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Review

Reconciling agriculture and stream restoration in Europe: A review relating to the EU Water Framework Directive

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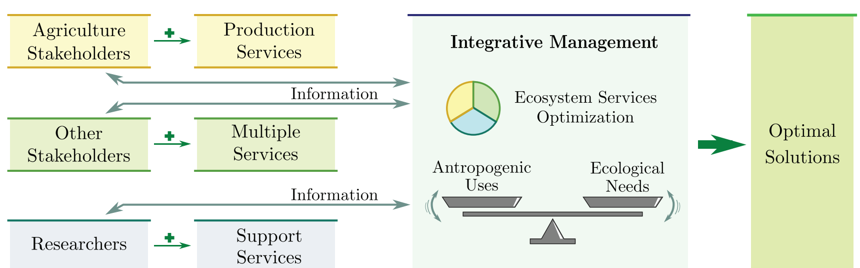
HIGHLIGHTS

- Agriculture is the main contributor to freshwater ecosystem degradation in Europe.
- The WFD deadline to reach good ecological state on European streams closed in 2015.
- Recent research on reconciling agriculture and stream restoration was integrated.
- Involving and acknowledging stakeholders is likely to improve restoration outcomes.
- Increasing peer-reviewed restoration reports is crucial for integrative management.

GRAPHICAL ABSTRACT



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ABSTRACT

Agriculture is widespread across the EU and has caused considerable impacts on freshwater ecosystems. To revert the degradation caused to streams and rivers, research and restoration efforts have been developed to recover ecosystem functions and services, with the European Water Framework Directive (WFD) playing a significant role in strengthening the progress.

Analysing recent peer-reviewed European literature (2009–2016), this review explores 1) the conflicts and difficulties faced when restoring agriculturally impacted streams, 2) the aspects relevant to effectively reconcile agricultural land uses and healthy riverine ecosystems and 3) the effects and potential shortcomings of the first WFD management cycle.

Our analysis reveals significant progress in restoration efforts, but it also demonstrates an urgent need for a higher number and detail of restoration projects reported in the peer-reviewed literature. The first WFD cycle ended in 2015 without reaching the goal of good ecological status in many European waterbodies. Addressing limitations reported in recent papers, including difficulties in stakeholder integration and importance of small headwater streams, is crucial. Analysing recent developments on stakeholder engagement through structured participatory processes will likely reduce perception discrepancies and increase stakeholder interest during the next WFD planning cycle.

Despite an overall dominance of nutrient-related research, studies are spreading across many important topics (e.g. stakeholder management, land use conflicts, climate change effects), which may play an important role in guiding future policy. Our recommendations are important for the second WFD cycle because they 1) help secure the development and dissemination of science-based restoration strategies and 2) provide guidance for future research needs.

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Contents

1. Introduction

1.1. Background

1.1.1. Connections between agriculture and freshwater ecosystems

A large part of Europe's land is dedicated to agricultural uses, which are driven by a variety of macro elements (e.g. socioeconomic and cultural drivers), as well as local factors (e.g. climate, topography, farmer motivation; Kristensen, 2016; Lima et al., 2015; van Vliet et al., 2015). These factors have an important influence on land suitability for agricultural use (i.e. natural and anthropogenic factors covary; Allan, 2004; Hughes et al., 2010) and often lead to an overuse of lands directly connected to stream networks (Conroy et al., 2016; Holden et al., 2004).

Agricultural activities often have large impacts on riverine ecosystems (Allan, 2004; Grizzetti et al., 2012; Ormerod et al., 2010; Windolf et al., 2012), which may range from physical impacts such as riparian clearance, erosion or water regulation for irrigation, to chemical impacts, such as increased nutrient runoff or pesticide contamination. Degradation is further aggravated by high degrees of hydromorphological change, which leads to the breakdown of the longitudinal and lateral continuity that is characteristic of riverine ecosystems (Bolpagni and Piotti, 2015).

Throughout Europe, agriculture is the type of land use with the most significant impacts on freshwater ecosystems (e.g. Davies et al., 2009; Poole et al., 2013) and, with an increasing recognition of the services provided by these ecosystems, there is growing public support for their restoration. Nowadays, it is a political priority to provide the necessary conditions for freshwater ecosystems to recover from anthropogenic impacts.

1.1.2. The importance of restoring streams and rivers

Freshwater ecosystems are highly diverse and complex (e.g. small headwaters, large rivers, estuaries; Allan, 2004; Culp and Baird, 2006; Yeakley et al., 2016) , providing a wide variety of ecosystem services including water abstraction (for human consumption or irrigation), flood protection or biodiversity maintenance. Streams and rivers are directly related to the surrounding terrains, and are affected by stressors (e.g. pollution) that may extend beyond on-site processes (Jansson et al., 2007; Naiman et al., 2002). Furthermore, pollutants may interact with each other, making it difficult to disentangle important pathways (Townsend et al., 2008).

When river management favours the provisioning of specific ecosystem services (e.g. irrigation), the remaining services may be severely diminished or even lost (Bullock et al., 2011). For example, channel simplification to increase water flow (i.e. to decrease groundwater levels) may impair flood regulation and biodiversity supporting services, particularly in other sections of the river system (e.g. further downstream). Thus, management options may severely change the ecosystem's structure and functioning (Jansson et al., 2007), and concerns over ecosystem service loss often drive riverine restoration efforts (Bernhardt and Palmer, 2007).

Restoring the structure and complexity of streams and rivers often increases their resilience and ability to dissipate external impacts, thus leading to a reliable and broad ecosystem service provisioning. This is particularly important when accounting for possible future variability (e.g. from climate change scenarios; Addy et al., 2016). Given the complexity associated with freshwater ecosystems, it is necessary that research extends across multiple fields and scales, and focus on target research areas that need greater attention to secure optimal restoration efforts.

1.1.3. The WFD as an integrative restoration tool

The European Water Framework Directive (WFD; EC, 2000) represents landmark legislation in the integrative European policies, requiring active stakeholder engagement (Andersson et al., 2012; Blackstock et al., 2010; Richter et al., 2013). The WFD's first cycle of water resources management took place between 2009 and 2015 (EC, 2000), aiming to have a significant role in increasing integrative restoration efforts, and thus increase European waterbodies' resilience and ability to provide key ecosystem services. With the end of this planning cycle, the deadline to achieve good ecological status on the European freshwater ecosystems has been reached. However, many European water bodies have failed to achieve good ecological conditions by 2015 (EEA, 2012). The WFD comprises two additional management cycles of 6 years each (the second ending in 2021 and the final in 2027), in which member states must strive to increase ecological quality of freshwater ecosystems.

With the second management cycle now underway, it is important to evaluate to what degree the first WFD cycle improved the coordination between multiple stakeholders towards successful riverine restoration. Particularly, given that agricultural land use is predominant across Europe (up to 44% land cover; Martino and Fritz, 2008) and that various management options may impact freshwater ecosystems differently, exploring the evolving relationship between stream restoration and agriculture is crucial.

1.2. Objectives of the review

This paper presents findings of a comprehensive review of peer-reviewed works, from the European Union, undertaken during the first management cycle (2009–2015), which targeted the relationships between agriculture impacts and restoration of lotic ecosystems. Furthermore, papers from 2016 were also included, to avoid exclusion due to publication delay (i.e. research may have been developed during the first cycle but only published afterwards) and to cover the beginning of the second WFD planning cycle.

1.2.1. Primary question

How is the relationship between multiple stakeholders evolving towards reconciling agricultural practices and the welfare of streams and rivers through restoration measures in the European Union?

1.2.2. Question components

Social. There are multiple stakeholders involved in the management of water basins, ranging from farmers (land-owners), NGOs and basin managers to politicians and researchers. This variety leads to a considerable diversity of interests and points of view, stressing the importance of achieving an integrative cooperation in basin management.

Technical. Agricultural impacts vary greatly depending on different target species (both animal and vegetal), management options and areas used by the farmer. Consequently, there are multiple pathways through which agriculture and freshwater ecosystems interact, leading to, for example, increasing nutrient concentrations, hydromorphological changes, or alterations in water level patterns.

Ecological. There is a great diversity of water bodies in Europe. In this review, we explore only the restoration of freshwater lotic ecosystems (i.e. streams and rivers).

Politico-demographic. The European Union, through the WFD, implemented an ecological view in freshwater ecosystem management. Therefore, it is of particular interest to explore how this European policy translates to national planning and action across all member states.

1.2.3. Secondary questions

This review includes important secondary questions, related to the primary question. Specifically, based on the retrieved information, we address the following questions:

- Has the number of restoration projects reported per year in peer-reviewed literature increased since 2009?
- Is recent agriculture-related research spreading across multiple topics of interest for freshwater restoration?
- Which knowledge gaps may undermine restoration projects?

2. Methodology

The reviewing process followed the guidelines suggested by Pullin and Stewart (2006).

2.1. Search terms

Search keywords were chosen for each of the question components (Section 1.2.2) and assembled to create a complex search string. Furthermore, to increase the string's efficiency, an additional fifth element containing common undesired terms was added after a preliminary test search. The specific keywords used were as follows (* represents a search engine wild-card):

Social terms: stakeholder*, engag*, participat*, manag*, land use*, land use configuration, land use conflict*.
Technical terms: riparian clearance, damming, fish migration*, regulation, irrigation, abstraction, sediment*, erosion, runoff, nitr*, phosph*, pesticide*, herbicide*, climate change, restor*, rehab*, ammend*, interve*.
Ecosystem terms: agricultur*, stream*, river*, watershed*, catchment*, basin*.
Politico-demographic terms: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom, Ireland, England, Scotland, Wales, Europe*, EU.
Negative terms: China, USA, America, Australia, Africa.

This string was applied to four different databases to assure a wide coverage: B-On, DTU-Findit, Web of Science and Scopus. The string was slightly adapted when applied to the various databases to cope with different operators (e.g. Scopus exclusion operator is "AND NOT"). A cross-match of the results from each database was done to remove duplicates.

By including search keywords related to restoration projects (e.g. restore, rehabilitate), the search string retrieved information on the number of annual restoration projects. Likewise, the diverse technical terms that span across multiple agricultural stressors were used to 1) assess recent research trends and 2) identify information gaps recently uncovered by researchers, which may undermine restoration efforts. Such information was used to answer the secondary questions (Section 1.2.3).

2.2. Screening

The papers returned by the different databases were evaluated for relevance based on the inclusion criteria at three successive levels: title, abstract and full-text. On each level, the compliance of the content to the criteria presented in Table 1 was examined. As Pullin and Stewart (2006) indicate, whenever there was uncertainty regarding the acceptance of a given paper, it would be accepted for further scrutiny (e.g. if the title relevance was ambiguous, the paper would proceed to abstract reading).

2.3. Data extraction

For the included papers, relevant data about the study characteristics were recorded in a spreadsheet. Specifically, we have recorded the agricultural land use types considered by the study (e.g. intensive or extensive agriculture, presence of livestock, presence of irrigation systems) and also the main topic(s) under scrutiny by the paper: stakeholders, land use changes, riparian clearance, damming, regulation, irrigation, fish migration, water abstraction, sediment flows, erosion, runoff, N forms, P forms, pesticides and lastly climate change effects. Furthermore, the annual number of papers related to specific restoration projects (i.e. both describing a project and revisiting it) was recorded. Data were summarised and linear regressions were applied to derive recent research trends on the topic.

3. Results

3.1. Selection process

The search process returned a total of 4561 papers after duplicate exclusion (Table 2).

Table 2
Number of papers returned by the search engines.

Database	Total	New	Duplicated
Scopus	3924	–	–
Web of Sci.	405	304	101
DTU Findit	301	151	146
B-on	454	178	276

3.1.1. Title analysis

The title reviewing led to the exclusion of 3827 papers (83.9% of the initial amount; Fig. 1a).

In total, 33.8% of the excluded papers were not related to ecological restoration (i.e. off-topic papers), targeting topics such as human health care or paleological reconstruction. Additionally, 51.2% of the exclusions resulted from a lack of focus on 1) riverine ecosystems (see Table 1), 2) agricultural land uses or 3) both. Lastly, despite the search string location limiters, 15% of the excluded papers were not related to the EU. A total of 734 papers moved to the abstract level.

3.1.2. Abstract analysis

During the abstract reading, a total of 406 papers were excluded (55.3%; Fig. 1b). Most initially selected papers were excluded due to a lack of focus on agricultural activities (e.g. papers studied the impacts of other land uses on freshwater ecosystems; 37.4%). Furthermore, 2.7% of the excluded papers were either not journal papers or not peer-reviewed. In total, 328 papers moved to the full text level.

3.1.3. Full text analysis

On the final analysis level, 83 papers were excluded (25.3%; Fig. 1c). Similarly to the abstract analysis above, the off-topic papers were related to increasing agricultural performance and outputs. The 25.3% excluded papers labelled as "Other" in Fig. 1c correspond to 1) 7 papers where we were unable to retrieve the full text, 2) 11 papers which were not written in English and 3) 3 papers that consisted of review protocols. Completing the reviewing process, a total of 245 papers were used to address the working questions.

3.2. Primary question

3.2.1. Social component

From the included papers, 53 (21.63%, Fig. 2) described developments in stakeholder management during the WFD's first cycle. From these, the majority (39.6%) explored how current ecological or socio-political contexts impact and reinforce the need for stakeholder integration, without delving in detail into the opinions of different stakeholder groups. Additionally, 13 papers focused exclusively on farmers and 7 exclusively on non-farmers, while 12 papers targeted both groups. Non-farmer stakeholder groups included the local community, politicians, NGOs and public or private entities (e.g. basin management entities or water companies), each targeted by 7–10 papers.

Different stakeholders value distinct aspects when discussing restoration plans: farmers and landowners focus their interest in the future of agricultural practices in the study areas (Ricart and Clarimont, 2016), while administrators privilege the achievement of programme objectives (Aggestam, 2014) and the local residents show interest in an integrative approach where both nature health and farmers' sustainability are assured (Jacobs and Buijs, 2011).

Table 1
Admission/exclusion criteria.

Criteria	Include	Exclude
Peer-reviewing	Peer-reviewed	Everything else
Year	$2009 \leq Y \leq 2016$	$Y < 2009$, $Y = 2017$
Geo-location	European Union	Everything else
Text language	English	Everything else
Ecosystem	Freshwater and lotic[a]	Sea/Ocean and/or lentic
Stressors	Agricultural stressors are predominant	Agricultural stressors absent or playing a minor role
Restoration	The study deals with restoring freshwater ecosystems impacted by agricultural stressors	The paper focuses on non-restoration topics such as increasing farm performance

[a] Papers where artificial wetlands were targeted as part of the river continuum were included. Papers concerned with the terminal sections of rivers (e.g. estuaries) were included.

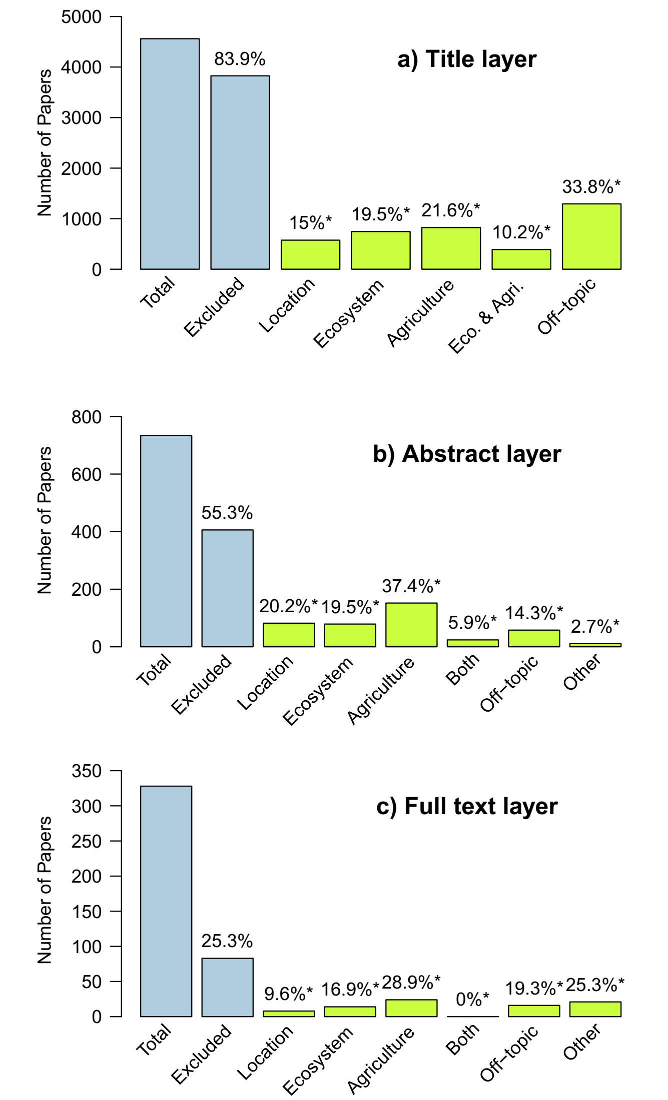

Fig. 1. Exclusion results based on the 3 levels of scrutiny (i.e. title, abstract and full text). Blue bars show the initial number of papers included for scrutiny and the number of excluded papers. Green bars show the number (and respective percentages) of papers excluded per motive (see Table 1). *Percentages related to the total number of excluded papers.

The reviewed papers (e.g. Aggestam, 2014; Finn and Ó uHallacháin, 2012) highlighted the importance of a directed effort towards different stakeholder groups, seeking the integration of different needs and demands. Involving stakeholders in the development of projects allowed collaborators to find integrative solutions and also to better understand restoration measures' impacts (Barataud et al., 2014; Bergfur et al., 2012; Jacobs and Buijs, 2011).

3.2.2. Technical component

Covering the period 2009–2016, the most researched topics were nitrogen, phosphorus, stakeholder management, pesticides and land use effects. Note that papers may, however, simultaneously focus on more than one topic (e.g. nitrogen and phosphorus; Fig. 2).

Additionally, there is an apparent increase in the yearly number of papers covering the restoration of freshwater ecosystems impacted by agriculture (Fig. 3). Nevertheless, it was not possible to establish a significant correlation between studied years and the annual number of papers relating to the subject.

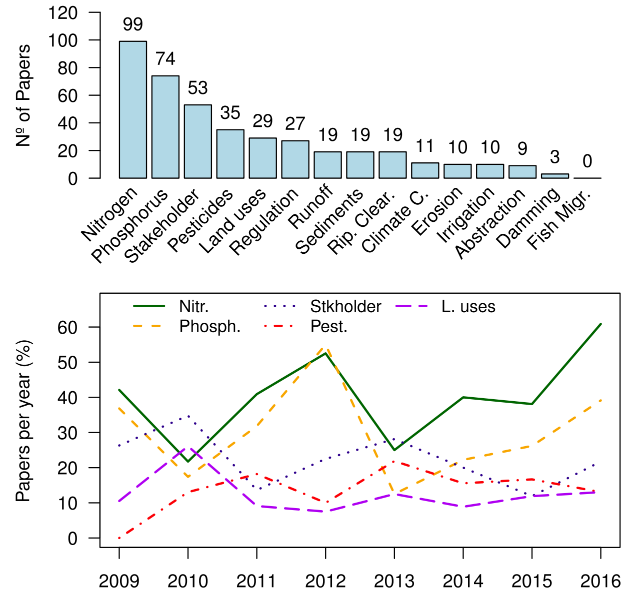

Fig. 2. Topics explored by recent studies (2009–2016). Top: Combined numbers of papers for the explored topics; Bottom: Evolution in yearly paper count for the top 5 topics. Note that a single paper may focus on more than one topic.

3.2.3. Ecosystem component

Over half of the accepted papers targeted arable land (31% exclusively and 24.9% alongside livestock, Fig. 4). Papers targeting livestock specifically accounted for 5%. However, 22, 6 and 34 papers targeting arable land, livestock or both, respectively, did not provide additional details about management intensity or culture planning. Intensive agriculture systems were studied to a larger extent (16.7%) than extensive systems (7.3%). Additionally, 96 papers (39.2%) did not provide specifications regarding agricultural type or management options.

In total, 21.6% of the reviewed papers reported the use of bioindicators both as a measure of impacts and also as a way to sensitise stakeholders. The most commonly used bioindicators are macroinvertebrates, followed by plants (both riparian and aquatic) and fish (62, 35 and 18% of the bioindicator-related papers, respectively). Other biotic indicators such as birds, amphibians or microbial community are less used in recent research (5.7 to 7.5% of the bioindicator-related papers).

3.2.4. Politico-demographic component

Approximately two thirds of the reviewed papers (160 in total) mentioned the WFD at least once along the presented research.

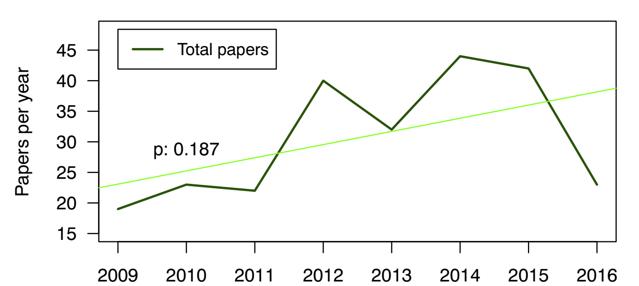

Fig. 3. Distribution of reviewed papers per year. Despite an apparent increase in the number of papers relating to the understanding and restoration of agriculturally impacted rivers and streams, no significant relationship was identified.

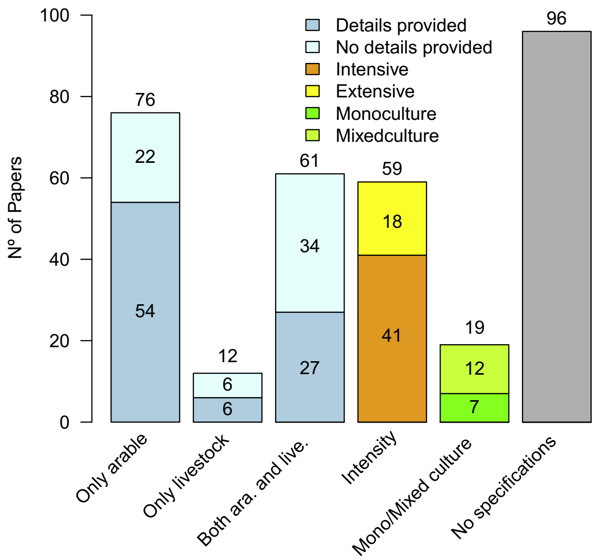

Fig. 4. Agricultural management options explored in recent research (2009–2016).

Furthermore, studies consistently present an overall positive view of the WFD's first management cycle, and point towards the need to continue working to restore freshwater ecosystems during the next cycles. Nevertheless, some papers explored potential shortcomings detected during the implementation of the first cycle and provided recommendation for future studies. Specifically, studies report limitations such as 1) the persistent difficulty in connecting river management to local communities (e.g. Benson et al., 2014); 2) the underestimated role of small headwater streams in watershed water quality (e.g. Lassaletta et al., 2010); 3) the need to ensure that planned mitigation measures achieve meaningful nutrient concentration reductions (e.g. Hirt et al., 2012) and 4) current difficulties in defining disproportionate restoration costs (e.g. Galioto et al., 2013).

From the 245 reviewed papers, 53.1% were related to either the UK, France, Denmark or Spain (Fig. 5). Furthermore, 19 papers (7.8%) brought together more than one European country in their studies. There is scarce representation of multiple European Union countries (e.g. Czech Republic, Romania) in recent peer-reviewed research captured by our review.

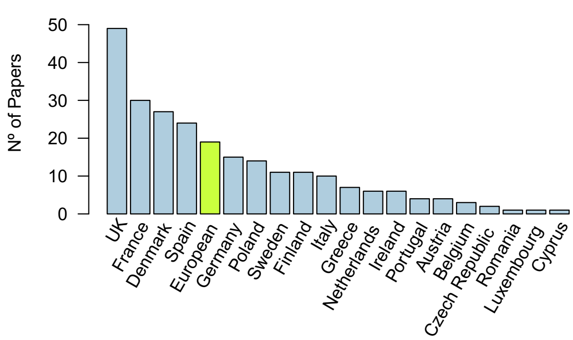

Fig. 5. Number of retrieved papers by European country. Papers which covered more than one country were labelled as "European" (green bar).

3.3. Secondary questions

3.3.1. Restoration report trends

From the reviewed papers, only 9 works described new restoration projects (Table 3), while 22 papers described the recent evolution of previously restored sites (Table 4). During the studied period, despite an apparent increase in the number of papers related to restoration per year, a significant correlation was not revealed (Fig. 6).

Amongst the reviewed papers, cases of restoration project success and failure were reported. For example, Bergfur et al. (2012) reports on the development of an integrative restoration plan, where stakeholders were consulted throughout the process and where solutions and compromises were developed in an integrative way (Fig. 7). The restoration was successful and assured commitment from all parts involved. Guerrin (2015) presents a contrasting example, where a series of conflicting situations weakened a restoration project and eventually led to its cancellation (Table 5).

3.3.2. Topics explored by recent research

Fig. 2 shows that, although recent research is spreading across multiple topics, there is an overall dominance of nutrient-related research. Linear regressions performed for each topic presented mostly high P-values (Table 6) for every topic except runoff, which presents a P-value slightly higher than 0.05. Nevertheless, despite an apparent increase in the number of papers per year (Fig. 3), the overall relative importance of each topic across the studied time period appears to remain largely constant, with the linear regressions for each topic presenting slopes varying between −1.5 % and +2.2%. Therefore, despite the yearly fluctuations, no specific topic appears to be evolving towards being increasingly more studied than others.

3.3.3. Knowledge gaps detected

To identify knowledge gaps pointed out by researchers in recent literature, the papers of each topic presented in Fig. 2 were analysed. The knowledge gaps presented in Table 7 are likely to play an important role in the development of restoration projects.

4. Discussion

4.1. How is the relationship between multiple stakeholders evolving towards reconciling agricultural practices and the welfare of streams and rivers through restoration measures in the European Union?

Recent European research on stakeholder management has focused farmer stakeholders more often than non-farmer stakeholders (see Section 3.2.1). Non-farmer stakeholders encompass a great diversity (e.g. from house owners to private companies) and, thus, understanding the driving forces behind each group is crucial for successful restoration efforts (e.g. Fig. 7; Bergfur et al., 2012). Furthermore, the complexity associated with basin management (e.g multiple agencies and policies) may lead to confusion by stakeholders (Cook, 2010), and it is important to promote the distribution of knowledge across every acting agent.

4.1.1. Social: reconciling multiple stakeholder groups

Increasing farmers' interest and willingness. Historically, it has frequently been a struggle to develop agricultural environmental regulation that could achieve meaningful ecosystem quality improvements (Collins et al., 2016; Doole et al., 2013). For example, breaches to formal regulations which aim to prevent diffuse pollution were commonly found during an inspection of Scottish watercourses (Christen et al., 2015). Farmers are often unaware of existing regulation or simply choose not to comply with regulations (Collins et al., 2016), as these landowners have grown sceptic of conflicting policy messages (Christen et al., 2015).

Table 3
Summary of papers reporting restoration projects found during the reviewing process.

Paper	Country	Main rest. measures	Restoration objective
Braukmann et al. (2010)	Germany	Integrative management (e.g. re-meander, extend buffer-zones, create ponds)	Reestablish fish passage, improve chemical/biological water quality and hydromorphology
Bergfur et al. (2012)	Scotland	Integrative management (e.g. extend buffer-strips, septic tank removal)	Reduce diffuse pollution from livestock and arable production to improve water quality and ecological status
Ekholm et al. (2012)	Finland	Gypsum amendment on agricultural soil	Reduce phosphorus content in runoff
Audet et al. (2013)	Denmark	Nutrient management through pond creation and riparian land-use conversion	Reduce water nitrogen and phosphorus levels
Gilvear et al. (2013)	Scotland	Assessment of multiple restoration options and their impact on ecosystem services	Improve the provision of multiple ecosystem services
Guerrin (2015)	France	Dike restructuring	Manage flood impacts
Uusitalo et al. (2015)	Finland	Chemical amendment through ferric sulfate dispenser	Reduce water phosphorus content
Horton et al. (2015)	Ireland	Cattle fencing, rock armouring of eroded banks and willow planting	Reduce sediment inputs to improve habitat quality for *Margaritifera margaritifera*
Darwiche-Criado et al. (2016)	Spain	Wetland area enlarging and facilitating water inflow	Increase the residence time and reduce nitrate content

Furthermore, farmers often appear to consider their role on freshwater pollution as insignificant, thus failing to acknowledge that there is indeed a problem in need of solving (Barnes et al., 2013b; Blackstock et al., 2010; Gachango et al., 2015). A long history of agricultural activities on a given land may induce stakeholders to believe that agriculture is a natural landscape element and, thus, diminish the awareness of the need to restore wetlands and floodplains (Crow et al., 2006; Schaich, 2009). Nevertheless, agriculture

Table 4
Summary of papers revisiting previously developed restoration projects found during the reviewing process.

Paper	Country	Main rest. measure	Previous restoration target	Study objective
Warner et al. (2010)	Netherlands	Multiple case studies	Flood management	Stakeholder engagement assessment
Audet et al. (2011)	Denmark	Channel re-meandering	Groundwater levels	Nutrient assessment
Hoffmann et al. (2011)	Denmark	Channel re-meandering	Nutrient concentration	Nutrient assessment
Sgouridis et al. (2011)	UK	New channel creation and reshaping of existing channels	Integrative restoration (e.g. flood storage capacity, habitat diversity, visual appearance)	Nitrate-ammonium reduction capacity assessment
Gonzaléz del Tánago et al. (2012)	Spain	Multiple case studies	Multiple	Review of recent Spanish restoration efforts
Hoffmann et al. (2012)	Denmark	Wetland restoration	Nutrient concentration	Nutrient assessment
Gabriele et al. (2013)	Austria	Re-meandering and riparian restoration	Not specified	Nutrient depuration capacity assessment
Grand-Clement et al. (2013)	UK	Peatland restoration	Integrative restoration (e.g. restore water reservoir, water quality, ecosystem resilience)	Peatland restoration cost-benefit analysis
Gumiero et al. (2013)	European	Multiple case studies	Multiple, primarily reducing flood risk	Review on the effects of socio-ecologic context (e.g. land uses) and societal needs in restoration approaches
Aggestam (2014)	Sweden	Wetland and riparian restoration	Nutrient concentration	Stakeholder assessment
Bregnballe et al. (2014)	Denmark	Channel re-meandering	Sediment and nutrient transport	Water bird assessment
Dietrich et al. (2014)	Sweden	Re-introducing cobbles and boulders	Habitat diversification	Riparian soil fertility phytometric assessment
Friberg et al. (2014)	Denmark	Channel re-meandering	Not specified	Macroinvertebrate community development
Kristensen et al. (2014)	Denmark	Channel re-meandering	Physical and hydrological interactions between the river and wetlands	Evaluate long-term restoration success
Poulsen et al. (2014)	Denmark	Channel re-meandering	Groundwater levels	Water flow and sediment deposition patterns
Veraart et al. (2014)	Denmark	Channel re-meandering	Improve hydrologic connectivity	Denitrification capacity assessment
Zieliński and Jekatierynczuk-Rudczyk (2014)	Poland	Channel re-meandering	Riverbed morphology	Nutrient assessment
Prem et al. (2015)	Denmark	Channel re-meandering	Groundwater levels	Soil redox status assessment
Simaika et al. (2015)	European	Multiple case studies	Not specified	Review restoration measures' effects on fish communities
Hein et al. (2016)	Austria	Floodplain restoration	Integrative restoration (e.g. diversify habitats and enhance ecosystem services)	Danube floodplain restoration options assessment
Muller et al. (2016)	France	Passive restoration	Riparian community	Riparian composition and water quality
Windolf et al. (2016)	Denmark	Re-meandering and wetland restoration	Not specified	Effect of restoration on water nitrogen concentrations

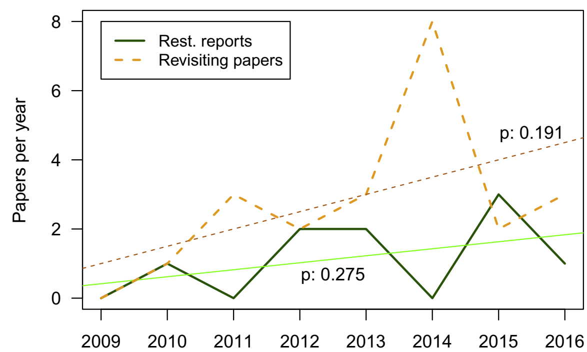

Fig. 6. Number of papers describing restoration projects and papers targeting the evolution of previously restored sites per year in peer-reviewed literature. Despite an apparent increase in papers per year, no significant relationships were revealed.

may impact freshwater ecosystems in multiple ways. Therefore, working towards implementing integrative management solutions (which take into account the importance of multiple ecosystem services and the interests of multiple stakeholders) may go a long way in improving stream conditions (Turunen et al., 2016), as demonstrated by the contrasting examples of the Rhône and Tarland case studies (Table 5 and Fig. 7, respectively).

Even when farmers acknowledge their role in freshwater diffuse pollution, there are often several barriers that keep them from uptaking mitigation measures, including 1) the costs of application and impacts on revenue (Gómez-Limón and Riesgo, 2012), 2) the bureaucracy related to accessing available funds (Christen et al., 2015) or 3) a lack of guidance on how to best apply such measures and on the effectiveness of alternative practices (Del Corso et al., 2015; Guillem and Barnes, 2013).

The frequent aversive reaction to imposed regulations (Barnes et al., 2013a,b), alongside the fact that farmers would rather face prosecution than change agricultural practices (Posthumus et al., 2011), highlight the need to rethink the way to approach agricultural landowners. It is necessary to find improved ways to convince farmers that their role in freshwater pollution is significant and that their help is needed to solve the problem (Howarth, 2011).

Farmers as an heterogeneous group. Agriculture is a highly heterogeneous activity (e.g. cultivating or keeping livestock) and may involve multiple different practices. Therefore, research and management must strive to communicate with (and find solutions applicable to) each particular stakeholder group (Balana et al., 2011; Tzoraki et al., 2014). For example, Franzén et al. (2016) pointed out that horse keepers are subjected to different regulations and are not usually members of farming associations, therefore potentially failing to receive information on land and water management. Working towards 1) targeting information channels which are more often

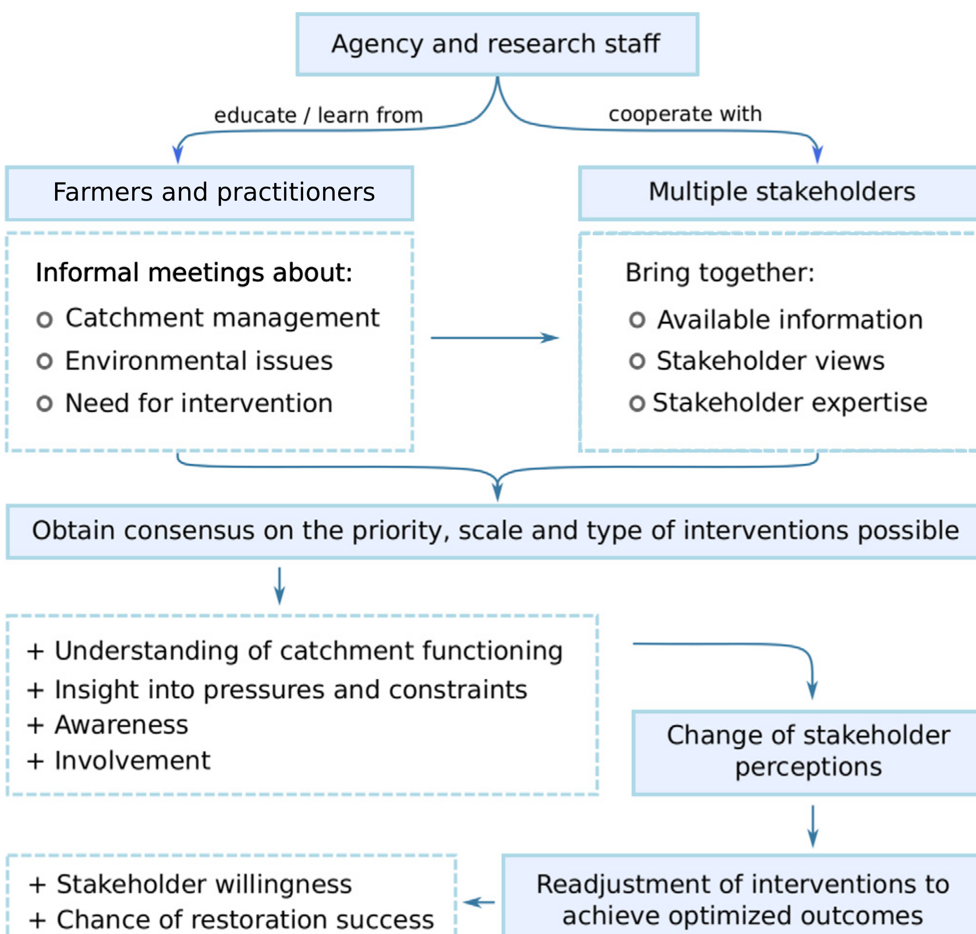

Fig. 7. Management-Stakeholder interactions developed during the Tarland project development, based on Bergfur et al. (2012). The development of an integrative approach led to the achievement of an inter-stakeholder compromise that optimised restoration outcomes and strengthened the provision of multiple ecosystem services.

Table 5
Summary of the constraining elements pointed out by Guerrin (2015) which led to the abandonment of a restoration project on the River Rhône, France. The lack of a solid scientific base, alongside considerable stakeholder opposition and lack of manager empowerment strongly compromised the project.

Institutional	• Young leading institution
	• Conflicting priorities between the management team and stakeholders
	• Lack of urban planning or property rights empowerment
	• Management team not responsible for project implementation, which leads to:
	  • Difficulties in assuring that measures will be taken into action;
	  • Lack of financial power to compensate stakeholders when needed.

Participation	• Late inclusion of stakeholders in the project • Inter-stakeholder conflicts and lack of public organisation • Failure to acknowledge local experience • Lack of scientific backup • Lack of incentive to change farming techniques
Public perception	• Stakeholder perception of negative impacts on the community • Farmers perceived that the project only represented constraints, not opportunities • Overall strong opposition to project implementation

used by stakeholders and 2) structuring message contents in a credible and constructive way may increase stakeholder awareness of freshwater impacts and increase the willingness to adopt new practices (Blackstock et al., 2010; Kay et al., 2012; Whitmarsh, 2011).

Integrating non-farmer stakeholders' perspectives. Restoring freshwater ecosystems brings together managers, farmers and multiple other entities such as local residents or private companies, whose visions of the ecosystem are highly variable. Christen et al. (2015) demonstrated that farmers and non-farmers tend to have different perceptions of key factors such as biodiversity or causality. Different perspectives influence both stakeholder beliefs and attitudes towards interventions (Jacobs and Buijs, 2011) and, therefore, exploring these divergences is crucial to assure integrative river management (Aggestam, 2014; Nainggolan et al., 2013). For example, while the local residents tend to consider biodiversity as a positive factor, farmers tend to view biodiversity as a negative factor due to a perception of increased bureaucracy and time requirements (Christen et al., 2015). Similarly, Brown et al. (2010) reports on the prioritisation of water management concerns by multiple stakeholders: while government authorities' and consultants' prioritise avoiding extreme events and securing water supply and distribution, environmental NGOs valued mostly the recovery of freshwater ecosystem services. This dissonance in perceived values may be mitigated by a clear selection and description of the target ecosystem services (e.g. flood control or erosion prevention), because it increases the stakeholders' awareness of less noticeable ecosystem functions (Barkmann et al., 2008; García-Llorente et al., 2012).

As noted in the results, stakeholders' perceptions play a pivoting role in restoration success, as the society's attitude towards any specific initiative will dictate the support and interest it receives. It is essential to conciliate the local community's preferences with the restoration objectives, to ensure stakeholder dedication and reinforce the interest for integrative management (Comín et al., 2014; Guerrin, 2015).

Focusing management on ecological processes (i.e. targeting primarily the balancing of ecosystem services rather than the return to a natural, pre-disturbance state) may increase stakeholder willingness to opt for integrative solutions (Fliervoet et al., 2013), therefore increasing restoration projects' chance of success. However, reconciling anthropocentric and ecocentric interests of multiple stakeholders (e.g. increasing crop yield and reducing nutrient loads) is a difficult task (Aggestam, 2014), and the failure to achieve this goal may ultimately lead to the abandonment of restoration projects (Guerrin, 2015).

Multifunctional approaches (i.e. targeting multiple ecosystem services) provide the integration of ecosystem uses and demands and promote the participation of multiple stakeholders (Barataud et al., 2014; Schindler et al., 2016). Such integrative management supports an informed cooperation between farmers, non-farmers, managers and researchers (Collins et al., 2016; Gumiero et al., 2013; Spiller et al., 2013a,b), reducing perception discrepancies and allowing the development of transparent policies and more coherent restoration plans (Fig. 7; Blackstock et al., 2010; Guillem et al., 2015; Merot et al., 2009).

Table 6
Slope and P-value of linear regressions applied to the yearly percentage of papers from each of the top 10 topics (see Fig. 2). The overall low P-values indicate considerable yearly fluctuations in topic relevance.

Topic	Slope	P-value
Nitrogen	0.022	0.299
Phosphorus	−0.001	0.961
Stakeholder	−0.015	0.221
Pesticides	0.014	0.199
Land uses	−0.006	0.564
Regulation	0.008	0.481
Runoff	−0.011	0.054
Sediments	0.010	0.335
Rip. Clear.	−0.001	0.924
Climate C.	0.009	0.289

4.1.2. *Technical: researching the multiple stream-agriculture interactions*

Freshwater ecosystems may be impacted by agriculture in multiple ways. As such, it is important that research spans across multiple areas and focuses on diversified stressors and ecosystem functions.

In the results captured by our review, most of the EU research was focused on the behaviour, effects and mitigation of nutrients, with 49.4% of the papers targeting at least one of the nutrients (i.e. nitrogen or phosphorus). Nevertheless, there are several other topics which have been frequently targeted by recent papers, such as stakeholder management, pesticides or land use management (Fig. 4).

The availability of knowledge about different sources of uncertainty (i.e. stressors which may undermine restoration efforts) is important for basin managers, because it ensures 1) a clear definition of the stressors present at a given site, 2) the development of integrative mitigation strategies and 3) the estimation of possible side effects or ecological risks. A clear and concise statement of these topics (1–3) is likely to increase stakeholder confidence in the restoration project, and may also prevent stakeholder backlash in the presence of adversities.

Table 7
Knowledge gaps identified in recent research (2009–2016), which may hinder the success of restoration efforts. The topics are further discussed in Section 4.4.

Knowledge gaps	Paper examples
Phosphorus legacy and reuse	Cordell et al. (2011), Jarvie et al. (2013), Prem et al. (2015), Schulte et al. (2010), Surridge et al. (2012)
Sediment tracking	González-Sanchis et al. (2015), Horton et al. (2015), Poulsen et al. (2014), Smith and Blake (2014), Smith et al. (2014)
Land use impacts and conflicts	Alahuhta et al. (2010), Felipe-Lucia and Comín (2015), Ripl and Eiseltová (2009), Theodoropoulos et al. (2015), Wasson et al. (2010)
Water regulation and abstraction	Aspe et al. (2016), Bizzi et al. (2012), Graveline et al. (2012), Ibor et al. (2011), Ricart et al. (2016)
Climate change effects	Aspe et al. (2016), Dimitriou and Mentzafou (2016), Girard et al. (2015), Hein et al. (2016), Vernier et al. (2016)

4.1.3. Ecological: reporting ecosystem diversity

Agricultural stressors may have different impacts depending on the land management of each specific agricultural field (Power, 2010; Tamburini et al., 2016). For example, it is expected that elevated nutrient inputs will have higher impacts for streams in intensive, non buffered monocultures than in extensive and mixed culture fields (Withers et al., 2014). Thus, it is important that research spreads across multiple management options. In our review, 39.2% of the papers did not provide specifications regarding the agricultural type or management options related to the study. Additionally, 25.3% only provided generic descriptions such as “arable land” or “livestock grazing”. Evaluation of restoration projects would benefit from previous peer-reviewed studies providing further details.

During the planning phase of restoration projects, the availability of previous studies which relate to equal or similar situations presents an important source of guidance. However, without a clear description of the previously studied cases, managers may mistakenly apply measures which are inappropriate for a specific restoration project. Ultimately, this reduces the clarity of the project and may lead to undesired outcomes, and even ecosystem degradation, which may reduce stakeholder willingness and lessen the interest in integrative management solutions.

When practicing stream restoration, it is also important that researchers and managers find ways to efficiently report results to stakeholders in a simple and captivating way. The integration of bioindicators in water quality analysis provides an efficient form of knowledge transfer between scientists and stakeholders through the use of databases (Carone et al., 2009). Several reviewed papers used bioindicators to monitor streams and rivers (Carone et al., 2009; Johnson et al., 2009; Peters et al., 2013).

The most commonly used bioindicator groups in the reviewed papers coincide with the bioindicators requested by the WFD (e.g. macroinvertebrates, fish, riparian plants). Nevertheless, the inclusion of other groups which are currently less studied (such as aquatic birds or amphibians) may also be captivating for stakeholders, as they may increase the recreational value of the landscape.

4.1.4. Politico-demographic: the first WFD management cycle

The WFD implementation had a considerable impact on stakeholder engagement, as it requires active involvement of all interested parties (Blackstock et al., 2010; EC, 2000). By implementing challenging ecological goals, the WFD became a central part of recent research (two thirds of the reviewed papers refer to the WFD). Furthermore, the first management cycle granted researchers and managers the opportunity to understand which tools and approaches are necessary to interact with stakeholders in a constructive manner (Klauer et al., 2012).

Addressing the limitations reported during the first WFD cycle (Section 3.2.4) is crucial to ensure prolonged stakeholder interest and guide the development of the second planning cycle.

Connecting to the local community. One of the main pillars of the WFD is the involvement of the local stakeholders in the task of managing freshwater ecosystems. Furthermore, the inclusion of the community through participatory processes is likely to increase stakeholder willingness to change practices, thus contributing to improved policy compliance (Rouillard et al., 2014).

Although the WFD led to an increase in participatory processes associated with freshwater restoration, Benson et al. (2014) reports on situations where basin management still lacks an inherent integration of the community participation and interests. Recent research has explored the use of Decision-Support Systems and Choice-Experiment methods, which aim to facilitate the interactions amongst stakeholders and provide robust backup for decision making (e.g. García-Llorente et al., 2012 de Kok et al., 2009; Latinopoulos, 2009). Although these tools may provide valuable insight, it is also important to promote active inter-stakeholder discussions, aiming to reduce perception discrepancies and synchronise the community towards common goals (Rouillard et al., 2014). During the next WFD cycles, continuing to promote an early inclusion of stakeholders is crucial to obtain optimised restoration results.

Potential disregard of headwaters. The WFD aims, amongst other objectives, to prevent the deterioration and enhance/restore Bodies of Surface Water (BSW) to a good ecological condition or higher (EC, 2000). A BSW is defined as a “discrete and significant element of surface water such as a lake, a reservoir, a stream, river or canal, part of a stream, river or canal, a transitional water or a stretch of coastal water” (EC, 2000). According to the Common Implementation Strategy of the WFD, for a BSW to be considered for water quality management, its catchment area must be of at least 10 km^2 (EC, 2003). Lassaletta et al. (2010) highlighted that, although member states have autonomy to further refine the inclusion/exclusion of small streams, the criteria provided by the WFD may lead to the exclusion of headwaters which play a vital role in the basin's water quality. Furthermore, these excluded streams (non-BSW) may account for a large part of the hydrographic net (Fig. 8) and, therefore, failing to acknowledge them may prevent restoration efforts downstream from producing satisfactory results (Dodds and Oakes, 2008; Lassaletta et al., 2010).

On the particular subject of stakeholder management, this situation may be troublesome because it may reduce stakeholder interest and willingness to change practices on the upland areas of basins (i.e. in non-BSW). Furthermore, if measures targeted at BSW are rendered ineffective by upland stressors, stakeholder interest and commitment to restoration projects may diminish if it is perceived that there is no causality between eco-friendly practices and enhanced ecosystem services (i.e. expenditures are increased but there is no gain in return).

Ecologically meaningful restoration plans. Implementing multiple restoration measures is likely to simultaneously lead to economic gains and losses by stakeholders (e.g. optimise fertilisation plans or promote the development of buffer strips, respectively; Panagopoulos et al., 2012). Thus, stakeholders are likely to search for a compromise between increasing the ecosystem's condition and keeping economic losses to a minimum (Chantre et al., 2016). Basin

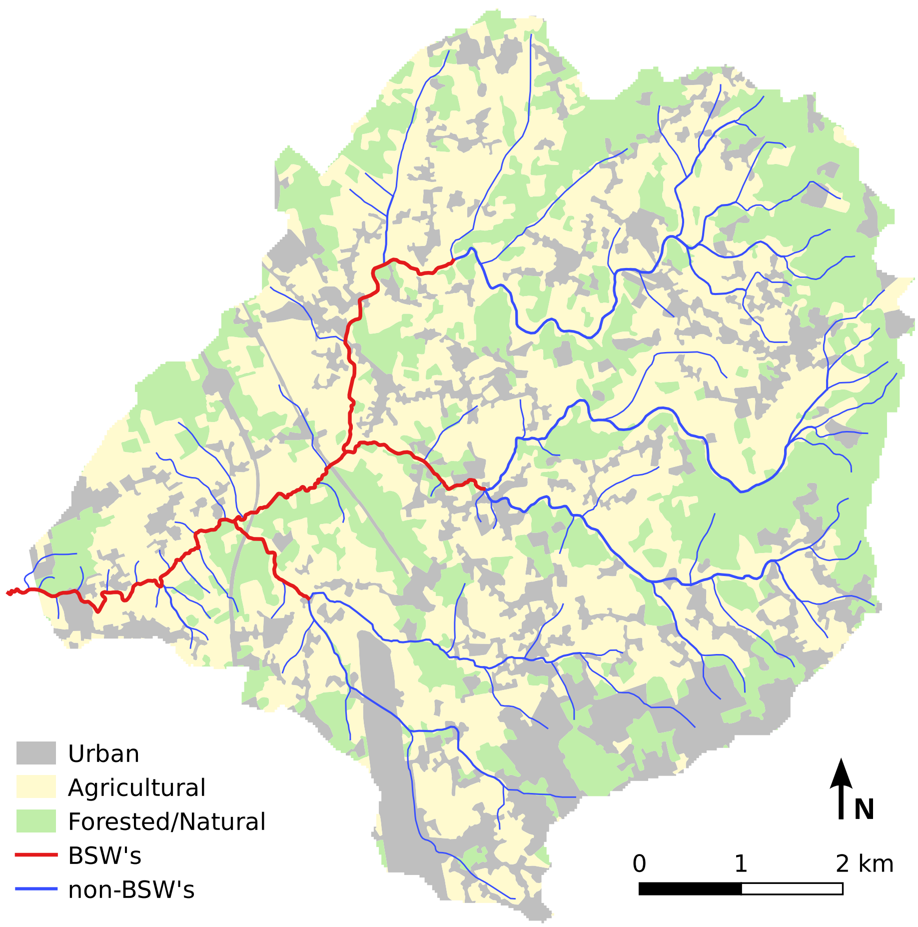

Fig. 8. The Water Framework Directive's measures apply only to Bodies of Surface Water (BSW). However, non-BSW may correspond to a large part of the hydrographic net, draining water from lands impacted by human activities. Restoration efforts targeted only at BSW may be ineffective if stressors exist further upstream, on non-BSW. The river Onda (Portugal) is shown as an example. Notice that non-BSW cross through areas used for agriculture and urbanisation.

managers and researchers must factor all these variables and find optimum solutions for each specific situation, providing the best ecological results while accounting for the importance of a high stakeholder interest and willingness (Vallée et al., 2015). For example, Bakopoulou et al. (2010) reported that Greek farmers are highly willing to use recycled water for irrigation in situations of fresh water deficit, which would potentially reduce water abstraction stress and decrease stakeholder water purchasing costs.

Nevertheless, such integrative solutions might not always be achievable, and measures easily acceptable for voluntary implementation might not be enough to achieve the desired ecological goals. In such situations, it is possible to adapt policies to include mandatory measures (e.g. fertilisation taxes; Trepel, 2016), which increase the legal pressure for stakeholders to change practices but may potentially reduce their willingness to participate in additional restoration programs. Alternatively, finding a compromise between agricultural exploration and ecosystem health may ensure the development of stable and resilient freshwater ecosystems that, albeit different from the natural, pre-disturbance state, still harbour increased biodiversity levels and deliver enhanced ecosystem services (Harabiš and Dolný, 2015; Hill et al., 2016; Rosenzweig, 2003).

Disproportionate costs. A limitation remains in understanding when is it that restoring a BSW to good ecological state should be considered "infeasible or disproportionately expensive" (sensu WFD; Del Saz-Salazar et al., 2009; EC, 2000; Klauer et al., 2016; Martin-Ortega et al., 2014). The ambiguity associated with the word "disproportionately" has been a subject of interest in multiple studies, which attempt to find a specific and reproducible way to apply this legal exception (e.g. Feuillette et al., 2016; Jensen et al., 2013; Klauer et al., 2016; Vinten et al., 2012).

While developing restoration plans, the difficulty in clearly defining policy regulations may contribute to stakeholder confusion (see Section 4.1.1). This may hinder the development of informed discussions between managers, researchers and stakeholders, and may ultimately lead to a decrease in stakeholder willingness to participate in restoration plans. Considering 1) the closure of the first WFD cycle, 2) the failed goal of achieving good water ecological quality by December 2015 and 3) the need to determine on which water bodies it will be necessary to aim for "less stringent environmental objectives", it is crucial to continue exploring and clarifying the issue of disproportionate costs.

Spreading research across Europe. In 2009, at the beginning of the first WFD management cycle, Stoate et al. (2009) pointed to the existence of a disparity between 1) EU countries with intensive agricultural management and high pollution rates but with extensive studies on ecological impacts and mitigation options and 2) EU countries with less farming intensification but also few studies on sustainable management or best management practices. Although the WFD's first cycle was a major milestone in increasing overall care for European freshwater ecosystems, the knowledge gap noticed by Stoate et al. (2009) is still perceivable amongst the results of our current review: the EU countries with highest representation in the selected papers are the United Kingdom, France, Denmark and Spain (combining up to 53.1% of the reviewed papers; Fig. 5). These potential imbalances need to be addressed, so that countries which have a developing agriculture may promote sustainable management solutions and avoid profound agricultural impacts on freshwater systems. Doing so is very important to promote a generalised increase in ecological state of surface waters across all EU territory.

4.2. Has the number of restoration projects reported per year in peer-reviewed literature increased since 2009?

The number of peer-reviewed papers describing recent restoration projects captured by our review was overall low (only 9 in total), with the total per year varying between 0 and 2 (Fig. 3). Nevertheless, a total of 22 papers revisited previous restoration works, indicating that, despite the low number of restoration papers captured by our review, restoration projects have been reported across the EU recently. Furthermore, online databases such as the RiverWiki (https://restorerivers.eu/) contain multiple non-peer-reviewed restoration reports. As noted by Finn and Ó uHallacháin (2012), many studies dedicated to evaluating the environmental effectiveness of restoration projects are only available in reports, theses or conference documents, and thus may not reach a wider public.

In the process of implementing integrative water management, learning from previous restoration studies is very important to avoid mistake repetition. Indeed, restoration projects do not always turn out as expected, as was the case of the Rhône project (Table 5). This may happen either by design constraints or due to considerable side effects (Bergfur et al., 2012; Hoffmann et al., 2011; Muller et al., 2016; Schirmer et al., 2014; Simaika et al., 2015). The re-establishment of ecosystem processes as a result of restoration measures after years of anthropogenic impacts may take several decades (Audet et al., 2015; Glendell et al., 2014; Smith et al., 2014). Insufficiently long post restoration monitoring programmes may not detect these improvements, negatively influencing the reported success of restoration measures (Braukmann et al., 2010).

There is an urgent need for increasing the number of peer-reviewed studies evaluating restoration projects throughout the EU. We recommend additional peer-reviewed evaluation efforts including data from 1) reports, theses and conference documents made available for scrutiny, 2) online river restoration databases, 3) funding bodies requiring evaluation as part of key restoration projects and 4) funding bodies allocating funds for evaluating restoration projects. A combination of such efforts would bring together restoration experiences from multiple sources, leading to EU wide developments of best practice documents to ensure economically efficient and successful restoration projects.

Importantly, previous restoration experiences may improve collaboration with stakeholders. Evaluating previous works often allows managers and researchers to 1) learn how to organise stakeholder cooperation and avoid potential conflicts, 2) identify ecosystem services which may be of greater interest for stakeholders, 3) develop informed restoration measures that are more likely to succeed and 4) clearly estimate at which time frames restoration results should be expected (Bergfur et al., 2012; Finn and Ó uHallacháin, 2012; Grand-Clement et al., 2013; Gumiero et al., 2013). Accounting for such elements often reduces stakeholder confusion and promotes informed discussions, therefore helping to increase stakeholder interest and willingness. For example, Guerrin (2015) analysed a restoration attempt on the river Rhône (which aimed to prevent flooding damage) and described how difficulties such as poor communication, lack of organisation and inappropriate stakeholder empowering may lead to project failure.

Recent papers exploring successful implementation of restoration programs in diverse areas promote 1) the understanding of how (and if) stakeholders value ecosystem functions and services and 2) the development of future win-win solutions (Aggestam, 2014; Gonzaléz del Tánago et al., 2012).

4.3. Is recent agriculture-related research spreading across multiple topics of interest for freshwater restoration?

The results show considerable yearly fluctuations in the percentage of papers targeting each topic (Table 6). This may also be detected by peaks in Fig. 2 (e.g. nitrogen- and phosphorus-related research corresponded to a high percentage in 2012; stakeholder-related research decreased in 2011 and 2015). Nevertheless, except fish migration, all the topics targeted by the search string were present in recent European research captured by our review (Fig. 2).

Interestingly, apart from water abstraction, pesticides and sediments (where the first paper detected is from 2010, 2010 and 2011, respectively), all other topics are present from the beginning of the studied time interval (yearly data not shown). This indicates that research covered multiple fields since the beginning of the first WFD cycle.

Despite an apparent increase in the number of papers published per year, the proportion of papers targeting each topic does not appear to be shifting, which leads to an overall dominance of nutrient-related research (Fig. 2).

The availability of abundant knowledge on multiple topics is important to guide current and future policies that play an important role in shaping farmers' habits. For example, the Common Agricultural Policy's new "Greening" subsidies require eco-friendly practices and may account for up to 30% of the total value granted to a farmer. Such rules promote a direct shift to eco-friendlier practices by farmers and, if complemented with an increase in participatory processes and integrative basin management schemes, may pave the way for an overall shift of stakeholders' perceptions towards nature's values.

4.4. Which knowledge gaps may undermine restoration projects?

The reviewing process identified uncertainties that may reduce the effectiveness of restoration measures and, consequently, lead to stakeholder interest decrease. Therefore, it is important that managers and researchers carefully assess the multiple interactions between stressors and the target ecosystem. Here, we briefly explore the knowledge gaps detected in Section 3.3.3.

Phosphorus legacy, an inherited problem

The issue of P legacy is a major constraint for ecosystem restoration. This legacy is the result of past practices and has led to the saturation of ecosystem compartments such as soil particles in many areas (Jarvie et al., 2013; Moreno-Mateos et al., 2010). This leads to a potentially unstable equilibrium where a shift in environmental conditions can cause the release of high amounts of P, for example by soil erosion or changes in redox conditions (Hoffmann et al., 2012; Meissner et al., 2010; Prem et al., 2015; Surridge et al., 2012).

Restoration efforts tend to produce few results whenever there is a pool of legacy P present, and might even worsen the ecological state due to the fact that restoring involves disturbing the existing ecosystem balance (Jarvie et al., 2013; Moreno-Mateos et al., 2010). However, depleting the legacy P pool by sustainable means (e.g. phytoremediation) may take anywhere between 15 to 60 years (Audet et al., 2015; Hoffmann et al., 2012; Schulte et al., 2010), a time interval that is not easily accepted by decision makers and public demands.

Identifying local situations of phosphorus saturation in early development phases of restoration projects enables managers and researchers to 1) avoid possible ecosystem degradation and 2) carefully addressing and discussing the matter with stakeholders. Promoting an informed discussion towards possible solutions and expected time-frames may prevent or diminish future conflicts with or amongst stakeholders.

Tracking sediments to the source

Excess sediments may have a great impact on freshwater systems, partly because these small particles may directly interfere with the fractal nature of the riverbed (Gabriele et al., 2013). By clogging the interstitial spaces, fine sediments can hinder the hyporheic exchanges (Teufl et al., 2013) and prevent the formation of microhabitats that are essential for the stream fauna (Bae et al., 2016; Harshbarger and Porter, 1982; Stockan et al., 2014).

However, since sediment sources are located upstream from the impacted areas, stakeholders may not perceive their role as significant. Recent modelling efforts have been applied to better understand sediment deposition patterns (Poulsen et al., 2014) and to prioritise restoration targets. Based on knowledge about geochemical behaviours (both in the soil and water), recent sediment source fingerprinting techniques have been applied to trace impacts back to the sources (Stockan et al., 2014). The use of such modelling tools may go a long way in reducing discrepancies between managers' and stakeholders' perspectives. Guaranteeing that stakeholders perceive the full potential of management options is crucial for the development of successful restoration plans.

Effects of land use and configuration

Land use changes may have profound impacts on the ecosystems, such as increasing runoff speed and reducing native vegetation cover (Allan, 2004; Cooper et al., 2013). Furthermore, these changes may lead to multiple stakeholder disputes (e.g. over uncommon resources or property rights; Brown and Raymond, 2014) and also management conflicts between land use and land aptitude (Pacheco and Sanches Fernandes, 2016). For example, agricultural fields may be implemented on soils which are prone to erosion, leading to an increase in nutrient leaching and soil loss (Pacheco and Sanches Fernandes, 2016; Valle Junior et al., 2015).

The configuration of different land uses in the landscape has also proven likely to affect freshwater ecosystems (Davies et al., 2009; Ding et al., 2016; Teels et al., 2006). However, as the impacts on a given land are determined by a multitude of factors (e.g. management options, abiotic conditions; Glendell et al., 2014; Mossman et al., 2015; Theodoropoulos et al., 2015; Wasson et al., 2010), linking ecosystem responses with the landscape use may prove challenging (Ding et al., 2016; Thackway and Specht, 2015). For example, Uuemaa et al. (2005) indicate that landscapes with a higher edge density (i.e. multiple land use patches) present lower nutrient and organic material losses, while Lee et al. (2009) suggests that landscapes with larger, aggregated land uses (i.e. lower edge density) may perform better at retaining pollutants.

When planning restoration projects, it is important that large scale interactions are clearly explained to stakeholders. Promoting amongst stakeholders the concept that some landscape-scale interactions are hard to disentangle and predict and that land uses may have diverse effects on freshwater ecosystems may prevent stakeholder backlash in situations where the affected services are less noticeable by stakeholders. Thus, early inclusion of stakeholders in restoration projects, such as in the Tarland initiative (Fig. 7), is likely to increase stakeholder knowledge. As explained in Section 4.1.1, describing the importance of less noticeable ecosystem services is likely to increase stakeholder willingness to opt for integrative solutions.

Water regulation and abstraction

Water regulation and abstraction are well known factors severely impacting lotic ecosystems, because they change the water flow profile of the stream (Abril et al., 2015; Arenas-Sánchez et al., 2016; Duponchelle et al., 2016; Piper et al., 2015; Pyne and Poff, 2016; Svendsen et al., 2010). However, agricultural activities may include water abstraction for irrigation and damming to provide pools for irrigation (Brummett et al., 2013), which may lead to stakeholder conflicts in restoration projects (Davis et al., 2015; Lange et al., 2014).

When presented with situations of water flow connectivity disruption (e.g. by changes in water levels or flow patterns), it is important that managers and researchers are able to 1) identify the ecosystem components being impacted (e.g. sediment transport, fish migration and spawning), 2) clearly explain these impacts to stakeholders and 3) demonstrate the importance of lost services (e.g. fish migration and spawning are important for fishing activities).

Nevertheless, the availability of water is crucial for optimised agricultural yields and, thus, finding solutions which allow the restoration of previously disrupted ecosystem services without loss of water storage services is very important to promote stakeholder interest and willingness to change.

One potential integrative solution is the creation of wetlands across the hydrographic network (Jensen et al., 2015; Koed et al., 2006; Poulsen et al., 2012), because wetlands maintain water reserves while reducing the need for more intrusive water barriers. However, if planned incorrectly, these natural lentic ecosystems might still weaken the river continuum and, therefore, prevent restoration objectives from fully being accomplished (Braukmann et al., 2010; Koed et al., 2006).

There is rarely a technical solution eliminating all ecosystem effects of transforming a lotic habitat into a lentic habitat (Pelicice et al., 2015). Furthermore, different groups of stakeholders are likely to have different perceptions about the effects of water regulation and abstraction (e.g. local farmers and fishermen). Therefore, working towards 1) finding solutions that reconcile the agricultural needs with the remaining ecosystem services and 2) clearly explaining these solutions to stakeholders is crucial to increase the willingness to adopt integrative management solutions.

Adapting to climate change

Nowadays, it is recognised that European agriculture will be considerably affected by climatic change (Kahil et al., 2015; Long et al., 2016), with Dono et al. (2016) indicating that, as soon as in the next decade (2020–2030), adapting agricultural management to face new climatic conditions will be necessary.

The effects of climate variation on agricultural production have been widely studied (e.g. decreased water availability, reduced crop yields, vulnerability to pests; Dono et al., 2016; Iglesias and Garrote, 2015; Olesen et al., 2011; Pulatov et al., 2015). To further aggravate these concerns, with the rising human population, food production must increase considerably in years to come (Elliott et al., 2014; Kahil et al., 2015; Long et al., 2016). Climate change may also impact agriculture by increasing the number and extent of wildfires. Such events may directly lead to crop destruction and, indirectly, hinder farming practicability by severely changing soil N and P contents and polluting freshwater reservoirs (i.e. due to leaching on subsequent rainfalls; Santos et al., 2015a,b). Ultimately, such changes may lead to stakeholder conflicts that should be carefully addressed.

Adapting to climate change will likely require policy efforts at different levels, including measures such as improving integrative water management or increasing the number of water reservoirs (Iglesias and Garrote, 2015). Increasing intra-regional farming diversity may also support farming resilience and complementarity (Dono et al., 2016; Kahil et al., 2015; Leclère et al., 2013). An interesting initiative to prepare agriculture for changing climate conditions is the "Climate-Smart Agriculture"(CSA), proposed by the Food and Agriculture Organization of the United Nations (FAO, 2013). However, in their work on the adoption of CSA-related technologies in some European countries, Long et al. (2016) found that a lack of consumer demand for products with lower environmental impacts, together with reported policy and cost barriers, could considerably reduce the uptake of measures by farmers.

Continuing research on the impacts of novel strategies (designed to cope with climate change under multiple management scenarios) might prove essential to backup management decisions. Moreover, further refining international and regional policies may also allow a broader adoption of more resilient agricultural practices. Importantly, it is necessary to assure that, with the growing pressures for an increased agricultural production, managers maintain focus on the need to successfully integrate multiple ecosystem uses in Europe's freshwater ecosystems.

5. Conclusion

Stakeholder management is a central topic in recent European literature. Nevertheless, it remains difficult to consensualize concepts, perceptions and decisions amongst managers, researchers and stakeholders. This is reflected in the difficulty to restructure catchment land uses, setting viable restoration goals and guaranteeing long-term stakeholder interest and willingness to opt for integrative management solutions. Land owners often consider their negative contribution insignificant and therefore believe that a change of agricultural practices (e.g. better control of fertiliser or pesticide application) is unnecessary. Basin managers and researchers must target all stakeholder groups and promote the dissemination of information on topics such as 1) how ecological relationships develop at catchment scales, 2) how the natural dynamics of freshwater systems are necessary to assure the health of these ecosystems and 3) how these healthy and balanced ecosystems (with enhanced ecosystem service provision) benefit the local community (e.g. flood prevention, erosion control, recreational fishing). Promoting informed discussions and reducing perception discrepancies may go a long way in resolving stakeholder conflicts, greatly increasing restoration efforts' probability of success.

Although a considerable amount of restoration reports would be expected during the implementation of the WFD's first cycle, only a limited amount was captured by our search for peer-reviewed examples.

Whilst the literature search and selection process endeavoured to capture a representative portion of recent research and restoration efforts being developed across Europe, we acknowledge that the review may be subject to limitations due to the inclusion of only peer-reviewed studies. Important online databases such as the RESTORE project and associated River Wiki or the European Centre for River Restoration (ECRR) represent valuable sources of restoration-related information which are easily assessable by both river managers and stakeholders. Nevertheless, the publishing and validation of restoration-related research through the process of peer review is of high importance to guarantee high quality information to steer future restoration efforts.

The availability of multiple restoration project reports in peer-reviewed literature is crucial to explore new methodologies and assure the future development and dissemination of well-informed, science-based restoration strategies and management decisions. This is important because restoration efforts often have direct consequences on species extinctions and provision of ecosystem services, as highlighted by Diefenderfer et al. (2016). A multidisciplinary approach often provides a better understanding of the ecosystem and helps preventing less desirable outcomes due to unforeseen constraints (e.g. migratory barriers).

The WFD has been a major milestone in raising awareness to the need of restoring Europe's rivers, but its application during the first management cycle was not without limitations. The deadline to have all rivers in good ecological state by 2015 failed. Expecting unrealistic restoration speeds, setting unprotective concentration thresholds or the difficulty to connect with the local communities were some of the reasons given to explain this failure. However, the WFD also opened way for a new mentality and, during future management cycles, working towards achieving a good ecological status for Europe's freshwater systems remains a priority.

During the coming WFD management cycles, it is crucial that basin managers continue to improve the communication and understanding between local communities, decision makers and researchers in order to produce and implement integrative management plans.

It is also important to closely address different farmer groups within a catchment, as well as continuing to progress towards better structured and informed policy messages. Working towards delivering integrative environmental education may play an important role in sensitising stakeholders and mitigating perception discrepancies.

Ultimately, successful restoration cases highlight the possibility to continue restoring European streams and rivers, allowing the provision of enhanced ecosystem services throughout the territory and successfully reconciling anthropogenic uses (such as agriculture) with the presence of healthy and diverse freshwater ecosystems.

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