Figure 1 | Holding back the flood. In 2011, the muddy floodwaters of the Mississippi were prevented from inundating Arkansas agricultural land (left) by flood defences; green areas on the right are forested regions on the floodplain. Munoz *et al.*[1] present a palaeoflood record for the Mississippi River that spans the past 500 years, and conclude that levee building and channelization have made destructive floods larger and more common than before.

HYDROLOGY

Mississippi rising

The Mississippi River is shackled by one of the world's largest systems of flood control. A palaeohydrological record suggests that those measures might actually be making floods worse. SEE LETTER P.95

SCOTT ST. GEORGE

The Mississippi River was once thought to be uncontrollable: no feat of engineering could prevent the river from bursting its banks and sending floodwaters across its natural domain. But since the late nineteenth century, an expanding system of levees, floodways and channel modifications (Fig. 1) has gradually brought the river to heel, largely confining its waters to the main channel and accelerating them downstream. On page 95, Munoz *et al.*[1] conclude that those same control measures have inadvertently raised the threat of flooding in the lower Mississippi to a level that is unprecedented in the past five centuries.

Some engineers and hydrologists have contended[2,3] that modifications to the Mississippi, and particularly the construction of the extensive levee system, have raised the height of the water and increased the volumetric flow rate (discharge) during major floods. The earliest available report of flooding on the Mississippi[4] described an inundation in May 1543, but the first permanent stream gauge was not established on the river until 1897, at Vicksburg, Mississippi. The discharge record from this gauge, and from several others in the river's catchment area, now includes more than a century's worth of observations. Nevertheless, because the most destructive of floods — such as the great floods that occurred in 1927, 1993 and 2011 — are relatively rare, the perspective offered by direct hydrological measurements is still too narrow to determine, with certainty, whether the hazard posed by the river is changing.

Munoz and colleagues have worked around that limitation by building their own extended record of flooding on the Mississippi, using evidence of high waters preserved by oxbow lakes and trees. An oxbow lake forms when a meander of a river is cut off to form a free-standing body of water. When such lakes are inundated by floods, they act as natural sediment traps for sand and silt carried in floodwaters. As those particles settle, they create a layer of coarse sediment on the bottom of the lake that is distinct from the clay and fine silt left behind when the lake is not hydrologically connected to the main channel[5]. Prolonged inundation with floodwater can cause some species of tree — particularly oak — to form wood that has abnormal features. The annual growth rings of such trees in the 'bottomland' hardwood forest of the Mississippi floodplain therefore contain a natural record of past floods[6]. By splicing together sedimentary sequences from lakes in Louisiana and Mississippi with 'flood-ring' signatures from living and dead trees in southeastern Missouri, the authors assembled a flood chronology for the lower Mississippi that stretches back to the early sixteenth century.

Together, these natural archives have kept a remarkably faithful account of past floods. The tree rings mark the occurrence of the great floods of 1844 and 1927, as well as *l'Année des Grandes Eaux* (the Year of the Great Waters) in 1785, which destroyed French–Canadian settlements in Illinois and Missouri. It is more difficult to date individual floods in the lake records because of the lower chronological resolution of that archive, but layers of coarse sediment can be matched to the great floods of 1851, 1927 and 2011, as well as to the flood reported by Spanish conquistadors in 1543. Overall, this new palaeoflood record suggests that, although flood hazards have waxed and waned through time, the Mississippi has risen higher and flooded more frequently in the past century than during any other period in the past 500 years.

The authors propose a provocative explanation for this recent hydrological intensification. Since the start of the twentieth century, records gathered using instruments show that the discharge of the Mississippi has slowly risen and fallen in concert with the surface temperature of the North Atlantic Ocean, which has alternated every two or three decades between warm and cold states[7]. Munoz and colleagues draw on proxy temperature estimates for the North Atlantic[8] to demonstrate that this dependency has held steady since the 1500s. Because the spate of major floods in the past century cannot be explained by the observed temperature behaviour of the North Atlantic, the authors conclude that the trend towards larger and more frequent floods is mostly due to the transformation by humans of the Mississippi River and its basin.

Blaming floods on the infrastructure that was built to guard against them will be controversial. The Mississippi basin has undergone upward trends in precipitation and evapotranspiration — the sum of evaporation and plant transpiration from Earth's surface — in the past several decades[9], so climatic factors other than the influence of the North Atlantic might also have affected the rhythm of the river. And, like the rest of North America, the Mississippi basin has warmed substantially since the end of the Little Ice Age[10] (a period of cooling that began in the sixteenth century and ended in the mid-nineteenth century[11]), so I think it is possible that the long-term trends in hydrology could be the result of climate change, rather than river engineering. Testing these competing explanations will require more palaeoflood work to be performed along the upper Mississippi and its main tributaries, where modifications to the river are less intensive and the climate still dominates the river's hydrology[12].

In the meantime, Munoz and co-workers' study makes it clear that a century or so of hydrological readings is not sufficient to take the measure of a river such as the Mississippi. Their palaeoflood record is compelling because it offers an opportunity to step back and consider the ebb and flow of the river on a timescale that befits its majesty. And if the authors are correct, and collective efforts to subdue the Mississippi have inadvertently pushed it to rise higher than ever, then the time might have come to consider loosening its restraints. ■

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1. Munoz, S. E. *et al. Nature* **556,** 95–98 (2018).
2. Pinter, N., Jemberie, A. A., Remo, J. W. F., Heine, R. A. & Ickes, B. S. *Geophys. Res. Lett.* **35,** L23404 (2008).
3. Watson, C. C., Biedenharn, D. S. & Thorne, C. R. *J. Hydraul. Eng.* **139,** 1071–1078 (2013).
4. Barry, J. M. *Rising Tide: The Great Mississippi Flood of 1927 and How it Changed America* (Simon & Schuster, 1998).
5. Toonen, W. H. J., Winkels, T. G., Cohen, K. M., Prins, M. A. & Middelkoop, H. *Catena* **130,** 69–81 (2015).
6. Therrell, M. D. & Bialecki, M. B. *J. Hydrol.* **529,** 490–498 (2015).
7. Enfield, D. B., Mestas-Nuñez, A. M. & Trimble, P. J. *Geophys. Res. Lett.* **28,** 2077–2080 (2001).
8. Gray, S. T., Graumlich, L. J., Betancourt, J. L. & Pederson, G. T. *Geophys. Res. Lett.* **31,** L12205 (2004).
9. Milly, P. C. D. & Dunne, K. A. *Geophys. Res. Lett.* **28,** 1219–1222 (2001).
10. Trouet, V. *et al. Environ. Res. Lett.* **8,** 024008 (2013).
11. Matthews, J. A. & Briffa, K. R. *Geogr. Ann. A* **87,** 17–36 (2006).
12. Wise, E. K., Woodhouse, C. A., McCabe, G. J., Pederson, G. T. & St-Jacques, J.-M. *J. Hydrometeorol.* **19,** 161–182 (2018).

ECOLOGY

Forests in flux as climate varies

How do changes in climate affect forest ecosystems? A study of temperate forests in the United States has assessed alterations in biomass and tree-species composition across a 20-year period of climate variability. **See Letter p.99**

SEBASTIAAN LUYSSAERT & J. HANS C. CORNELISSEN

Documenting and understanding changes induced by climate in the composition and function of vegetation is essential for planning adaptation strategies, because chances to intervene do not arise often for forests that contain trees with long lifespans. Moreover, most of the effects exerted by climate change on the composition and biomass of vegetation probably occur incrementally rather than abruptly[1], which makes their detection a challenge. On page 99, Zhang *et al.*[2] report an analysis of changes in forest biomass in the eastern United States over two decades, during a time when some regions became drier and others became wetter.

Ecological studies have long focused on analyses in which the main groupings for organisms being studied are determined by evolutionary relationships such as belonging to the same genus. However, such kinship can hide functional differences. For example, even among closely related species of oak tree (*Quercus* spp.), some will thrive under moist conditions, whereas others are more suited to dry climates. In the past decade, the use of functional rather than kinship-driven approaches to grouping has provided many important insights[3], and Zhang and colleagues' work can be added to the list of studies that have successfully done this.

Zhang *et al.* sought to investigate whether shifts in climate affect forest characteristics such as the prevalence of drought-tolerant species and the total biomass of the tree population. The authors compared temperate-forest inventory data[4] gathered during the 1980s and the 2000s. This inventory includes surveys of around 100,000 plots, in which data such as species name and a standardized measurement of tree diameter were recorded for roughly 3 million trees. Diameter measurements allow the amount of biomass that is present above the surface of the ground to be estimated for a particular tree on the basis of previous studies of growth patterns for