.1. Publication characteristics: average frequency of categories

The average frequency of categories in the corpus (Table 1) provided an overview of research on the Rhône. The research focus over the study period was mainly located on the upstream sites along the course of the river in France, from the Upper Rhône to Pierre-Bénite (75%; see map in supplementary materials, S.1). These represented the areas most concerned by restoration measures since 2000. The

main study objects were physicochemical aspects (53%), followed by biological aspects (32%), and, more rarely, sociological aspects (11%). The studies were mainly on aquatic topics (76%), but did not exclude terrestrial aspects. Long-term studies (>10 years: 43%) with fieldwork (79%) dominated the corpus.

Only 4% of the articles had a clear socio-ecological focus. Although many studies (45%) belonged purely to the ecological pole, 35% combined aspects from the sociological and ecological poles (Table 1). Most studies were associated with contracts, with a significant proportion relating to a long-term monitoring programme of Rhône ecological restoration (RhônEco, 22%). The funding sources of these contracts were diverse (private, regional, national and European), with the regional Water Agency a significant contributor (18%). The research angle (positioning) on the Rhône River was predominantly biophysical and chemical (55%), followed by social and environmental risks (15%), with a few articles studying the river as a human habitat, a context for leisure or a resource (3–4% each). The keywords referring to socio-ecological and similar conceptual frameworks were little used, absent in 71% of the articles.

3.2. Multivariate analysis of the publication characteristics

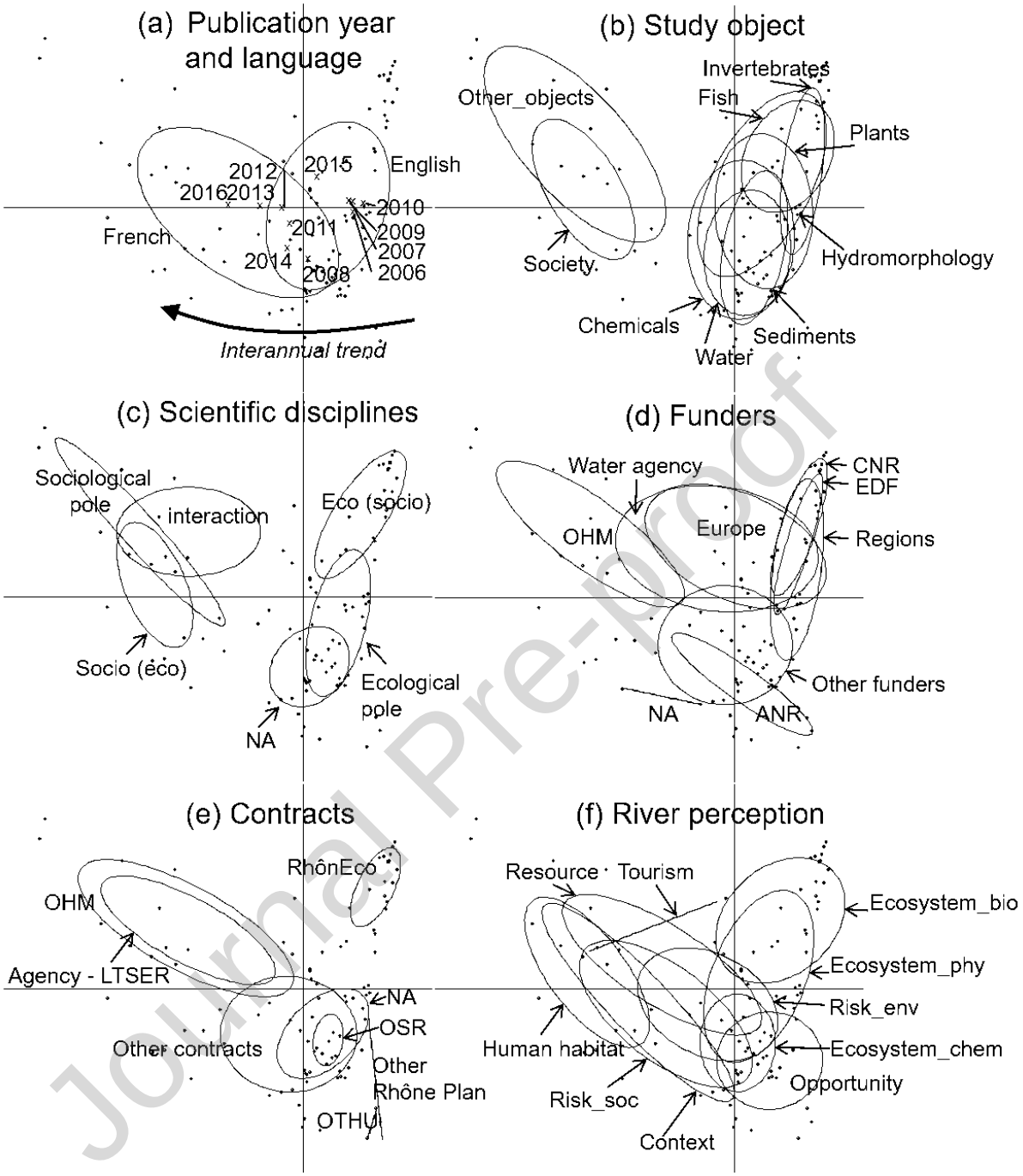

Figure 1: FCA factorial map showing the position of the 97 articles (dots) along the two first axes of the FCA. The different panels show the average position of articles according to specific categories: (a) publication year and language, (b) study object, (c) scientific disciplines, (d) funders, (e) contracts, and (f) river perception. Note that publication year and language were included as "supplementary" characteristics, i.e. they did not contribute to the analysis, in contrast to all other characteristics. Ellipses correspond to the 67% distribution of articles for the different modalities of each characteristic.

Characteristics and categories are defined in Table 1. Characteristics selected for this figure were those most contributing to the FCA axes (Table 2), but we replaced "type of object" by "river perception", as this was more informative. Note that the axes are constant in panels (a)–(f) to enable comparison.

Characteristic	Axis 1	Axis 2
Study location	0.24	0.23
Study duration	0.12	0.33
Fieldwork	0.43	0.01
Study object	**0.67**	0.18
Type of object	**0.54**	0.05
River perception	0.40	0.31
Contracts	**0.50**	**0.64**
Funders	0.27	**0.41**
Keywords mentioned	0.46	0.15
Scientific disciplines	**0.74**	**0.40**

Table 2. Contributions of the characteristics of the reading grid on the two first axes of the FCA shown in Fig. 1. The four characteristics most contributing to axis 1 and the three characteristics most contributing to axis 2 are in bold. Characteristic definitions are in Table 1.

The first two axes of the FCA represented 18% of the global variability of the reading grid. The four characteristics most contributing to the first (horizontal) axis were "scientific disciplines" and "study object", and secondarily "type of object" and "contract" (Table 2). Factorial maps (Fig. 1) indicated a temporal trend along the first axis (Fig. 1a), with articles published after 2010 on the left side of the map. Recent articles focused more on sociological objects (Fig. 1b), and the scientific disciplines more frequently involved sociological aspects (the three corresponding categories on the left side of Fig. 1c). Funders of recent sociological articles were mostly the Human–Environment Observatory (OHM: *Observatoire Hommes-Milieux*) and the Water Agency, whose large ellipse on Fig. 1d reflects its continuous contribution over time. The narrow ellipses associated with the hydropower companies

(CNR: *Compagnie Nationale du Rhône*; and EDF: *Electricité de France*) and the regional authorities, on the right side of Fig. 1d, reflect their contribution to earlier and/or ecological articles. The Human–Environment Observatory and the specific agreement between the Water Agency and the Rhône LTSER were the contracts consistently associated with recent articles (Fig. 1e).

River perception changed over time, from perceptions of the river as an ecosystem (right side on Fig. 1f) to perceptions linked to human life in more recent articles. Nevertheless, the perception ellipses overlap more than in the other categories, indicating a gradual change. Notably, there is a bridge between articles associated with the perception of environmental and societal risk over the whole study period.

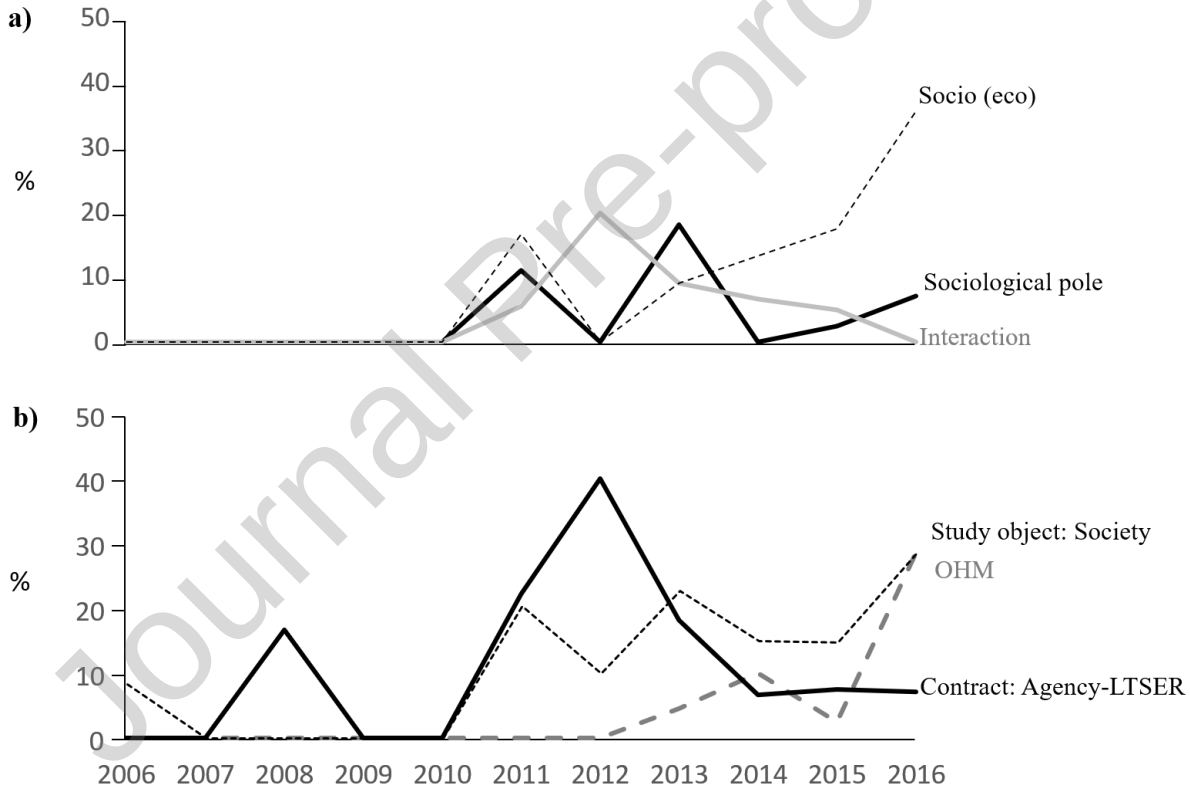

Figure 2: Percentage of selected categories corresponding to the sociological aspects of the reading grid (Table 1) over time with (a) changes in scientific disciplines and (b) changes in the sociological component of the corpus (study object, related contracts). In (a), "Sociological pole" refers to studies about human societies and people, "Socio (eco)" refers to sociological dominance in the study and ecology in this context, and "Interaction" refers to balanced studies involving ecological and sociological interactions.

The temporal dynamics of some categories (Fig. 2), selected for their position on the left side of the first (horizontal) axis of Figure 1, illustrate the multivariate results. The sociological component was absent in articles before 2010 (Fig 2a). After 2010, the "sociological pole" of the corpus emerged, but developed irregularly, while "Socio (eco)" articles strongly increased, reaching 36% in 2016 (Fig 2a). The "Interaction" aspect of the corpus highlights a peak in a socio-ecological approach in 2010–2012. Correspondingly, the percentage of articles with society as the main study object increased from 0 to 29% between 2010 and 2016 (Fig 2b). The Human–Environment Observatory increasingly financed research, reaching 28% in 2016. The agreement with the Water Agency financed many contracts after 2010, reaching 40% in 2012 (Fig 2b).

The three characteristics contributing most to the second (vertical) axis of the FCA were "contracts", "funders" and "scientific disciplines" (Table 2). This axis principally separated articles from 2015 in the upper part of the factorial map (Fig. 1a). These articles were associated with the "RhônEco" contract dedicated to the ecological effects of Rhône ecological restoration measures (Fig. 1e) and its co-funding by hydropower companies (EDF, CNR), Europe and the Water Agency (Fig. 1d). They were mostly ecological studies with society as a context (Fig. 1c). Going back to the raw data indicated that 11 out of 20 articles in 2015 belonged to a special issue concerning ecological restoration of the Rhône River (Lamouroux et al., 2015), strongly structuring the corpus on the vertical axis. Articles on the lower part of the factorial map had less specific characteristics. However, many focused on physicochemical aspects of the Rhône and addressed risks.

3.3. Global description of the publication narrative

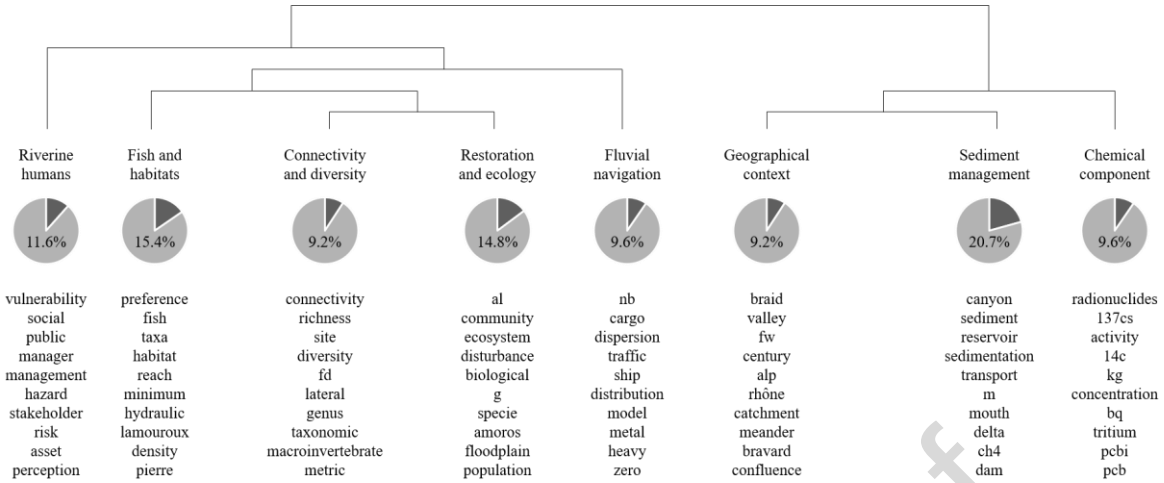

Figure 3. Eight classes identified in the corpus, named according to their lexical content, and their dendrogram (based on Reinert's classification). The percentages correspond to the proportion of text segments classified in each class (i.e. the ratio between the number of text segments classified in a class and the total number of text segments in the final classification). For each class, the characteristic lexical forms are ordered by decreasing χ^2 values of linkage to the class. For this function, the software takes into account all lexical forms; this is why the figure contains proper nouns (e.g. "Bravard"), measurement units (e.g. "kg") and non-meaningful forms (e.g. "al").

The top-down hierarchical clustering classified the text segments within eight classes (i.e. lexical worlds, Fig. 3), which we named according to their lexical content. This dendrogram marked a first segmentation dividing text segments into two parts, each having a semantic unity. The first had five classes (including 60.6% of the text segments) and concerned information on the biological and social components of studies (left side of the dendrogram). The second grouped three classes (including 39.5% of the text segments) and focused on the physical and chemical components of the Rhône River (right side of the dendrogram).

The classes "riverine humans" and "fluvial navigation" together accounted for 21.2% of the text segments classified by the software. Both concern socio-economic issues and relate notably to human vulnerability and risk in riverine areas (e.g. "vulnerability", "social"). Three classes described river ecology and restoration, accounting for 39.4% of the text segments in total: "fish and habitats",

"connectivity and diversity" and "restoration and ecology". The class "geographical context" grouped 9.2% of the text segments and described geomorphic attributes of the river. Finally, the classes "sediment management" and "chemical component" together accounted for 30.3% of the text segments and described how sediments are analysed and managed.

Overall, the "riverine humans" class contained the most terms referring to sociological aspects. Nevertheless, most classes contained aspects of human impacts or uses (e.g. pollution, restoration, navigation, or sediment management).

Figures 4, 5 and 6 show the similarity graphs for the three main classes of the dendrogram (see weights in Fig. 3): "riverine humans", "fish and habitats" and "sediment management". The "riverine humans" class (Fig. 4) is structured with two nodes dominated by the lexical forms "environmental" (on the left) and "restoration" (on the right), linked together by the issue of "management" and the "local" scale. The "environmental" aspect combines challenges related to the Rhône as an environment for humans (e.g. the "vulnerability" aspect), and elements of knowledge (the "study" branch). The "restoration" part combines ecological and sociological facets of restoration projects.

The "fish and habitats" class (Fig. 5) also links two nodes, one dominated by "flow" and "restoration" measures (on the left) occurring on the river, and one related to scientific "models". They both connect to a third node (in the middle) dominated by the word "fish" and associated with aquatic communities. The "flow–restoration" node joins the "fish" node via a "reach" node, the "reach" being a section of the Rhône River between two dams, corresponding in practice to a local management unit. On the right side, the scientific "models" node joins the "fish" node via the concept of "habitat", referring to the suitability of environmental conditions for aquatic organisms.

In contrast to the two other classes, the "sediment management" class (Fig. 6) is organized around a single main node. The numerous words surrounding this central node are related to the measurement and physical understanding of sediment transport. The various branches around the "sediment" node refer to topographic and hydrological drivers of sediment fluxes (branches dominated by the words "river", "channel" and "floods"). One of the secondary branches (in the centre of the lower half) is

clearly related to flushing sediment from dam reservoirs, which is an important operation occurring about every three years in the Rhône due to high sediment inputs from the Alps.

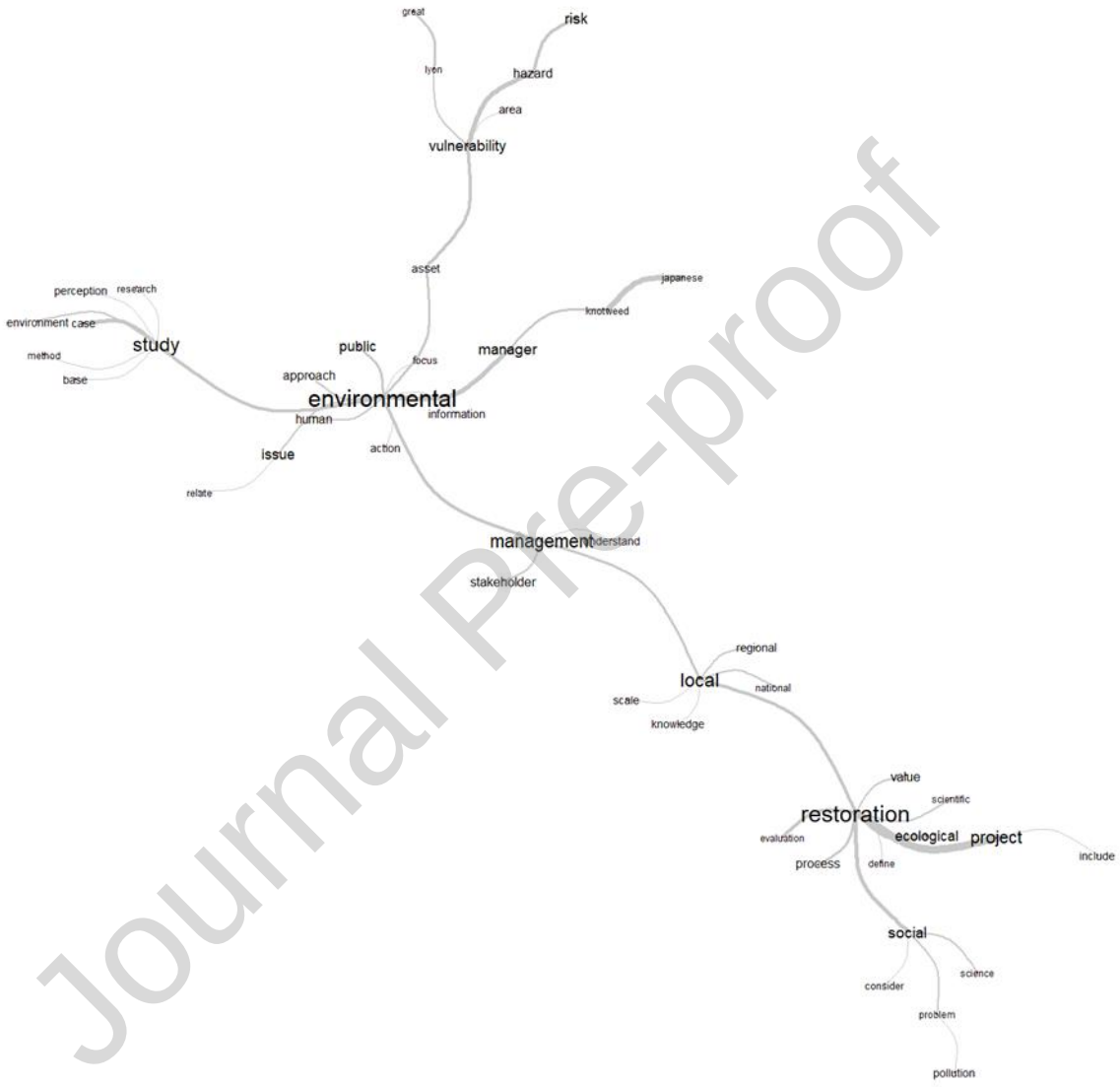

Figure 4: Similarity graph for the "riverine humans" cluster.

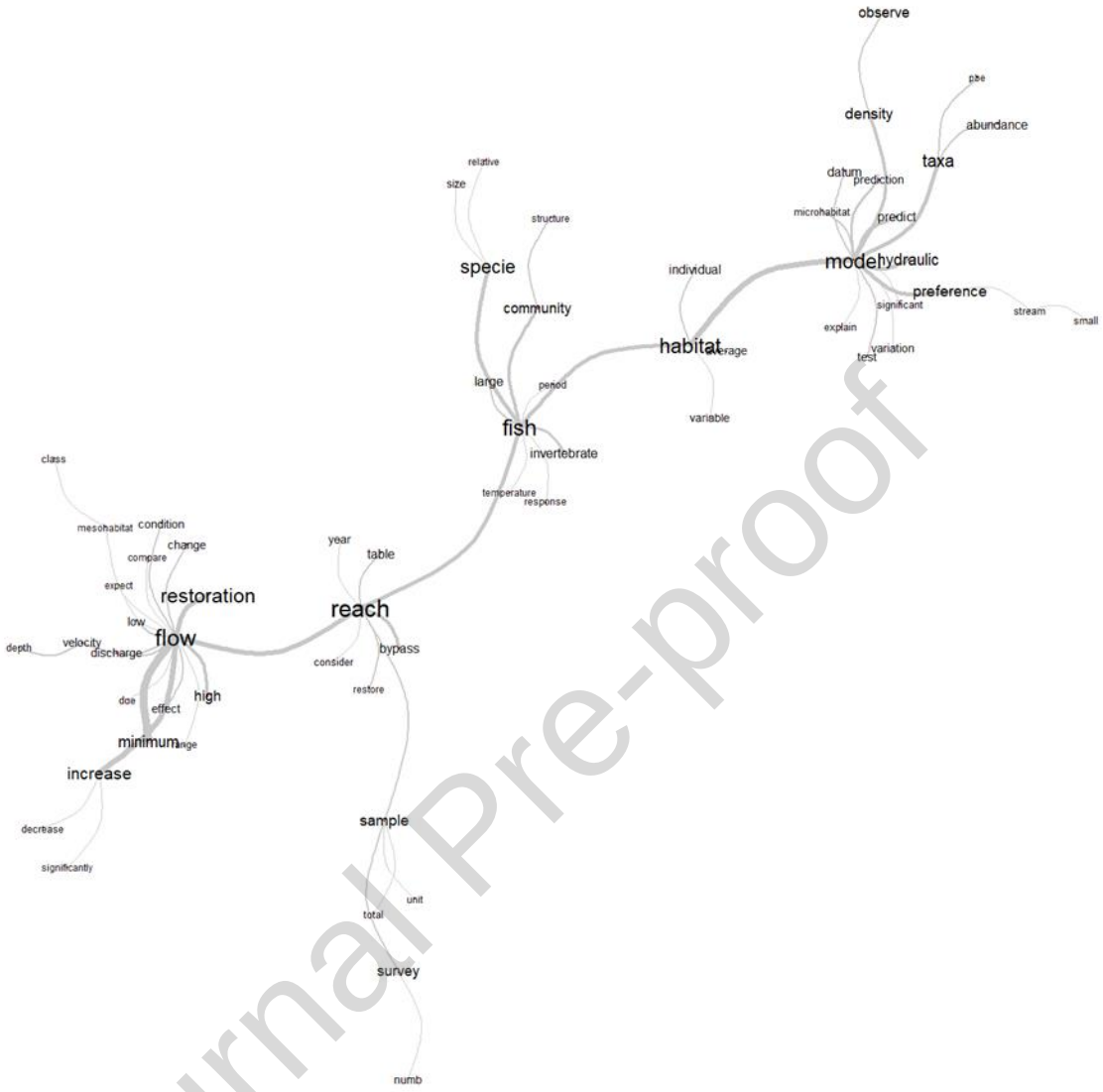

Figure 5: Similarity graph for the "fish and habitats" cluster.

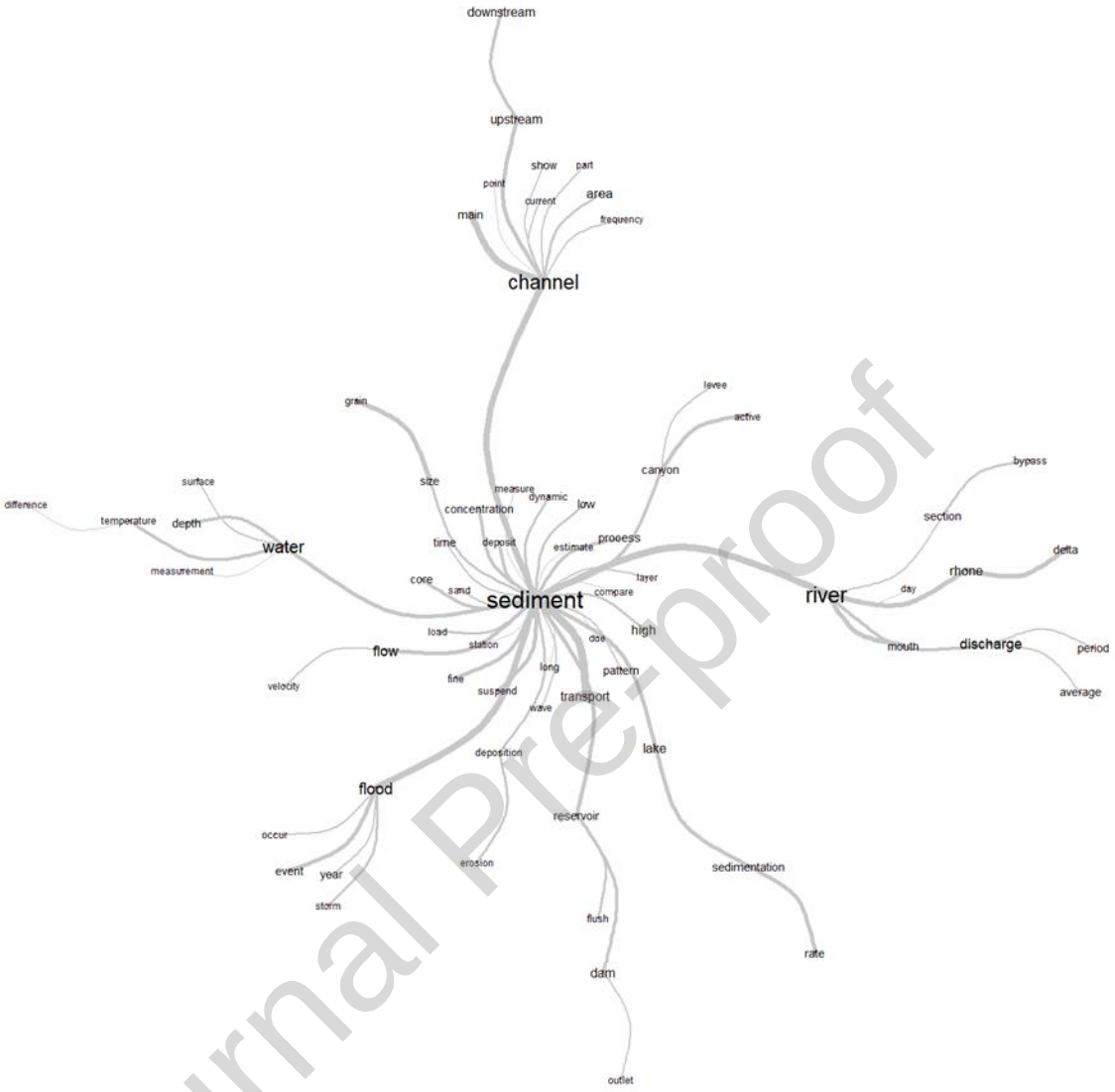

Figure 6: Similarity graph for the "sediment management" cluster.

4. DISCUSSION

The review of published articles by the Rhône River LTSER over the period 2006–2016 demonstrated that scientific publications can allow an important window into how socio-ecological research is implemented within that platform. It revealed information about the nature of the research, its temporal trajectory, and the research approach of the scientific group. The results indicated that the nature of the LTSER's research of the Rhône River over that period was primarily biophysical and chemical. Only secondarily was the river studied as a societal or environmental risk factor. The dominant study objects were physicochemical aspects, followed by biological and sociological aspects. Correspondingly, 3 out of 8 lexical classes found in publications related to the river ecosystem. The research was 79% field-based and often conducted over the long term (>10 years in 43% of cases), a key element in LTER/LTSER networks.

The research dynamics were revealed by the multivariate analysis, showing a clear increase in interdisciplinarity after 2010 and a stronger consideration of social aspects over the years, reflecting a continuous development from LTER to LTSER research. Nevertheless, while 35% of articles combined sociological and ecological aspects, few (4%) had a clear focus on socio-ecological interactions (Table 1). This suggests that interdisciplinarity emerges gradually over time, probably due to the time needed for exchanges across disciplines and scientific acculturation. Correspondingly, our experience is that the governance and functioning of the Rhône LTSER encourage interdisciplinarity, without excluding purely biophysical or purely social studies. The Rhône LTSER ranks 13 out of 25 in terms of the integration of social sciences among international LTSER platforms, and many other platforms are strongly dominated by purely ecological or purely social studies (Dick et al., 2018, fig. 8). In this context, it is likely that the need for exchanges between disciplines before conducting transdisciplinary research is largely shared by LTSER groups and other inter- and transdisciplinary research groups. As pointed out by Holzer et al. (2018b), transdisciplinarity requires communication within interdisciplinary teams – this is necessary to carry out complex research projects that call on high standards of collaboration both between disciplines and with non-academic stakeholders.

The results of our review show the progressive emergence of transdisciplinarity in the Rhône research

group. First, most publications were in the framework of identified contracts (84%) and funders (98%), reflecting interactions with multiple partners. Funders included a mix of private and public bodies at the regional, national and European levels. Second, the multivariate analysis indicated that the increase of interdisciplinarity over time was particularly associated with specific contracts: contracts from a national Human–Environment Observatory created in 2011 (OHM), and a specific agreement between the Water Agency and the Rhône LTSER. The co-construction of research was particularly strong in the framework of the Water Agency agreement, in which research actions were debated and developed between researchers and water managers during several meetings per year. Inter- and transdisciplinarity were a clear target in this co-construction. Third, human influences were omnipresent in Rhône River research. Most clusters contained aspects of human impacts or uses (e.g. pollution, restoration, navigation or sediment management). Furthermore, management and restoration issues had a strong weight in similarity graphs, particularly those related to classes on "fish and habitats" and "riverine humans". Overall, this reflects that while research on the Rhône was largely dominated by biophysical and chemical studies, it was also deeply grounded in the management context of a river with strong anthropic influences and interests.

The analyses (and particularly the similarity graphs) provide useful information concerning the research approach of the Rhône LTSER, beyond what we initially expected. The publications made no explicit reference to specific conceptual frameworks, as conceptual keywords were absent in 71% of publications, and absent from lexical classes and similarity graphs. However, the analyses revealed applied research deeply rooted in a management context in which scientists study research questions in relation to social issues and try to provide knowledge that is relevant to decision-makers and adapted to specific, concrete, local situations. The global description of the publication narrative shows descriptive vocabulary regarding producing knowledge and understanding, with no mention of choices, advantages, interests, services, costs or benefits. The "fish and habitat" similarity graph nicely illustrates the research approach associated with ecological restoration of the river (e.g. Lamouroux et al., 2015). Fish communities have a central position on this graph, linking academic interests (testing predictive habitat models) and the implementation of restoration measures (by river "reach", i.e. a local river segment).

This indicates that researchers learn from restoration operations, while informing managers of their effects. The "riverine humans" similarity graph also suggests that the environmental management of the river combines human vulnerability and knowledge to define restoration actions with social and ecological elements, adapted to local contexts. The integration of management actions and academic knowledge is less evident on the "sediment management" graph, probably because interactions on this topic only started to increase in the period 2006-–2016 and were not yet visible in publications.

A limitation of the narrative analysis was the exclusion of the 26 articles in French, which may have influenced the conclusions. This is illustrated by the word clouds for the English and the French corpus (shown as Supplementary Material, Figures S.2 and S.3). The French word cloud (S.3) refers more to environmental management challenges. In this word cloud, the authors recognize that the core nature of their work on the Rhône River relies on fieldwork and dialogue with stakeholders.

Beyond the Rhône example in this study, adapting and applying our methods to different research groups would be of interest to improve the characterization of different socio-ecological research approaches and practices. The methods help to meet the need of pursuing reflexive publication analyses (Dick et al., 2018). This could add to the socio-ecological research evaluation protocol proposed by Holzer et al. (2018b), which assesses whether the objectives set by a transdisciplinary research group are met and identifies the difficulties to be overcome. Our approach expands this by paying attention to the angle the research takes. In particular, indicators such as the degree of interdisciplinarity (with five modalities to help characterize intermediate situations, which are frequent) and the perception of the socio-ecological system are good candidates for characterizing diverse research practices.

More importantly, a narrative analysis can help to describe the complexity of research approaches. Within the already diverse context of transdisciplinary research, the socio-ecological system concept itself allows a wide range of interpretations and can rely on different conceptual frameworks. In particular, it can rely on different ethical foundations. Our method could be particularly useful for exploring the ethical bases of SES research, as it highlights the main perspectives adopted in the scientific language of a research group, thus enabling research angles about human–nature relationships to be explicitly discussed, challenged and refined.

Different socio-ecological research networks can take very diverse approaches to the same concept. Within the LTSER network, for example, there are conceptual variations between the different LTSER platforms themselves. Approaches often focus on ecosystem services and human stewardship of the environment: for example, the popular conceptual framework of Collins et al. (2011). This framework enables analysing how human behaviour affects ecosystems and how the resulting dynamics influence ecosystem services. It aims at the sustainable management of socio-ecological systems, i.e. guaranteeing an equal distribution, in the present and for the future, of ecosystem services between human populations. Drawing from Collins et al. (2011), and based on the experience of the French LTSER network, Bretagnolle et al. (2019) developed an operational framework in which the interactions of a social and a biophysical template are detailed with the vocabulary of ecosystem services (e.g. "stocks", "goods and services", "benefits").

Nevertheless, such anthropocentric views of the "socio-ecological system", centred on human interests and frames of reference, are not the only possible or existing understandings of the concept in the LTSER network and beyond. As the idea of "socio-ecological system" aims at studying human-nature relationships, diverse ethical perspectives on such relationships seem important to identify and discuss within and between different socio-ecological research networks. In particular, the research field of environmental ethics has debated anthropocentric views of human-nature relationships: since the 1970s, many scholars have considered anthropocentrism an attitude that must be overcome, arguing that the worldview it conveys is the root of the environmental crisis we are facing (Callicott and Frodeman, 2009, chap. "Anthropocentrism"). As explored by environmental ethics, other approaches are possible, in which considering humans within nature does not necessarily mean that nature should be considered solely as an environment to manage. For example, Maris (2015a) argues that notions such as "natural capital" and "ecosystem services" do not challenge the worldview underlying the system that is causing the current ecological crisis. In this worldview, nature is "absorbed" in the technical, economic and technocratic spheres of our human world; nature is deprived of exteriority, otherness and agency (Maris, 2015b). Initiatives that link ecology and environmental ethics have emerged that question the fundamentals of current human–nature relationships and broaden the effort of transdisciplinarity beyond

the dominant economic and technical visions of nature (Rozzi et al., 2013). In particular, Rozzi et al. (2012) have developed an ethical component within socio-ecological research with a specific approach for a Chilean LTSER; this views humans as cohabitants of ecosystems, along with "other-than-human" beings. The methodology developed in the Chilean LTSER network strives to respect "otherness", i.e. "the expression of ancient cultures, life forms, and habitats not yet immersed in global society", to "recontextualize the global economy, politics, and culture", aiming "toward a new understanding of humans as cohabitants of ecosystems" (Rozzi et al., 2012, p. 233).

By characterizing research approaches, publication analyses could help to better grasp this diversity of ethical foundations and approaches and their influence on SES research.

CONCLUSION

The findings of this study have had a concrete impact. Sharing the detailed analysis of the publications of the Rhône LTSER led the group to consider actions to increase the degree of inter- and transdisciplinary research (e.g. involving additional teams in social sciences and environmental economics; developing interdisciplinary actions). Conducting such analyses on different corpuses or different time periods (e.g. every 10–15 years) would help to inform the collective research strategy of the LTSER platform. Similar methods could be applied within any socio-ecological research group or similar research infrastructure to help clarify its approach, how its research is practiced over time and the specific themes and research angles it develops. This could promote the diversity of points of view in socio-ecological and, more generally, transdisciplinary research, and enable dialogue between them.

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: