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Rapid Communication

River sediments, great floods and centennial-scale Holocene climate change

MARK G. MACKLIN* **and JOHN LEWIN**
Institute of Geography and Earth Sciences, The University of Wales, Aberystwyth, Ceredigion, SY23 3DB, Wales, UK

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ABSTRACT: A new analysis of all 346 published ^{14}C dated Holocene alluvial units in Britain offers a unique insight into the regional impacts of global change and shows how surprisingly sensitive British rivers have been to relatively modest but repeated changes in climate. Fourteen major but probably brief periods of flooding are identified bracketed within the periods 400–1070, 1940–3940, 7520–8100 and at ca. 10 420 cal. yr BP. There is a strong correspondence between climatic deteriorations inferred from mire wet shifts and major periods of flooding, especially at ca. 8000 cal. yr BP and since ca. 4000 cal. yr BP. The unusually long and complete British record also demonstrates that alterations in land cover have resulted in a step change in river basin sensitivity to variations in climate. This has very important implications for assessing and mitigating the impact of increasing severe flooding. In small and medium-sized river basins land use is likely to play a key role in either moderating or amplifying the climatic signal. Copyright © 2003 John Wiley & Sons, Ltd.

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KEYWORDS: Holocene floods; river sediments; centennial-scale climate change; Britain.

Introduction

The key issue confronting river basin managers around the world today is how, and at what rate, will river systems respond to the climate change that we are presently experiencing as the result of increased emissions of greenhouse gases. This includes not just shifts in the hydrological regime but also equally important morphological transformations of river sediment systems that result in accelerated erosion and/or sedimentation. Unfortunately, a direct record of river channel change, which can be compared with the climate series, very rarely extends beyond the past 50 yr in most parts of the world. An alternative approach is to use the geological record of river alluviation to explore cause and effect relationships, as has been used to extend the flood series of extreme events back several hundred (Macklin *et al.*, 1992; Maas *et al.*, 2001) or thousands (Ely *et al.*, 1993; Knox, 1993) of years in some catchments. However, problems of alluvial deposit preservation and dating control, as well as the availability of a local palaeoclimate record, have so far precluded the more widespread use of fluvial sediment archives in documenting the effects of climate change. In this paper, we present for the first time an 11 500-yr record of river response to climate change for the United Kingdom. This new analysis offers a unique historical insight into the regional impacts of global change and shows how surprisingly sensitive British rivers have been to relatively modest but repeated changes in climate.

*Correspondence to: Prof. Mark G. Macklin, Institute of Geography and Earth Sciences, The University of Wales, Aberystwyth, Ceredigion, SY23 3DB, Wales, UK. E-mail: mvm@aber.ac.uk

Method

We have critically assessed all 346 British ^{14}C dated Holocene alluvial units published up to 2002. Major sources are cited in our previous papers (Macklin and Lewin, 1993; Macklin, 1999) with more recent additions. A full list of sources is available from the authors (www.aber.ac.uk/rivers/jqs). In contrast to our previous reviews, we have separated ^{14}C dates into four different alluvial environments:

1 channel deposits, created by migrating rivers and bed sediment accretion;
2 fills in abandoned channels produced by river cut-offs and avulsions;
3 floodplain surfaces liable to overbank sedimentation;
4 flood basins, characterised by intercalating peat and minerogenic sediment incursions.

We then identified whether or not a ^{14}C date in a fluvial sequence coincided with a modification in sedimentation rate or style, allowing us to pick out geomorphologically significant changes in river activity over the Holocene. Former floodplain surfaces and flood basins were found to be the most reliable in this respect, particularly where coarser gravel or sand splays episodically bury finer grained floodplain sediments, or when mineral sediment incursions from trunk rivers into flood basins cover valley mire peats. Finally, we removed all ^{14}C dates on archaeological material, mindful of the high probability of these being in a secondary context, and because human intervention (inadvertent or deliberate) can create artificial

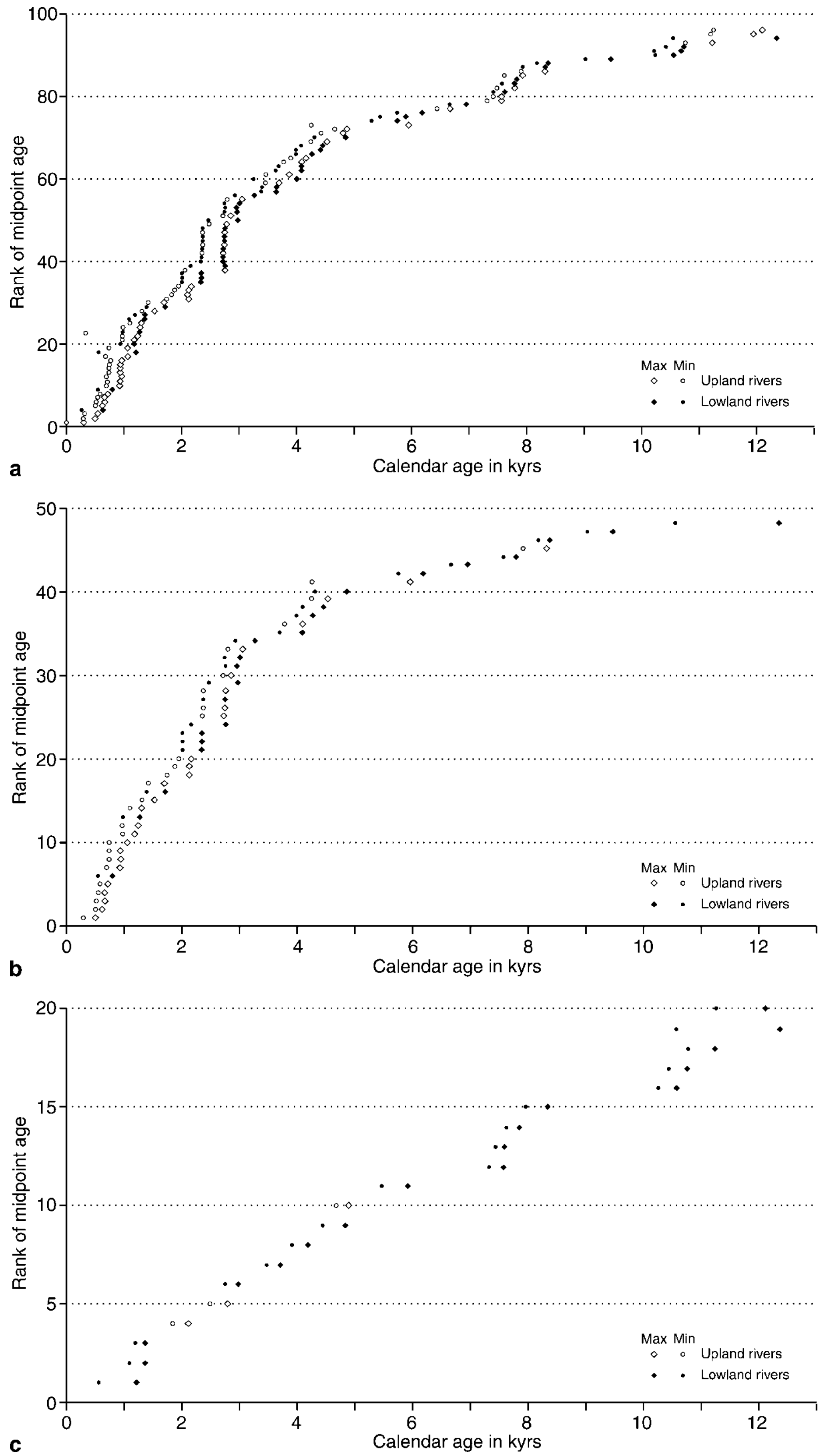

Figure 1 Plots of ^{14}C dated Holocene alluvial units from both upland and lowland catchments in Britain (a), which mark geomorphologically significant changes in river activity. In Fig. 1b and c alluvial units are plotted separately for floodplain and flood-basin environments, respectively, to illustrate the influence of depositional context on the preservation of extreme flood events

depositional niches (pits, ditches, etc.), which may bias the alluvial record towards periods of human occupancy in river valleys. From this analysis we have identified 96 alluvial units from river basins across the whole of Britain where we are satisfied that geomorphologically significant changes in river behaviour can be dated with some confidence.

British Holocene flood episodes

In Fig. 1a we have plotted, in ranked calendar age (2σ range), all dated alluvial units from both upland and lowland river systems in Britain that are followed by a major and abrupt change in sedimentation style and/or facies. This also has been done separately (Fig. 1b c) for floodplain and flood-basin related dates in order to evaluate the influence of depositional environment on the recording and preservation of extreme flood events. A clear pattern emerges from Britain over the past 11 500 yr, with episodes of river system change marked by clustering of ^{14}C dates. These appear as steps in the ranked fluvial unit age plot, punctuated by a paucity or, more often, an absence of dated fluvial units during some periods. The significantly fewer number of fluvial deposits recorded before ca. 5000 cal. yr BP has, however, been shown to reflect selective preservation, with older Holocene alluvial fills being eroded and removed by later phases of valley floor reworking (Lewin and Macklin, in press).

To identify more precisely the timing of major geomorphological change in British rivers and, by inference, episodes of major flooding, further analysis was undertaken. Where a step in the rank–age plot comprised three or more alluvial units, all with ages that overlapped at the 2σ range, a mid-point was calculated for the group and the flooding episode. Using ^{14}C dated units from all four depositional environments, 14 major episodes spanning the period ca. 400–10 420 cal. yr BP can be identified (Table 1). However, because of a prominent ^{14}C plateau between ca. 2350 and 2750 cal. yr BP, there is a considerable age range for the ca. 2520 cal. yr BP flood 'episode'. It is quite possible that several phases of major flooding occurred around this time but because of variations in ^{14}C production these presently cannot be resolved into separate events. When the same exercise is carried out using floodplain and flood basin related units separately, virtually identical flooding episodes emerge (Table 1). However, floodplain environments provide a high-resolution flood record only for the latter half of the Holocene (back to ca. 5000 cal. yr BP), whereas within flood basins only early Holocene flood episodes are well represented. River depositional environment has therefore had a strong but varying influence on flood unit preservation during the Holocene. There are also regional differences in terms of both the age and number of alluvial units found in upland river systems of north and west Britain, compared with those recorded in lowland rivers within the south and east of the country. The prominent early Holocene flood episodes recorded in flood-basin environments are all found in lowland rivers (Fig. 1c), suggesting that during this period there were particularly high rates of sediment transfer from river channels to adjacent alluvial wetlands. It is also clear, particularly from the floodplain-related alluvial unit plot (Fig. 1b), that over the past 2000 yr upland river basins in Britain would appear to have been considerably more prone to deposition from severe flooding.

Great floods and varying river basin sensitivity to centennial-scale climate change

In Table 1 and in Fig. 2 Holocene flood episodes are compared with proxy climate records from Britain (Hughes *et al.*, 2000), central Europe (Haas *et al.*, 1998) and the North Atlantic (Bond *et al.*, 2001). There is a strong correspondence between climatic deteriorations inferred from mire wet shifts in Britain and major periods of flooding, especially at ca. 8000 cal. yr BP and since ca. 4000 cal. yr BP. This indicates that short-term, centennial-scale climatic variability has been a primary factor in governing British Holocene alluvial episodes. However, the very small number of flood units found in the alluvial record between ca. 5000 and 6000 cal. yr BP,

Table 1 Dates of major Holocene flood episodes in Britain

Major flood episodes identified from all dated alluvial units in Britain	Major flood episodes identified from dated floodplain surfaces	Major flood episodes identified within flood basins	Climatic deteriorations inferred from mire wet shifts in Britain (from Hughes *et al.*, 2000)	North Atlantic ice-rafting events (from Bond *et al.*, 1997)
400			450	
560	600		600	
790	840		800	
1070	1110		1100	
			1350	1400
			1750	
1940	2000		2000	
2180	2180		2250	
2520	2570		2600	
2860	2900		2900	2800
3550	3660–4840		3500	
3940			4000	
			4350	4300
			5300	
			5900	5900
7520		7290–8360		
7720			7800	
8100			8020–8320	8200
10 420		10 200–11 220		9450

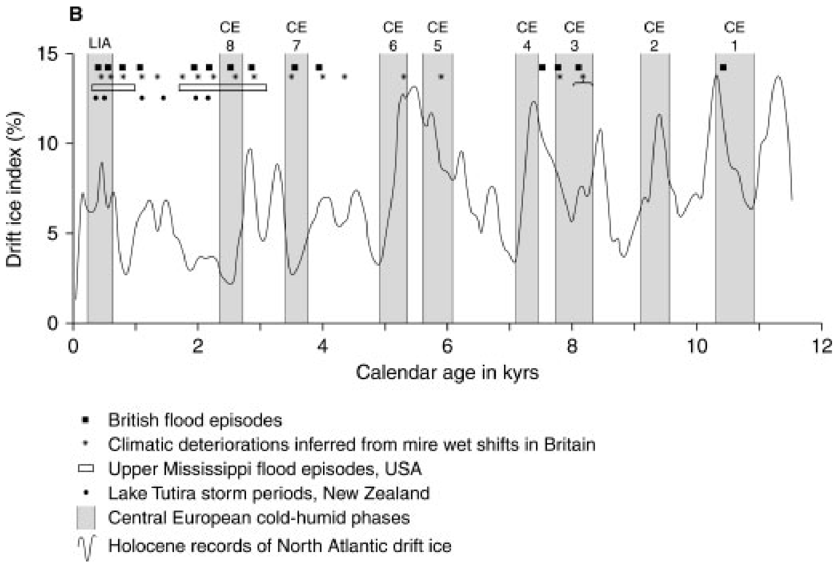

Figure 2 Comparison of British Holocene flood episodes with proxy climate records for Britain, Central Europe and the North Atlantic. Well-dated storm periods for Lake Tutira, New Zealand and flood episodes in the upper Mississippi basin, USA are also plotted towards the top of the diagram. 'LIA' and 'CE' refer to the Little Ice Age and the Central European Cold-Humid Phases from Haas *et al*. (1998)

during a notably cold and humid period, suggests that during the Holocene British rivers have displayed varying sensitivity to climate change. One likely explanation for this variable behaviour is the impact of prehistoric and later agriculture on river basin land cover. The marked increase in the number of flood units after ca. 4500 cal. yr BP coincides with the development of larger scale agriculture in the Bronze Age, which saw the beginnings of more permanent tree clearance. The conversion of forest to grassland, or arable fields, not only would have increased runoff and sediment supply but also would have made river basin sedimentation considerably more responsive to changes in climate. This is supported by basin-wide sediment yield modelling (Coulthard and Macklin, 2001). Land-use change therefore may account for the greater number of major sedimentation change events recorded in upland areas of Britain since ca. 2000 cal. yr BP, immediately following deforestation in the Iron Age and Roman periods. The very limited and highly localised effect of earlier neolithic clearance on woodland cover would not have created a landscape predisposed to accelerated runoff and erosion, explaining the small-scale response of river systems to climatic deteriorations between ca. 5000 and 6000 cal. yr BP.

Finally, to evaluate teleconnections between longer term flood histories with other middle latitude river basins, in Figure 2 well-dated storm periods from Lake Tutira, New Zealand (Page and Trustrum, 2000) and flood episodes in the upper Mississippi basin, USA (Knox, 1993) are also plotted. These, respectively, coincided with major increases in sedimentation rates and gravel deposition on floodplain surfaces. Although detailed regional records of extreme events at these sites extend back only to ca. 3000 cal. yr BP, the evidence for a high degree of synchrony between flood episodes in Britain with other Northern and Southern Hemisphere river systems over the past 2000–3000 yr suggests that British rivers are hydrologically very sensitive to global climatic changes.

Conclusions

The emerging evidence for an increase in the frequency of severe floods in major world rivers during the twentieth century (Milly *et al*., 2002) is therefore entirely consistent with the Holocene fluvial sedimentary record where river systems appear to reflect global climate changes. The unusually long and complete British record also demonstrates that changes in land cover, principally the conversion of woodland to agricultural grassland, have resulted in a step change in river basin sensitivity to variations in climate. Such sensitivity might otherwise be absent from humid temperate environments. This has very important implications for assessing and mitigating the impact of increasing severe flooding. In small and medium-sized river basins land use is likely to play a key role in either moderating or amplifying the climatic signal. In Britain river basin managers and planners now have the advantage of hindsight provided by the Holocene alluvial record and can hopefully avoid mistakes made by their prehistoric farming ancestors.

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References

Bond G, Kromer B, Beer J, Muscheler R, Evans MN, Showers W, Hoffmann S, Lotti-bond R, Hajdas I, Bonani G. 2001. Persistent solar influence on North Atlantic climate during the Holocene. *Science* **294**: 2130–2136.

Coulthard JC, Macklin MG. 2001. How sensitive are river systems to climate and land-use changes? A model based evaluation. *Journal of Quaternary Science* **16**(4): 347–351.

Ely LL, Enzel Y, Baker VR, Cayan DR. 1993. A 5000-year record of extreme floods and climate change in the southwestern United States. *Science* **262**: 410–412.

Haas JN, Richoz I, Tinner W, Wick L. 1998. Synchronous Holocene climatic oscillations recorded on the Swiss Plateau and at timberline in the Alps. *The Holocene* **8**(3): 301–309.

Hughes PDM, Mauquoy D, Barber KE, Langdon PG. 2000. Mire-development pathways and palaeoclimatic records from a full Holocene peat archive at Walton Moss, Cumbria, England. *The Holocene* **10**(4): 465–479.

Knox JC. 1993. Large increases in flood magnitude in response to modest changes in climate. *Nature* **361**: 430–432.

Lewin J, Macklin MG. In press. Preservation potential for Late Quaternary river alluvium. *Journal of Quaternary Science*.

Maas GS, Macklin MG, Warburton J, Woodward JC, Meldrum E. 2001. A 300-year history of flooding in an Andean mountain river system: the Rio Alizos, southern Bolivia. In *River Basin Sediment Systems: Archives of Environmental Change*, Maddy D, Macklin MG, Woodward JC (eds). Balkema: Lisse; 297–323.

Macklin MG. 1999. Holocene river environments in prehistoric Britain: human interaction and human impact. *Journal of Quaternary Science* **14**(6): 521–530.

Macklin MG, Lewin J. 1993. Holocene river alluviation in Britain. *Zeitschrift für Geomorphologie Supplement-Band* **88**: 109–122.

Macklin MG, Rumsby BT, Heap T. 1992. Flood alluviation and entrenchment: Holocene valley floor development and transformation in the British uplands. *Geological Society of America Bulletin* **104**: 631–643.

Milly PCD, Wetherald RT, Dunne KA, Delworth TL. 2002. Increasing risk of great floods in changing climate. *Nature* **415**: 514–517.

Page M, Trustrum N. 2000. High resolution lake sediments from New Zealand- a record of late Holocene storm history, vegetation change and landscape response. *PAGES Newsletter* **8**(3): 17–18.