Sediment Dynamics and the Hydromorphology of Fluvial Systems (Proceedings of a symposium held in Dundee, UK, July 2006). IAHS Publ. 306, 2006.

River flood plains as carbon sinks

D. E. WALLING, D. FANG, A. P. NICHOLAS & R. J. SWEET

Department of Geography, University of Exeter, Exeter EX4 4RJ, UK

d.e.walling@exeter.ac.uk

Abstract There is increasing recognition that overbank sedimentation on river flood plains is likely to represent an important sink in the global carbon cycle, significantly reducing the land–ocean transport of POC. There have, however, been few detailed studies of carbon storage on river flood plains and little is currently known about the role of UK rivers in this component of the carbon cycle. This paper reports the findings of a study aimed at investigating carbon sequestration associated with overbank deposition on the flood plains of six rivers in southern England, embracing a range of catchment characteristics and hydrological conditions. A total of 46 shallow sediment cores were collected at representative sites along the flood plains of the six rivers. These cores were sectioned and analysed to determine the depth distribution of both organic carbon and the fallout radionuclide ^{137}Cs. The ^{137}Cs data were used to estimate rates of sedimentation, which could in turn be used to estimate carbon sequestration rates. The results demonstrate appreciable spatial variability in the organic carbon content of overbank sediment deposits, both between rivers and between individual sites along a flood plain. The average organic carbon content of the upper 24 cm of the overbank sediments from the individual rivers ranged between 2.17 and 5.07%. The estimates of carbon sequestration rate obtained for the flood plains of the individual rivers were characterized by mean values ranging between 69.2 and 114.3 g m^{-2} year^{-1}. These results confirm that the flood plains of British rivers are significant carbon sinks.

Key words carbon cycle; carbon sinks; carbon storage; flood plain deposition; river flood plains; sediment cores; sediment deposition

INTRODUCTION

Current interest in global carbon cycling has identified terrestrial sedimentation and the land–ocean transfer of suspended sediment as important components of the carbon cycle (Stallard, 1998). Current estimates of the particulate organic carbon (POC) flux associated with land–ocean suspended sediment transfer indicate that this is of the order of 0.2 to 0.3 Gt year^{-1} (see Ludwig & Probst, 1996; Stallard, 1998; Beusen *et al.*, 2005). In a study that focused on the conterminous United States, Smith *et al.* (2001) attempted to link the land–ocean transfer of POC to the mobilization of sediment and associated POC by soil erosion. This work emphasized the importance of sedimentation in reservoirs and what the authors termed "other sedimentation" in greatly reducing the potential flux associated with soil erosion. The two sinks were accorded similar magnitudes, but whereas reservoir sedimentation was explicitly recognized, no clear indication of the main components of the "other sedimentation" and their relative importance was provided. The existence and magnitude of the "other sedimentation" sink was essentially inferred by balancing the sediment budget and making assumptions concerning the organic carbon content of the sediment. It is important to identify and quantify this sink more precisely, since several workers have used the apparent discrepancy between the mass of soil organic carbon (SOC) mobilized by soil erosion and the much smaller POC flux reaching the oceans, to suggest that a significant proportion of the SOC mobilized by erosion is rapidly oxidized and is not transported to the oceans (e.g. Shlesinger, 1995; Lal, 2004). In terms of the global carbon cycle, there is clearly a very important difference between conversion of SOC to CO_2 and its sequestration in sediment deposits.

In recent years, a number of authors (e.g. Allison *et al*., 1998; Walling *et al*., 1999; Walling & Owens, 2002; Aalto *et al*., 2002; Walling, 2003) have emphasized the importance of overbank sedimentation on river flood plains in reducing fine sediment transfer by rivers, and such sedimentation clearly has important implications for the land–ocean POC flux. Walling (2003) has suggested that up to 50% of the total load delivered to river channel systems may be deposited on their flood plains before reaching the river basin outlet and the sea. If this is the case, the depositional flux of POC associated with fine sediment deposition on river flood plains could be of a similar magnitude to the land–ocean POC flux, and thus of the order of 0.2 to 0.3 Gt year^{-1}, although Stallard (1998) suggested that the flood plain deposition flux was somewhat lower and currently of the order of 0.08 Gt year^{-1}. Stallard (1998) did, however, indicate that flood plain deposition was likely to have been greater in "pre-technological" times and provided a value of 0.2 Gt year^{-1} for that period. It is difficult to speculate as to the likely relative magnitude of the flood plain depositional flux in "pre-technological" and "technological" times, since this will reflect human modification of both the extent and morphology of the flood plains, as well as changes in both flood magnitude and fine sediment loads. In the former case, human occupation of river flood plains, resulting in the construction of levees and other flood control measures, is likely to have reduced the area of potential inundation, but this could have been offset by increased flood frequency, and therefore increased flood plain inundation, as well as increased sediment loads resulting from land clearance and intensification of land use. However, the construction of reservoirs could be expected to reduce flood plain sedimentation by reducing both the magnitude and frequency of overbank flooding, as well as the magnitude of the suspended sediment load potentially available for deposition. Notwithstanding these uncertainties, it is clear that overbank sedimentation of POC on river flood plains is likely to represent a significant component of the global carbon cycle and merits further attention.

To date, there have been few attempts to couple investigation of overbank sediment deposition on river flood plains with an assessment of their resulting role as carbon sinks. Most assessments of the likely significance of flood plains as carbon sinks have been based on inference, albeit reasonable, that sediment deposition will result in deposition of POC. To develop an improved understanding of the role of river flood plains as carbon sinks, there is an important need to obtain more information on the organic carbon (OC) content of overbank flood plain deposits and its spatial variability, as well as the deposition fluxes involved and rates of post-depositional oxidation or degradation of the deposited organic matter. Such work needs to be undertaken in different physiographic environments and over a range of spatial scales, in order to generate an improved understanding of the key controls and the potential for generalization. This contribution reports such information relating to the organic carbon content of overbank flood plain deposits and associated rates of organic carbon accumulation obtained from a recent investigation of overbank sediment deposition on the flood plains of six rivers in southern Britain.

THE STUDY RIVERS AND THEIR FLOOD PLAINS

The study reported here represents part of a larger study of overbank sedimentation on river flood plains in southern Britain (see, for example, Sweet *et al*., 2003). The six rivers investigated were selected to be representative of a range of conditions, including both the underlying geology and terrain characteristics of their catchments and their hydrological response. The location of the rivers is shown in Fig. 1 and further details of their hydrological and catchment characteristics are provided in Table 1. Key contrasts include those between the Rivers Usk and Exe, which rise in the wetter upland areas of the Brecon Beacons and Exmoor, respectively, and the Rivers Culm and Stour, whose catchments are more lowland in character and receive substantially less rainfall. The rivers Torridge and Axe can be seen as intermediate between these two extremes, draining areas of moderate relief. There are also important contrasts in underlying geology between the catchments. Indurated Devonian and Carboniferous slates and sandstones occupy much of the catchments of the Exe, Usk and Torridge, whereas, softer and more permeable Permian, Triassic, Jurassic and Cretaceous sandstones, marls, shales, and chalk are found in the catchments of the Culm, Axe and Stour. The above contrasts in topography, underlying geology and annual precipitation, are reflected by further contrasts in soils and land use. Information on the suspended sediment yields of the study catchments is limited, but estimates of the specific suspended sediment yields are also provided in Table 1. These values must be seen as relatively low by world standards. Similarly, only limited information is available on the grain size composition and organic carbon content of the suspended sediment loads of the study rivers. Available data indicate that the sediment loads are relatively fine and median grain size or D_{50} values for the absolute size distributions are likely to be within the range 5–15 μm and the percent sand content is typically approx. 10% (cf. Walling & Woodward, 2000). The only detailed data available for the organic carbon content of suspended sediment is for the River Exe at Thorverton. Walling & Kane (1984) report an average organic carbon content of suspended sediment for the River Exe of 7.1%, with values ranging from approx. 4.5% to approx. 10% and showing a well defined inverse relationship with discharge. In the case of the River Exe, Walling & Kane (1984) show that the organic carbon content of suspended sediment was enriched approx. 2-fold compared with pasture soils in the catchment and about 3-fold compared to arable soils. This enrichment reflects both the selectivity of sediment mobilization and transfer processes, as well as the addition of autochthonous organic matter during transport through the channel system.

The flood plains of the study rivers are characterized by subdued microtopography, with the local relief rarely exceeding 1 m. The mean width of the flood plains bordering the main channel systems of the rivers range from approx. 300 m (River Torridge) to 630 m (River Stour). Distinct natural levees are generally absent from the flood plains, probably as a result of the low sand content of the suspended sediment

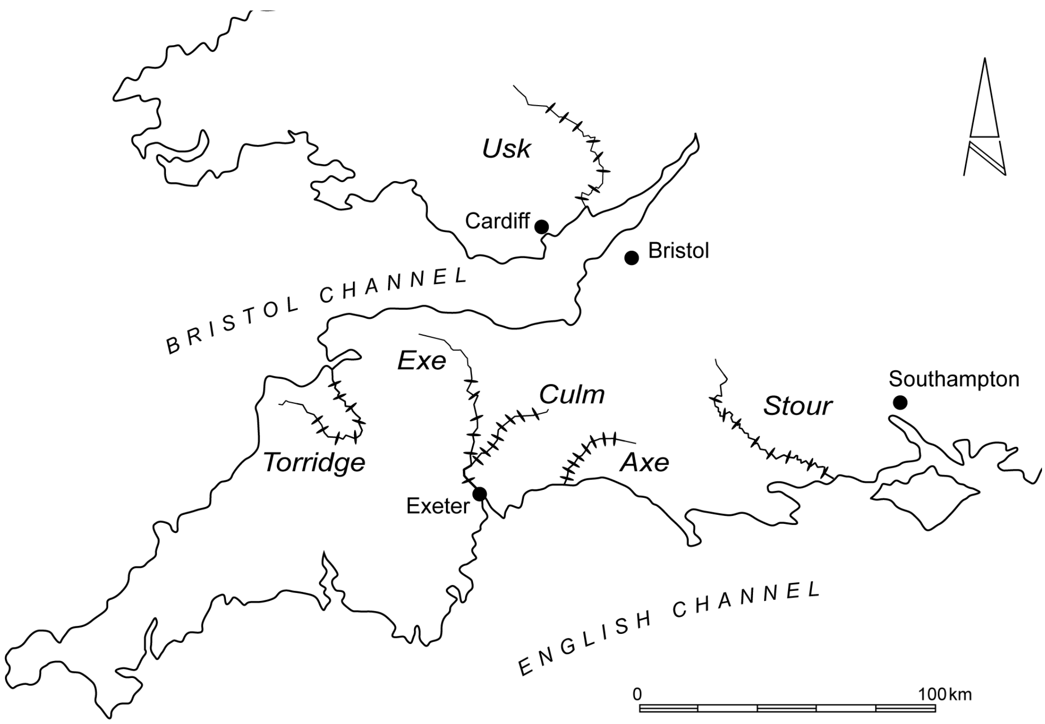

Fig. 1 The location of the six study rivers in southern England and the position of the points along the river flood plains where sediment cores were collected.

Table 1 Some characteristics of the study rivers and their catchments.

River	Catchment area[a] (km^2)	Mean altitude (m)	Mean slope ($m\ km^{-2}$)	Dominant lithology	Mean annual ppt (mm)	Specific sediment yield[c] ($t\ km^{-2}\ year^{-1}$)
Axe	303	134	90	sandstone, marl, shale	991	approx. 50
Culm	276	140	71	sandstone, marl	952	approx. 25
Exe[b]	908	208	116	sandstone, slate, marl	1148	approx. 30
Stour	1067	85	51	clay, chalk	861	approx. 30
Torridge	723	156	83	slate, sandstone	1176	approx. 75
Usk	1124	273	149	sandstone	1304	approx. 50

[a] The catchment area listed represents the catchment area above the lowest flood plain reach investigated.
[b] The data for the River Exe are based on the combined catchments of the Rivers Exe and Culm.
[c] The values of specific suspended sediment yield listed are estimates based on available data.

loads transported by the rivers. The flood plains of the rivers are regularly inundated for short periods on several occasions each year, typically during the winter months, although the depth of inundation rarely exceeds 1 m. The soils of the flood plains investigated are generally well drained during the drier months of the year and when waterlogging occurs it is commonly short-lived and primarily associated with periods of inundation. The land use of the flood plains is principally permanent pasture.

DATA COLLECTION

Attention focused on the flood plains bordering the main channels of the six study rivers. In each case, the main channel was subdivided into a number of segments (six for the Exe and eight for all the other rivers) and representative reaches of flood plain (approx. 600 m in length) were identified for each of these segments. Within each of these reaches a sediment core was recovered from a site selected to be representative of the reach (see Fig. 1). These cores were collected to a depth of approx. 60 cm, using a motorized percussion corer equipped with a 6.9 cm internal diameter core tube. Visual inspection of the cores confirmed that, in all cases, they were composed entirely of fine overbank deposits and that there was no evidence of major downcore changes in texture. The sediment cores were sectioned into 2 cm depth increments either in the field or immediately on return to the laboratory.

The sediment samples associated with the individual depth increments were freeze dried, disaggregated and sieved to <2 mm to remove any coarse organic material and the OC content of a representative aliquot from each depth increment was determined by pyrolysis using a Carlo Erba C/N analyser. As part of the wider investigation, the individual sections of the cores were also assayed for their ^{137}Cs activity by gamma spectrometry, in order to derive estimates of medium-term sedimentation rates at the sampling points (cf. Walling & He, 1997; Walling *et al*., 1999). For this analysis, the sediment samples representing individual depth increments were placed in sealed plastic pots and assayed using an HPGe gamma detector. Count times were typically approx. 50 000 s, providing a precision of approx. ±5% at the 95% level of confidence.

RESULTS

Representative examples of the information on the OC content of the flood plain sediment cores provided by the laboratory analysis are presented in Fig. 2. In each case, the OC depth distribution evidences a well-defined exponential decrease with depth from the surface, with OC concentrations at 20 cm depth being only approx. 40–50% of those at the surface. A depth distribution of this shape is typical of pasture soils (see Brady, 1974) and primarily reflects the increased density of grass roots and other organic residues in the upper levels of the soil profile. In addition, since the flood plain surface is accreting and new POC is deposited during flood events, in combination with the deposited sediment, any tendency for the recently deposited organic matter to degrade during progressive burial could also be expected to result in a reduction in the OC content of the deposited sediment with increasing depth. In this context, increasing depth is equivalent to increasing time. Figure 2 also emphasizes the potential spatial variability of the OC content of overbank flood plain sediments. The three sites are characterized by surface OC contents of approx. 2, 5, and 10%, respectively.

Further information on the spatial variability of the OC content of the overbank sediment deposits collected from the flood plains bordering the six study rivers is presented in Fig. 3. In an attempt to take account of the variation of the OC content of the flood plain sediments with depth, the data relate to the mean OC content of the upper 24 cm of the individual profiles. Values of OC content are provided for each of

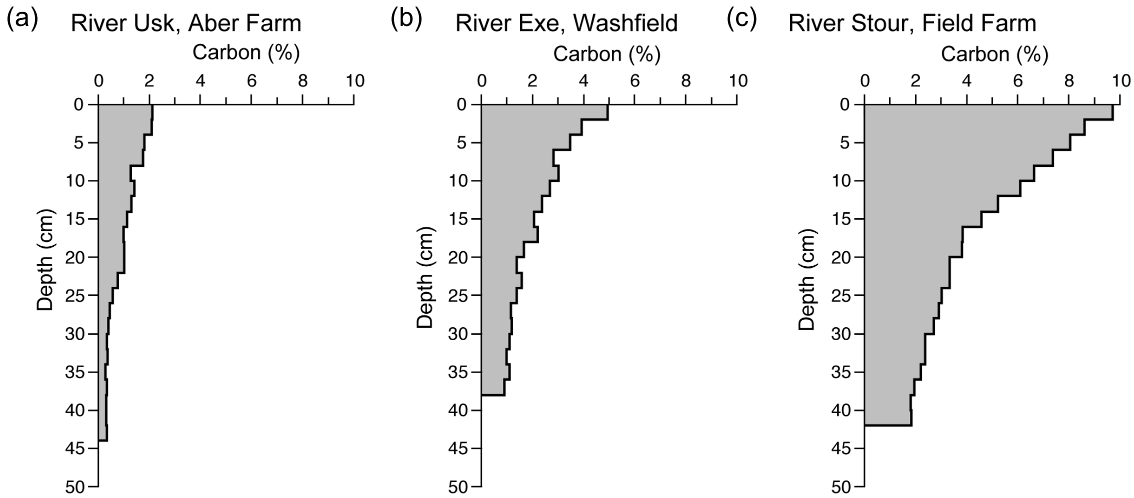

Fig. 2 Representative examples of the depth distribution of the OC content of the overbank flood plain deposits from the flood plains of the study rivers.

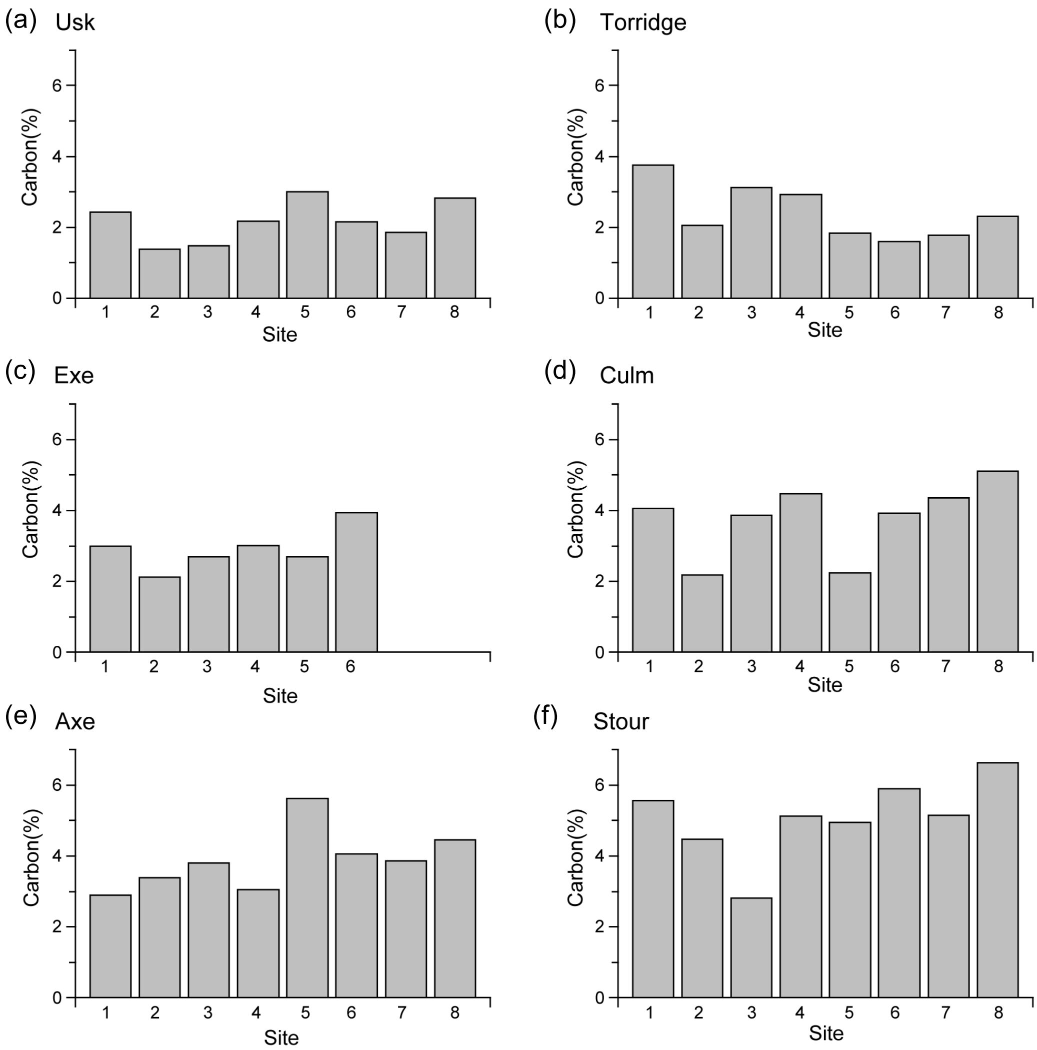

Fig. 3 The average OC content of the upper 24 cm of the flood plain cores collected from the study rivers. Site 1 in the sequence represents the most upstream site.

the reaches sampled along the study rivers and these data provide clear evidence of variations both between the study rivers and along the individual rivers. In considering the differences between the rivers, all rivers provide evidence of variation in OC content between individual flood plain sites along the river, but it is possible to distinguish three groups of rivers, characterized by significantly different values of mean OC content for their overbank sediments. The first group, comprises the Rivers Usk, Torridge and Exe, with mean values of 2.17%, 2.43% and 2.91%, respectively. The second group comprises the Rivers Culm and Axe, with substantially higher mean values of 3.77% and 3.89%, respectively, and the final group comprises a single river, namely the Stour with an even higher mean value of 5.07%.

Detailed explanation of the above contrasts in the mean OC content of flood plain sediments between the six study rivers falls outside the scope of this contribution, but a number of potential controls can be briefly considered. In the first place, there would appear to be a contrast between the rivers draining catchments underlain by older resistant rocks, that in turn are characterized by significant areas of upland, often with moorland (i.e. the Rivers Usk, Torridge and Exe), and the rivers draining more lowland catchments underlain by softer sedimentary rocks (i.e. the Rivers Culm, Axe and Stour). The contrasts might also be expected to reflect, at least in part, the OC content of the catchment soils, but no clear link is apparent. For example, available information on the OC content of the soils of England and Wales suggests that the soils of upland areas are frequently characterized by higher OC contents, whereas the results presented above indicate that the OC content of flood plain sediments is lowest for the more upland catchments (i.e. the Usk, Torridge and Exe). It is, nevertheless, important to recognize that some of the OC associated with fluvial sediment may be of autochthonous origin and could therefore reflect both the addition of autochthonous organic particulate material and the development of organic coatings on the sediment particles, whilst in the fluvial system. There is, however, no clear relationship between the mean OC content of the overbank sediments and their grain size composition, although the River Stour stands out as having both the finest overbank sediments and overbank sediments with the highest OC content. Data from a greater number of flood plains are clearly required in order to establish the key controls on the spatial variability of the OC content of overbank flood plain sediments within the UK. This needs to include more precise information on the OC content of the fine sediment transported by those rivers sediment, since this will clearly exert an important influence on the OC content of the overbank deposits.

The data presented in Fig. 3 also provide information on downstream variations in the OC content of the overbank flood plain deposits. Significant variations exist between the individual sites along the flood plains and, although no clear trends are evident, it can be suggested that for all rivers, with the exception of the River Torridge, there is some evidence of a small downstream increase in the OC content of the overbank deposits. In the case of the River Torridge, however, the trend is reversed, with the OC content of the flood plain deposits declining downstream. The somewhat anomalous behaviour of the sediments of the River Torridge has already been highlighted by Walling *et al.* (2004), who noted that along this river the D_{50} (median diameter) and % sand content of the flood plain deposits increased downstream and the specific surface area and clay content decreased, whereas for other rivers there was either no significant trend or the trend shown by the River Torridge was reversed.

The information on the ^{137}Cs and OC depth profiles available for the individual reaches on the study rivers affords an opportunity to estimate the rates of OC sequestration on their flood plains. Figure 4 provides representative examples of the OC and ^{137}Cs depth profiles for cores collected from the flood plains of the Rivers Axe, Exe and Torridge. The ^{137}Cs depth profiles exhibit the classic shape expected of a depositional environment (see, for example, Walling & He, 1992), with radiocaesium activities increasing from the base towards the peak of ^{137}Cs activity, which can be linked to the period of peak fallout in 1963, and declining above the 1963 horizon towards the surface. The ^{137}Cs depth profile can be used to estimate the sedimentation rate at the point from which the core was collected (see, for example Walling & He, 1997) and if this information is combined with information on the OC content of the flood plain sediments, it is possible to estimate the OC accretion or sequestration rate. Since Fig. 2 shows that the OC content of flood plain sediments characteristically declines exponentially with depth, it is important to take account of this downcore decrease and in this study the estimate of sedimentation rate obtained from the ^{137}Cs

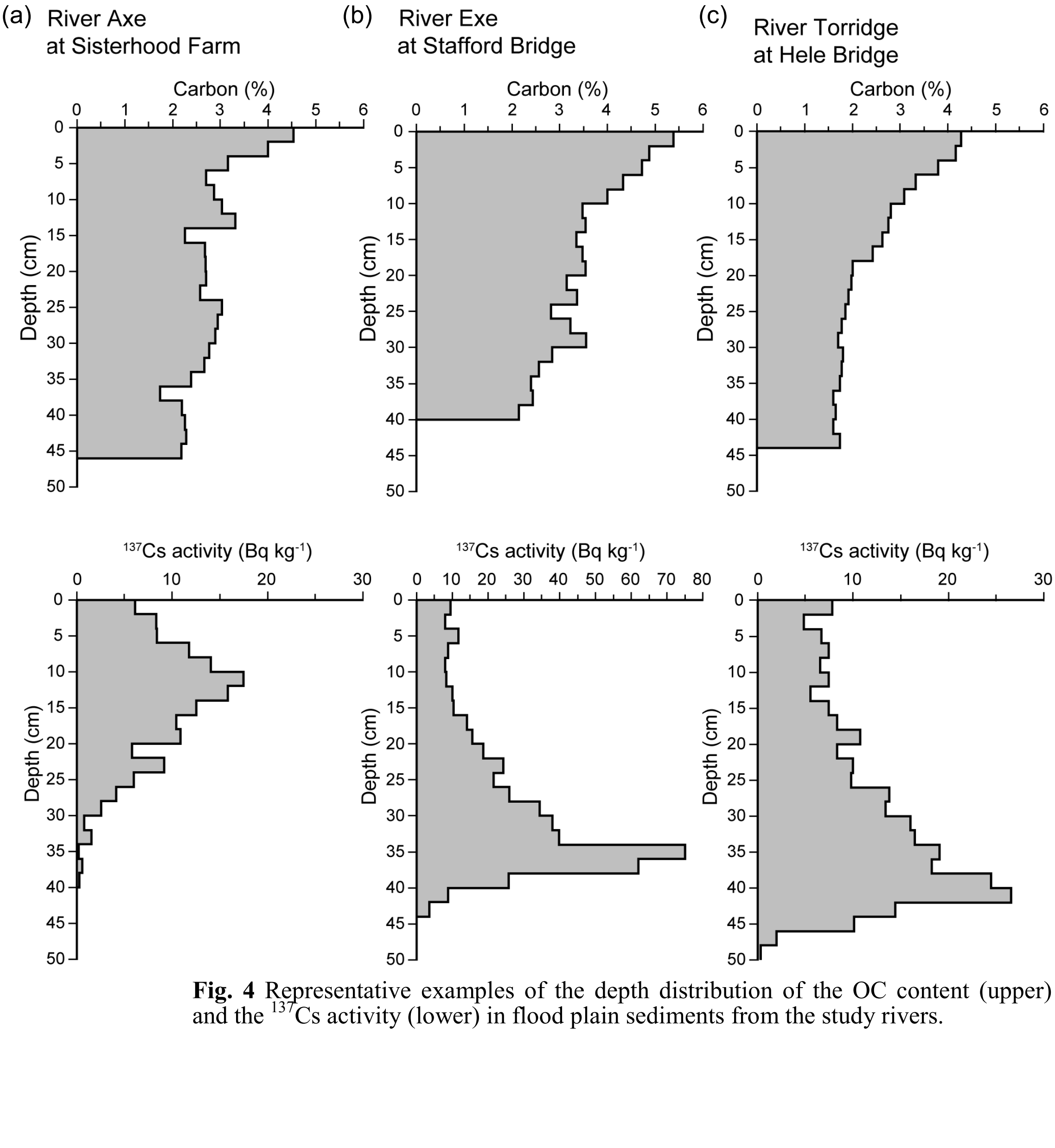

Fig. 4 Representative examples of the depth distribution of the OC content (upper) and the ^{137}Cs activity (lower) in flood plain sediments from the study rivers.

depth profile has been combined with the value of OC content associated with the 1963 horizon, in order to estimate the medium-term OC sequestration rate (g m^{-2} $year^{-1}$). Assuming a constant sedimentation rate, OC sequestration rates may be higher near the surface, but these reflect inputs of fresh organic carbon from both recently deposited sediment and the pasture vegetation, whereas the values at depth represent a more stable value of OC content after storage and degradation for about 35–40 years. These values of OC content are therefore seen as providing more representative values for estimating medium-term OC sequestration rates.

Estimates of medium-term OC sequestration rates for the individual reaches of the flood plains of the study rivers, derived using the procedure outlined above, are presented in Fig. 5. These evidence variability both between the individual rivers and along those rivers. This variability will in turn reflect variations in both overbank sedimentation rates and the OC content of the deposited sediment. Overall, however, the data presented in Fig. 5 demonstrate a substantial degree of consistency, with only

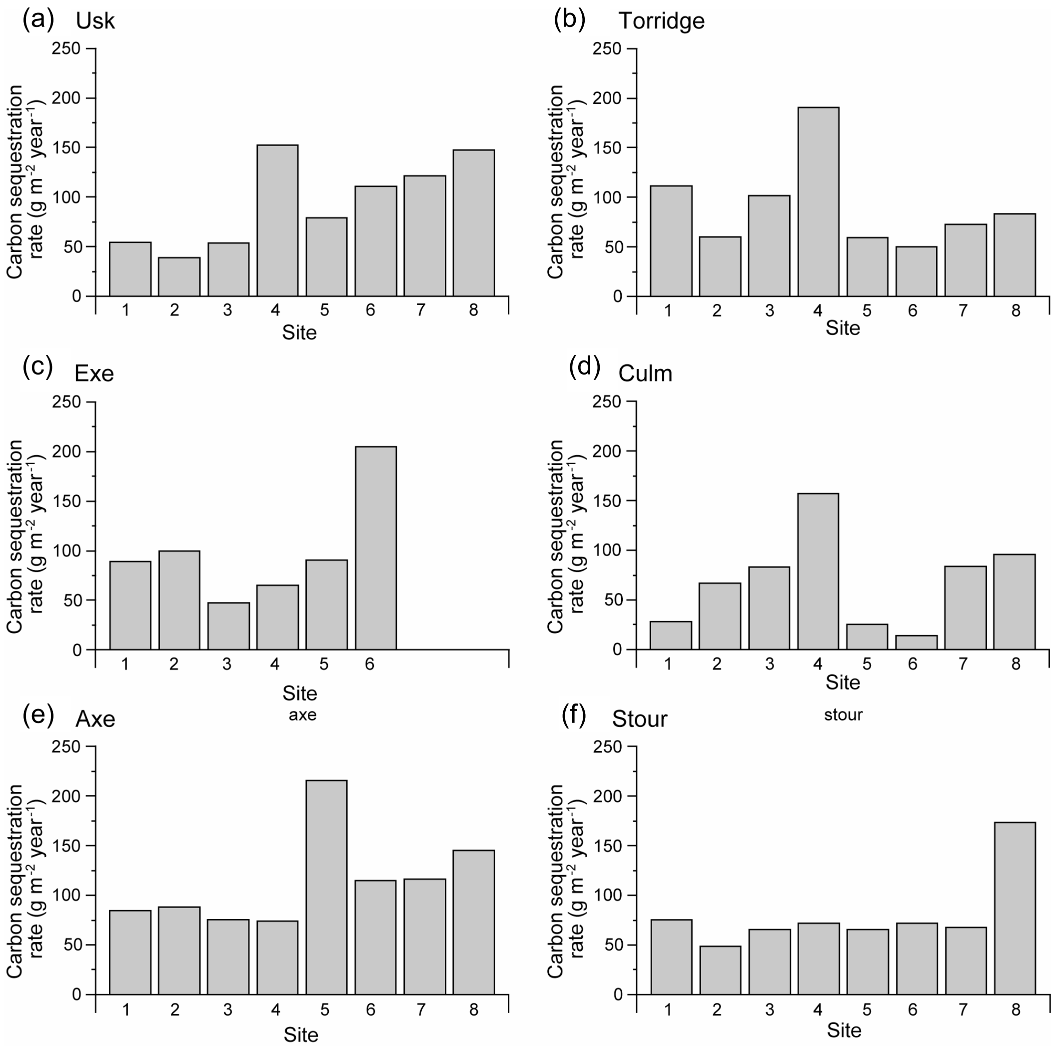

Fig. 5 The estimates of medium-term OC sequestration rate obtained for the individual coring sites along the flood plains of the study rivers. Site 1 in the sequence represents the most upstream site.

relatively limited variation around the mean OC sequestration rate, for all the sites sampled, of 91.5 g m^{-2} $year^{-1}$. The mean values for the sites on the individual rivers range between a maximum of 114.3 g m^{-2} $year^{-1}$ for the River Axe and a minimum of 69.2 g m^{-2} $year^{-1}$ for the River Culm. The mean values for the Usk (94.7 g m^{-2} $year^{-1}$), Torridge (91.1 g m^{-2} $year^{-1}$) and Exe (99.5 g m^{-2} $year^{-1}$) are very similar, whilst that for the River Stour (80.1 g m^{-2} $year^{-1}$) is slightly lower. The individual rivers show no clear pattern of downstream variation, although it could be suggested that OC sequestration rates increase downstream along the Usk, Exe and Axe flood plains.

To the authors' knowledge these are the first estimates of carbon sequestration rates obtained for the flood plains of UK rivers and it is therefore important to place them into a broader context by comparing them with values reported for rivers elsewhere. However, few such data are available. Reference can, nevertheless, be made to the work reported by Noe & Hupp (2005) at several sites on the flood plains of the Chickahominy (1217 km^2), Mattaponi (2362 km^2) and Pocomoke (23 871 km^2) Rivers within the Atlantic Coastal Plain in Virginia, Maryland and Delaware, USA. In their case, the accumulation of sediment and organic carbon and other nutrients was measured directly, by establishing feldspar marker horizons on the flood plain surface and measuring the accumulation of sediment and carbon on these marker horizons after a period of 3–6 years. The mean values of carbon accumulation reported for the individual sites ranged from 61 to 212 g m^{-2} $year^{-1}$, and are thus of a similar order of magnitude to those documented for the UK study rivers, although in several cases they are somewhat higher. The values reported by Noe & Hupp (2005) could, however, be expected to be higher than those reported in this paper, since the former relate to surface deposits which, as indicated above, should be characterized by higher OC contents than those found at depth and that were used in the current study.

PERSPECTIVE

The results presented above provide important new information on the role of the flood plains of British rivers as carbon sinks, as well as providing data that can be compared with those from other areas of the world, with a view to developing an improved understanding of the wider significance of overbank sedimentation on river flood plains for carbon sequestration. The information on both the OC content of overbank sediments and the carbon sequestration rates involved serve to emphasize the importance of river flood plains as carbon sinks. Further investigations are required to document a wider range of river systems, in order to identify the key controls on the OC content of overbank sediments, which in turn exercises an important influence on sequestration rates. This should involve comparison of the OC content of suspended sediment with that of the overbank sediment deposits. Information on carbon sequestration rates also needs to be used to generate estimates of the magnitude of the total depositional fluxes involved in particular river basins, in order to elucidate the importance of flood plain sinks within their overall sediment and carbon budgets. Similar investigations could usefully be undertaken in river systems in other areas of the world and in contrasting environments, in order to provide a broader global perspective of this component of the global carbon cycle.

Acknowledgement The work reported in this paper was supported by NERC Research Grants GR3/12635 and NERC/A/S/2001/01076. This support, the assistance of local landowners in permitting access to the study reaches and the help of Sue Rouillard in producing the figures are gratefully acknowledged.

REFERENCES

Aalto, R., Dunne, T., Nittrouer, C. E., Maurice-Bourgoin, L. & Montgomery, D. R. (2002) Fluvial transport of sediment across a pristine tropical foreland basin: channel—flood plain interaction and episodic flood plain deposition. In: *The Structure, Function and Management Implications of Fluvial Sedimentary Systems* (ed. by F. J. Dyer, M. C. Thoms & J. M. Olley) (Proc. Alice Springs Symp. Sept. 2002), 339–344. IAHS Publ. 276. IAHS Press, Wallingford, UK.

Allison, M. A., Kuehl, S. A., Martin, S. C. & Hassan, A. (1998) Importance of flood-plain sedimentation for river sediment budgets and terrigenous input to the oceans: insights from the Brahmaputra-Jamuna River. *Geology* **26**, 125–178.

Bellamy, P. H., Loveland, P. J., Bradley, R. I., Lark, R. M. & Kirk, G. J. D. (2005) Carbon losses from all soils across England and Wales 1978–2003. *Nature* **437**, 245–247.

Beusen, A. H. W., Dekkers, A. L. M., Bouwman, A. F., Ludwig, W. & Harrison, J. (2005) Estimation of global river transport of sediments and associated particulate C, N and P. *Global Biogeochem. Cycles* **19**, art. no. GB4S05.

Brady, N. C. (2000) *The Nature and Properties of Soils*. Macmillan Publishing Co., New York, USA.

Lal, R. (2004) Soil carbon sequestration impacts on global climate change and food security. *Science* **304**, 393.

Ludwig, W. & Probst, J. -L. (1996) Predicting the oceanic input of organic carbon by continental erosion. *Global Biogeochem. Cycles* **10**, 23–41.

Noe, G. B. & Hupp, C. R. (2005) Carbon, nitrogen and phosphorus accumulation in flood plains of Atlantic Coastal Plain rivers. *Ecol. Applications* **15**, 1178–1190.

Shlesinger, W. H. (1995) Soil respiration and changes in soil carbon stocks. In: *Biotic Feedback in the Global Climatic System: Will the Warming Feed the Warming*? (ed. by G. M. Woodwell & F. T. Mackezie), 159–168. Oxford University Press, New York, USA.

Smith, S. V., Renwick, W. H., Buddemeier, R. W. & Crossland, C. J. (2001) Budgets of soil erosion and deposition for sediments and sedimentary organic carbon across the conterminous United States. *Global Biogeochem. Cycles* **15**, 697–707.

Stallard, R. F. (1998) Terrestrial sedimentation and the carbon cycle: coupling weathering and erosion to carbon burial. *Global Biogeochem. Cycles* **12**, 231–257.

Sweet, R J., Nicholas, A. P, Walling, D. E. & Fang, X. (2003) Morphological controls on medium-term sedimentation rates on British lowland river flood plains. *Hydrobiologia* **494**, 177–183.

Walling, D. E. (2003) River flood plains as sediment sinks. In: *From Watershed Slopes to Coastal Areas: Sedimentation Processes at Different Scales* (Papers from the Venice Workshop, December, 2003), Paper 1.3, UNESCO-ICCORES.

Walling, D. E. & He, Q. (1992) Interpretation of caesium-137 profiles in lacustrine and other sediments: the role of catchment-derived inputs. *Hydrobiologia* **235/6**, 219–230.

Walling, D. E. & He, Q. (1997) Use of fallout ^{137}Cs in investigations of overbank sediment deposition on river flood plains. *Catena* **29**, 263–282.

Walling, D. E. & Kane, P. (1984) Suspended sediment properties and their geomorphological significance. In: *Catchment Experiments in Fluvial Geomorphology* (ed. by T. P. Burt & D. E. Walling), 311–334, Geo Books, Norwich, UK.

Walling D. E. & Owens, P. N. (2002) The role of flood plain sedimentation in catchment sediment and contaminant budgets. In: *The Structure, Function and Management Implications of Fluvial Sedimentary Systems* (ed. by F. J. Dyer, M. C. Thoms & J. M. Olley) (Proc. Alice Springs Symp. Sept. 2002), 407–416. IAHS Publ. 276. IAHS Press, Wallingford, UK.

Walling, D. E. & Woodward, J. C. (2000) Effective particle size characteristics of fluvial suspended sediment transported by lowland British rivers. In: *The Role of Erosion and Sediment Transport in Nutrient and Sediment Transfer* (ed. by M. Stone) (Proc. Waterloo Symp., July 2000), 129–139. IAHS Publ. 263. IAHS Press, Wallingford, UK.

Walling, D. E., Owens, P. N. & Leeks, G. J. L. (1999) Rates of contemporary overbank sedimentation and sediment storage on the flood plains of the main channel systems of the Yorkshire Ouse and River Tweed, UK. *Hydrol. Processes* **13**, 993–1009.

Walling, D. E., Fang, D., Nicholas, A. P. & Sweet, R. J. (2004) The grain size characteristics of overbank deposits on the flood plains of British lowland rivers. In: *Sediment Transfer through the Fluvial System* (ed. by V. Golosov, V. Belyaev & D. E. Walling) (Proc. Moscow Symp. August, 2004), 223–234. IAHS Publ. 288. IAHS Press, Wallingford, UK.