

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

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1 **Riparian research and legislation, are they working towards the same**
2 **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

69 broader sustainability alongside agricultural production (Kaine et al., 2017). This requires
70 policy-makers to appreciate the tight financial situation that farmers usually operate within and
71 make up for the fact that riparian areas provide services that are not directly traded in markets
72 (Orr and Colby, 2004). Key to the success of agri-environment schemes is to have farmer input
73 into their design. Ahnström et al. (2009) highlighted that the lack of integration of “farmers’
74 perceptions and knowledge of nature” in the design of agri-environment schemes was a major
75 problem that needs addressing.

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

81 The impending departure of the UK from the EU, through which much of the legislation
82 and initiatives protecting our environment have derived, highlights the need for careful
83 consideration of alternatives and the development of strong new policies that set a clear
84 direction. Recently, the EU has set an ambitious target of which UK is a signatory country, to
85 halt biodiversity decline and to ensure well-functioning of ecosystems to provide essential
86 services to people by 2020 (Maes et al., 2016). Although a considerable effort has been made
87 in recent decades to stop further ecosystem decline in the UK (i.e. increase of 12.9 million ha
88 of protected areas from 2012 to 2017; Defra and JNCC, 2017), recent reports do not suggest a
89 positive picture of the current state of biodiversity. For example, the recent publication of the
90 ‘Biodiversity Intactness Index’, which is an indicator of how intact a country’s biodiversity is,
91 places the UK in the 29th lowest position out of 218 countries assessed (Scholes and Biggs,
92 2005; Hayhow et al., 2016). Regarding riparian areas, one of the most diverse and valuable
93 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 identifying 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 Commission, 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

119 associated floodplain (McKay and King, 2006); and iv) future outlook, current status and
120 impacts (e.g. influence of climate change on riparian dynamics) (Seavy et al., 2009). We also
121 considered riparian guidance and best management practices as they usually refer to certain
122 binding actions required by public organisations to qualify for Common Agricultural Policy
123 (CAP) payments.

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125 2.2. Literature review of scientific research

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

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

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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~~)

178 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> Target 1. Reinforce the implementation of Natura 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	<ul style="list-style-type: none"> 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 (CO₂, N₂O) 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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

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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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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)	2009	<ul style="list-style-type: none"> • 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

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

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

234 Most of the EU and UK-based policies reviewed here address the protection of riparian
235 areas in two ways: i) limiting activities that can be undertaken within the riparian buffer zone,
236 e.g. limiting fertilizer application (2 m from the edge of the river) (Nitrates Directive
237 91/676/EEC) or limiting water abstraction from rivers and lakes to $<20 \text{ m}^3 \text{ day}^{-1}$ (Land Drainage
238 Act, 1994), or ii) monitoring, mapping and evaluating the ecological and chemical status of
239 riparian zones and adjacent ecosystems. Examples of initiatives that include monitoring

240 programs are the WFD (2000), Nitrates Directive (1991), EU Biodiversity Strategy (2020) and
241 River Basin Plan Management (RBPM). ~~They seek to ensure the sustainable management~~
242 ~~through effective monitoring and reviewing actions implemented by the Member States to~~
243 ~~achieve the wider objectives of other EU Directives.~~ In recent years, 70% of the measures
244 adopted to address the environmental pressures of agriculture involved the establishment of
245 riparian buffer strips funded via agri-environmental payment schemes (Dworak et al., 2009) .
246 For example, the European Council regulation No 1698/2005 stipulates that ‘support shall be
247 granted annually and per hectare to farmer in order to compensate for costs incurred and income
248 foregone resulting from disadvantages in the areas concerned related to the implementation of
249 Directives 79/409/EEC, 92/43/EEC and 2000/60/EC’. Hence, at a national scale, this translates
250 for example into a compensation of £301 to £400 (per hectare per year) if a 4 m to 6 m buffer
251 strip on the edge of cultivated land is established in England (Natural England, 2015) or the
252 entitlement to the BPS of a variable income with the commitment to a 2 to 10 m buffer strip and
253 Good Agricultural and Environmental Condition (GAEC) and Statutory Management
254 Requirements (SMR) (BSP, 2017). However, it is worth noting that to be able to claim for these
255 payments at least 5 ha of eligible land is required.

256 An important point presented within the River Basin Management Plans (RBMPs), and
257 commonly stressed within legislation affecting riparian areas, is the commitment and the
258 importance of engaging and promoting collaboration with stakeholders, including local
259 authorities, communities, developers and industry. The importance of stakeholder collaboration
260 is crucial, as for example in Wales, only 7% of the land is owned or managed by the competent
261 authority itself (NRW, 2015). Current riparian management policies strongly promote landowner
262 collaboration and participation, often via the different payment schemes (e.g. BPS, Glastir),
263 which are subject to compulsory cross-compliance measures to promote sustainable farming
264 techniques. However, studies such as Ahnström et al. (2009) or Ingram (2008) report

265 contradictory responses from land managers. While they claim to be technically well informed
266 and willing to embrace good ecological practices (e.g. application of manures outside the riparian
267 zone or the establishment of a riparian buffer), evidence shows there is a need for clearly
268 articulated information to better communicate costs and benefits of the measures applied and
269 how they will be recompensed for services provided (Holden et al., 2017) . ~~In this respect, the~~
270 ~~report by DEFRA (2004) on catchment sensitive farming also indicated that when landowners~~
271 ~~were provided with the right and precise information (often face to face) their actions were much~~
272 ~~more effective, costs were reduced and as a result they become less dependent on subsidies.~~

273 There is no shortage of reports (EA, 2004; UK NEA, 2011; EU Technical Report No
274 9/2015, EU Biodiversity, 2020) that warn about the decline of ecosystem service provision
275 associated with riparian areas (e.g. river water quality, biodiversity). Some argue this may be due
276 to the lack of linkage between the many different elements that feed into policy (ecology,
277 geomorphology, soil science, hydrology and fisheries science, etc.) (Kohm and Franklin, 1997;
278 Hickey and Doran, 2004). Most of the recent EU and UK legislation acknowledges this and
279 attempts to halt or reverse this loss of ecosystem service provision. The EU Biodiversity Strategy
280 2020 and the Environment Wales Act (2016) are two recent European and regional examples of
281 this, respectively. However, policy-makers, researchers and scientists need to work together to
282 better understand the effectiveness and potential impact of decisions (Holden et al., 2017).

283

284 3.2. Research review

285 The search yielded a total of 820 publications addressing the topic of riparian areas from
286 1997 to 2017 in the UK. The scientific publications were scrutinised and 161 articles of pertinent
287 material with respect to ‘riparian studies in the UK’ were selected. We acknowledge that we may
288 have missed some publications focused on riparian areas due to the multiple terms used to refer

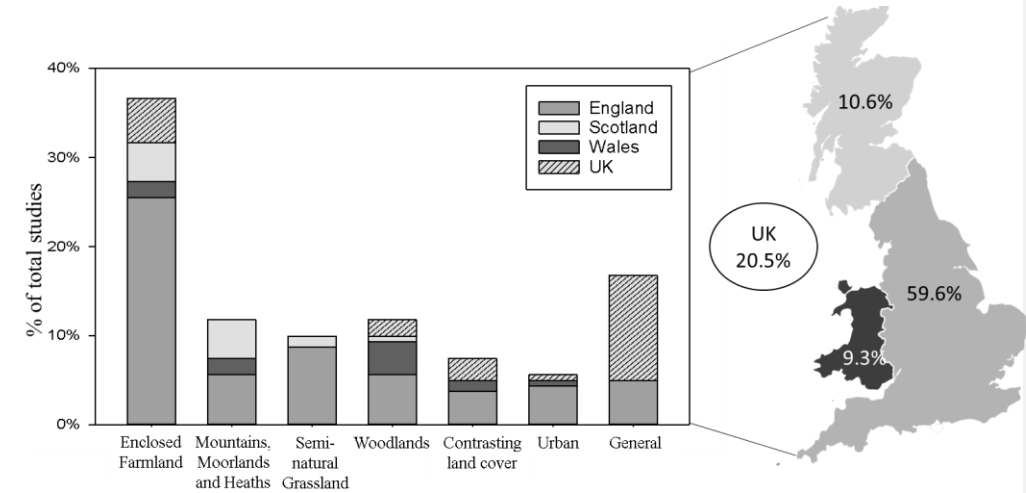
289 them (i.e. floodplain, buffer strip, riverine systems). Despite this, we feel that our broad cross-
 290 section was sufficient to identify general trends.

291

292 *3.2.1. Riparian studies by geographical scope within the UK and land cover focus*

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

302



303 **Fig. 1.** Percentage of total number of studies on riparian areas by country (right) and land cover
 304 target (left) according to the UK NEA Broad Habitat categories (based on papers published from
 305

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.

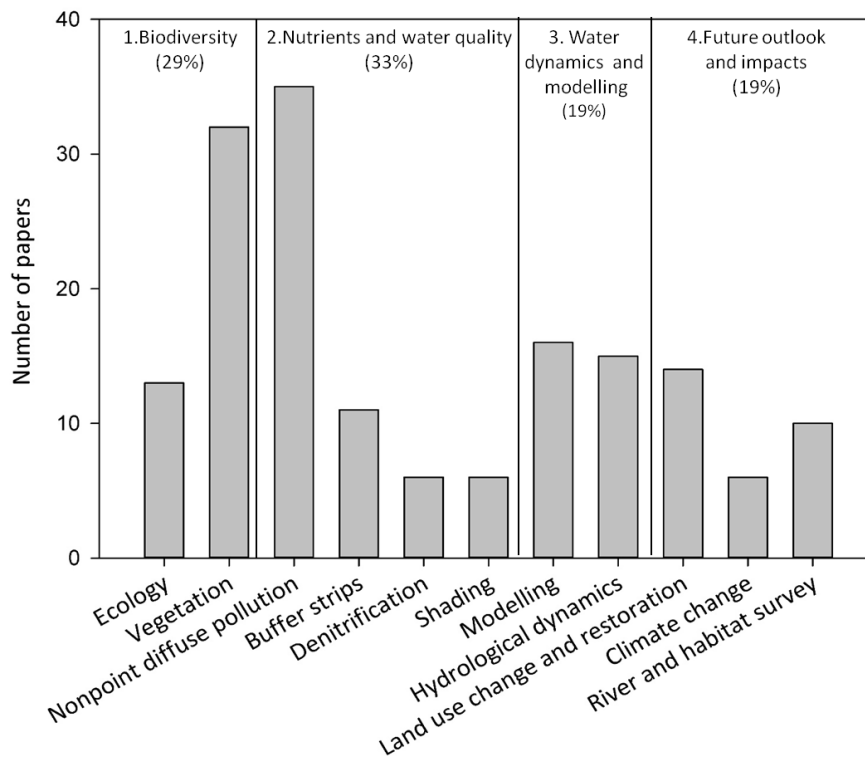
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With respect to land cover, apart from papers based on Wales, most of the riparian publications focused their research on enclosed farmland (i.e. mostly arable and improved grassland). The rest of the habitat types contributed about 10% of the total 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, Tschardt et al. (2005) also highlighted

333 that local habitats different from grassland ecosystems might be essential to improve the delivery
334 of ecosystem services, enhancing local diversity and providing a natural corridor of special
335 importance in simple landscapes dominated by arable fields. Hence the importance of their study.
336

337 *3.2.2. Riparian studies by subject matter*

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



343
344

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

348

349 3.2.2.1. “Biodiversity” publications

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

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

377

378 3.2.2.2. “Nutrients and water quality” publications

379 Of all papers published between 1997 and 2017, about 33% related to nutrients and water
380 quality (Table S54). Within this body of work, the largest number of publications (20%) explored
381 non-point source (NPS) pollution and its effect on water quality within riparian zones (Nisbet,
382 2001; Jarvie et al., 2008; Hutchins et al., 2010; Wilkinson et al., 2014); particularly, phosphorus
383 and sediments (Steiger et al., 2001; Roberts et al., 2013; Osei et al., 2015; McCall et al., 2017;
384 Vinten et al., 2017). This focus of attention responds principally to the need to meet
385 environmental standards imposed by the WFD that requires good ecological and chemical status
386 and drinking water standards without increasing the costs of treatment that have to be paid by
387 consumers (Kay et al., 2009). Pretty et al. (2000) estimated that the annual costs of removing
388 contaminants such as pesticides, nitrates, phosphorus (and sediment), and organic carbon losses
389 in water for drinking in the UK to be £120 M, £16 M, £55 M and £106 M, respectively on average
390 for 1996. In this regard, agriculture (diffuse pollution) has been highlighted for special attention
391 because of the pressure it exerts on UK freshwaters, particularly in England and Wales rivers
392 (Defra, 2004; European Commission, 2012). Maltby et al. (2013) estimated an increase of 40%
393 of cultivable area in England between 1940 and 1980, whilst 88% of the land area of Wales was
394 utilised as agricultural land in 2015 (Armstrong, 2016). In view of this pressure, agricultural
395 stewardship schemes (e.g. Glastir, BPS), may offer an effective way to halt riparian degradation.

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

402 Together with phosphorus and sediments, nitrogen (N) also represents a major
403 contributor to global environmental problems such as freshwater eutrophication and greenhouse
404 gas emissions (Canfield et al., 2010; Erisman, 2013). Because of this, and due to the fact that
405 denitrification represents a permanent removal of NO_3^- , 3% of the publications focused on this
406 topic. Specifically, they tended to assess the role of hydrology on denitrification as well as other
407 environmental issues (Hefting et al., 2004; Macheferf and Dise, 2004; Sgouridis and Ullah,
408 2015). However, despite the major contribution of denitrification to greenhouse emissions and
409 the UK commitment to reduce emission by at least 80% by 2050 (from the baseline year 1990)
410 (e.g. Climate change Act , 2008), the numerous technical challenges and the cost of accurately
411 measuring it in the field have probably reduced the volume of research in the UK.

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

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

438 An additional effect of a well-structured vegetative buffer strip is the provision of shade.
439 The role of riparian areas in providing shade is being increasingly explored because of its
440 potential to alleviate water pollution (Warren et al., 2016). Recently, some studies have shown
441 that riparian shading could become a valuable tool to mitigate river nutrient enrichment, being
442 in some cases, even more effective than reducing nutrient loads in reducing eutrophication risk
443 (Hutchins et al., 2010, 2012). ~~Shade helps reduces incoming solar radiation thereby preventing~~
444 ~~excess warming and exposure to sunlight which reduces the opportunity for excessive in-stream~~
445 ~~plant growth.~~ This suggests that riparian shading could offer a cost-effective alternative to reduce

446 the estimated damage costs of freshwater eutrophication which for England and Wales is
447 expected to cost between £75.0–114.3 million yr⁻¹ (Pretty et al., 2003). However, this topic only
448 compromised 4% of the total publications, with some highlighting it as an area that needs further
449 research (Orr et al., 2015). In that respect, guidelines, as shown in Table 3, are a common
450 approach to raising awareness of the importance of riparian shade. However, it isn't always the
451 case that altering conditions to support riparian vegetation will entail beneficial environment
452 consequences (i.e. channel widening, excessive shade, limit the growth of macrophytes) (Collier
453 et al., 1995; Parkyn et al., 2005). Consequently, riparian owners and managers should carefully
454 assess the impacts of restoration measures before undertaking action.

455

456 3.2.2.3. *Water dynamics and modelling*

457 Water dynamics and modelling accounted for 19% of the total publications (Table S65).
458 Modelling and hydrology within riparian areas produced similar number of papers (10%). These
459 studies tended to explore hydrological interactions within riparian areas in order to predict further
460 sources of variation (Soulsby and Tetzlaff, 2008; Del Tánago et al., 2016; House et al., 2016b).
461 Previous studies have emphasised that understanding the underlying processes between riparian
462 areas and hydrology could provide essential information due to the intertwined relationship with
463 biogeochemical cycles, vegetation type and flood processes (Décamps, 1995; Bendix and Hupp,
464 2000; Grabowski and Gurnell, 2016). ~~Notably, the potential of riparian areas to reduce and~~
465 ~~mitigate flood events has been extensively documented (Anderson et al., 2006; Johnson et al.,~~
466 ~~2008).~~ This has particular relevance for England and Wales, where the expected average cost of
467 flood damage is of the order of £1.2 billion per year (Ramsbottom et al., 2012). However, only
468 one study focused on riparian areas and flood management from a modelling perspective
469 (McLean, 2013).

470

471 **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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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

472 ¹ Department for Environment, Food & Rural Affairs

473 ² Centre Ecology and Hydrology

474

GUIDELINES					
Name	Agency	Year	Objective	Type	Action applied by
River Restoration and Biodiversity	IUCN ³ NCUK ⁴	2016	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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.

497

3.2.2.4. Future outlook, current ecological status and impacts

Riparian areas are sensitive 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 influence and frequently disturbed 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;

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

517 Alongside riparian restoration, there is growing evidence that managed adaptation could
518 reduce the impacts of climate change on ecosystems (Thomas et al., 2016). In this respect,
519 climate change was the focus of 4% of the papers which mostly dealt with the role of riparian
520 trees in water cooling and eutrophication (House et al., 2016a; Halliday et al., 2016). There is
521 evidence that further increases in global temperature cannot now be prevented (IPCC,
522 2014). Therefore, strategies such as the EU Biodiversity Strategy 2020 aim to increase resilience
523 of key resources and provide legal protection to minimise the impacts of, and adapt ecosystems
524 to, climate change. However, by definition, riparian zones are transition areas ~~between land and~~
525 ~~freshwater ecosystems~~ and are therefore affected by both aquatic-terrestrial remedial and
526 mitigation measures. It is therefore difficult to identify which specific actions are directed
527 specifically towards riparian areas.

528 River and habitat surveys accounted for 6% of the total publications. Studies tended to
529 use the standard riverine hydromorphology survey in the UK (River Habitat Survey; RHS) in
530 order to characterise reach streams by recording physical characteristics and thus evaluate their
531 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.

536

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.

555

556

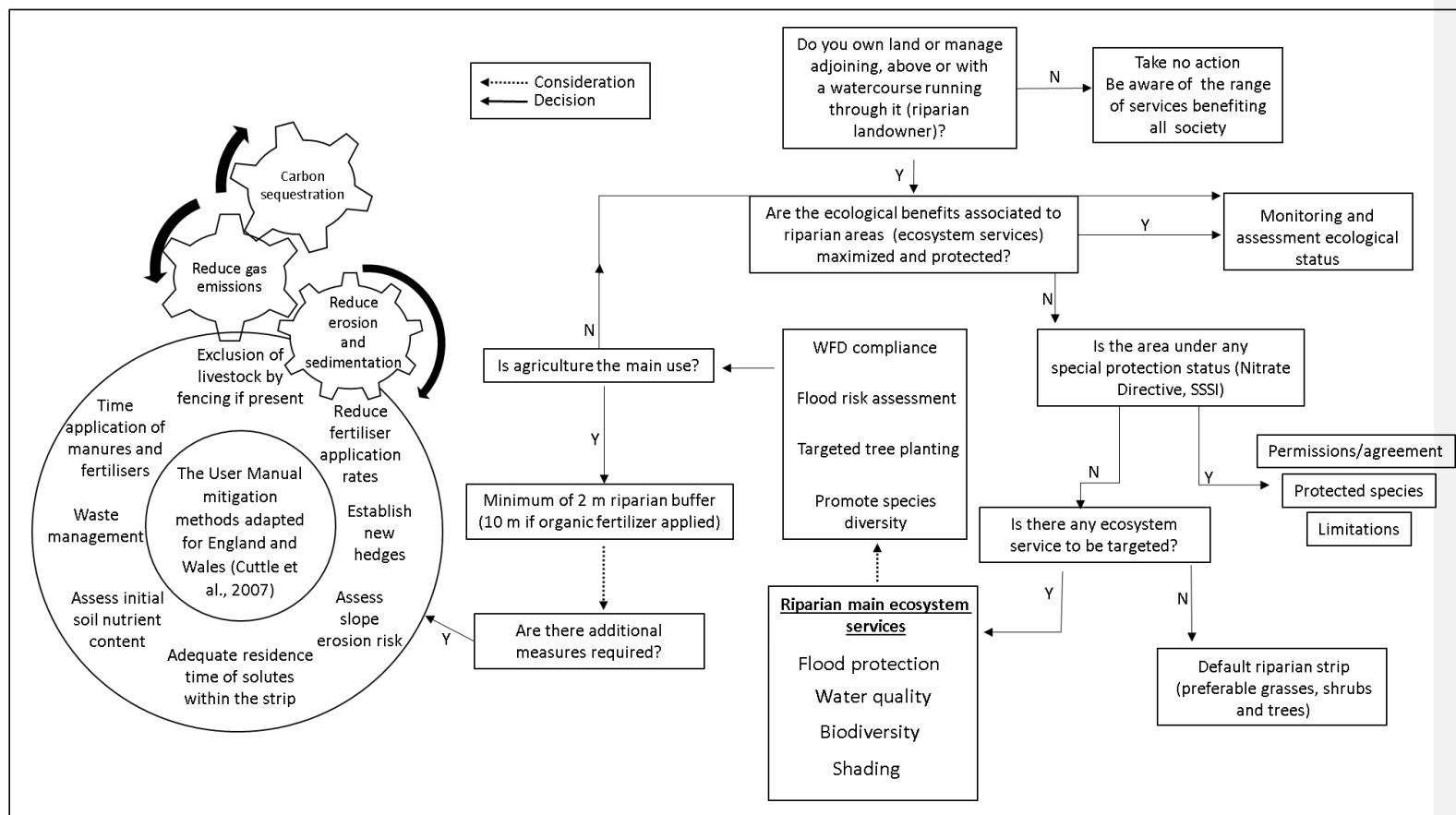


Fig. 3. Flow chart assessment and prescription procedures that promote ecosystem conservation and services within riparian areas. The flow chart provides key questions and prioritization measures with the aim to guide riparian users and owners throughout the process of riparian assessment.

560 **4. Conclusions**

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

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

574

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578 **References**

- 579 ~~Addy, S., Cooksley, S., Dodd, N., Waylen, K., Stockan, K., Byg., A and Holstead, K., 2016.~~
580 ~~River Restoration and Biodiversity: Nature based solutions for restoring rivers in the UK~~
581 ~~and Republic of Ireland. CREW reference: CRW2014/10.~~
- 582 Adhikari, K., Hartemink, A. E., 2016. Linking soils to ecosystem services—A global review.
583 *Geoderma* 262, 101-111.
- 584 Aguiar, T. R., Bortolozzo, F. R., Hansel, F. A., Rasera, K., Ferreira, M. T., 2015. Riparian buffer
585 zones as pesticide filters of no-till crops. *Environmental Science and Pollution Research*
586 22, 10618-10626.
- 587 Ahnström, J., Höckert, J., Bergeå, H. L., Francis, C. A., Skelton, P., Hallgren, L., 2009. Farmers
588 and nature conservation: What is known about attitudes, context factors and actions
589 affecting conservation? *Renewable Agriculture and Food Systems* 24, 38-47.
- 590 Allen, D. J., Darling, W. G., Goody, D. C., Lapworth, D. J., Newell, A. J., Williams, A. T., et
591 al., 2010. Interaction between groundwater, the hyporheic zone and a Chalk stream: a
592 case study from the River Lambourn, UK. *Hydrogeology Journal* 18, 1125-1141.
- 593 ~~Anderson, B. G., Rutherford, I. D., Western, A. W., 2006. An analysis of the influence of~~
594 ~~riparian vegetation on the propagation of flood waves. *Environmental Modelling and*~~
595 ~~*Software* 21, 1290-1296.~~
- 596 Armstrong, E., 2016. Research Briefing. The Farming Sector in Wales. National Assembly for
597 Wales. Research Service. Paper Number: 16-053. Available at:
598 [http://www.assembly.wales/Research%20Documents/16-053-Farming-sector-in-](http://www.assembly.wales/Research%20Documents/16-053-Farming-sector-in-Wales/16-053-Web-English2.pdf)
599 [Wales/16-053-Web-English2.pdf](http://www.assembly.wales/Research%20Documents/16-053-Farming-sector-in-Wales/16-053-Web-English2.pdf)

600 Baker, M. E., Wiley, M. J., 2004. Characterization of woody species distribution in riparian
601 forests of Lower Michigan, USA using map-based models. *Wetlands* 24, 550-561.

602 Basic Payment Scheme(BSP) rules for 2017. Rural Payments Agency and Department for
603 Environment, Food and Rural Affairs. Available at:
604 [https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/645304/](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/645304/BPS_2017_scheme_rules.pdf)
605 [BPS_2017_scheme_rules.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/645304/BPS_2017_scheme_rules.pdf)

606 Belsky, A. J., Matzke, A., Uselman, S., 1999. Survey of livestock influences on stream and
607 riparian ecosystems in the western United States. *Journal of Soil and Water Conservation*
608 54, 419-431.

609 Bendix, J., Hupp, C. R., 2000. Hydrological and geomorphological impacts on riparian plant
610 communities. *Hydrological Processes* 14, 2977-2990.

611 Bergfur, J., Demars, B. O. L., Stutter, M. I., Langan, S. J., Friberg, N., 2012. The Tarland
612 Catchment Initiative and its effect on stream water quality and macroinvertebrate indices.
613 *Journal of Environmental Quality* 41, 314-321.

614 Blackwell, M. S., Hogan, D. V., Maltby, E., 1999. The use of conventionally and alternatively
615 located buffer zones for the removal of nitrate from diffuse agricultural run-off. *Water*
616 *Science and Technology* 39, 157-164.

617 Bond, T. A., Sear, D., Edwards, M., 2012. Temperature-driven river utilisation and preferential
618 defecation by cattle in an English chalk stream. *Livestock Science* 146, 59-66.

619 Bradford, M. A., Schumacher, H. B., Catovsky, S., Eggers, T., Newington, J. E., Tordoff, G.
620 M., 2007. Impacts of invasive plant species on riparian plant assemblages: interactions
621 with elevated atmospheric carbon dioxide and nitrogen deposition. *Oecologia* 152, 791-
622 803.

623 Broetto, T., Tornquist, C. G., Campos, B. H. C. D., & Schneider, J. C., 2017. Relationships
624 between Agriculture, Riparian Vegetation, and Surface Water Quality in Watersheds.
625 Revista Brasileira de Ciência do Solo, 41.

626 Byrne, P., Reid, I., Wood, P. J., 2013. Stormflow hydrochemistry of a river draining an
627 abandoned metal mine: the Afon Twymyn, central Wales. Environmental Monitoring
628 and Assessment, 1-16.

629 Canfield, D. E., Glazer, A. N., Falkowski, P. G., 2010. The evolution and future of Earth's
630 nitrogen cycle. Science, 330(6001), 192-196.

631 Clarke, S. J., Wharton, G., 2000. An investigation of marginal habitat and macrophyte
632 community enhancement on the River Torne, UK. River Research and Applications 16,
633 225-244.

634 Clements, F. E., 1905. Research methods in ecology. University Publishing Company.

635 Clerici, N., Weissteiner, C. J., Paracchini, L. M., Strobl, P., 2011. Riparian zones: where green
636 and blue networks meet: pan-European zonation modelling based on remote sensing and
637 GIS. Luxembourg: Publications Office of the European Union.

638 Clilverd, H. M., Thompson, J. R., Heppell, C. M., Sayer, C. D., Axmacher, J. C., 2016. Coupled
639 Hydrological/Hydraulic Modelling of River Restoration Impacts and Floodplain
640 Hydrodynamics. River Research and Applications 32, 1927-1948.

641 Cockel, C. P., Gurnell, A. M., 2012. An investigation of the composition of the urban riparian
642 soil propagule bank along the River Brent, Greater London, UK, in comparison with
643 previous propagule bank studies in rural areas. Urban Ecosystems 15, 367-387.

644 Collier, K. J., Cooper, A. B., Davies-Colley, R. J., Rutherford, J. C., Smith, C. M., Williamson,
645 R. B., 1995. Managing riparian zones. A contribution to protecting New Zealand's rivers

646 and streams. Volumes I & II. NIWA, Department of Conservation. Science Publications,
647 PO Box 10, 420.

648 Cuttle, S. P., Macleod, C. J. A., Chadwick, D. R., Scholefield, D., Haygarth, P. M., Newell-
649 Price, P., Shepherd, B.J. Chambers, Humphrey, R., 2007. An inventory of methods to
650 control diffuse water pollution from agriculture (DWPA). Defra ES0203, London.

651 Davenport, A. J., Gurnell, A. M., Armitage, P. D., 2004. Habitat survey and classification of
652 urban rivers. *River Research and Applications* 20, 687-704.

653 De Groot, R., Brander, L., Van Der Ploeg, S., Costanza, R., Bernard, F., Braat, Let al., 2012.
654 Global estimates of the value of ecosystems and their services in monetary units.
655 *Ecosystem Services* 1, 50-61.

656 Décamps, H., Planty-Tabacchi, A.M. Tabacchi, E., 1995 Changes in the hydrological regime
657 and invasions by plant species along riparian systems of the Adour River, France.
658 *Regulated Rivers: Research and Management* 11, 23–33.

659 ~~Defra, 2004. Summary of Responses to the Joint Defra HM Treasury Consultation~~
660 ~~‘Developing Measures to Promote Catchment Sensitive Farming’. Defra, London.~~

661 Dudgeon, D., Arthington, A. and Gessner, M., 2006. Freshwater biodiversity: importance,
662 threats, status and conservation challenges. *Biological Reviews* 81, 163-182.

663 Dworak, T., Berglund, M., Grandmougin, B., Mattheiss, V., Holen, S., 2009. International
664 review on payment schemes for wet buffer strips and other types of wet zones along
665 privately owned land. Study for RWS-Waterdienst. Ecologic Institute, Berlin/Wien.

666 Erba, S., Buffagni, A., Holmes, N., O’Hare, M., Scarlett, P., Stenico, A., 2006. Preliminary
667 testing of river habitat survey features for the aims of the wfd hydro-morphological

668 assessment: an overview from the STAR Project. The Ecological Status of European
 669 Rivers: Evaluation and Intercalibration of Assessment Methods, 281-296.

670 Erisman, J. W., Galloway, J. N., Seitzinger, S., Bleeker, A., Dise, N. B., Petrescu, Leach, A. R.
 671 de Vries, W., 2013. Consequences of human modification of the global nitrogen
 672 cycle. Philosophical Transactions of the Royal Society B, 368, 20130116.

673 European Commission, 2012. Report from the Commission to the European Parliament and
 674 the Council on the implementation of the Water Framework Directive (2000/60/EC). River
 675 Basin Management Plans. Available at: [http://ec.europa.eu/environment/water/water-](http://ec.europa.eu/environment/water/water-framework/pdf/3rd_report/CWD-2012-379_EN-Vol3_UK.pdf)
 676 [framework/pdf/3rd_report/CWD-2012-379_EN-Vol3_UK.pdf](http://ec.europa.eu/environment/water/water-framework/pdf/3rd_report/CWD-2012-379_EN-Vol3_UK.pdf)

677 Fischer, R. A., Martin, C. O., Ratti, J. T., Guidice, J., 2001. Riparian terminology: confusion
 678 and clarification. EMRRP Technical Note Series. U.S. Army Engineer Research and
 679 Development Center, Vicksburg, MS, USA.

680 Forestry Commission (FC), 2017. The UK forestry standard. Forestry commission, Edinburgh.
 681 Available at: FCFC001/FC(ECD/JW)/eBOOK/JUL 17

682 García-Orenes, F., Morugán-Coronado, A., Zornoza, R., Scow, K., 2013. Changes in soil
 683 microbial community structure influenced by agricultural management practices in a
 684 Mediterranean agro-ecosystem. PloS one 8, e80522.

685 González del Tánago, M., García de Jalón, D., 2006. Attributes for assessing the environmental
 686 quality of riparian zones. Limnetica 25, 389-402.

687 Grabowski, R. C., Gurnell, A. M., 2016. Diagnosing problems of fine sediment delivery and
 688 transfer in a lowland catchment. Aquatic Sciences 78, 95-106.

689 Gurnell, A. M., Grabowski, R. C., 2016. Vegetation–Hydrogeomorphology Interactions in a
 690 Low- Energy, Human- Impacted River. River Research and Applications 32, 202-215.

691 Halliday, S. J., Skeffington, R. A., Wade, A. J., Bowes, M. J., Read, D. S., Jarvie, H. P.,
 692 Loewenthal, M., 2016. Riparian shading controls instream spring phytoplankton and
 693 benthic algal growth. *Environmental Science: Processes and Impacts* 18, 677-689.

694 Harrison, S. S. C., Pretty, J. L., Shepherd, D., Hildrew, A. G., Smith, C., Hey, R. D., 2004. The
 695 effect of instream rehabilitation structures on macroinvertebrates in lowland
 696 rivers. *Journal of Applied Ecology* 41, 1140-1154.

697 Hawes, E., Smith, M., 2005. Riparian buffer zones: Functions and recommended widths. *Yale*
 698 *School of Forestry and Environmental Studies* 15, 1-15

699 Hayhow, D.B., Burns, F., Eaton, M.A., Al Fulaij, N., August, T.A., Babey, L., Bacon, L.,
 700 Bingham, C., Boswell, J., Boughey, K.L., Bereton, T., Brookman, E., Brooks,
 701 D.R., Bullock, D.L., Burke O., Collins, M., Corbert, L., Cornish, N., De Massimi, S.,
 702 Densham, J., Dunn, E., Elliott S., Gent, T., Godber, J., Hamilton, S., Havery, S., Hawkins,
 703 S., Henney, J., Holmes, K., Hutchinson, N., Isaac, N.J.B., Johns, D., Macadam, C.R.,
 704 Mathews, F., Nicolet, P., Noble, D.G., Outhwaite, C.L., Powney, G.D., Richardson, P.,
 705 Roy, D.B., Sims, D., Smart, S., Stevenson, K., Stroud, R.A., Walker, K.J., Webb, J.R.,
 706 Webb T.J., Wyinde, R., Gregory, R.D., 2016. *State of Nature 2016. The State of Nature*
 707 *Partnership*.

708 Hefting, M., Clement, J. C., Dowrick, D., Cosandey, A. C., Bernal, S., Cimpian, C., Pinay, G.,
 709 2004. Water table elevation controls on soil nitrogen cycling in riparian wetlands along
 710 a European climatic gradient. *Biogeochemistry* 67, 113-134.

711 Hickey, M. B. C., Doran, B., 2004. A review of the efficiency of buffer strips for the
 712 maintenance and enhancement of riparian ecosystems. *Water Quality Research Journal of*
 713 *Canada* 39, 311-317.

714 Hill, A. R., 1996. Nitrate removal in stream riparian zones. *Journal of Environmental Quality*
715 25, 743-755.

716 Hladyz, S., Åbjörnsson, K., Giller, P. S., Woodward, G., 2011. Impacts of an aggressive
717 riparian invader on community structure and ecosystem functioning in stream food
718 webs. *Journal of Applied Ecology* 48, 443-452.

719 Holden, J., Haygarth, P. M., Dunn, N., Harris, J., Harris, R. C., Humble, A., Jenkins, A.,
720 MacDonald, J., McGonigle, D.F., Meacham, T., Orr, H. G., Pearson, P.L, Ross,
721 M., Sapiets, A., Benton, T., 2017. Water quality and UK agriculture: challenges and
722 opportunities. *Wiley Interdisciplinary Reviews: Water* 4, 1-16.

723 House of Lords, 2017. Brexit: environment and climate change 12th Report. Available at:
724 <https://publications.parliament.uk/pa/ld201617/ldselect/ldcom/109/109.pdf>

725 House, A. R., Thompson, J. R., Acreman, M. C., 2016a. Projecting impacts of climate change
726 on hydrological conditions and biotic responses in a chalk valley riparian
727 wetland. *Journal of Hydrology* 534, 178-192.

728 House, A. R., Thompson, J. R., Sorensen, J. P. R., Roberts, C., Acreman, M. C., 2016b.
729 Modelling groundwater/surface water interaction in a managed riparian chalk valley
730 wetland. *Hydrological Processes* 30, 447-462.

731 Hulme, P. E., Bremner, E. T., 2006. Assessing the impact of *Impatiens glandulifera* on riparian
732 habitats: partitioning diversity components following species removal. *Journal of*
733 *Applied Ecology* 43, 43-50.

734 Hutchins, M. G., 2012. What impact might mitigation of diffuse nitrate pollution have on river
735 water quality in a rural catchment? *Journal of Environmental Management* 109, 19-26.

736 Hutchins, M. G., Johnson, A. C., Deflandre-Vlandas, A., Comber, S., Posen, P., Boorman, D.,
 737 2010. Which offers more scope to suppress river phytoplankton blooms: reducing
 738 nutrient pollution or riparian shading? *Science of The Total Environment* 408, 5065-
 739 5077.

740 Ingram, Julie, 2008 "Are farmers in England equipped to meet the knowledge challenge of
 741 sustainable soil management? An analysis of farmer and advisor views." *Journal of*
 742 *Environmental Management* 86, 214-228.

743 IPCC, 2014. *Climate Change, 2014: Impacts, Adaptation, and Vulnerability. Part A: Global*
 744 *and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report*
 745 *of the Intergovernmental Panel on Climate Change.* (eds Field CB, Barros VR, Dokken
 746 DJ et al.), pp. 1–32. Cambridge University Press, Cambridge, UK and New York, NY,
 747 USA.

748 Jangid, K., Williams, M. A., Franzluebbers, A. J., Schmidt, T. M., Coleman, D. C., Whitman,
 749 W. B., 2011. Land-use history has a stronger impact on soil microbial community
 750 composition than aboveground vegetation and soil properties. *Soil Biology and*
 751 *Biochemistry* 43, 2184-2193.

752 Jarvie, H. P., Haygarth, P. M., Neal, C., Butler, P., Smith, B., Naden, P. S., Joynes, A., Neal,
 753 M., Wickham H., Armstrong, L., Harman, S., Palmer-Felgate, E.J., 2008. Stream water
 754 chemistry and quality along an upland–lowland rural land-use continuum, south west
 755 England. *Journal of Hydrology* 350, 215-231.

756 ~~Johnson, R., Watson, M., McQuat, E., 2008. The way forward for natural flood management~~
 757 ~~in Scotland. Report for Scottish Environment LINK MNV/WWF/0808/1038. Mountain~~
 758 ~~Environments Ltd, Callander.~~

759 Jontos, R., 2004. Vegetative buffers for water quality protection: an introduction and guidance
760 document. Connecticut Association of Wetland Scientists White Paper on Vegetative
761 Buffers. Draft version, 1, 22.

762 Kaine, G., Young, J., Lourey, R., Greenhalgh, S., 2017. Policy choice framework: guiding
763 policy makers in changing farmer behavior. *Ecology and Society* 22,2.

764 Kay, P., Edwards, A. C., Foulger, M., 2009. A review of the efficacy of contemporary
765 agricultural stewardship measures for ameliorating water pollution problems of key
766 concern to the UK water industry. *Agricultural Systems* 99, 67-75.

767 Kohm, K. A., Franklin, J. F. (Eds.), 1997. Creating a forestry for the 21st century: The science
768 of ecosystem management. Island Press.

769 Kronvang, B., Andersen, H. E., Nordemann, P. J., Heckrath, G., Rubaek, G., Kjaergaard, C.,
770 2011. Effect of 10 m buffer strips on phosphorous losses. Notes to the Danish
771 Environmental Ministry. Aarhus University, Aarhus, Denmark.

772 Lapworth, D. J., Gooddy, D. C., Allen, D., Old, G. H., 2009. Understanding groundwater,
773 surface water, and hyporheic zone biogeochemical processes in a Chalk catchment using
774 fluorescence properties of dissolved and colloidal organic matter. *Journal of Geophysical*
775 *Research: Biogeosciences* 114.

776 Lymperopoulou, D. S., Adams, R. I., Lindow, S. E., 2016. Contribution of vegetation to the
777 microbial composition of nearby outdoor air. *Applied and Environmental Microbiology*,
778 82, 3822-3833.

779 Machefert, S. E., Dise, N. B., 2004. Hydrological controls on denitrification in riparian
780 ecosystems. *Hydrology and Earth System Sciences Discussions* 8, 686-694.

781 Maes, J., Liqueste, C., Teller, A., Erhard, M., Paracchini, M. L., Barredo, J. I., et al., 2016. An
 782 indicator framework for assessing ecosystem services in support of the EU Biodiversity
 783 Strategy to 2020. *Ecosystem services* 17, 14-23.

784 Maltby, E., Acreman, M., Blackwell, M. S. A., Everard, M., Morris, J., 2013. The challenges
 785 and implications of linking wetland science to policy in agricultural landscapes–
 786 experience from the UK National Ecosystem Assessment. *Ecological Engineering* 56,
 787 121-133.

788 Maltby, E., Ormerod, S., Acreman, M., Dunbar, M., Jenkins, A., Maberly, S., Newman,
 789 J., Blackwell, M., Ward, R., 2014. Freshwaters: openwaters, wetlands and floodplains
 790 [chapter 9]. In: UK National Ecosystem Assessment: understanding nature's value to
 791 society. Technical Report. Cambridge, UK, UNEP-WCMC, 295-360.

792 Manchester, S. J., Bullock, J. M., 2000. The impacts of non- native species on UK biodiversity
 793 and the effectiveness of control. *Journal of Applied Ecology* 37, 845-864.

794 Maskell, L. C., Bullock, J. M., Smart, S. M., Thompson, K., Hulme, P. E., 2006. The
 795 distribution and habitat associations of non-native plant species in urban riparian
 796 habitats. *Journal of Vegetation Science* 17, 499-508.

797 McCall, S. J., Hale, M. S., Smith, J. T., Read, D. S., Bowes, M. J., 2017. Impacts of phosphorus
 798 concentration and light intensity on river periphyton biomass and community
 799 structure. *Hydrobiologia* 1, 315-330.

800 McGonigle, D. F., Harris, R. C., McCamphill, C., Kirk, S., Dils, R., Macdonald, J., Bailey, S.,
 801 2012. Towards a more strategic approach to research to support catchment-based policy
 802 approaches to mitigate agricultural water pollution: A UK case-study. *Environmental*
 803 *Science and Policy* 24, 4-14.

804 McKay, S. F., King, A. J., 2006. Potential ecological effects of water extraction in small,
805 unregulated streams. *River Research and Applications* 22, 1023-1037.

806 McVittie, A., Norton, L., Martin-Ortega, J., Siameti, I., Glenk, K., Aalders, I., 2015.
807 Operationalizing an ecosystem services-based approach using Bayesian Belief
808 Networks: an application to riparian buffer strips. *Ecological Economics* 110, 15-27.

809 Millard, P., Singh, B. K., 2010. Does grassland vegetation drive soil microbial diversity?
810 Nutrient Cycling in Agroecosystems 88, 147-158.

811 Moggridge, H. L., Gurnell, A. M., 2010. Hydrological controls on the transport and deposition
812 of plant propagules within riparian zones. *River Research and Applications* 26, 512-527.

813 Moro, D., Gadal, S., 2008. Benefits of habitat restoration to small mammal diversity and
814 abundance in a pastoral agricultural landscape in mid-Wales. *Biodiversity and*
815 *Conservation in Europe*, 301-315.

816 ~~Morris, J., Camino, M., 2011. UK national ecosystem assessment. Cambridge, UK.~~

817 Nagasaka, A., Nakamura, F., 1999. The influences of land-use changes on hydrology and
818 riparian environment in a northern Japanese landscape. *Landscape Ecology* 14, 543-556.

819 Natural England, 2015. Countryside stewardship manual. NE608; Natural England,
820 [https://www.gov.uk/government/publications/countryside-stewardship-manual-print-](https://www.gov.uk/government/publications/countryside-stewardship-manual-print-version)
821 [version.](https://www.gov.uk/government/publications/countryside-stewardship-manual-print-version)

822 Natural Resources Wales (NRW), 2017. A guide to your rights and responsibilities of riverside
823 ownership in Wales. Available at: [https://naturalresources.wales/media/680422/living-](https://naturalresources.wales/media/680422/living-on-the-edge-final-jan-2017.pdf)
824 [on-the-edge-final-jan-2017.pdf](https://naturalresources.wales/media/680422/living-on-the-edge-final-jan-2017.pdf)

825 Nisbet, T. R., 2001. The role of forest management in controlling diffuse pollution in UK
826 forestry. *Forest Ecology and Management* 143, 215-226.

827 Orr, H. G., Johnson, M. F., Wilby, R. L., Hatton- Ellis, T., Broadmeadow, S., 2015. What else
828 do managers need to know about warming rivers? A United Kingdom perspective. Wiley
829 Interdisciplinary Reviews: Water 2, 55-64.

830 Orr, P., Colby, B., 2004. Groundwater management institutions to protect riparian habitat.
831 Water Resources Research, 40.

832 Osei, N. A., Gurnell, A. M., Harvey, G. L., 2015. The role of large wood in retaining fine
833 sediment, organic matter and plant propagules in a small, single-thread forest
834 river. Geomorphology 235, 77-87.

835 Parkyn, S. M., Davies-Colley, R. J., Cooper, A. B., Stroud, M. J., 2005. Predictions of stream
836 nutrient and sediment yield changes following restoration of forested riparian buffers.
837 Ecological Engineering 24, 551-558.

838 Petersen, I., Masters, Z., Hildrew, A. G., Ormerod, S. J., 2004. Dispersal of adult aquatic insects
839 in catchments of differing land use. Journal of Applied Ecology 41, 934-950.

840 Poff, B., Koestner, K. A., Neary, D. G., and Henderson, V., 2011. Threats to riparian
841 ecosystems in Western North America: An analysis of existing literature. Journal of the
842 American Water Resources Association 47, 1241-1254.

843 Pretty, J. N., Mason, C. F., Nedwell, D. B., Hine, R. E., Leaf, S., Dils, R., 2003. Environmental
844 costs of freshwater eutrophication in England and Wales. Environmental Science and
845 Technology 37, 201-208.

846 Pretty, J.N., Brett, C., Gee, D., Hine, R.E., Mason, C.F., Morison, J.I.L., Raven, H., Rayment,
847 M.D., van der Bijl, G., 2000. An assessment of the total external costs of UK agriculture.
848 Agricultural Systems 65, 113–136.

849 Ramsbottom, D., Sayers, P., Panzeri, M., 2012. Climate change risk assessment for the floods
850 and coastal erosion sector. Defra Project Code GA0204. Report to Defra, London, UK.

851 Richardson, J. S., Naiman, R. J., Bisson, P. A., 2012. How did fixed-width buffers become
852 standard practice for protecting freshwaters and their riparian areas from forest harvest
853 practices? *Freshwater Science* 31,232-238

854 Roberts, W. M., Matthews, R. A., Blackwell, M. S., A., Peukert, S., Collins, A. L., Haygarth,
855 P. M., 2013. Microbial biomass phosphorus contributions to phosphorus solubility in
856 riparian vegetated buffer strip soils. *Biology and Fertility of Soils* 49, 1237-1241.

857 Sadler, J. P., Bell, D., Fowles, A., 2004. The hydroecological controls and conservation value
858 of beetles on exposed riverine sediments in England and Wales. *Biological Conservation*
859 118, 41-56.

860 Scholes, R. J., Biggs, R., 2005. A biodiversity intactness index. *Nature* 434, 45-49.

861 Seavy, N. E., Gardali, T., Golet, G. H., Griggs, F. T., Howell, C. A., Kelsey, R., Small, S.,
862 Viers, H. and Weigand, J.F., 2009. Why climate change makes riparian restoration more
863 important than ever: recommendations for practice and research. *Ecological Restoration*
864 27, 330-338.

865 Sinnadurai, P., Jones, T. H., Ormerod, S. J., 2016. Squeezed out: the consequences of riparian
866 zone modification for specialist invertebrates. *Biodiversity and Conservation* 14, 3075-
867 3092.

868 Soulsby, C., Tetzlaff, D., 2008. Towards simple approaches for mean residence time estimation
869 in ungauged basins using tracers and soil distributions. *Journal of Hydrology* 363, 60-74.

870 Steiger, J., Gurnell, A. M., Petts, G. E., 2001. Sediment deposition along the channel margins
871 of a reach of the middle River Severn, UK. *River Research and Applications* 17, 443-
872 460.

873 Stockan, J.A. Fielding, D., 2013 Review of the impact of riparian invasive non-native plant
874 species on freshwater habitats and species. CREW report CD 2013/xx. Available online
875 at: crew.ac.uk/publications.

876 Stromberg, J. C., Beauchamp, V. B., Dixon, M. D., Lite, S. J., Paradzick, C., 2007. Importance
877 of low- flow and high- flow characteristics to restoration of riparian vegetation along
878 rivers in arid south- western United States. *Freshwater Biology* 52, 651-679.

879 Stutter, M. I., Chardon, W. J., Kronvang, B., 2012. Riparian buffer strips as a multifunctional
880 management tool in agricultural landscapes: introduction. *Journal of Environmental*
881 *Quality* 41, 297-303.

882 Sutherland, W. J., Armstrong- brown, S., Armsworth, P. R., Tom, B., Brickland, J., Campbell,
883 C. D. et al., 2006. The identification of 100 ecological questions of high policy relevance
884 in the UK. *Journal of Applied Ecology* 43, 617-627.

885 Sutherland, W. J., Pullin, A. S., Dolman, P. M., Knight, T. M., 2004. The need for evidence-
886 based conservation. *Trends in Ecology Evolution* 19, 305-308.

887 Tanner, R. A., Gange, A. C., 2013. The impact of two non-native plant species on native flora
888 performance: potential implications for habitat restoration. *Plant Ecology* 214, 423-432.

889 Tanner, R. A., Varia, S., Eschen, R., Wood, S., Murphy, S. T., Gange, A. C., 2013. Impacts of
890 an invasive non-native annual weed, *Impatiens glandulifera*, on above-and below-ground
891 invertebrate communities in the United Kingdom. *PloS one* 8, e67271.

892 Terry, J. A., Benskin, C. M. H., Eastoe, E. F., Haygarth, P. M., 2014. Temporal dynamics
 893 between cattle in-stream presence and suspended solids in a headwater
 894 catchment. *Environmental Science: Processes and Impacts* 16, 1570-1577.

895 Tickner, D. P., Angold, P. G., Gurnell, A. M., Mountford, J. O., Sparks, T., 2001. Hydrology
 896 as an influence on invasion: Experimental investigations into competition between the
 897 alien *Impatiens glandulifera* and the native *Urtica dioica* in the UK. *Plant Invasions:
 898 Species Ecology and Ecosystem Management*. Leiden, Netherlands: Blackhuys
 899 Publishers, 159-168.

900 Truscott, A. M., Palmer, S. C. F., Soulsby, C., Hulme, P. E., 2008. Assessing the vulnerability
 901 of riparian vegetation to invasion by *Mimulus guttatus*: relative importance of biotic and
 902 abiotic variables in determining species occurrence and abundance. *Diversity and
 903 Distributions* 14, 412-421.

904 Tscharntke, T., Klein, A. M., Kruess, A., Steffan- Dewenter, I., Thies, C., 2005. Landscape
 905 perspectives on agricultural intensification and biodiversity–ecosystem service
 906 management. *Ecology Letters* 8, 857-874.

907 UK National Ecosystem Assessment (NEA), 2011. The UK National Ecosystem Assessment:
 908 Synthesis of the key Findings. UNEP-WCMC, Cambridge.

909 Vaughan, I. P., 2010. Habitat indices for rivers: derivation and applications. *Aquatic
 910 Conservation: Marine and Freshwater Ecosystems* 20.

911 Verry, E., Dolloff, C., Manning, M., 2004. Riparian ecotone: a functional definition and
 912 delineation for resource assessment. *Water, Air, & Soil Pollution: Focus* 4, 67-94.

913 Vidon, P. G., Hill, A. R., 2004. Landscape controls on the hydrology of stream riparian zones.
 914 *Journal of Hydrology* 292, 210-228.

915 Vinten, A., Sample, J., Ibiyemi, A., Abdul-Salam, Y., Stutter, M., 2017. A tool for cost-
 916 effectiveness analysis of field scale sediment-bound phosphorus mitigation measures and
 917 application to analysis of spatial and temporal targeting in the Lunan Water catchment,
 918 Scotland. *Science of The Total Environment* 586, 631-641.

919 Wadsworth, R. A., Collingham, Y. C., Willis, S. G., Huntley, B., Hulme, P. E., 2000.
 920 Simulating the spread and management of alien riparian weeds: are they out of
 921 control? *Journal of Applied Ecology* 37, 28-38.

922 Wales Audit Office (WAO), 2016. The development of Natural Resources Wales. Available
 923 at:
 924 [http://www.senedd.assembly.wales/documents/s61640/Auditor%20General%20for%20](http://www.senedd.assembly.wales/documents/s61640/Auditor%20General%20for%20Wales%20Report%20The%20Development%20of%20Natural%20Resources%20Wales%20February%202016.pdf)
 925 [Wales%20Report%20The%20Development%20of%20Natural%20Resources%20](http://www.senedd.assembly.wales/documents/s61640/Auditor%20General%20for%20Wales%20Report%20The%20Development%20of%20Natural%20Resources%20Wales%20February%202016.pdf)
 926 [Wales%20February%202016.pdf](http://www.senedd.assembly.wales/documents/s61640/Auditor%20General%20for%20Wales%20Report%20The%20Development%20of%20Natural%20Resources%20Wales%20February%202016.pdf)

927 Walker, N. F., Hulme, P. E., Hoelzel, A. R., 2009. Population genetics of an invasive riparian
 928 species, *Impatiens glandulifera*. *Plant Ecology*, 203(2), 243.

929 Warren, D. R., Collins, S. M., Purvis, E. M., Kaylor, M. J., Bechtold, H. A., 2017. Spatial
 930 variability in light yields colimitation of primary production by both light and nutrients
 931 in a forested stream ecosystem. *Ecosystems* 20, 198-210.

932 Wenger, S., 1999. A review of the scientific literature on riparian buffer width, extent and
 933 vegetation. Institute of Ecology, University of Georgia, Athens (1999).

934 Wilby, R. L., Johnson, M. F., Toone, J. A., 2014. Nocturnal river water temperatures: spatial
 935 and temporal variations. *Science of the Total Environment* 482, 157-173.

936 Wilkinson, M. E., Quinn, P. F., Barber, N. J., Jonczyk, J., 2014. A framework for managing
937 runoff and pollution in the rural landscape using a Catchment Systems Engineering
938 approach. *Science of the Total Environment* 468, 1245-1254.

939 Wipfli M.S., 2005. Trophic linkages between headwater forests and downstream fish habitats:
940 implications for forest and fish management. *Landscape and Urban Planning* 72, 205–
941 213.

942