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Recent changes in riparian and floodplain vegetation in England and Wales and its geomorphic implications

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Abstract

Recent river studies in the United Kingdom have observed an increase in riparian vegetation and its potential impact on river channel change and sedimentation. Here, we quantify changes in floodplain and riparian vegetation during the first two decades of the 21st century along reaches of eight gravel-bed rivers in England and Wales that exhibit varied active and stable, single and multi-thread planforms. The analysis employs information drawn from open-access sources including national LiDAR surveys and the photographic analysis of repeat aerial and satellite imagery. Most reaches show an increase in woody vegetation across their floodplains reflecting both natural colonisation and deliberate planting, and all but one of the reaches show an increase in woody riparian vegetation cover along their riverbanks. Of the six reaches that have exposed riverine sediments, five show a reduction in exposed sediment area as a result of vegetation encroachment. Contrasts in the rate, extent and location of riparian change were associated with the stability of the channel planform, with differences seen between stable and more active reaches. The significance of riparian woodland in promoting riverbank stability is demonstrated. Riparian vegetation development varies between river reaches, largely in response to differing rates of channel movement but also because of multiple and diverse local decisions regarding the management of in-channel and channel-adjacent vegetation by landowners rather than a single national policy. We consider the relevance of our findings and the value of remote monitoring for future river management interventions.

KEYWORDS
aerial imagery, gravel bed rivers, LiDAR, riparian vegetation change, river restoration, United Kingdom

1 | INTRODUCTION

Naturally functioning riparian zones have long been recognised as crucial for sustaining biodiversity at a variety of spatial and temporal scales and for offering dynamic, complex assemblages of habitats (Gregory et al., 1991; Lind et al., 2019; Naiman et al., 1993, 2005; Tabacchi et al., 1998). In the context of climate change, well-developed riparian vegetation can also help to shade and cool rivers, further sustaining habitats for a variety of organisms (Marteau et al., 2022; Woodland Trust, 2016). In recent decades, research on riparian vegetation has increasingly highlighted its impacts on fluvial processes and forms (see reviews by Corenblit et al., 2007, 2009, 2015; Gurnell, 2014; Gurnell et al., 2012, 2016). Riparian vegetation impacts on fluvial processes include changes in flow resistance and the propagation of flood waves (Anderson et al., 2006; Darby, 1999; James & Makoa, 2006; Lee et al., 2022), near-bank turbulence (McBride et al., 2007), the retention of sediments (Bertoldi & Gurnell, 2020; Corenblit et al., 2009, 2014) and the erosion and stability of riverbanks (Beeson & Doyle, 1995; Pizzuto et al., 2010; Pollen-Bankhead & Simon, 2010; Simon & Collison, 2002) and floodplain surfaces (Griffin & Smith, 2004). These changes have impacts on fluvial forms including adjustments in river channel size (Allmendinger et al., 2005), position and lateral dynamics (Camporeale & Ridolfi, 2010; Micheli & Kirchner, 2002; Perucca et al., 2007) and geomorphological style (Dawson et al., 2022; Gurnell et al., 2009; Tal & Paola, 2010; Török & Parker, 2022).

In the heavily developed landscapes of much of England and Wales, natural riparian and floodplain vegetation has long been cleared, frequently to permit agricultural development up to the margins of rivers, or has been degraded, notably in response to grazing pressure (Goudie & Migon, 2020). In addition, the presence of riparian woodland has often been the source of contention with residents who have been subject to flooding and have called for its removal (Environment Agency, 2022b; McEwan, 2022). A combination of changes in policies and controls regarding the ways in which riparian, farming and other floodplain activities are prioritised and regulated, including the discontinued EU set-aside policy and the introduction of Countryside Stewardship grants (DEFRA, 2018, 2023), may have resulted in some recovery of riparian and floodplain vegetation, providing a focus for the present research. Given the recent nature of these policy changes the current impact is likely to be slight but of increasing importance in future.

In recent decades there has been increasing recognition of the potential impact of climate and environmental change. The development of riparian vegetation should be considered in a context where there have been increases in the average temperatures across the United Kingdom of 0.8°C and increases in rainfall amounts of 7.3%, comparing the periods 1961–1990 and 1991–2020 (Kendon et al., 2022). It is postulated that these changes will affect both vegetation growth (Ray et al., 2010) and flood frequency (Hannaford et al., 2021) but with considerable regional variation. Areas in southern, central and eastern parts of the United Kingdom are likely to experience soil moisture deficits reducing tree growth whilst greater flood magnitude and frequency in northern and western area may result in the frequent removal of riparian vegetation.

Studies of the interactions among vegetation and fluvial processes have involved a variety of spatial scales from local field observations and experiments relating to the colonisation and growth performance of individual species and their effects (Asaeda et al., 2011; Corenblit et al., 2016; Francis & Gurnell, 2006; Moggridge & Gurnell, 2009; Sarneel et al., 2014) through reach scale interactions between aquatic or riparian vegetation and landform construction and turnover (Francis et al., 2009; Gurnell & Bertoldi, 2022; Jerin, 2019; Oorschot et al., 2016) to changes in the river's flow and sediment transport regimes in response to floodplain or catchment-wide changes in vegetation cover and related land management practices (Farguell et al., 2022; Kreutzweiser et al., 2009; Liébault et al., 2005; Scorpio & Piégay, 2021; Smith, 2004; Zhang et al., 2017). These may range over timescales from days to millennia, but from a river management perspective, knowledge of riparian vegetation changes over recent decades is particularly valuable considering the environmental and river management/conservation changes now affecting riparian habitats and river channel stability. Given ongoing climate change, together with changes in governmental environmental policies that are impacting rivers, it is important to establish quantitative evidence of riparian vegetation changes against which any present or future management interventions may be judged.

Therefore, this study quantifies changes over approximately the last two decades along eight extended river reaches in England and Wales, with a view to capturing and estimating the geomorphological and management relevance of such recent changes. It uses readily available survey evidence and an applicable methodology, including information in the public domain such as aerial and satellite imagery and the UK National LiDAR survey and Vegetation Object Model (Environment Agency, 2022c). This aims at supporting practical objectives in the management of extended river reaches: (a) we examine whether and where riparian vegetation has expanded across reaches of eight different river systems; (b) we establish whether any observed changes in riparian and floodplain vegetation vary with the geomorphological style of river; and (c) we assess the potential of any such vegetation changes to influence the geomorphological development of the eight investigated reaches.

2 | METHODS

2.1 | Study reaches

Eight rivers were identified that represented broad coverage of the geomorphological styles that are currently present in the middle reaches of rivers in England and Wales (Figures 1 and 2 and Tables 1 and 2). In all but one case, it was possible to select a river reach for analysis that had previously been subject to geomorphological investigation (Table 3). All selected reaches are designated as 'Main River' by the Environment Agency, meaning that river management activities and other interventions are regulated via environmental permits. In addition, several of the reaches fall within areas designated as Sites of Special Scientific Interest (SSSI) or Special Area of Conservation (SAC; Table 3) and thus have management plans that affect riparian vegetation.

One reach, several kilometres in length (maximum = 7.0, minimum = 4.4), was selected for detailed study from each river (Table 3). All are gravel-bed reaches, are representative of the broad geomorphological style of the middle reaches of each river and have few settlements and little transport infrastructure that could impede channel dynamics.

The research utilised public domain imagery available through Google Earth or obtained from commercial sources and LiDAR data available from Government data portals in England and Wales (Table 3).

The outer limit of the 'floodplain' for each reach was defined as the boundary enclosing the Environment Agency's Flood Zones 2 and 3. This is an area within which flooding is likely to occur more frequently than once in 100 (zone 2) and 1000 (zone 3) years.

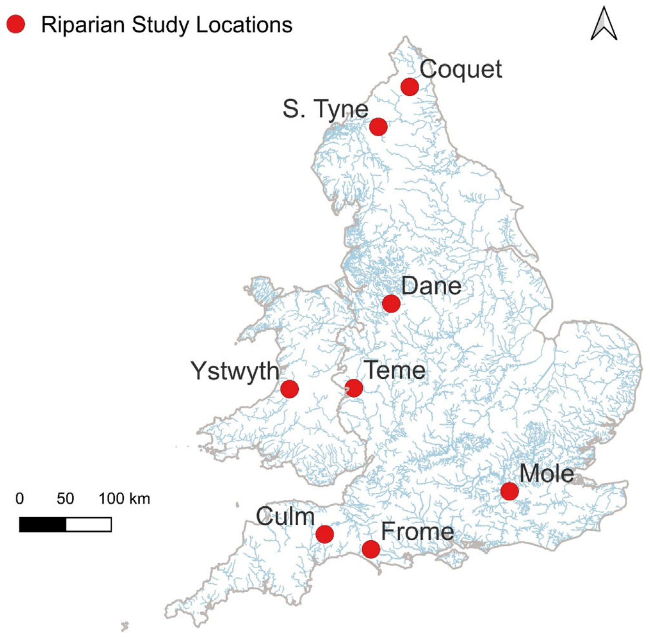

FIGURE 1 Riparian study locations in middle reaches of gravel-bed rivers of England and Wales (United Kingdom). [Color figure can be viewed at wileyonlinelibrary.com]

The 'riparian zone' was defined for this study as the area of floodplain occupied by the bankfull channel including any exposed riverine sediments (Brewer et al., 2001; Eyre & Lott, 1997; O'Callaghan et al., 2013; Petts et al., 2000) plus any other parts of the floodplain area enclosed within a strip equivalent to 2/3rd of the bankfull channel width away from the bankfull channel margins (following de Sosa et al., 2018; New South Wales Government, 2012) (Figure 3). The boundaries of the bankfull channel were identified for each date when vegetation patterns were assessed. Interpretation error was minimised by using a consistent protocol following the stable vegetated boundary that best approximates bankfull width (Donovan et al., 2019). These boundaries were initially interpreted and digitised based on Google Earth imagery and then corroborated and, where necessary, adjusted using evidence from LiDAR surveys. Based on an analysis of positional accuracy undertaken for the River Teme (Dawson & Lewin, 2023), the root-mean-square error (RSME) of bank positions were estimated at ca. 1–1.5 m, like that determined by Donovan et al. (2019).

2.2 | Assessment of vegetation coverage and change

Several different computations were applied to all eight reaches to explore vegetation coverage, type and change over approximately two decades.

First, detailed changes in the distribution of vegetation along each reach were identified using a combination of aerial and satellite

FIGURE 2 Oblique aerial images of the eight study reaches viewed downstream. Images sourced from Google Earth (sources and copyright information provided in Table 1). [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 1 The eight gravel-bed study reaches and their geomorphological characteristics extracted from LiDAR data, satellite imagery, published information and the authors' field knowledge.

River (reach) name	River reach planform style and stability	Channel sediments	In-channel bar forms	Floodplain relief	Channel gradient	Floodplain gradient	Average bankfull channel width (m)	Average floodplain width (m)	Average riparian zone width (m)
Coquet (Rothbury)	Active meandering with a high degree of lateral instability	Medium to coarse gravel with overbank sediments comprising well sorted sands and sandy silts	Extensive un-vegetated point-bars associated with channel migration	Swales and palaeo-channels widely evident	0.0016	0.0020	36.5	350	84.7
Culm (Uffcombe)	Meandering/ anastomosing	Medium to coarse gravel with bank sediments comprising well sorted sands and sandy silts	Lateral and mid channel partly vegetated and un-vegetated bars associated with bank migration	Planar with evidence of former anasto-mosing channels	0.0041	0.0072	12.7	300	29.2
Dane (Congleton)	Active meandering	Medium to coarse gravel with overbank sediments comprising well sorted sands and sandy silts	Lateral and mid-channel partly vegetated and un-vegetated bars associated with channel migration. Local presence of vegetated islands	Swales and remnant point bar forms associated with channel migration in zone bounded by a low terrace	0.0018	0.0036	16.1	320	37.3
Frome (Maiden Newton)	Stable meandering	Medium to coarse gravel with bank sediments comprising of sandy silts	Stable banks with few low bar forms. Local presence of vegetated islands	Tabular with local relief related to former meander cut-offs	0.0025	0.0034	8.6	190	19.9
Mole (Cobham)	Stable meandering	Medium gravel with bank sediments comprising of sandy silts	Stable banks with few low bar forms	Tabular. Little floodplain relief	0.0011	0.0017	14.9	500	34.6
South Tyne (Lambley)	Wandering	Coarse gravel with overbank sediments comprising well sorted sands and sandy silts	Extensive lateral bars. Locally, mid channel bar forms and channel division. Bars partly vegetated with extensive un-vegetated areas	Confined floodplain, locally showing remnant bar and channel relief	0.0061	0.0072	58	180	134.6

TABLE 1 (Continued)

River (reach) name	River reach planform style and stability	Channel sediments	In-channel bar forms	Floodplain relief	Channel gradient	Floodplain gradient	Average bankfull channel width (m)	Average floodplain width (m)	Average riparian zone width (m)
Teme (Leint-Wardine)	Active meandering	Medium to coarse gravel with overbank sediments comprising well sorted sands and sandy silts	Extensive lateral and mid- channel partly vegetated and un-vegetated bars associated with channel migration. Locally, mid channel bar forms.	Locally extensive palaeo-channels and meander cut-offs	0.0011	0.0018	18.9	800 (184–1200)	43.8
Ystwyth (Grog-Wynion)	Active meandering/ wandering	Medium to coarse gravel, with limited sandy overbank sediments	Extensive lateral and point, largely un-vegetated bars resulting from channel migration. Some mid-channel bar forms and channel division	Abandoned channels from formerly braided/wandering planform	0.0031	0.0032	37.1	200	86.1

Note: The bankfull width is defined by the limits of the stable vegetated boundary at the channel edge following Donovan et al. (2019).

TABLE 2 Selected catchment and climatic characteristics.

Station	Base flow index	Standard average annual rainfall (mm)	Median catchment altitude (m)	Overall catchment steepness m/km	Proportion of time catchment soils are wet	Mean annual temperatures
Coquest (Rothbury)	0.4	905	277	140.7	0.45	8.5
Culm (Woodmill)	0.58	971	142.4	70.1	0.44	10.4
Dane (Hulme Walfield)	0.41	1017	241.4	113.8	0.5	9.1
Frome (Dorchester)	0.78	1010	150.9	100.4	0.38	10.9
Mole (Esher)	0.51	760	73.8	46.5	0.35	10.7
South Tyne (Alston)	0.27	1522	519.3	119	0.64	7.8
Teme (Tenbury)	0.61	841	214.4	116.1	0.35	9
Ystwyth (Penparcau)	0.36	1456	250	159.8	0.63	8.7

Note: Catchment data are taken from the closest proximate hydrometric gauging station in the National River Flow Archive (Centre for Ecology and Hydrology, 2023). Climate data from Climate-Data.org (2023).

imagery and LiDAR data as has been used previously in the reconstruction of vegetation and related fluvial landform change (Bertoldi et al., 2011; Dufour et al., 2012; Fernandes et al., 2011; Garófano-Gómez et al., 2013; Huylenbroeck et al., 2020; Nagler et al., 2005; Rodríguez-González et al., 2017). The image analysis and digitisation were undertaken using QGIS v3.28 (QGIS Development Team, 2023). Using a similar approach to Bachiller-Jareno et al. (2019), areas of woodland and smaller patches of floodplain trees and shrubs over 2.5 m in height in 2020–2021 were delimited for the entire floodplain area using the National LiDAR Survey Vegetation Object Model (Environment Agency, 2022c). This LiDAR-derived raster image was vectorised to provide a first pass representation of all vegetation over 2.5 m in height. The mapped areas were then adjusted manually using information from 2020 to 2021 Google Earth imagery to ensure that they enclosed the entire visible canopy and included trees not identified in the Vegetation Object Model. Hedgerows, and scrub <2.5 m in height and in-channel terrestrial plants were then identified visually from the aerial and satellite imagery and were manually digitised at the same scale to provide complete coverage of the woody floodplain vegetation. Extending the approach of Hooke and Chen (2016), the vegetation types were further subdivided and classified into eight groups based on visual interpretation of available images, as defined in Table 4. The visual interpretations and resulting vegetation classification was validated in the field at three of the studied reaches (Mole—July 2022, Teme—May 2023 and Ystwyth—October 2021).

The 2020–2022 vegetation distribution was then compared and edited using available imagery to provide vegetation distributions for the period 1999–2003 for all reaches apart from the Dane (which was edited for the 2006 vegetation distribution). These distributions reflected image availability and provided two data sets for each reach separated by approximately two decades. These data sets supported the visual assessment of changes in vegetation, particularly woody vegetation, within each reach and the identification of areas of recent woody vegetation development. Where significant seasonal differences affected the images used for two survey dates, the interpreted vegetation extent was checked against other available aerial surveys obtained at earlier or later dates to avoid seasonal differences in the vegetation affecting the outcomes of the two-decade comparisons.

A second analysis explored aggregate vegetation cover changes over the riparian zone, the floodplain and the area of exposed riverine sediments. The area and percentage of the riparian zone occupied by (a) woodland, scrub and in-channel terrestrial vegetation and (b) woodland and scrub alone were computed. Within the floodplain, (c) the percentage area under all woody vegetation and (d) under hedgerows alone were computed. The area occupied by exposed, unvegetated, riverine sediments was then considered and (e) any changes in area between the two dates were computed.

An exploratory analysis was undertaken using multiple linear regression to consider whether the observed variations in the extent and rate of change of riparian cover could be explained by regional variation using catchment and climatic data (Table 3) (Centre for Ecology and Hydrology, 2023; Climate-Data.org, 2023).

Two further analyses were undertaken on the six river reaches dominated by progressive lateral erosion during the period of analysis. The South Tyne and Ystwyth reaches, where significant avulsions and channel switching had taken place, were excluded. Firstly, using the 2020–2021 data sets the relationship between the bankfull channel width and bounding vegetation was explored (Micheli et al., 2004; Török & Parker, 2022). Within each studied reach, bankfull widths were extracted at 100 m intervals along the entire reach and then the margins of each measured width were classified according to whether the channel was bounded by woody vegetation on two channel margins, one channel margin or no channel margins to assess whether there was any statistically significant difference in channel width associated with these three cover classes.

TABLE 3 The eight study reaches, identifying previous published scientific studies, conservation designations (Sites of Special Scientific Interest [SSSI], Special Area of Conservation [SAC]) and any formal management plans associated with each reach.

River (reach) name	Reach length (km)	Previous scientific studies	Conservation designation (SSSI/SAC)	Management plans	Location (UTM coordinates) zone 30 U	Image sources (date and provider)	LiDAR survey dates
Coquet (Rothbury)	7.0	Charlton et al., 2003; Fuller et al., 2005	SSSI 1996	NRA 1994	566,785 m E 6129217 m N	12/2002: Google: ©Infoterra & Bluesky 10/2022: Google ©CNES/Airbus	1998 2018
Culm (Uffcombe)	4.4	Brown et al., 2021; Hooke, 1979	No	Blackdown AONB (2023)	479,127 m E 5,639,916 m N	6/2002: Google: ©Infoterra & Bluesky 7/2022: Google: ©Maxar Technologies	2005 2020
Dane (Congleton)	6.4	Hooke 1987, 1995a,b; 2004; Hooke & Chen, 2016; Hooke & Yorke, 2010	SSSI 1994	None	548,294 m E 5,892,839 m N	12/2006: Google: ©Infoterra & Bluesky, Get Mapping plc. 4/2021: Google ©Airbus	2006 2020
Frome (Maiden Newton)	6	Grabowski & Gurnell, 2016; Gurnell & Grabowski, 2016; Gurnell et al., 2006	SSSI 1998 (Downstream of Study Area)	None	531,151 m E 5623492 m N	12/2002: Google: ©Infoterra & Bluesky 6/2022: Google: ©Landsat/ Copernicus	2006 2021
Mole (Cobham)	5.5	None	No	None	680,063 m E 5689697 m N	12/2003: Google: ©Infoterra & Bluesky 5/2022: Google: ©Maxar Technologies	2006 2021
South Tyne (Lambley)	4.4	Macklin & Lewin, 1989; Macklin et al., 1998; Macklin, 1997; Passmore & Macklin, 2000; Passmore et al., 1993	SSSI (Part) 1991	None	533,768 m E 6085396 m N	12/2003: Google: ©Infoterra & Bluesky 4/2022: Google: ©Maxar Technologies, CNES/Airbus	2009 2019
Teme (Leintwardine)	6.7	Dawson & Lewin, 2023	SSSI 1995	JBA Consulting (2013)	508,657 m E 5,800,130 m N	12/1999: Google: ©Infoterra & Bluesky 4/2021: Google: ©Landsat/ Copernicus	2008 2020
Ystwyth (Grogwynion)	5.5	Dawson et al., 2022; Lewin, 1976; Lewin et al., 1977	SAC 2006	Countryside Council for Wales (2008)	438,451 m E 5798094 m N	6/2001: Aerial Digimap © Getmapping plc 4/2021: Google © CNES/Airbus	2012 2022

Note: The table also shows the public domain image and LiDAR sources used at each location. Data access: English LiDAR data accessed on various dates 2021–2023 through the Defra Data Service Platform: https://environment.data.gov.uk/DefraDataDownload/?Mode=survey. Welsh LiDAR data accessed on various dates 2019–2023 through DataMapWales https://datamap.gov.wales/maps/new#/. Google data accessed through published API's and via Google Earth Pro on various dates 2019–2023.

Secondly, digital elevation model of difference (DoD) models were derived from paired LiDAR surveys obtained in 1999–2012 and 2018–2021 (depending on location) (Environment Agency, 2022c) using the Geomorphic Change Analysis software (Wheaton et al., 2009; Williams, 2012) implemented in ArcMap 10.8 (ESRI, 2021). A simple threshold of 0.18 m, the published combined

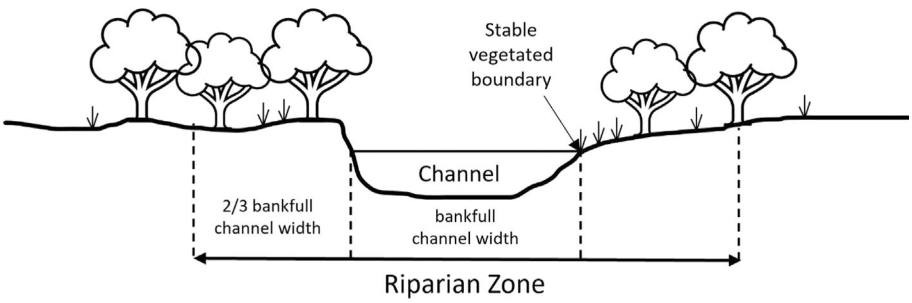

FIGURE 3 Schematic showing the definition of the riparian zone and bankfull channel width.

RSME of the surveys (Environment Agency, 2022c), was applied to identify areas of positive or negative elevational change both through lateral bank migration, but also due to overbank scour and deposition. The eroded areas within the riparian zone identified on the DoD were polygonised and a comparison between the area of woodland and scrub areas existing prior to the earlier (2008–2009) LiDAR survey was derived and calculated.

3 | RESULTS

3.1 | Vegetation change

Detailed changes in floodplain vegetation are visualised in maps showing the distribution of vegetation classes (Table 4) for 2020–2022 and 1999–2003 (2006 for the Dane). Aggregate vegetation cover changes are summarised in Figure 4, which includes comments on the broad nature of any observed changes in vegetation type and cover. Maps for the two reaches showing the most geomorphic change, the Teme and the Ystwyth, are presented in Figures 5 and 6, with maps for the remaining reaches included in the Supporting information.

The overall cover of woody vegetation across the floodplain (Figure 4) increased by 5%–23% in six of the eight reaches with small reductions observed along the Mole and South Tyne. Locally there has been natural extension and infilling of gaps between areas of floodplain woodland. The most stable meandering reaches (Culm, Frome, Mole) show very different changes in floodplain woodland over the studied period, with the Frome showing a marked proportional increase, the Culm a small increase and the Mole a small reduction (Figures S2, S4, and S5). Of the more active, meandering reaches (Coquet, Dane and Teme), the Coquet and Teme both show notable increases in floodplain woody vegetation cover from a low initial areal coverage (Figure S1 and Figure 5); in contrast, the Dane shows a small increase from a small initial area that is confined to the river channel margins (Figure S3).

The area of hedgerows alone (Figure 4) shows a decrease in three reaches (Culm, Mole, Teme) and no hedgerows are present in one reach (Ystwyth). The large percentage increase in the area of floodplain hedgerows along the Frome can be attributed to an expansion of the hedgerow canopy area rather than any increase in the length of hedgerows, whilst the increase along the South Tyne reflects localised

TABLE 4 The vegetation classification applied to the eight study reaches to establish changes over approximately two decades.

Category	Description
Woodland	Woodland vegetation comprising four or more trees, with trees >2.5 m in height and where the spacing is <2 m between trees
Sparse woodland	Areas of woodland comprising four or more trees where the spacing between trees is >2 m between trees
Bankside wood	Woody vegetation adjacent to the current river channel not forming part of a more extensive area of woodland
Hedgerows, wood along former channel margins and isolated floodplain trees	Woody vegetation forming boundaries or occurring in isolated groups of less than four trees away from the current river channel
Dense scrub	Woody vegetation <2.5 m high with a spacing between woody plants of <2 m
Sparse scrub	Woody vegetation <2.5 m high with a spacing between woody plants of more than 2 m
Low vegetation within bankfull channel limits	Herbs, grasses and small saplings growing on riverine sediments exposed during low flows
Exposed riverine sediments	Areas of unvegetated river sediments exposed during low flows

hedgerow planting. Therefore, apart from the South Tyne, no reaches show the presence of new hedgerows over the last two decades but rather a small decline, which is in common with trends observed nationally (Carey et al., 2008).

All reaches apart from the South Tyne show an increase of vegetation in the riparian zone of between 2% and 43% (Figure 4). In contrast, the South Tyne reach shows an overall small decline in riparian woodland and scrub cover plus in-channel terrestrial vegetation and a more marked decline when in-channel terrestrial vegetation is removed from this computation (Figure 4). This decline in riparian woody vegetation is due to channel migration (Figure S6) that has

River Name	Area of the Riparian Zone covered by woodland, scrub, and terrestrial vegetation within bankfull limits			Percentage of the Riparian Zone Area covered by woodland and scrub			Description of changes observed in the Riparian Zone	Area of Floodplain		Area of Exposed Riverine Sediments
	Present (date between 2020 and 2022) (m^2)	Previous (date between 1999 and 2006) (m^2)	Change (%)	Present (%)	Previous (%)	Change (%)		Change in Wooded Area (%)	Change in Hedgerow Area (%)	Change in Exposed Riverine Sediments (%)
Coquet	69,393	57,591	20	13	11	18	Limited along-bank expansion of channel margin riparian woodland on stable banks. Expansion of areas of scrub on the floodplain. Woodland planting on golf course development	17	4	−3
Culm	58,271	54,522	7	41	38	7	Some along-bank expansion of channel margin woodland on stable banks. Local expansion of areas of floodplain woodland	5	−7	−95
Dane	123,963	99,884	24	51	44	26	Local expansion of areas of woodland across the floodplain. Along-bank expansion of channel margin riparian wood on stable banks. Development of woodland and scrub on areas exposed by channel migration	8	18	−59
Frome	58,915	41,919	41	47	34	41	Extensive along-bank expansion of channel margin riparian woodland on stable banks	23	13	
Mole	90,982	88,968	2	46	45	2	Some along-bank expansion of channel margin riparian woodland on stable banks	−1	−4	
S Tyne	143,768	153,080	−6	20	27	−10	Some expansion of herbs, grasses and small saplings on exposed riverine sediments. Removal of channel margin woodland by channel migration	−7	55	4
Teme	95,116	66,450	43	24	16	46	Extension of wood and scrub onto areas abandoned by channel migration. Expansion of wood and development of scrub in meander cut-offs. Along bank expansion of channel margin riparian wood on stable banks	20	−8	−1
Ystwyth	173,658	135,963	28	36	21	44	Extensive growth of scrub, especially floodplain across exposed riverine sediments	19		−31

KEY (shading used to indicate percentage change)

none present | < −40% | −40 to < −10% | −10 to 0% | >0 to 10% | >10 to 40% | > 40%

FIGURE 4 Aggregate changes in vegetation cover across the riparian zone and floodplain and changes in the area of exposed riverine sediments observed over approximately two decades at each of eight river reaches. [Color figure can be viewed at wileyonlinelibrary.com]

removed marginal riparian woodland which has not been replaced elsewhere by colonisation.

The two most active reaches, the Teme and Ystwyth, based on changes in channel position, show contrasting channel behaviour (Figures 5 and 6), but both have experienced expansion in riparian woodland and scrub over two decades. Along the Teme reach (Figure 5), changes in woodland and scrub extent reflect migration of the actively meandering channel. Woodland and scrub have colonised areas abandoned during channel migration and have expanded along meander cut-offs. Woodland has also expanded along stable channel margins. In contrast, along the highly dynamic Ystwyth reach observed over several decades (Figure 6), areas of riverine gravels that were previously unvegetated or formerly covered by low herbs and grasses have been colonised by woody shrubs (Figure 6) and, like the Teme, woodland cover has expanded along more stable bank sections (Dawson et al., 2022).

Reductions in the area occupied by exposed (unvegetated) riverine sediments are seen in all reaches apart from the South Tyne, Mole and Frome. No exposed riverine sediments were recorded on the Mole and Frome. The increase on the South Tyne reflects the overall expansion of the bankfull channel through lateral bank erosion (Figure S6) under flood conditions and the redistribution of sediments. A reduction in exposed (unvegetated) sediments of 31% along the Ystwyth reach is associated with the expansion of scrub cover. Higher percentage area reductions of 95% and 59% are also seen in association with relatively smaller areas of exposed riverine sediments on the Culm and Dane reaches, respectively (Figure 4). Here, the observed reductions are attributable to vegetation colonisation of the exposed sediment surfaces (Figures S2 and S3).

An analysis, using multiple regression, of whether the variation in the extent and rates of riparian vegetation change could be explained by regional climatic and differences in catchment parameters (Table 3) failed to identify significant relationships within the limitations of the data set.

3.2 | Geomorphic change

Associations between the presence of woodland adjacent to the channel and the width of the channel were explored using box and whisker plots (Figure 7) along the six single thread reaches. Variance in width with the sample (tree cover) groups (no bankside trees; one wooded bank; both banks wooded) is high at all locations, but some patterns are apparent across the six plots. Along the Dane only one cross section lacked tree cover. The Culm and the Frome reaches show all three classes of tree cover but there is little difference in the

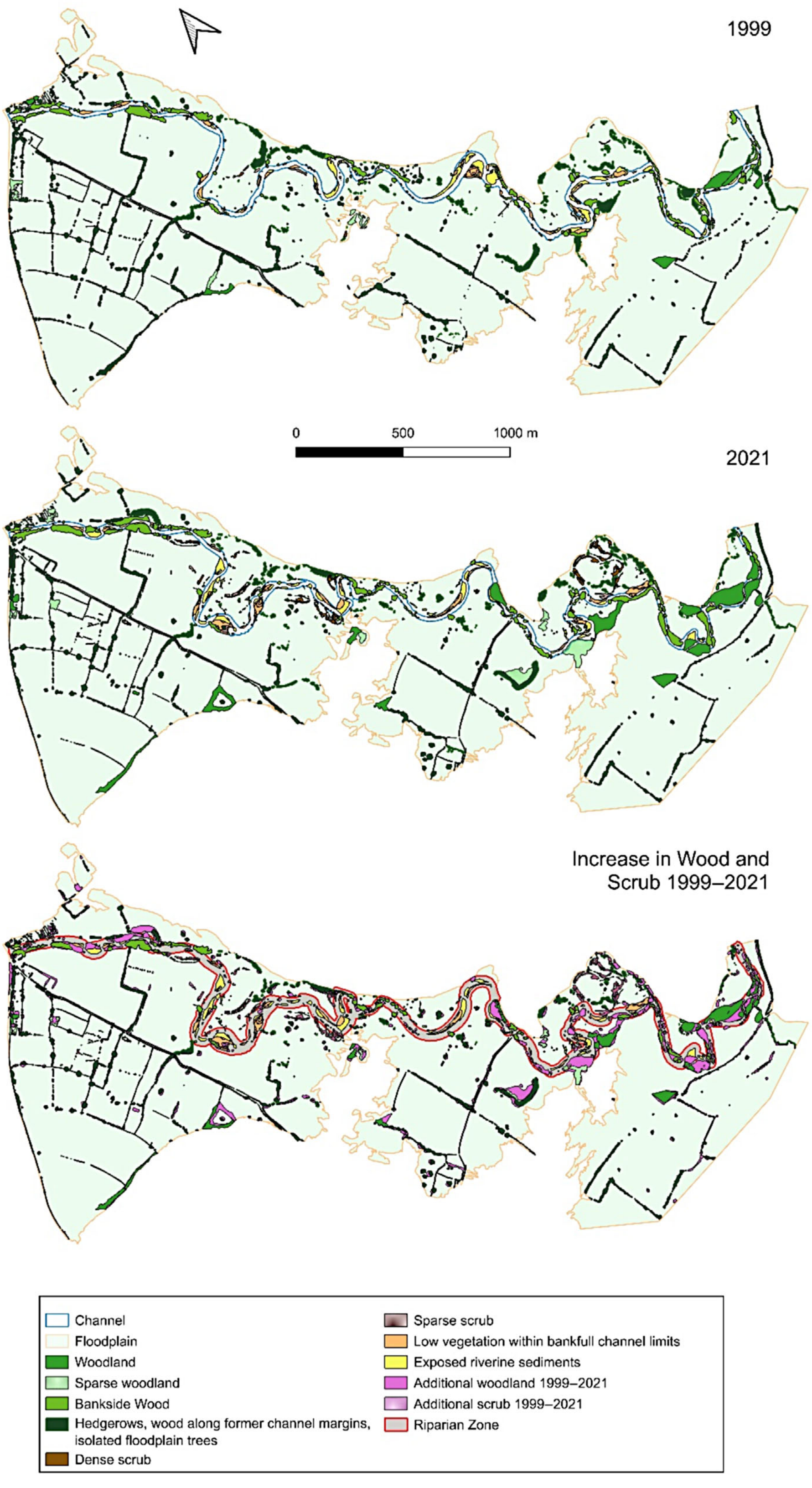

FIGURE 5 Vegetation change River Teme 1999–2021. Vegetation change includes: (a) Extension of woodland and scrub onto areas abandoned by channel migration, (b) Expansion of woodland and development of scrub in meander cut-offs, (c) Along-bank expansion of channel margin woodland. [Color figure can be viewed at wileyonlinelibrary.com]

channel widths assigned to each of the three tree cover classes. The remaining three reaches (Coquet, Mole and Teme) appear to show some difference in channel width between tree cover groups. However, this variance is only statistically significant for the longest reach (Teme, one-way analysis of variance: degrees of freedom 2, 125; $F = 10.08$; $P = 0.00009$).

The relationship between the extent of erosion in the riparian zone through bank migration or overbank scour, computed from the

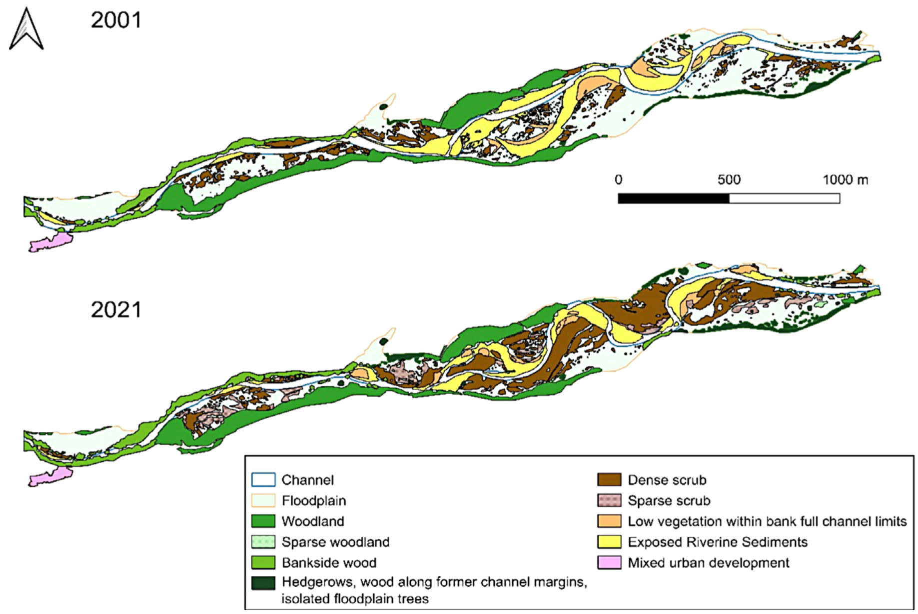

FIGURE 6 Vegetation change along the River Ystwyth reach between 2001 and 2021. Location dominated by very actively migrating channel. Figure shows extensive growth of scrub (*Ulex europeaus*) on floodplain extending onto exposed riverine sediments that has influenced the channel dynamics and planform (Dawson et al., 2022). [Color figure can be viewed at wileyonlinelibrary.com]

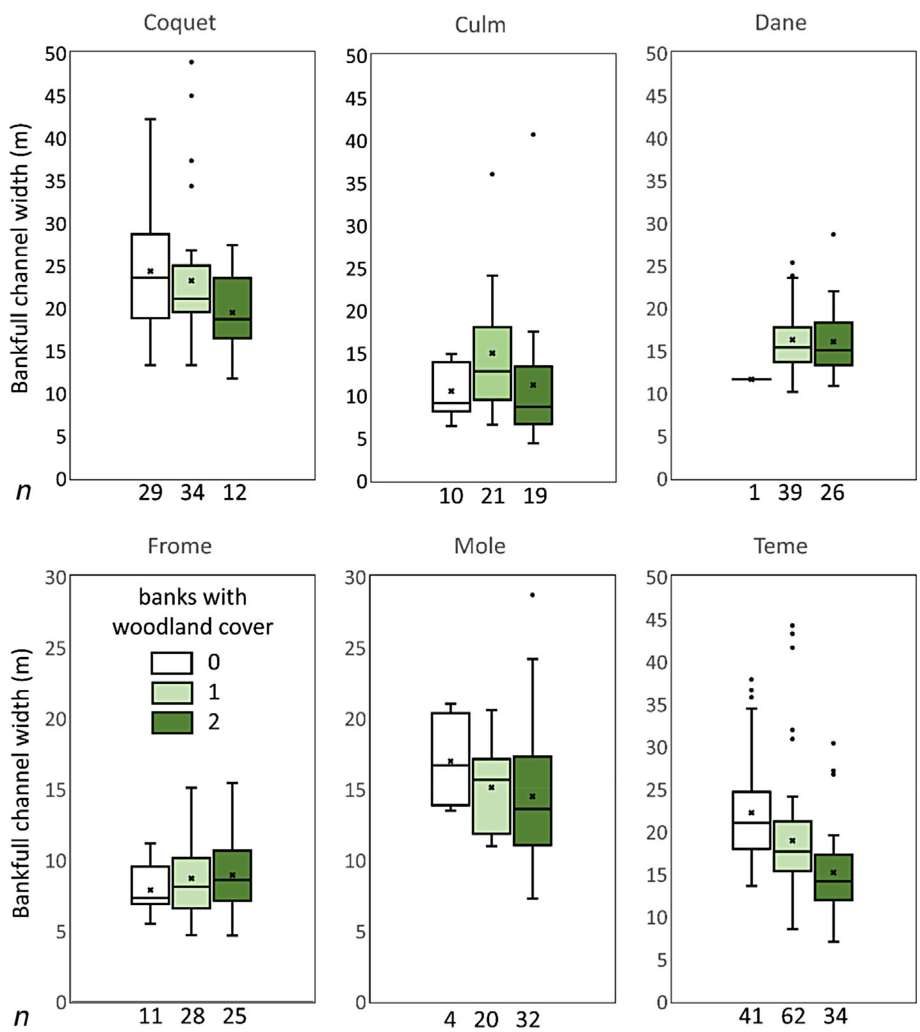

FIGURE 7 Box and whisker plots for bankfull channel width according to woodland cover on 0, 1 or 2 banks at cross sections spaced at 100 m intervals along six single thread reaches. The number (*n*) of cross sections assigned to each woodland cover class is shown below each box and whisker plot. [Color figure can be viewed at wileyonlinelibrary.com]

DoD model extracted from LiDAR surveys obtained in 1998–2009 and 2019–2022 (see Table 3), and the extent of coverage of the riparian zone that was previously under woodland or scrub cover were investigated. The vegetation cover was derived from the earlier vegetation map for each reach. The area of the riparian zone that was eroded and the area of the riparian zone previously under woodland

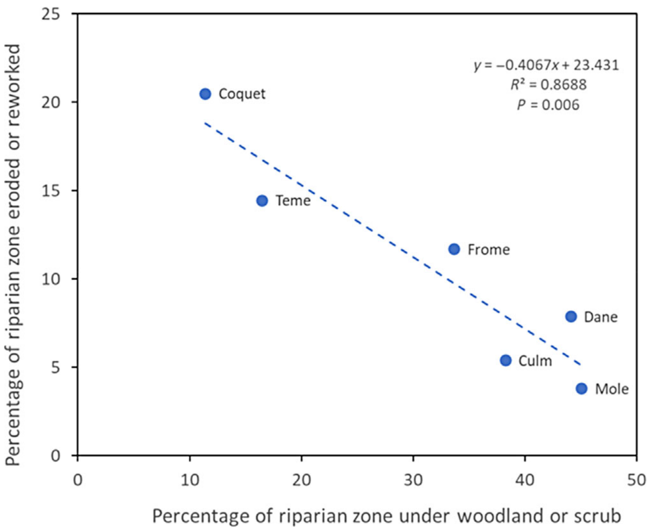

FIGURE 8 Relationship between the percentage of the riparian zone eroded or reworked and the percentage area of the riparian zone under woodland and scrub preceding the erosion/reworking (time period over which the erosion area is computed, varies with available LiDAR data, Table 1). [Color figure can be viewed at wileyonlinelibrary.com]

and scrub cover were expressed as a percentage of the total area of the riparian zone. Despite the small sample size there is a statistically significant simple linear regression relationship indicating a decline in the percentage area eroded (dependent variable) as the percentage area under woodland and scrub (independent variable) increases ($P = 0.006$; Figure 8).

4 | DISCUSSION

Our analysis of eight gravel-bed, floodplain, middle reaches of English and Welsh rivers has revealed several significant changes:

i. An expansion in floodplain woody vegetation, although two reaches (Mole, South Tyne) show small reductions;
ii. An expansion in riparian zone woody vegetation cover, although the South Tyne shows a reduction;
iii. A reduction in exposed riverine sediments in five of the six reaches that have them, with the South Tyne again being the exception;
iv. A negative relationship between the proportion of the riparian zone eroded and the proportion under woody vegetation prior to the erosion along the six meandering reaches; and
v. Some evidence for a reduction in the bankfull width of single-thread channels where the banks of the six meandering reaches are covered by woodland.

While previous research (Table 1) gives local data on the morphodynamics of all but one of the reaches, our comparative observations provide new and additional information on recent changes in vegetation and their effects on river channel dynamics.

The overall increases in floodplain woody vegetation can be attributed both to expansion within the riparian zone but also as a result of tree planting as part of forestry operations or landscaping around country estates and golf courses (e.g. Coquet, Mole). Locally, expansion in the area of woodland can be observed alongside former channel features (e.g. Dane, Teme) and through localised increases in the canopy of existing hedgerows. The small reductions in floodplain woodland along the Mole and South Tyne can be attributed to landscaping activities and lateral channel migration, respectively.

The Dane, Frome and Teme show the greatest proportional increase in riparian woody vegetation through tree growth of all eight reaches. In most cases this has resulted from the expansion of existing areas of bankside trees along relatively stable riverbanks and colonisation of point bars or abandoned channels created by lateral channel migration. The Dane now shows few bank tops that are not wooded (Figure 7) and a relatively small amount of erosion in the studied period (Figure 8) in contrast to past observations by Hooke (2008, 2015). Furthermore, although the proportional aerial increase in riparian woody vegetation is much smaller along the Culm, the woody vegetation located close to the river (Figure S2) has matured with almost all sparse woodland converted into mature woodland cover. The Mole, Teme and Culm show relatively high riparian vegetation cover and low erosion rates in comparison with other, more active, meandering rivers (Figure 7). This is reflected in the low, and in some cases decreasing presence of exposed riverine sediments.

A contrasting geomorphic response on the active wandering reaches was observed as between the South Tyne and the River Ystwyth. On the Ystwyth, an increase in woody scrub vegetation, mainly *Ulex europeaus* (gorse), has led to partial channel stabilisation, substantial reduction in exposed riverine sediments and planform change. The rapid increase in woody scrub cover on the Ystwyth has been attributed to recent changes in local vegetation management practice and a reduction in natural grazing (Dawson et al., 2022). The differing response on the South Tyne reflects local factors such as long-term channel entrenchment inducing higher specific stream powers during floods (Passmore & Macklin, 2000). Here, removal of woody vegetation by bank erosion during floods has not been balanced by vegetation encroachment along more stable bank sections.

Although there are regional contrasts in the nature of the eight reaches and catchments studied (Tables 2 and 3) it has not been possible to identify regional differences in the extent and change of riparian cover on the basis of a limited data set. However, the changes in riparian vegetation observed across the studied reaches suggest that local increases observed by Hooke and Chen (2016) are more widespread and may indicate a national trend. It is likely that expansion in riparian tree and scrub cover is attributable to colonisation by riparian species of the Salicaceae family (willow, poplar) (González et al., 2018; Karrenberg et al., 2002) and *U. europeaus* (Dawson et al., 2022; Roberts & Florentine, 2021).

The influence of woody riparian and floodplain vegetation on channel morphology, bank erosion and overbank scour (Figures 7 and 8) has been widely noted (Darby, 1999; Gurnell, 2014; Hooke, 2015; Osterkamp et al., 2012). Hooke (2008, 2015) postulated that an increase in riparian woody vegetation along the River Dane between 1984 and 2007 was having a stabilising effect on the floodplain and channel banks. They noted similar effects on the adjacent River Bollin, arguing that increased stabilisation by vegetation would increase the threshold for erosion (Hooke, 2022). Micheli et al. (2004) estimated that agricultural floodplains were 80%–150% more erodible than forested ones and Allmendinger et al. (2005) found that vegetation-mediated deposition and lateral channel migration are both higher along non-forested reaches than forested reaches, whilst Beeson and Doyle (1995) determined that major bank erosion was 30 times more prevalent on non-vegetated than on vegetated bends. As highlighted by Gurnell (2014) the aboveground vegetation biomass affects the flow field whilst root systems affect the stability of the substrate (Burylo et al., 2012; Holloway et al., 2017a, 2017b; Simon et al., 2006). Lee et al. (2022) found that the resistance to erosion of riparian vegetation under flood conditions increased with increasing vegetation maturity, and Török and Parker (2022) determined that in situations where the bed material was coarse (D50 > 16 mm) an increased density of vegetation resulted in greater bank erosion resistance, although the role of vegetation varied depending on the ratio of characteristic root zone depth to channel width and depth.

However, our examination of the variations in the channel width in response to the presence of woody riparian vegetation only partially supports some of the findings of previous work (Charlton et al., 1978; Micheli et al., 2004; Török & Parker, 2022) that the presence of woody vegetation tends to lead to a reduced channel width. The contrast in behaviour between the River Teme and the other reaches seems to be related to the degree of recent channel activity under flood conditions (Dawson & Lewin, 2023) whilst the relative absence of woody riparian vegetation on the River Coquet may mean that it is too sparse to influence channel form. Our findings indicate that even within relatively short reaches where the discharge regime and slope do not vary there are other determinants on the local channel geometry apart from the threshold fluid entrainment stress of the most resistant material lining the channel (Dunne & Jerolmack, 2020), including local bed roughness; the influence of aquatic macrophytes; and interactions between introduced fine sediment and wood both living and dead (Gurnell & Grabowski, 2016).

Our observations on the expansion of bankside riparian vegetation indicate that a prerequisite for establishment is local landform stability sufficient to support initial woody vegetation colonisation and growth in former channel bends and bar areas to allow the colonising plants to eventually mature. Hooke (2008) similarly observed on the River Dane that periods with relatively low flood magnitudes allowed the establishment of willow on previously exposed bar features. Although there have been regional, climate driven, increases in flood magnitudes (Hannaford et al., 2021) the relationship between flood frequency and riparian growth is inconsistent between several of the reaches studied, in large part because extreme UK floods are limited in geographical extent. As a consequence, the incidences and timings of transformative hydrological events within the study period of this present paper are not similar. On the South Tyne it is apparent that major floods in January 2005 and May 2013 resulted in the removal of significant areas of riparian woodland accounting for the observed reductions. In contrast both on the Coquet and most notably on the Ystwyth there have been significant increases in riparian woodland and scrub despite increases in flood frequency and magnitude during the study period (Centre for Ecology and Hydrology, 2023; Dawson et al., 2022). On the River Teme an exceptional flood in February 2020 only resulted in localised removal of riparian woodland, the presence of woody vegetation acting as a major control on channel change (Dawson & Lewin, 2023).

The limited number of sites examined precludes a detailed analysis of the effect of soil moisture deficits on riparian tree growth, but it is noted that the two sites showing least riparian expansion are located in areas predicted by Ray et al. (2010) as having the greatest soil moisture deficits under conditions of climate change.

However, it should be recognised that one of the main determinants of change in the riparian and floodplain tree cover along many English and Welsh rivers is the application of various management practices employed by the land and riverbank owners within the existing regulatory frameworks. Although the European Water Framework Directive (2000) and its subsequent UK-specific replacement, the Water Environment (Water Framework Directive) (England and Wales) Regulations (2017), have the stated aim of improving the quality of river corridors and, where possible, returning rivers to a more natural state as highlighted by González del Tánago et al. (2021), riparian vegetation is not explicitly considered. Implementation of the directive in the United Kingdom has been through the development of river basin management plans on a regional basis. These have focused on the ecological status of the water bodies and groundwater (Environment Agency, 2022a).

A similar overarching, but broader, set of objectives is contained within the UK Government's 25-year Environment Plan (DEFRA, 2018). More specific, local guidance is contained in the management and restoration plans associated with SSSI or SAC designations (Table 1), with riparian planting and control being identified as a specific objective in the Culm, Teme and Ystwyth management plans (Blackdown Hills Area of Outstanding Natural Beauty (AONB), 2023; Countryside Council for Wales, 2008; JBA Consulting, 2013). Other initiatives encouraging the planting of riparian vegetation include the England Woodland Creation Offer (Forestry Commission, 2021) which provides financial incentives for planting riparian woodland; the nationwide Keeping Rivers Cool project that aims to increase riparian shade through planting and livestock fencing (Woodland Trust, 2016); and the Catchment Based Approach, a civil society-led initiative that works in partnership with government, local authorities, water companies and farmers to support the delivery of the 25-year environment plan (CaBA, 2023). In short, riparian management in England and Wales is determined by a combination of Environment Agency/Natural Resources Wales direct management or control via environmental permits on main rivers; ownership of the riparian zone and the responsibilities that fall upon landowners, including maintaining vegetation unless it obstructs navigation or is likely to cause flooding to other landowner's properties (Environment Agency, 2018); landowner involvement in schemes to plant woodland and riparian vegetation;

and specific management objectives associated with a river or reach being part of a designated SSSI or SAC.

Given the complex and sometimes uncoordinated controls on riparian management it is not possible to attribute the observed changes in riparian vegetation across the study reaches entirely to natural processes, nor is it possible to assign them to any single policy initiative. Changes reflect local decisions such as planting or felling of woodland (Teme, Mole); the introduction of fencing to exclude cattle, which Hooke and Chen (2016) identified as a cause of change on the River Dane; and discouragement of the removal of bankside vegetation particularly where the reach falls within a designated SSSI (e.g. River Teme). The extent to which local decisions have been influenced by strategic legislation such as The Water Environment Regulations (2017), the 25-year Environment Plan and the supporting Catchment Based Approach civil society-led initiatives, is unclear, but it is likely that in combination these have established a context that has encouraged the preservation and expansion of riparian vegetation and thus the increased functioning of natural riparian processes.

5 | CONCLUSIONS

Changes in woody riparian vegetation were apparent in all the investigated reaches representing a range of fluvial environments in England and Wales. Despite considerable inter-reach variation, an increase in woody vegetation along the riparian margins of the main river channel was observed in all but one reach. Contrasts in the rate, extent and location of riparian change were associated with the stability of the channel planform, with differences seen between stable and more active reaches. In addition, the influence of riparian vegetation on fluvial dynamics was illustrated by the predominance of bank erosion and over bank scour where riparian woody vegetation was absent. However, the controls on bank stability and channel form by the root systems of bank side trees identified in other studies are inconsistently and often weakly evident across the six study reaches where riparian wood predominates, indicating that, in each environment, there are several controls on channel width beyond enhanced bank resistance due to the presence of root systems.

Increases in the total area of floodplain woodland and scrub were noted along six of the reaches studied, a consequence both of deliberate planting and changes in management practices such as scrub clearance. No common trend was observed in hedgerow extents with some reaches showing an increase, whilst others showed a small decline.

In the heavily managed agricultural landscapes of the studied reaches, the observed riparian changes also reflect the consequences of multiple and diverse local decisions regarding the management of in-channel and channel-adjacent vegetation by landowners rather than because of a single overarching national policy. These occur within several frameworks, designations and legislation, the resultant effect of which will be specific to the reach concerned, but which collectively may be influenced by strategic legislation and longer-term environment plans. In the context of environmental and climate change we posit that continuous woody riparian vegetation is significant in maintaining bank stability, constraining lateral channel migration and retaining sediments in addition to its effect in sustaining habitats through shading and cooling rivers. This represents supporting justification for action aimed at deterring riverbank clearance (Environment Agency, 2022b; McEwan, 2022).

The effect of climate change, for instance, expressed through changes in flood magnitude and frequency, on the observed development of riparian vegetation cannot, at this stage, be distinctly identified from our data with inconsistent patterns in the response of vegetation to high magnitude floods being observed between different reaches. In addition, further analysis is required on the regional effects of soil moisture deficits on riparian growth. However, the use of aerial and satellite imagery and LiDAR data now available over decadal timescales represents an important opportunity for establishing changes likely under climate change to come and provides practical value for riparian and floodplain management at this scale.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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REFERENCES

Allmendinger, N. E., Pizzuto, J. E., Potter, N., Jr., Johnson, T. E., & Hession, W. C. (2005). The influence of riparian vegetation on stream width, eastern Pennsylvania, USA. *Geological Society of America Bulletin*, *117*(1–2), 229–243.

Anderson, B. G., Rutherfurd, I. D., & Western, A. W. (2006). An analysis of the influence of riparian vegetation on the propagation of flood waves. *Environmental Modelling & Software*, *21*(9), 1290–1296. https://doi.org/10.1016/j.envsoft.2005.04.027

Asaeda, T., Gomes, P. I. A., Sakamoto, K., & Rashid, M. H. (2011). Tree colonization trends on a sediment bar after a major flood. *River Research and Applications*, *27*(8), 976–984. https://doi.org/10.1002/rra.1372

Bachiller-Jareno, N., Hutchins, M. G., Bowes, M. J., Charlton, M. B., & Orr, H. G. (2019). A novel application of remote sensing for modelling impacts of tree shading on water quality. *Journal of Environmental Management*, *230*, 33–42. https://doi.org/10.1016/j.jenvman.2018.09.037

Beeson, C. E., & Doyle, P. F. (1995). Comparison of bank erosion at vegetated and non-vegetated channel bends. *JAWRA Journal of the American Water Resources Association*, *31*(6), 983–990. https://doi.org/10.1111/j.1752-1688.1995.tb03414.x

Bertoldi, W., Drake, N. A., & Gurnell, A. M. (2011). Interactions between river flows and colonizing vegetation on a braided river: Exploring spatial and temporal dynamics in riparian vegetation cover using satellite data. *Earth Surface Processes and Landforms*, *36*(11), 1474–1486. https://doi.org/10.1002/esp.2166

Bertoldi, W., & Gurnell, A. M. (2020). Physical engineering of an Island-braided river by two riparian tree species: Evidence from aerial images and airborne lidar. *River Research and Applications*, *36*(7), 1183–1201. https://doi.org/10.1002/rra.3657

Blackdown Hills Area of Outstanding Natural Beauty (AONB). (2023). *Connecting the Culm creating a better future for the river Culm*. https://connectingtheculm.com/

Brewer, P. A., Mass, G. S., & Macklin, M. G. (2001). A fifty year history of exposed riverine sediment dynamics on welsh rivers. In J. A. A. Jones, K. Gilman, A. Jigorel, & J. Griffin (Eds.), *Water in the celtic world: Managing resources for the 21st century* (pp. 245–252). British Hydrological Society.

Brown, A. G., Rhodes, E. J., Davis, S., Zhang, Y., Pears, B., Whitehouse, N. J., Bradley, C., Bennett, J., Schwenninger, J.-L., Firth, A., Firth, E., Hughes, P., & Walling, D. (2021). Late Quaternary evolution of a lowland anastomosing river system: Geological-topographic inheritance, non-uniformity and implications for biodiversity and management. *Quaternary Science Reviews*, *260*, 106929. https://doi.org/10.1016/j.quascirev.2021.106929

Burylo, M., Rey, F., Mathys, N., & Dutoit, T. (2012). Plant root traits affecting the resistance of soils to concentrated flow erosion. *Earth Surface Processes and Landforms*, *37*, 1463–1470.

CaBA. (2023). *About the catchment based approach*. CaBA https://catchmentbasedapproach.org/about/

Camporeale, C., & Ridolfi, L. (2010). Interplay among river meandering, discharge stochasticity and riparian vegetation. *Journal of Hydrology*, *382*(1–4), 138–144. https://doi.org/10.1016/j.jhydrol.2009.12.024

Carey, P. D., Wallis, S., Chamberlain, P. M., Cooper, A., Emmett, B. A., Maskell, L. C., McCann, T., Murphy, J., Norton, L. R., Reynolds, B., Scott, W. A., Simpson, I. C., Smart, S. M., & Ullyett, J. M. (2008). *Countryside survey: UK results from 2007*. UK Centre for Ecology and Hydrology. https://countrysidesurvey.org.uk/history/2007

Centre for Ecology and Hydrology. (2023). *National river flow archive*. Centre for Ecology and Hydrology https://nrfa.ceh.ac.uk/

Charlton, F. G., Brown, P. M., & Benson, R. W. (1978). *The hydraulic geometry of some gravel bed rivers in Britain. Report INT-180*. Hydraulics Research Station.

Charlton, M. E., Large, A. R. G., & Fuller, I. C. (2003). Application of airborne LiDAR in river environments: The River coquet, Northumberland, UK. *Earth Surface Processes and Landforms*, *28*(3), 299–306. https://doi.org/10.1002/esp.482

Climate-Data.org. (2023). *Climate data*. https://en.climate-data.org/

Corenblit, D., Davies, N. S., Steiger, J., Gibling, M. R., & Bornette, G. (2015). Considering river structure and stability in the light of evolution: Feedbacks between riparian vegetation and hydrogeomorphology. *Earth Surface Processes and Landforms*, *40*(2), 189–207. https://doi.org/10.1002/esp.3643

Corenblit, D., Steiger, J., Charrier, G., Darrozes, J., Garófano-Gómez, V., Garreau, A., González, E., Gurnell, A. M., Hortobágyi, B., Julien, F., Lambs, L., Larrue, S., Otto, T., Roussel, E., Vautier, F., & Voldoire, O. (2016). *Populus nigra* L. establishment and fluvial landform construction: Biogeomorphic dynamics within a channelized river. *Earth Surface Processes and Landforms*, *41*(9), 1276–1292. https://doi.org/10.1002/esp.3954

Corenblit, D., Steiger, J., González, E., Gurnell, A. M., Charrier, G., Darrozes, J., Dousseau, J., Julien, F., Lambs, L., Larrue, S., Roussel, E., Vautier, F., & Voldoire, O. (2014). The biogeomorphological life cycle of poplars during the fluvial biogeomorphological succession: A special focus on *Populus nigra* L. *Earth Surface Processes and Landforms*, *39*(4), 546–563. https://doi.org/10.1002/esp.3515

Corenblit, D., Steiger, J., Gurnell, A. M., Tabacchi, E., & Roques, L. (2009). Control of sediment dynamics by vegetation as a key function driving biogeomorphic succession within fluvial corridors. *Earth Surface Processes and Landforms*, *34*(13), 1790–1810. https://doi.org/10.1002/esp.1876

Corenblit, D., Tabacchi, E., Steiger, J., & Gurnell, A. M. (2007). Reciprocal interactions and adjustments between fluvial landforms and vegetation dynamics in river corridors: A review of complementary approaches. *Earth-Science Reviews*, *84*(1–2), 56–86. https://doi.org/10.1016/j.earscirev.2007.05.004

Countryside Council for Wales. (2008). *Core management plan including conservation objectives for Grogwynion SAC*. Natural Resources Wales.

Darby, S. E. (1999). Effect of riparian vegetation on flow resistance and flood potential. *Journal of Hydraulic Engineering*, *125*(5), 443–454. https://doi.org/10.1061/(ASCE)0733-9429(1999)125:5(443)

Dawson, M., Gurnell, A., & Lewin, J. (2022). Biogeomorphic recovery of a river reach affected by mining. *Earth Surface Processes and Landforms*, *47*(15), 3497–3514. https://doi.org/10.1002/esp.5470

Dawson, M., & Lewin, J. (2023). The heterogeneous geomorphological impact of an exceptional flood event and the role of floodplain vegetation. *Earth Surface Processes and Landforms*. https://doi.org/10.1002/esp.5707

de Sosa, L. L., Glanville, H. C., Marshall, M. R., Abood, S. A., Williams, A. P., & Jones, D. L. (2018). Delineating and mapping riparian areas for ecosystem service assessment. *Ecohydrology*, *11*(2), e1928. https://doi.org/10.1002/eco.1928

DEFRA. (2018). *A green future: Our 25 year plan to improve the environment*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/693158/25-year-environment-plan.pdf

DEFRA. (2023). *Countryside stewardship: Get funding to protect and improve the land you manage*. https://www.gov.uk/guidance/countryside-stewardship-get-funding-to-protect-and-improve-the-land-you-manage

Donovan, M., Belmont, P., Notebaert, B., Coombs, T., Larson, P., & Souffront, M. (2019). Accounting for uncertainty in remotely-sensed measurements of river planform change. *Earth-Science Reviews*, *193*, 220–236. https://doi.org/10.1016/J.EARSCIREV.2019.04.009

Dufour, S., Muller, E., Straatsma, M., & Corgne, S. (2012). Image utilisation for the study and management of riparian vegetation: Overview and applications. In P. E. Carbonneau & H. Piégay (Eds.), *Fluvial remote sensing for science and management* (pp. 215–239). Wiley. https://doi.org/10.1002/9781119940791.ch10

Dunne, K. B. J., & Jerolmack, D. J. (2020). What sets river width? *Science Advances*, *6*(41), eabc1505. https://doi.org/10.1126/sciadv.abc1505

Environment Agency. (2018). *Owning a watercourse*. https://www.gov.uk/guidance/owning-a-watercourse

Environment Agency. (2022a). *River basin management plans, updated 2022: Progress report*. https://www.gov.uk/government/publications/river-basin-management-plans-updated-2022-progress-report/river-basin-management-plans-updated-2022-progress-report

Environment Agency. (2022b). *Natural England and Environment Agency launch joint legal action in response to River Lugg damage*. https://www.gov.uk/government/news/natural-england-and-environment-agency-launch-joint-legal-action-in-response-to-river-lugg-damage

Environment Agency. (2022c). *National LiDAR survey*. https://www.Data.Gov.Uk/Dataset/F0db0249-F17b-4036-9e65-309148c97ce4/National-Lidar-Programme

ESRI. (2021). *ArcMap (10.8)*. Environmental Systems Research Institute.

European Union Act of Parliament: European Water Framework Directive, (2000). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32000L0060

Eyre, M. D., & Lott, D. A. (1997). *Invertebrates of exposed riverine sediments, entomological monitoring services, R&D project record W1/i525/1*. Environment Agency.

Farguell, J., Úbeda, X., & Pacheco, E. (2022). Shrub removal effects on runoff and sediment transport in a mediterranean experimental catchment (Vernegà River, NE Spain). *Catena*, *210*, 105882. https://doi.org/10.1016/j.catena.2021.105882

Fernandes, M. R., Aguiar, F. C., & Ferreira, M. T. (2011). Assessing riparian vegetation structure and the influence of land use using landscape metrics and geostatistical tools. *Landscape and Urban Planning*, *99*(2), 166–177. https://doi.org/10.1016/J.LANDURBPLAN.2010.11.001

Forestry Commission. (2021). *England woodland creation offer*. https://www.gov.uk/guidance/england-woodland-creation-offer

Francis, R. A., Corenblit, D., & Edwards, P. J. (2009). Perspectives on biogeomorphology, ecosystem engineering and self-organisation in Island-braided fluvial ecosystems. *Aquatic Sciences*, *71*(3), 290–304. https://doi.org/10.1007/s00027-009-9182-6

Francis, R. A., & Gurnell, A. M. (2006). Initial establishment of vegetative fragments within the active zone of a braided gravel-bed river (river Tagliamento, NE Italy). *Wetlands*, *26*, 641–648.

Fuller, I. C., Large, A. R. G., Heritage, G. L., Milan, D. J., & Charlton, M. E. (2005). Derivation of annual reach-scale sediment Transfers in the River Coquet, Northumberland, UK. In *Fluvial sedimentology VII* (pp. 61–74). Wiley. https://doi.org/10.1002/9781444304350.ch4

Garófano-Gómez, V., Martínez-Capel, F., Bertoldi, W., Gurnell, A., Estornell, J., & Segura-Beltrán, F. (2013). Six decades of changes in the riparian corridor of a Mediterranean river: A synthetic analysis based on historical data sources. *Ecohydrology*, *6*(4), 536–553. https://doi.org/10.1002/eco.1330

González del Tánago, M., Martínez-Fernández, V., Aguiar, F. C., Bertoldi, W., Dufour, S., García de Jalón, D., Garófano-Gómez, V., Mandzukovski, D., & Rodríguez-González, P. M. (2021). Improving river hydromorphological assessment through better integration of riparian vegetation: Scientific evidence and guidelines. *Journal of Environmental Management*, *292*, 112730. https://doi.org/10.1016/J.JENVMAN.2021.112730

González, E., Martínez-Fernández, V., Shafroth, P. B., Sher, A. A., Henry, A. L., Garófano-Gómez, V., & Corenblit, D. (2018). Regeneration of Salicaceae riparian forests in the northern hemisphere: A new framework and management tool. *Journal of Environmental Management*, *218*, 374–387. https://doi.org/10.1016/j.jenvman.2018.04.069

Goudie, A., & Migon, P. (2020). *Landscapes and landforms of England and Wales*. Springer International Publishing. https://doi.org/10.1007/978-3-030-38957-4

Grabowski, R. C., & Gurnell, A. M. (2016). Diagnosing problems of fine sediment delivery and transfer in a lowland catchment. *Aquatic Sciences*, *78*(1), 95–106. https://doi.org/10.1007/s00027-015-0426-3

Gregory, S. V., Swanson, F. J., McKee, W. A., & Cummins, K. W. (1991). An ecosystem perspective of riparian zones. *Bioscience*, *41*(8), 540–551. https://doi.org/10.2307/1311607

Griffin, E. R., & Smith, J. D. (2004). Floodplain stabilization by woody riparian vegetation during an extreme flood. In J. Bennett & A. Simon (Eds.), *Water science and application* (pp. 221–236). Wiley. https://doi.org/10.1029/008WSA16

Gurnell, A. M., van Oosterhout, M. P., de Vlieger, B., & Goodson, J. M. (2006). Reach-scale interactions between aquatic plants and physical habitat: River Frome, Dorset. *River Research and Applications*, *22*(6), 667–680. https://doi.org/10.1002/rra.929

Gurnell, A. (2014). Plants as river system engineers. *Earth Surface Processes and Landforms*, *39*(1), 4–25. https://doi.org/10.1002/esp.3397

Gurnell, A., Surian, N., & Zanoni, L. (2009). Multi-thread river channels: A perspective on changing European alpine river systems. *Aquatic Sciences*, *71*(3), 253–265. https://doi.org/10.1007/s00027-009-9186-2

Gurnell, A. M., & Bertoldi, W. (2022). The impact of plants on fine sediment storage within the active channels of gravel-bed rivers: A preliminary assessment. *Hydrological Processes*, *36*(7), e14637. https://doi.org/10.1002/hyp.14637

Gurnell, A. M., Bertoldi, W., & Corenblit, D. (2012). Changing river channels: The roles of hydrological processes, plants and pioneer fluvial landforms in humid temperate, mixed load, gravel bed rivers. *Earth-Science Reviews*, *111*(1–2), 129–141. https://doi.org/10.1016/j.earscirev.2011.11.005

Gurnell, A. M., Corenblit, D., García de Jalón, D., González del Tánago, M., Grabowski, R. C., O'Hare, M. T., & Szewczyk, M. (2016). A conceptual model of vegetation-hydrogeomorphology interactions within river corridors. *River Research and Applications*, *32*(2), 142–163. https://doi.org/10.1002/rra.2928

Gurnell, A. M., & Grabowski, R. C. (2016). Vegetation-hydrogeomorphology interactions in a low-energy, human-impacted river. *River Research and Applications*, *32*(2), 202–215. https://doi.org/10.1002/rra.2922

Hannaford, J., Mastrantonas, N., Vesuviano, G., & Turner, S. (2021). An updated national-scale assessment of trends in UK peak river flow data: How robust are observed increases in flooding? *Hydrology Research*, *52*(3), 699–718. https://doi.org/10.2166/nh.2021.156

Hooke, J. M., & Yorke, L. (2010). Rates, distributions and mechanisms of change in meander morphology over decadal timescales, River Dane, UK. *Earth Surface Processes and Landforms*, *35*(13), 1601–1614. https://doi.org/10.1002/esp.2079

Holloway, J. V., Rillig, M. C., & Gurnell, A. M. (2017a). Physical environmental controls on riparian root profiles associated with black poplar (*Populus nigra* L.) along the Tagliamento River, Italy. *Earth Surface Processes and Landforms*, *42*(8), 1262–1273. https://doi.org/10.1002/esp.4076

Holloway, J. V., Rillig, M. C., & Gurnell, A. M. (2017b). Underground riparian wood: Reconstructing the processes influencing buried stem and coarse root structures of black poplar (*Populus nigra* L.). *Geomorphology*, *279*, 199–208. https://doi.org/10.1016/j.geomorph.2016.07.027

Hooke, J., & Chen, H. (2016). Evidence of increase in woody vegetation in a river corridor, Northwest England, 1984–2007. *Journal of Maps*, *12*(3), 484–491. https://doi.org/10.1080/17445647.2015.1044039

Hooke, J. M. (1979). An analysis of the processes of river bank erosion. *Journal of Hydrology*, *42*(1–2), 39–62. https://doi.org/10.1016/0022-1694(79)90005-2

Hooke, J. M. (1987). Changes in meander morphology. In *International geomorphology 1986. Proc. 1st conference* (Vol. 1).

Hooke, J. M. (1995a). Processes of channel planform change on meandering channels in the UK. In M. Gurnell & G. E. Petts (Eds.), *Changing River channels* (pp. 87–116). John Wiley and Sons.

Hooke, J. M. (1995b). River channel adjustment to meander cutoffs on the River Bollin and River Dane, northwest England. *Geomorphology*, *14*(3), 235–253. https://doi.org/10.1016/0169-555X(95)00110-Q

Hooke, J. M. (2004). Cutoffs galore!: Occurrence and causes of multiple cutoffs on a meandering river. *Geomorphology*, *61*(3–4), 225–238. https://doi.org/10.1016/j.geomorph.2003.12.006

Hooke, J. M. (2008). Temporal variations in fluvial processes on an active meandering river over a 20-year period. *Geomorphology*, *100*(1–2), 3–13.

Hooke, J. M. (2015). Variations in flood magnitude–effect relations and the implications for flood risk assessment and river management. *Geomorphology*, *251*, 91–107. https://doi.org/10.1016/j.geomorph.2015.05.014

Hooke, J. M. (2022). Morphodynamics of a meandering channel over decadal timescales in response to hydrological variations. *Earth Surface Processes and Landforms*, *47*(8), 1902–1920. https://doi.org/10.1002/esp.5354

Huylenbroeck, L., Laslier, M., Dufour, S., Georges, B., Lejeune, P., & Michez, A. (2020). Using remote sensing to characterize riparian vegetation: A review of available tools and perspectives for managers. *Journal of Environmental Management*, *267*, 110652. https://doi.org/10.1016/J.JENVMAN.2020.110652

James, C. S., & Makoa, M. J. (2006). Conveyance estimation for channels with emergent vegetation boundaries. *Proceedings of the Institution of Civil Engineers - Water Management*, *159*(4), 235–243. https://doi.org/10.1680/wama.2006.159.4.235

JBA Consulting. (2013). *Restoring the river Teme SSSI a river restoration plan non – Technical summary*. JBA Consulting.

Jerin, T. (2019). Biogeomorphic effects of woody vegetation on bedrock streams. *Progress in Physical Geography: Earth and Environment*, *43*(6), 777–800. https://doi.org/10.1177/0309133319851027

Karrenberg, S., Edwards, P. J., & Kollmann, J. (2002). The life history of Salicaceae living in the active zone of floodplains. *Freshwater Biology*, *47*(4), 733–748. https://doi.org/10.1046/j.1365-2427.2002.00894.x

Kendon, M., McCarthy, M., Jevrejeva, S., Matthews, A., Sparks, T., Garforth, J., & Kennedy, J. (2022). State of the UK climate 2021. *International Journal of Climatology*, *42*(S1), 1–80. https://doi.org/10.1002/joc.7787

Kreutzweiser, D., Capell, S., Good, K., & Holmes, S. (2009). Sediment deposition in streams adjacent to upland clearcuts and partially harvested riparian buffers in boreal forest catchments. *Forest Ecology and Management*, *258*(7), 1578–1585. https://doi.org/10.1016/j.foreco.2009.07.005

Lee, C., Lee, K., Kim, H., Baek, D., Kim, W., Woo, H., Cho, K., & Kim, D. (2022). Impacts of an extreme flood event on the riparian vegetation of a monsoonal cobble-bed stream in southern Korea: A multiscale fluvial biogeomorphic framework. *River Research and Applications*, *38*(6), 1101–1114. https://doi.org/10.1002/rra.3974

Lewin, J. (1976). Initiation of bed forms and meanders in coarse-grained sediment. *Geological Society of America Bulletin*, 281–285.

Lewin, J., Davies, B. E., & Wolfenden, P. J. (1977). Interactions between channel change and historic mining sediments. In K. J. Gregory (Ed.), *River channel changes* (pp. 357–367). Wiley.

Liébault, F., Gomez, B., Page, M., Marden, M., Peacock, D., Richard, D., & Trotter, C. M. (2005). Land-use change, sediment production and channel response in upland regions. *River Research and Applications*, *21*(7), 739–756. https://doi.org/10.1002/rra.880

Lind, L., Hasselquist, E. M., & Laudon, H. (2019). Towards ecologically functional riparian zones: A meta-analysis to develop guidelines for protecting ecosystem functions and biodiversity in agricultural landscapes. *Journal of Environmental Management*, *249*, 109391. https://doi.org/10.1016/j.jenvman.2019.109391

Marteau, B., Piégay, H., Chandesris, A., Michel, K., & Vaudor, L. (2022). Riparian shading mitigates warming but cannot revert thermal alteration by impoundments in lowland rivers. *Earth Surface Processes and Landforms*, *47*(9), 2209–2229. https://doi.org/10.1002/esp.5372

McBride, M., Hession, W. C., Rizzo, D. M., & Thompson, D. M. (2007). The influence of riparian vegetation on near-bank turbulence: A flume experiment. *Earth Surface Processes and Landforms*, *32*(13), 2019–2037. https://doi.org/10.1002/esp.1513

Macklin, M. G., & Lewin, J. (1989). Sediment transfer and transformation of an alluvial valley floor: The River South Tyne, Northumbria, U.K. *Earth Surface Processes and Landforms*, *14*(3), 233–246. https://doi.org/10.1002/esp.3290140305

Macklin, M. G., Passmore, D. G., & Newson, M. D. (1998). Controls of short and long term river instability: processes and patterns in gravel-bed river, the Tyne basin, northern England. In P. E. Klingeman, R. L. Beschta, J. Bradley, & P. D. Komar (Eds.), *Proceedings of the 4th International gravel bed Rivers conference* (pp. 257–278). Water Resources Publication.

Macklin, M. G. (1997). Fluvial geomorphology of North-East England. In K. J. Gregory (Ed.), *Fluvial geomorphology of great Britain* (pp. 202–238). Chapman and Hall.

McEwan, G. (2022). *What natural England has to say about teme bank clearance*. https://www.herefordtimes.com/news/23107530.natural-england-say-teme-bank-clearance/

Micheli, E. R., & Kirchner, J. W. (2002). Effects of wet meadow riparian vegetation on streambank erosion. 1. Remote sensing measurements of streambank migration and erodibility. *Earth Surface Processes and Landforms*, *27*(6), 627–639. https://doi.org/10.1002/esp.338

Micheli, E. R., Kirchner, J. W., & Larsen, E. W. (2004). Quantifying the effect of riparian forest versus agricultural vegetation on river meander migration rates, central Sacramento River, California, USA. *River Research and Applications*, *20*(5), 537–548. https://doi.org/10.1002/rra.756

Moggridge, H. L., & Gurnell, A. M. (2009). Controls on the sexual and asexual regeneration of Salicaceae along a highly dynamic, braided river system. *Aquatic Sciences*, *71*(3), 305–317. https://doi.org/10.1007/s00027-009-9193-3

Nagler, P., Glenn, E. P., Hursh, K., Curtis, C., & Huete, A. (2005). Vegetation mapping for change detection on an arid-Zone River. *Environmental Monitoring and Assessment*, *109*(1–3), 255–274. https://doi.org/10.1007/s10661-005-6285-y

Naiman, R. J., Decamps, H., & McClain, M. E. (2005). *Riparia — Ecology conservation and management of streamside communities*. Elsevier Academic Press.

Naiman, R. J., Decamps, H., & Pollock, M. (1993). The role of riparian corridors in maintaining regional biodiversity. *Ecological Applications*, *3*(2), 209–212. https://doi.org/10.2307/1941822

New South Wales Government. (2012). *Guidelines for riparian corridors on waterfront land*. https://www.ipcn.nsw.gov.au

O'Callaghan, M. J., Hannah, D. M., Williams, M., & Sadler, J. P. (2013). Exposed riverine sediments (ERS) in England and Wales: Distribution, controls and management. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *23*(6), 924–938. https://doi.org/10.1002/aqc.2376

Oorschot, M., Kleinhans, M., Geerling, G., & Middelkoop, H. (2016). Distinct patterns of interaction between vegetation and morphodynamics. *Earth Surface Processes and Landforms*, *41*(6), 791–808. https://doi.org/10.1002/esp.3864

Osterkamp, W. R., Hupp, C. R., & Stoffel, M. (2012). The interactions between vegetation and erosion: New directions for research at the interface of ecology and geomorphology. *Earth Surface Processes and Landforms*, *37*(1), 23–36.

Passmore, D. G., Macklin, M. G., Brewer, P. A., Lewin, J., Rumsby, B. T., & Newson, M. D. (1993). Variability of late Holocene braiding in Britain. *Geological Society, London, Special Publications*, *75*(1), 205–229. https://doi.org/10.1144/GSL.SP.1993.075.01.13

Passmore, D. G., & Macklin, M. G. (2000). Late Holocene channel and floodplain development in a wandering gravel-bed river: The river South Tyne at Lambley, northern England. *Earth Surface Processes and Landforms*, *25*(11), 1237–1256. https://doi.org/10.1002/1096-9837(200010)25:11<1237::AID-ESP134>3.0.CO;2-S

Perucca, E., Camporeale, C., & Ridolfi, L. (2007). Significance of the riparian vegetation dynamics on meandering river morphodynamics. *Water Resources Research*, *43*(3), 1-10. https://doi.org/10.1029/2006WR005234

Petts, G. E., Gurnell, A. M., Gerrard, A. J., Hannah, D. M., Hansford, B., Morrissey, I., Edwards, P. J., Kollmann, J., Ward, J. V., Tockner, K., & Smith, B. P. G. (2000). Longitudinal variations in exposed riverine sediments: A context for the ecology of the Fiume Tagliamento, Italy. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *10*(4), 249–266. https://doi.org/10.1002/1099-0755(200007/08)10:4<249::AID-AQC410>3.0.CO;2-R

Pizzuto, J., O'Neal, M., & Stotts, S. (2010). On the retreat of forested, cohesive riverbanks. *Geomorphology*, *116*(3–4), 341–352. https://doi.org/10.1016/J.GEOMORPH.2009.11.008

Pollen-Bankhead, N., & Simon, A. (2010). Hydrologic and hydraulic effects of riparian root networks on streambank stability: Is mechanical root-reinforcement the whole story? *Geomorphology*, *116*(3–4), 353–362. https://doi.org/10.1016/j.geomorph.2009.11.013

QGIS Development Team. (2023). *QGIS geographic information system (3.28)*. QGIS Association. https://www.qgis.org/

Ray, D., Morison, J., & Broadmeadow, M. (2010). *Climate change impacts and adaptation in England's woodlands*. https://cdn.forestresearch.gov.uk/2010/08/fcrn201.pdf

Roberts, J., & Florentine, S. (2021). Biology, distribution and control of the invasive species *Ulex europaeus* (gorse): A global synthesis of current and future management challenges and research gaps. *Weed Research*, *61*(4), 272–281. https://doi.org/10.1111/wre.12491

Rodríguez-González, P. M., Albuquerque, A., Martínez-Almarza, M., & Díaz-Delgado, R. (2017). Long-term monitoring for conservation management: Lessons from a case study integrating remote sensing and field approaches in floodplain forests. *Journal of Environmental*

Management, *202*, 392–402. https://doi.org/10.1016/J.JENVMAN.2017.01.067

Sarneel, J. M., Janssen, R. H., Rip, W. J., Bender, I. M. A., & Bakker, E. S. (2014). Windows of opportunity for germination of riparian species after restoring water level fluctuations: A field experiment with controlled seed banks. *Journal of Applied Ecology*, *51*(4), 1006–1014. https://doi.org/10.1111/1365-2664.12288

Scorpio, V., & Piégay, H. (2021). Is afforestation a driver of change in Italian rivers within the Anthropocene era? *Catena*, *198*, 105031. https://doi.org/10.1016/J.CATENA.2020.105031

Simon, A., & Collison, A. J. C. (2002). Quantifying the mechanical and hydrologic effects of riparian vegetation on streambank stability. *Earth Surface Processes and Landforms*, *27*(5), 527–546. https://doi.org/10.1002/esp.325

Simon, A., Pollen, N., & Langendoen, E. (2006). Influence of two woody riparian species on critical conditions for streambank stability: UPPER Truckee River, California. *Journal of the American Water Resources Association*, *42*(1), 99–113. https://doi.org/10.1111/j.1752-1688.2006.tb03826.x

Smith, J. D. (2004). The role of riparian shrubs in preventing floodplain unravelling along the Clark Fork of the Columbia River in deer Lodge Valley, Montana. In S. J. Bennett & A. Simon (Eds.), *Riparian vegetation and fluvial geomorphology. Water science and application* (pp. 71–85). American Geophysical Union.

Tabacchi, E., Correll, D. L., Hauer, R., Pinay, G., Planty-Tabacchi, A., & Wissmar, R. C. (1998). Development, maintenance and role of riparian vegetation in the river landscape. *Freshwater Biology*, *40*(3), 497–516. https://doi.org/10.1046/j.1365-2427.1998.00381.x

Tal, M., & Paola, C. (2010). Effects of vegetation on channel morphodynamics: Results and insights from laboratory experiments. *Earth Surface Processes and Landforms*, *35*(9), 1014–1028. https://doi.org/10.1002/esp.1908

Török, G. T., & Parker, G. (2022). The influence of riparian woody vegetation on bankfull alluvial river morphodynamics. *Scientific Reports*, *12*(1), 18141. https://doi.org/10.1038/s41598-022-22846-1

The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017, (2017). https://www.legislation.gov.uk/uksi/2017/407

Wheaton, J. M., Brasington, J., Darby, S. E., & Sear, D. A. (2009). Accounting for uncertainty in DEMs from repeat topographic surveys: Improved sediment budgets. *Earth Surface Processes and Landforms*, *35*, 136–156. https://doi.org/10.1002/esp.1886

Williams, R. D. (2012). DEM's of Difference. Geomorphological Techniques; *British Society for Geomorphology*. http://bsg.obdev.co.uk/assets/publications/subsections/pdfs/OnsitePublicationSubsection/14/2.3.2_demsofdifference.pdf

Woodland Trust. (2016). *Keeping rivers cool: A guidance manual: Creating riparian shade for climate change adaptation*. https://www.woodlandtrust.org.uk/media/1761/keeping-rivers-cool.pdf

Zhang, M., Liu, N., Harper, R., Li, Q., Liu, K., Wei, X., Ning, D., Hou, Y., & Liu, S. (2017). A global review on hydrological responses to forest change across multiple spatial scales: Importance of scale, climate, forest type and hydrological regime. *Journal of Hydrology*, *546*, 44–59. https://doi.org/10.1016/j.jhydrol.2016.12.040

SUPPORTING INFORMATION

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