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Riparian research and legislation, are they working towards the same common goals? A UK case study

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Abstract

The value of riparian areas has long been recognised due to their contribution in supporting wildlife diversity and their capacity to deliver a wide range of ecosystem services. Their multiple uses (e.g. flood prevention, biodiversity, pollutant attenuation) combined with an inconsistent use of terminology (e.g. river bank, floodplain, wetland, buffer strip), however, has led to the development of fragmented policies associated with riparian areas. This review brings together current EU and UK legislation alongside research publications focused on riparian areas. We critically evaluate the current legislative framework relating to riparian areas and identify key scientific knowledge gaps which need to be addressed to support future decision-making. Our findings revealed several major problems associated with riparian policy and management, including: (i) the fragmented nature of legislation concerning riparian areas; (ii) the presence of redundant policy instruments, (iii) a lack of practical objectives, (iv) contradictory measures, and (v) unachievable targets. Further, our results suggest that most research is focused on agricultural systems and single ecosystem attributes or functions, rather than supporting an ecosystem-service approach that is widely aspired to in policy statements. We recommend that future research could better support riparian protection policies by focusing less on what the different ecosystems 'are', and more on what they can 'offer' by way of multiple benefits.

Keywords: Ecosystem services; freshwater protection; Riparian management; buffer strip, multiple benefits, river restoration

1. Introduction

The value of riparian areas has long been recognised due to their abundant vegetation, ability to support wildlife diversity and capacity to provide a range of ecosystem services (Hawes and Smith, 2005; Clerici et al., 2011; Aguiar et al., 2015). The riparian zone was first described a century ago (Clements, 1905) and its definition has been continually evolving as our understanding of different ecological and hydrological processes has improved (Baker, 2004; Verry et al., 2004). Historically, they have been the subject of numerous legal conflicts over water rights, partly because there has been no consensus about their delineation and the challenges faced by different owners and water users (Fischer et al., 2001).

There have been many attempts to improve the way that riparian zones are managed and regulated to provide multiple simultaneous benefits (e.g. biodiversity, flood control, cultural services). Furthermore, the growing demand for water, the decline in water quality due to agricultural intensification and industrial pollution, the increasing abstraction for domestic and industrial use and the modification of watercourses over the last 200 years (UK NEA, 2011; Broetto et al., 2017), have made protection of riparian zones increasingly important.

National and regional UK regulations established that riparian landowners (i.e. any landowner whose property is adjoined, above or with a watercourse running through it; NRW, 2017) are ultimately responsible for preserving and managing the riparian zone in collaboration with local organizations. However, inconsistent use of terminology and fragmented policies around riparian areas make it difficult to identify which specific management applications are effective under different scenarios, particularly regarding prevention of land degradation.

Efforts to engage and collaborate with key stakeholders, especially farmers, have been encouraged through European Union (EU) legislation and national initiatives to ensure farming strategies contribute to the sustainable management of riparian areas. It has been found that clear and targeted support is required to assist farmers to develop a focus on conservation and broader sustainability alongside agricultural production (Kaine et al., 2017). This requires policy-makers to appreciate the tight financial situation that farmers usually operate within and make up for the fact that riparian areas provide services that are not directly traded in markets (Orr and Colby, 2004). Key to the success of agri-environment schemes is to have farmer input into their design. Ahnström et al. (2009) highlighted that the lack of integration of "farmers' perceptions and knowledge of nature" in the design of agri-environment schemes was a major problem that needs addressing.

Another major issue is the lack of dialogue between scientists and policy-makers which has resulted in the popular perception that policies lack an evidence base, with both parties often in disagreement with each other (Sutherland et al., 2004, 2006). Therefore, identifying knowledge gaps between scientists and policy-makers and understanding the way information is exchanged has become an essential task in the design of effective legislation.

The impending departure of the UK from the EU, through which much of the legislation and initiatives protecting our environment have derived, highlights the need for careful consideration of alternatives and the development of strong new policies that set a clear direction. Recently, the EU has set an ambitious target of which UK is a signatory country, to halt biodiversity decline and to ensure well-functioning of ecosystems to provide essential services to people by 2020 (Maes et al., 2016). Although a considerable effort has been made in recent decades to stop further ecosystem decline in the UK (i.e. increase of 12.9 million ha of protected areas from 2012 to 2017; Defra and JNCC, 2017), recent reports do not suggest a positive picture of the current state of biodiversity. For example, the recent publication of the 'Biodiversity Intactness Index', which is an indicator of how intact a country's biodiversity is, places the UK in the 29th lowest position out of 218 countries assessed (Scholes and Biggs, 2005; Hayhow et al., 2016). Regarding riparian areas, one of the most diverse and valuable ecosystems in terms of services to people, there is evidence that suggests that disturbance factors such as anthropogenic activities (i.e. land use changes, pollution), changes in hydrological regimes or invasion of non-native species, have heavily degraded and made them less resilient and more prone to further degradation (González del Tánago and García de Jalón, 2006; Dudgeon et al., 2006; Sinnadurai et al., 2016). Therefore, scientific research could greatly assist in identifiying driving factors of riparian degradation and guiding new policy instruments to develop the most effective restoration strategies (Maltby et al., 2013).

This paper brings together legislation and associated regulations and guidance relative to riparian areas from the EU and the UK with the aim to determine how current conservation efforts can be improved and to guide the development of new strategies. Additionally, we conduct a comprehensive analysis of scientific publications focused on riparian areas within the UK, in order to identify scientific gaps that will likely need to be addressed to support future decision-making.

2. Methods

2.1. Literature review of legislation

Sources from the EU and the UK were used to evaluate the most recent legislation either directly or indirectly related to riparian areas. We acknowledge that there is a vast body of legislation applicable to riparian areas which may not be presented in this study, however, our aim was to present a general legislative framework highlighting the most important actions. Four areas of particular legislative importance were identified: i) biodiversity, as riparian areas are considered one of the most diverse and priority habitat types as expressed in national biodiversity strategies (Clerici et al., 2011; Forestry Comission, 2017); ii) nutrients and water quality as riparian zones can help control non-point pollutant sources in freshwaters (Jontos, 2004; Aguiar et al., 2015); iii) water dynamics and modelling due to riparian areas potentially modifying natural flow regimes, thus altering biotic communities, river systems and their associated floodplain (McKay and King, 2006); and iv) future outlook, current status and impacts (e.g. influence of climate change on riparian dynamics) (Seavy et al., 2009). We also considered riparian guidance and best management practices as they usually refer to certain binding actions required by public organisations to qualify for Common Agricultural Policy (CAP) payments.

2.2. Literature review of scientific research

Three major scientific search engines (i.e. Web of Science, Science Direct and Jstor) were used to locate scientific publications with 'riparian' or 'buffer strip' and 'UK' as keywords. The search was refined according to each engine's advanced search options (Table S1). Firstly, we classified publications according to their country of origin to identify any trends in the geographical focus of riparian studies. A paper was included in the category 'UK' if it addressed different regions of UK or covered broad topics such as reviews or habitat surveys. Additionally, publications were divided with respect to the dominant land cover on which the research was based. The UK NEA Broad Habitat categories (UK NEA, 2011) were used as a classification framework for the different land cover types described in each publication. A detailed description of the broad habitat types considered here is provided in Table S2. Two additional categories ('Contrasting land cover' and 'General') were added to encompass studies conducted across multiple habitat types and studies that by the nature of the research could not be included within any specific habitat category (i.e. general reviews, models, studies on specific species).

Secondly, the publications were grouped into four thematic categories according to their subject matter (paralleling those used for the legislative review). In addition, subcategories were added to these to provide a further level of detail (Table 1). It should be noted that some publications covered more than one category.

Table 1. Main categories and subcategories used to itemize the publications relating to riparian areas within the UK.

Category	Subcategory
1. Biodiversity	1.1. Ecology 1.2. Vegetation
2. Nutrients and water quality	2.1. Riparian buffer strips 2.2. Nonpoint of diffuse (NPD) pollution 2.3. Denitrification 2.4. Shading
3. Water dynamics and modelling	3.1. Modelling of riparian interactions with abiotic parameters (i.e. geology, climate, hydrology, vegetation). 3.2. Hydrological dynamics and interactions with groundwater
4. Future outlook and impacts	4.1. Land use change and restoration 4.2. Climate change 4.3. River and habitat survey

3. Results and discussion

3.1. Legislative review

Riparian regulation covered a broad range of disciplines as it is influenced by both terrestrial and aquatic regulations. At a European scale, the legal framework concerning riparian areas is built via a number of mechanisms such as strategies, directives and regulations (Table S23, see also supplementary information for key legislative concepts). However, although these pieces of legislation normally establish the goals that all EU countries must achieve, they do not usually include mandatory and standardised measures, leaving the way goals are incorporated into national legislation up to each Member State. For example, Regulation (EU) No 1307/2013 stipulates the creation of buffer strips along watercourses but leaves the decision of the buffer width to the discretion of each Member State. Another similar example is the specific requirement for buffer strips according to the Nitrates Directive

(91/676/EEC) if the land is included inside National Vulnerable Zones (NVZs) defined by Member States. Further, the introduction of the EU Water Framework Directive (WFD) greatly encouraged the study of riparian areas as they were identified as key elements involved in the determination of good ecological status of water bodies. Thus, a broad range of methods to evaluate riparian conditions and their main physical features came into being (González del Tánago and García de Jalón, 2006). However, the most recent legislation relating to environmental issues, seems to be switching the emphasis towards a more functional side of ecosystems requiring an assessment and mapping of physical attributes but relating them with the multiple services they provide and their interactions with adjacent ecosystems. Hence, it is now possible to create conceptual models which allow ecosystem services to be linked to human wellbeing (Maes et al., 2016). However, it is worth noting that while the regulatory system encourages the uptake of a multidisciplinary ecosystem services-based approach, the legislative information is supplied by fragmented policies spread across over different issues and sectors (e.g. biodiversity, flooding, Table S23)

Table 2. Compilation of legislation affecting riparian areas both directly and indirectly in a European, national (UK) and regional (England, Scotland, Wales,

Legislation name	Scope of application	Year	Objective	Type	Action applied by
1. Biodiversity					
Council Directive 92/43/EEC	Europe	1992	• Protecting natural habitat both terrestrial and aquatic. • Designation of Special Areas of Conservation (SAC) of sites selected (Annex I habitat) (Annex II species). • Creation of Natura 2000 as a network of special areas of conservation.	Directive	Member States
EU Biodiversity Strategy to 2020	Europe	2015	• Target 1. Reinforce the implementation of Natural 2000. • Target 2. Maintenance of ecosystem services. Map and evaluate the status of ecosystems along with their economic value. • Cross-compliance, which includes Statutory Management Requirements and Good Agricultural and Environmental Condition.	Strategy	Member States
Environment (Wales) Act	Regional (Wales)	2016	• Duty on conserve biodiversity and enhancing the resilience of ecosystems and the benefits they provide. • UK Biodiversity Action Plan (UK BAP) which entails the creation of a list of priority habitats. • Greenhouse emissions (CO_2, N_2O) at least 80% lower than the baseline year (1990).	Act	Natural Resources Wales Local and regional authorities
The Natural Environment and Rural Communities (NERC) Act	Regional (England)	2006	• General duty on all public bodies office-holders to conserve biodiversity which includes restoring or enhancing a population or habitat. • UK Biodiversity Action Plan (UK BAP) which entails the creation of a list of priority habitats. • Providing codes of practice to offer recommendations, advice and information on how to stop the damage caused by non-native animals and plants.	Act	Environment Agency Local and regional authorities
Nature Conservation Act 2004	Regional (Scotland)	2004	• General duty on all public bodies to conserve biodiversity which includes restoring or enhancing a population or habitat. • UK Biodiversity Action Plan (UK BAP) which entails the creation of a list of priority habitats. • Duty to give notification of sites of special interest.	Act	Scottish Environment Protection Agency Local and regional authorities
Wildlife and Natural Environment Act 2011	Regional (Northern Ireland)	2011	• General duty on all public bodies to conserve biodiversity which includes restoring or enhancing a population or habitat. • UK Biodiversity Action Plan (UK BAP) which entails the creation of a list of priority habitats. • Power of wildlife inspector to examine specimens and take samples if there is evidence of a relevant offence against biodiversity.	Act	Northern Ireland environment agency Local and regional authorities

Northern Ireland) scale.

Legislation name	Scope of application	Year	Objective	Type	Action applied by
2. Nutrients and water quality					
Nitrates Directive (91/676/EEC)	Europe	1991	• Halting water pollution, specifically nitrates, through the use of good farming practices that can be either voluntary or compulsory in NVZs. • Designate Nitrate Vulnerable Zones" (NVZs). • National monitoring and reporting.	Directive	Member States
Directive 2000/60/EC (Water Framework Directive (WFD))	Europe	2000	• Assessing river and riverine habitats ecological conditions. • Establishing river basin management plan (RBMP) tool to guaranteeing that the highest ecological and chemical status possible is achieved. • Monitoring programs to check the river status.	Directive	Member States
Regulation (EU) No 1307/2013	Europe	2013	• Common rules for direct support schemes for farmers under the Common Agricultural Policy (CAP) (Title III). • Management of landscape features (riparian woody vegetation). • Buffer strips along the watercourse (Annex IX) but without define a width.	Regulation	Member States
Water Abstraction and Impoundment (Licensing)	Regional (Northern Ireland)	2006	• The abstraction of less than 10 m^3 of water in any one day.	Regulation	Northern Ireland Environment Agency Landowner
The Water Environment (Controlled Activities)	Regional (Scotland)	2011	• General Binding Rule 2. Limitation of river water abstraction of less than 10 m^3 of water in any one day. • General Binding Rule 19. Prevention of significant erosion or poaching of land within 5 m of any surface water or wetland. • General Binding Rule 20. It stablishes a buffer strip at least 2 m wide to be left between surface waters and wetlands and cultivated land.	Regulation	Scottish Environment Protection Agency Landowner
The Environmental Permitting	Regional (England and Wales)	2016	• The erection of fencing is not located on the bed or banks from the river. • The repair and protection of main river banks using natural materials if the length of the bank is not more than 10 m and other circumstances expose in article 13.2. • Construction of bankside wildlife refuge structures.	Regulation	Natural Resources Wales Environment Agency Landowner

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Legislation name	Scope of application	Year	Objective	Type	Action applied by
2. Nutrients and water quality					
Basic Payment Scheme (BPS)	Regional (general)	2016/ 2017	• Statutory Management Requirements (SMR) 1. Nitrate Vulnerable Zones (NVZs). • Good Agricultural and Environmental Condition (GAEC) 1. Water-Establishment of buffer strips (minimum of 2 m). • GAEC 5. Soil and carbon stock. Monitoring excessive bank erosion alongside watercourses where livestock have access.	Scheme	Natural Resources Wales Environment Agency Scottish Environment Protection Agency Northern Ireland environment agency Landowner
Other schemes Glastir	Regional (Wales)	2016	• Commitment to cross-compliance (Basic Payment Scheme). • Commitment to the Whole Farm Code (WFC). • Paid management options: buffer to control erosion and rough grass buffer zone.	Agri-environment scheme	Natural Resources Wales Landowner
3. Water dynamics and management					
Directive 2007/60/EC	Europe	2007	• Identifying the river basins and associated coastal areas at risk of flooding. • Elaborating flood risk maps and establish flood risk management plans focused on prevention, protection and preparedness. • Monitoring programs to check river status.	Directive	Member States
Land Drainage Act	National (UK)	1991	• Regulating land drainage and water abstraction. • Creation of Internal Drainage Boards (IDB) to maintain water levels and secure the provision of water. • Securing flood protection.	Act	Natural Resources Wales Environment Agency Scottish Environment Protection Agency Northern Ireland environment agency
The Water Environment (Floods Directive) Regulations	Regional (Northern Ireland)	2009	• Development of flood risk map of protected areas which potentially could be affected if any flood scenario. • Identifying the flood extent and flood conveyance routes and areas which have the potential to retain flood water such as natural flood plains. • Assessing natural features (for example flood plains, wetlands or woodlands) which can assist in the retention of water.	Regulation	Northern Ireland environment agency
Flood Risk Management Act 2009	Regional (Scotland)	2009	• Creation of flood risk assessment, maps and plans at a proper scale specifying land and water management actions. • Considering measures to manage flood water by altering (including enhancing) or restoring natural features and characteristics. • Local flood risk management plan to supplement the relevant flood risk management plan	Act	Scottish Water Local authorities

Legislation name	Scope of application	Year	Objective	Type	Action applied by
3. Water dynamics and management					
Flood and Water Management Act 2010	Regional (England and Wales)	2010	• Creation of a strategy for flood and coastal erosion risk management in England and Wales. • Enhancing the constitution of local flood authorities. • Assessing flood risk from surface runoff, groundwater and ordinary watercourses.	Act	Natural Resources Wales Environment Agency Local authorities
River Basin Plan Management (specific for each River Basin District (RBD))	Local (RBD, general)	2015/ 2016	• Monitoring rivers water ecological status. • Manage ecosystem services at the most appropriate scale. • Commitment of engaging and promoting collaboration with stakeholders, including local authorities, communities, developers and industry.	Strategic documents	Natural Resources Wales Environment Agency Scottish Environment Protection Agency Northern Ireland environment agency RBD
4. Future outlook and impacts					
Paris agreement on climate change	Global	2016	• Limit the amount of greenhouse gases emitted by human activity to the same levels that trees, soil and oceans can absorb naturally. • Keeping average warming below 2°C. • Establishing a global goal of "enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change".	Treaty	Parties to the Convention
Climate change Act	National (UK)	2008	• Reducing emissions from the devolved administrations (Scotland, Wales and Northern Ireland) by at least 80% of 1990 levels by 2050. • Legally binding 'carbon budgets' set by the UK Government.	Act	Regional governments
Wales passed the Environment (Wales) Act	Local (Wales)	2016	• Sustainable management of natural resources (e.g. air, water, soil, geological and physiographical features and processes). • Enhancing a biodiverse natural environment with healthy functioning ecosystems. • Assessing and reporting diversity between and within ecosystems as well as their conditions and connections.	Act	Welsh Ministers Natural Resources Wales Local authorities
The Climate Change Act	Regional (Scotland)	2000	• Commitment of a 56% of reduction of greenhouse emissions by 2020. • Creation of programmes for adaptation to climate change giving clear objectives to enhance resilience of the system. • Duty to produce a land use strategy where sustainable objectives are indicated.	Act	Scottish Environment Protection Agency

Together with EU legislation, UK legislation (primary and secondary legislation or subordinate legislation), as well as common law, also support riparian regulatory processes. In the case of environmental issues, this is largely the responsibility for devolved administrations within different parts of the UK. Therefore, each nation is responsible for setting their own policies and providing incentives as well as designating public bodies (e.g. The Environmental Agency in England or NRW in Wales) to ensure the delivery of measures agreed by each Government for the protection and enhancement of the environment. Although legislation related to riparian areas follows a common framework between the different parts of the UK, there are clear regional differences in policy (House of Lords, 2017). For example, Wales has set its own targets with respect to climate change mitigation, while Scotland explicitly specified binding rules within it's Water Environment Regulation to limit specific activities from taking place within riparian areas.

Based on the legislative information gathered, riparian legislation within the UK seems to be more incentivised (through the use of different agri-environment schemes and good management practices) rather than by enforcement. The Basic Payment Scheme (BPS) or specific documents provided by each nation (e.g. 'A guide to your rights and responsibilities of riverside ownership in Wales'; NRW, 2017) provide specific binding actions (cross-compliance measures) that the landowner is required to follow in order to benefit from direct payment schemes.

Most of the EU and UK-based policies reviewed here address the protection of riparian areas in two ways: i) limiting activities that can be undertaken within the riparian buffer zone, e.g. limiting fertilizer application (2 m from the edge of the river) (Nitrates Directive 91/676/EEC) or limiting water abstraction from rivers and lakes to <20 m^3 day^{-1} (Land Drainage Act, 1994), or ii) monitoring, mapping and evaluating the ecological and chemical status of riparian zones and adjacent ecosystems. Examples of initiatives that include monitoring programs are the WFD (2000), Nitrates Directive (1991), EU Biodiversity Strategy (2020) and River Basin Plan Management (RBPM).~~ They seek to ensure the sustainable management through effective monitoring and reviewing actions implemented by the Member States to achieve the wider objectives of other EU Directives.~~ In recent years, 70% of the measures adopted to address the environmental pressures of agriculture involved the establishment of riparian buffer strips funded via agri-environmental payment schemes (Dworak et al., 2009) . For example, the European Council regulation No 1698/2005 stipulates that 'support shall be granted annually and per hectare to farmer in order to compensate for costs incurred and income foregone resulting from disadvantages in the areas concerned related to the implementation of Directives 79/409/EEC, 92/43/EEC and 2000/60/EC'. Hence, at a national scale, this translates for example into a compensation of £301 to £400 (per hectare per year) if a 4 m to 6 m buffer strip on the edge of cultivated land is established in England (Natural England, 2015) or the entitlement to the BPS of a variable income with the commitment to a 2 to 10 m buffer strip and Good Agricultural and Environmental Condition (GAEC) and Statutory Management Requirements (SMR) (BSP, 2017). However, it is worth noting that to be able to claim for these payments at least 5 ha of eligible land is required.

An important point presented within the River Basin Management Plans (RBMPs), and commonly stressed within legislation affecting riparian areas, is the commitment and the importance of engaging and promoting collaboration with stakeholders, including local authorities, communities, developers and industry. The importance of stakeholder collaboration is crucial, as for example in Wales, only 7% of the land is owned or managed by the competent authority itself (NRW, 2015). Current riparian management policies strongly promote landowner collaboration and participation, often via the different payment schemes (e.g. BPS, Glastir), which are subject to compulsory cross-compliance measures to promote sustainable farming techniques. However, studies such as Ahnström et al. (2009) or Ingram (2008) report contradictory responses from land managers. While they claim to be technically well informed and willing to embrace good ecological practices (e.g. application of manures outside the riparian zone or the establishment of a riparian buffer), evidence shows there is a need for clearly articulated information to better communicate costs and benefits of the measures applied and how they will be recompensed for services provided (Holden et al., 2017) . In this respect, the report by DEFRA (2004) on catchment-sensitive farming also indicated that when landowners were provided with the right and precise information (often face-to-face) their actions were much more effective, costs were reduced and as a result they become less dependent on subsidies.

There is no shortage of reports (EA, 2004; UK NEA, 2011; EU Technical Report No 9/2015, EU Biodiversity, 2020) that warn about the decline of ecosystem service provision associated with riparian areas (e.g. river water quality, biodiversity). Some argue this may be due to the lack of linkage between the many different elements that feed into policy (ecology, geomorphology, soil science, hydrology and fisheries science, etc.) (Kohm and Franklin, 1997; Hickey and Doran, 2004). Most of the recent EU and UK legislation acknowledges this and attempts to halt or reverse this loss of ecosystem service provision. The EU Biodiversity Strategy 2020 and the Environment Wales Act (2016) are two recent European and regional examples of this, respectively. However, policy-makers, researchers and scientists need to work together to better understand the effectiveness and potential impact of decisions (Holden et al., 2017).

3.2. Research review

The search yielded a total of 820 publications addressing the topic of riparian areas from 1997 to 2017 in the UK. The scientific publications were scrutinised and 161 articles of pertinent material with respect to 'riparian studies in the UK' were selected. We acknowledge that we may have missed some publications focused on riparian areas due to the multiple terms used to refer them (i.e. floodplain, buffer strip, riverine systems). Despite this, we feel that our broad cross-section was sufficient to identify general trends.

3.2.1. Riparian studies by geographical scope within the UK and land cover focus

The largest number of papers on riparian areas within the UK were associated with England (59.6%), followed by articles considering the whole of the UK (20.5%) while Scotland and Wales contributed significantly fewer papers (ca. 10% each) (Fig. 1). No studies were found from Northern Ireland with the search criteria used in this review. Research based on Scotland tended to focus equally on the habitat types 'Enclosed Farmland' and 'Mountains, Moorland and Heaths' even though the latter covers 44% of its land area. In contrast, Wales focused primarily on 'Woodlands' which only accounts for ca. 15% of its territory (UK NEA, 2011). Riparian research from England was concentrated on 'Enclosed Farmland' reflecting its important contribution within the landscape (55.3% of its total land; UK NEA, 2011).

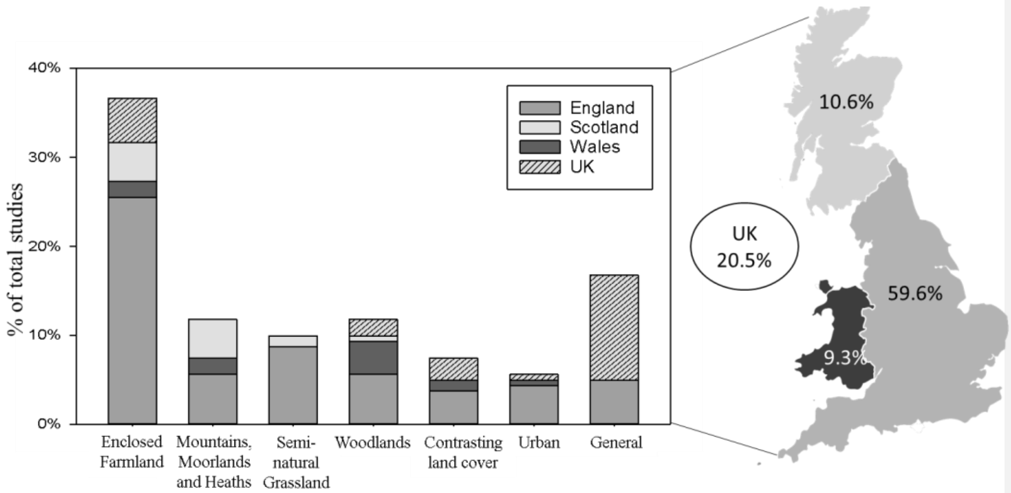

Fig. 1. Percentage of total number of studies on riparian areas by country (right) and land cover target (left) according to the UK NEA Broad Habitat categories (based on papers published from

1997 to 2017). Different bar colours represent the individual contribution of each country to that specific category. Two additional categories named 'Contrasting land cover' and 'General' were added to encompass studies conducted across different habitat types (minimum two habitat types) and studies that by the nature of the research could not be included within any specific habitat category (i.e. general reviews, models, studies on specific species), respectively. Studies developed across different regions of UK or focus on topics such as reviews or habitat surveys were categorized within the 'UK' category.

With respect to land cover, apart from papers based on Wales, most of the riparian publications focused their research on enclosed farmland (i.e. mostly arable and improved grassland). The rest of the habitat types contributed about 10% of the total number of papers except for 'Contrasting land cover' and 'Urban' categories whose percentage of contribution were slightly lower (7.5-5.6% respectively). Overall, the percentage contribution of each habitat type to riparian research seemed to reflect two things: firstly, the relative importance of each UK NEA Broad Habitat within the UK, and secondly, that agriculture and farming have been recognised as the major source of freshwater ecosystem decline within the UK and other developed countries (UK NEA, 2011; McGonigle et al., 2012). Thus, it is not surprising that 'Enclosed Farmland' which accounts for 55%, 19% and 41% of England, Scotland and Wales respectively was the primary focus of riparian research across the UK. However, although it is important to work on strategies that help us to mitigate the negative effects of agriculture, we cannot overlook the pivotal role in provisioning services that minority habitats (such as wetlands or semi-natural grasslands) accomplish, despite the relatively small surface area they cover. Evidence to support this also comes from studies such as De Groot et al. (2012) where it was estimated that globally, inland wetlands possess a value of \$25,682 ha^{-1} y^{-1}, 9 times greater than the estimate for grasslands based on the ecosystem services market price. ~~Morris and Camino (2011) also provided an estimated value of £467 ha^{-1} y^{-1} for inland wetlands due to their contribution to water quality improvement.~~ In addition, Tscharntke et al. (2005) also highlighted that local habitats different from grassland ecosystems might be essential to improve the delivery of ecosystem services, enhancing local diversity and providing a natural corridor of special importance in simple landscapes dominated by arable fields. Hence the importance of their study.

3.2.2. Riparian studies by subject matter

Based on subject matter, the studies were categorized according to four broad themes and several subcategories (Table 1). The largest number of publications were associated with ‘Nutrients and water quality’ (33%), followed by ‘Biodiversity’ (29%). The categories ‘Water dynamics and modelling’ and ‘Future outlook, current ecological status and impacts’ contributed similar amounts (ca. 19%) of the total articles published (Fig. 2).

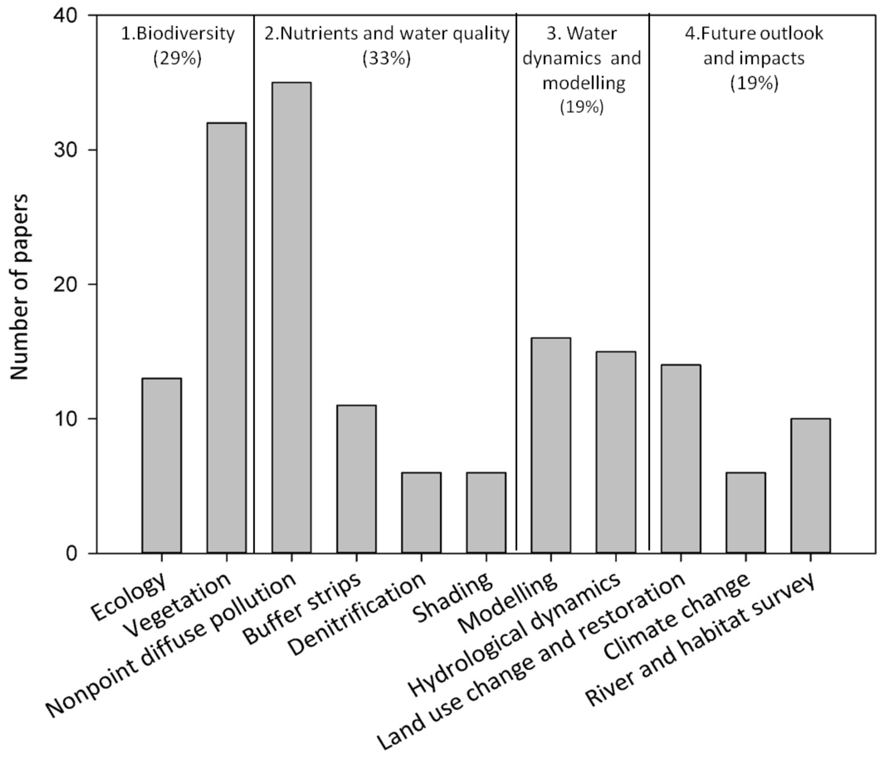

Fig. 2. Number of papers related to riparian areas in the UK over the period of 1997-2017. Graph based on 161 individual papers. Subcategories grouped according to the subject matter as explained in section 2.2

3.2.2.1. "Biodiversity" publications

The study of biodiversity accounted for 29% of the total number of papers on riparian areas (Table S43). The largest number of papers (21%) within this category focused on riparian vegetation (Fig. 2). It is worth noting that a large number of these studies were focused on the impacts of the spread of non-native species on other communities (e.g. invertebrates (Tanner et al., 2013), native flora (Bradford et al., 2007; Truscott et al., 2008; Tanner and Gange, 2013)) or ecosystem functioning (Hulme and Bremner, 2006; Hladyz et al., 2011). The propagation and distribution of non-native species is also a recurring theme within this subcategory (Wadsworth et al., 2000; Tickner et al., 2001; Maskell et al., 2006; Walker et al., 2009). Manchester and Bullock (2000) detailed the principal non-native species introduced in the UK and their possible impact on UK native biota. However, they also revealed that although they are major plant invaders along streams and rivers, the supportive evidence about their effects on aquatic habitats and species is often contradictory and scarce (Stockan and Fielding, 2013). Additionally, there was no shortage of studies focused on vegetation propagules, distribution and diversity, ecological successions and hydrogeomorphological dynamics (Moggridge and Gurnell, 2010; Cockel and Gurnell, 2012; Gurnell and Grabowski, 2016). Historically, riparian research has largely focused on vegetation because it is relatively easy to assess, exerts a strong influence on the soil microbial community and even influences the nearby air around it (Verry et al., 2004; Lymperopoulou, et al., 2016). However, evidence suggests that other factors such as land use history or management practices have a stronger effect in driving microbial diversity and abundance in the soil and that these factors are not being as extensively studied (Millard and Singh, 2010; Jangid et al., 2011; García-Orenes et al., 2013).

In contrast, ecological papers examining relationships between biota and the environment only represented 8% of the total publications (Fig. 2). Research within this subject matter addressed changes to the distribution and conservation of populations of invertebrates, small mammals or birds (Sadler et al., 2004; Moro and Gadal, 2008; Sinnadurai et al., 2016). However, most of the studies are focused on particular species or agricultural systems, with little perspective of the ecosystem as a whole.

3.2.2.2. "Nutrients and water quality" publications

Of all papers published between 1997 and 2017, about 33% related to nutrients and water quality (Table S54). Within this body of work, the largest number of publications (20%) explored non-point source (NPS) pollution and its effect on water quality within riparian zones (Nisbet, 2001; Jarvie et al., 2008; Hutchins et al., 2010; Wilkinson et al., 2014); particularly, phosphorus and sediments (Steiger et al., 2001; Roberts et al., 2013; Osei et al., 2015; McCall et al., 2017; Vinten et al., 2017). This focus of attention responds principally to the need to meet environmental standards imposed by the WFD that requires good ecological and chemical status and drinking water standards without increasing the costs of treatment that have to be paid by consumers (Kay et al., 2009). Pretty et al. (2000) estimated that the annual costs of removing contaminants such as pesticides, nitrates, phosphorus (and sediment), and organic carbon losses in water for drinking in the UK to be £120 M, £16 M, £55 M and £106 M, respectively on average for 1996. In this regard, agriculture (diffuse pollution) has been highlighted for special attention because of the pressure it exerts on UK freshwaters, particularly in England and Wales rivers (Defra, 2004; European Commission, 2012). Maltby et al. (2013) estimated an increase of 40% of cultivable area in England between 1940 and 1980, whilst 88% of the land area of Wales was utilised as agricultural land in 2015 (Armstrong, 2016). In view of this pressure, agricultural stewardship schemes (e.g. Glastir, BPS), may offer an effective way to halt riparian degradation.

However, although there must be a common framework for protecting riparian areas (e.g. no cropping within riparian area), there is a need to identify context-specific solutions rather than expecting a one-size buffer fits-all solution (i.e. setting a fixed riparian buffer width of 2 m from the watercourse) (Kay et al., 2009). For example, Bergfur et al. (2012) found that the replacement of a septic tank was just as effective as implementing a riparian buffer to stop N and other nutrients entering into watercourses in a monitored catchment.

Together with phosphorus and sediments, nitrogen (N) also represents a major contributor to global environmental problems such as freshwater eutrophication and greenhouse gas emissions (Canfield et al., 2010; Erisman, 2013). Because of this, and due to the fact that denitrification represents a permanent removal of NO_3^-, 3% of the publications focused on this topic. Specifically, they tended to assess the role of hydrology on denitrification as well as other environmental issues (Hefting et al., 2004; Machefert and Dise, 2004; Sgouridis and Ullah, 2015). However, despite the major contribution of denitrification to greenhouse emissions and the UK commitment to reduce emission by at least 80% by 2050 (from the baseline year 1990) (e.g. Climate change Act , 2008), the numerous technical challenges and the cost of accurately measuring it in the field have probably reduced the volume of research in the UK.

The impact of cattle on water quality is also a recurring theme within this subcategory (Bond et al., 2012; Terry et al., 2014). Livestock management is considered a keystone for achieving the required ‘good ecological status’ required by the WFD since the effects of mismanagement on riparian areas are becoming increasingly apparent (e.g. erosion and destabilization of rivers banks) (Belsky et al., 1999; Bond et al., 2012; Terry et al., 2014). The importance of restricting livestock access to watercourses is especially relevant in the UK context, considering that agriculture is heavily focused on grazing livestock (Armstrong, 2016). However, although livestock restrictions to watercourse constitute a strong advisable measure against water pollution, there is no enforcement in this respect in the UK to date.

The implementation of riparian buffer strips is a well-established tool to protect surface and ground water quality from anthropogenic activities (Blackwell et al., 1999; Kaila et al., 2012; Stutter et al., 2012). Research has tended to determine the effectiveness of the buffer for removal of nutrients. However, it was only covered by 6% of the total studies concerning riparian areas in the UK. It could be argued that the lack of research on this topic is due to the fact that this management tool was advocated in the UK just two decades ago (Muscutt et al., 1993) whereas in some parts of North America its use goes back to the 1950s (Richardson et al., 2012). Although it was not one of the most recurrent topics for riparian research within the UK, there is an extensive body of literature (mainly from the Unite States) focused on riparian buffer strips. In this sense, Iit is interesting to note that most of these studies and the ones gathered here, focused on evaluating variable widths for riparian buffers to maximize benefits. However, using variable buffer widths would require a regulatory system that is flexible and site-specific base, instead of implementing a uniform buffer width at landscape scale as is currently being done. Some studies have shown that applying a mandatory buffer at the landscape scale is an ineffective policy to target nutrient removal (Kronvang et al., 2011). Rather they recommended that buffer strips (in this case 10 m-wide) should be targeted to critical areas where they would have been much more cost-effective.

An additional effect of a well-structured vegetative buffer strip is the provision of shade. The role of riparian areas in providing shade is being increasingly explored because of its potential to alleviate water pollution (Warren et al., 2016). Recently, some studies have shown that riparian shading could become a valuable tool to mitigate river nutrient enrichment, being in some cases, even more effective than reducing nutrient loads in reducing eutrophication risk (Hutchins et al., 2010, 2012). Shade helps reduces incoming solar radiation thereby preventing excess warming and exposure to sunlight which reduces the opportunity for excessive in-stream plant growth. This suggests that riparian shading could offer a cost-effective alternative to reduce the estimated damage costs of freshwater eutrophication which for England and Wales is expected to cost between £75.0−114.3 million yr^{-1} (Pretty et al., 2003). However, this topic only compromised 4% of the total publications, with some highlighting it as an area that needs further research (Orr et al., 2015). In that respect, guidelines, as shown in Table 3, are a common approach to raising awareness of the importance of riparian shade. However, it isn't always the case that altering conditions to support riparian vegetation will entail beneficial environment consequences (i.e. channel widening, excessive shade, limit the growth of macrophytes) (Collier et al., 1995; Parkyn et al., 2005). Consequently, riparian owners and managers should carefully assess the impacts of restoration measures before undertaking action.

3.2.2.3. Water dynamics and modelling

Water dynamics and modelling accounted for 19% of the total publications (Table S65). Modelling and hydrology within riparian areas produced similar number of papers (10%). These studies tended to explore hydrological interactions within riparian areas in order to predict further sources of variation (Soulsby and Tetzlaff, 2008; Del Tánago et al., 2016; House et al., 2016b). Previous studies have emphasised that understanding the underlying processes between riparian areas and hydrology could provide essential information due to the intertwined relationship with biogeochemical cycles, vegetation type and flood processes (Décamps, 1995; Bendix and Hupp, 2000; Grabowski and Gurnell, 2016). ~~Notably, the potential of riparian areas to reduce and mitigate flood events has been extensively documented (Anderson et al., 2006; Johnson et al., 2008).~~ This has particular relevance for England and Wales, where the expected average cost of flood damage is of the order of £1.2 billion per year (Ramsbottom et al., 2012). However, only one study focused on riparian areas and flood management from a modelling perspective (McLean, 2013).

Table 3. Chronological compilation of riparian guidelines at the national (UK) scale.

GUIDELINES					
Name	**Agency**	**Year**	**Objective**	**Type**	**Action applied by**
Engineering in the Water Environment Good Practice Guide: Riparian Vegetation Management	Scottish Environment Protection Agency	2009	• Manage riparian vegetation across contrasting habitat types • Creation of buffer strips with recommended widths. • Management of non-native plant species	Technical guidance	Landowner Competent authority
Planting trees to protect water. The role of trees and woods on farms in managing water quality and quantity	Woodland Trust	2012	• Raise awareness of main water quality problems related to agricultural practices: causes-cost effect. • General recommendations for water quality improvement as (i.e. margin of 10 m from any water body to establish cattle feeders). • Emphasizing the role of riparian trees and recommendations for species choice.	Research report and guidance	Landowner
New Guidance on Aquatic and Riparian Plant Management – Controls for Vegetation in Watercourses	Environment Agency, DEFRA[1], CEH[2] Private parties	2014	• Developing good practice guidance on the management of aquatic plants and vegetation both in and alongside watercourses. • Providing field guide in order to identify non-native species. • Providing a decision-making tool applying site-specific knowledge.	Technical guidance	Natural Resources Wales Internal Drainage Boards Lead Local Flood Authorities/local authorities Canal & River Trust
Keeping Rivers Cool	Woodland Trust	2016	• Creating riparian shade for climate change adaptation. • Providing shade maps for most of England and part of Wales in order to identify where planting and fencing will be more beneficial. • Assisting in the species selection and plantation structure.	Guidance	Landowner Public authorities

[1] Department for Environment, Food & Rural Affairs

[2] Centre Ecology and Hydrology

GUIDELINES					
Name	**Agency**	**Year**	**Objective**	**Type**	**Action applied by**
River Restoration and Biodiversity	IUCN[3] NCUK[4]	2016	• Raising awareness about why rivers and their associated floodplain are important for UK biodiversity. • Identifying causes by which they have been altered. • Recommendations and practice guidance for river restoration.	Report	Researchers and policy-makers
The UK Forestry Standard	Forestry Commission	2017	• Recommendation of a mix of shaded and lightly shaded habitat within the riparian zone to enhance biodiversity. • Control the spread of invasive and non-native species. • Provide and maintain defined buffer areas along watercourses and water bodies.	UK Forestry Standard Guidelines	Forest and woodland managers (Natural Resources Wales is the organisation in charge of public forests in Wales)
A guide to your rights and responsibilities of riverside ownership in Wales[5]	Natural Resources Wales	2017	• Explanation of rights and responsibilities of riparian landowners. • Flood risk management assessment. • Maintaining the bed and banks of the watercourse and the vegetation growing on the banks.	Guidance	Landowner

[3] International Union for the Conservation of Nature

[4] National Committee UK

[5] The same type of guidance is provided by the Environment Agency for England

Predictive models, particularly related to the delivery of ecosystem services, are increasingly informing European and national legislation (Maltby et al., 2013; Adhikari and Hartemink, 2016). Nonetheless, only one study was found that explored riparian areas from this perspective (McVittie et al., 2015). Results from that study showed how models could be used efficiently to integrate physical attributes (land cover, soil type, rainfall), terrestrial and aquatic process (e.g. erosion, river flow) and management intervention using Bayesian Belief Networks (BBN). Thus, the parameters introduced will ultimately aim to outline the fundamental ecological processes that deliver ecosystem services within riparian areas. This kind of riparian model could inform more integrated policies.

With respect to hydrology, research has tended to focus on the interactions between stream and groundwater or the relationship between the hyporheic zone and biogeochemical processes (Lapworth et al., 2009; Allen et al., 2010; Canfield et al., 2013). Although many report how management of buffer strips can assist in reducing nutrient loads entering streams, some (e.g. Hill 1996; Vidon and Hill, 2004) argue that we first need to understand riparian hydrology to better predict the fate of contaminants in riparian zones.

3.2.2.4. Future outlook, current ecological status and impacts

Riparian areas are sentitive ecosystems as they are coupled tightly with hydrological regimes, connected to longitudinal and lateral fluxes of energy and nutrients that in turn are under strong climatic influnece and frequently distubed by anthropogenic activities (Wipfli, 2005). Nineteen percent of the publications found focused on the future outlook, current ecological status and impacts of riparian zones (Table S76) with land use change and restoration contributing the largest number of papers, representing 9% of the total. Studies within this category explored the effect of restoration and land use change on invertebrates (Harrison et al., 2004; Petersen et al., 2004), vegetation and floodplain dynamics (Clarke and Wharton, 2000;

Clilverd et al., 2016), amongst others. There is evidence throughout history that riparian areas have been heavily affected by land use changes in order to increase agricultural productivity (Seavy et al., 2009; Poff et al., 2011). Flood incidents can increase where intense use reduces the time available for water to infiltrate and therefore, the frequency and magnitude of flood peak flows increase (Nagasaka and Nakamura, 1999). That may be the reason why, researchers within this category usually approach the restoration of riparian areas as a way to return the natural defences for flood protection. Studies such as Stromberg et al. (2007) have also stressed the importance of flood restoration for native riparian vegetation and their consequences for sediment transport. ~~Others highlight the importance of riverine ecosystem restoration including riparian zones for improvements in physico-chemical and biologicla status (Addy et al., 2016).~~

Alongside riparian restoration, there is growing evidence that managed adaptation could reduce the impacts of climate change on ecosystems (Thomas et al., 2016). In this respect, climate change was the focus of 4% of the papers which mostly dealt with the role of riparian trees in water cooling and eutrophication (House et al., 2016a; Halliday et al., 2016). There is evidence that further increases in global temperature cannot now be prevented (IPCC, 2014). Therefore, strategies such as the EU Biodiverstiy Strategy 2020 aim to increase resilience of key resources and provide legal protection to minimise the impacts of, and adapt ecosystems to, climate change. However, by definition, riparian zones are transition areas ~~between land and freshwater ecosystems~~ and are therefore affected by both aquatic-terrestrial remedial and mitigation measures. It is therefore difficult to identify which specific actions are directed specifically towards riparian areas.

River and habitat surveys accounted for 6% of the total publications. Studies tended to use the standard riverine hydromorphology survey in the UK (River Habitat Survey; RHS) in order to characterise reach streams by recording physical characteristics and thus evaluate their conservation status (Davenport et al., 2004; Erba et al., 2006; Vaughan et al., 2010). This category aims to meet the EU desire to assess an ecosystem's ecological status. Despite this, Maltby et al. (2014) stated that approaches taken to date in mapping and assessing different freshwater ecosystems as 'priority habitats' do not necessarily reflect their actual or potential contribution to ecosystem services, thereby impeding the legislative work to protect them.

3.2.3. Riparian future research needs

There are limited examples of studies which have attempted to account for the multiple functions that interact (often in a complex way) within riparian areas. The analysis of riparian studies suggests that research is largely focused on single features (e.g. specific riparian species) or functions of riparian areas. Specifically, a lot of effort has been made on the study of riparian vegetation and nutrient dynamics. Although there is no doubt that studies focused on single species or nutrients offer underpinning information to help us to understand how the ecosystem as a whole works, there is a need to guide future research and managerial activities towards a more multidisciplinary integrated approach. In this way, the whole range of ecosystem services could be maximised, and we could reduce or avoid less desirable outcomes. For example, the restriction of livestock to the watercourse is being increasingly recommended to halt P and sediments loads into the river. However, seasonal grazing is beneficial to maintain a good level of biodiversity within riparian areas so both functions should be considered. In turn, this much more realistic view of the ecosystem which considers that the different environmental processes do not occur in isolation, could offer a better understanding of management actions required to ensure the continuation of multiple benefits (Fig. 3). We present some key questions that should be considered when assessing riparian areas either for restoration purposes, management or research that can increase the range of services provided by riparian areas.

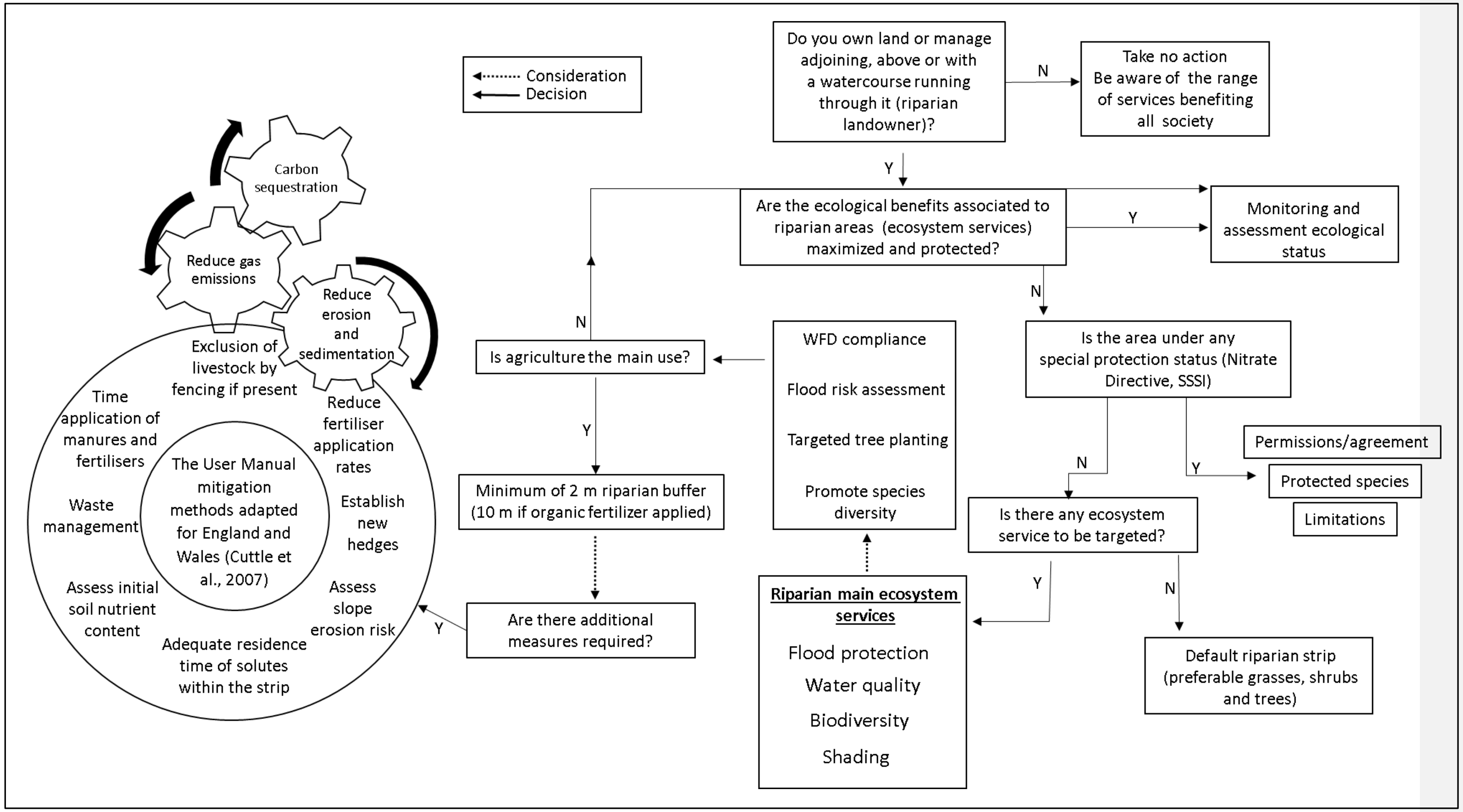

Fig. 3. Flow chart assessment and prescription procedures that promote ecosystem conservation and services within riparian areas. The flow chart provides key questions and prioritization measures with the aim to guide riparian users and owners throughout the process of riparian assessment.

4. Conclusions

Improving and enhancing the communication between scientists and policy-makers is essential to help form policies that are based on robust scientific evidence. Results from this study revealed that legislation concerning riparian areas appears fragmented, contains redundant policy instruments and in places lacks practical objectives or contains contradictory measures or unachievable targets.

On the other hand, most recent EU and UK legislation calls for integration and a more ecosystem ~~service based~~service-based approach to riparian management to maximise, value and preserve not only the physical ecosystem attributes and individual services but also the set of services that could be provided. Our study indicates riparian research tends to focus on single ecosystem processes (i.e. N cycle, riparian species) or attributes (e.g. specific species or nutrients). More integrated research could help support better policy making in this area by developing a better holistic understanding of riparian functioning and that helps us value less what ecosystems are and more what they can offer.

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