is too patchy. Extending this coverage is straightforward in principle, but paleoecological approaches are more difficult to interpret. Lake sediment records and comparison of such records with geomorphological data indicate landscape destabilization, but provide no direct information about carbon cycling. Organic matter concentration records provide some information, but owing to physical sorting during transport, lake sediments are not an unbiased sample of catchment soils. On the other hand, dissolved organic carbon (DOC) is less subject to alteration during transport and should reflect catchment carbon dynamics. For example, Iron Age agriculture in southern Sweden strongly impacted the diatom-inferred lake pH, causing it to deviate substantially from its expected trajectory driven by base depletion and climate change (Fig. 2a, expected pattern simulated using ALLOGEN, Boyle, in press). This pH discrepancy implies a halving of the DOC concentration in response to land-use change (Fig. 2b), an interpretation supported by (Fig. 2c, P. Rosén, unpubl.) the newly developed infrared reflectance methods for inferring lake water DOC (Rosén and Persson, 2006). Direct paleoecological reconstruction of past DOC concentration is pivotal to assessing the possible global significance of such land-use change. Diatom inferred DOC records have long existed, but with as many critics as supporters independent methods are essential. Rosén and Persson (2006) may supply an appropriate method that provides constraints for the biogeochemical significance of Holocene vegetation, fire and land-use changes.

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The challenge of reconstructing human impact on large river systems

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In fluvial systems, flooding as well as the associated erosion, transport and deposition of sediments are controlled by climate impacts and moderated by land use. Even though land use and climate are not independent, they change at different spatial and temporal scales, exerting a complex driver pattern on fluvial systems. With respect to the PAGES Focus 4 (PHAROS), which addresses the long-term interactions between past climate, human activities, and other ecological processes, it is of great importance to understand the spatial and temporal dynamics of erosion and sedimentation in more detail. In hydrological and geomorphological terms, the data are proxies for long-term changes in flood regime; the long-term erosion of soil, sediment and organic matter; and the changing sediment flux to coastal systems. From an ecological point of view, the importance lies in terms of understanding nutrient delivery downstream (to the coastal zone) and in modifying channel and riparian habitats. River systems are characterized by intricate behavior with variable sediment sources, temporal gaps in downstream sediment propagation and changing trapping efficiency of sediment sinks. The most promising concept for understanding such complexities is the sediment budget approach. If available at a variety of spatial and temporal scales, sediment budgets allow unraveling the dynamic behavior and thus the trajectory of river response. Despite numerous sediment budgets available for small drainage basins and longer time spans (millennia) as well as for large drainage basins and short time spans (decades), little is known about the response of large fluvial systems on temporal scales that match the period of human impact—knowledge that is essential for the integration of river based sediment fluxes in global biogeochemical cycles.

On the time scales of centuries and millennia, rivers cannot be viewed as conveyor belts that just deliver eroded soil and sediment to the oceans. Within-basin storage on slopes and in floodplains is essential and often exceeds delivery (Hoffmann, 2007). Also, the coupling relationships and the efficiency of sediment delivery between system components are dynamic functions that change as a river basin adjusts to external triggers.

A multitude of results from case studies is available for many river catchments. Data for sediment transport and deposition are available from colluvial deposits, lake sediments and floodplain sediments. This data is usually scattered and upscaling for deriving system-wide information is difficult. Presently, databases of dated floodplain units are being built for several river systems (e.g. Macklin et al., 2006) to improve this situation, facilitate system-wide analyses, and establish gaps in knowledge. Information stored includes sedimentary environment, stratigraphy and age. Much of these data are used to reconstruct the frequency of deposited floodplain units, which can be interpreted as a proxy for flood frequency and magnitude. Here we focus on floodplain data as an archive of sediment flux for specific large river catchments. Currently available data is still insufficient for constructing sediment flux but allows extracting age and depth information for individual system components. This can be used for calculating sedimentation rates in a way similar to Shi (2002) and Knox (2006) for the Yellow and Mississippi rivers, respectively. This approach loses temporal resolution as it only allows constructing average rates—the effect of which is shown in the inset of Figure 1c.

The Yellow River (Fig. 1a) shows in general increasing maximum sedimentation rates during the Holocene (Shi, 2002). The general slow increasing trend is superimposed by strongly accelerated sedimentation rates due to human impacts during the last 2,500 years. Based on the assumption that the natural increasing trend (before the human impact) did not change during the last 2,500 years, Shi (2002) calculated a 1.6 fold increase of mean sedimentation rates during the last 2,500 years due to human impacts.

The Yellow River is characterized by a long history of agricultural activities with an overall increasing intensity over several thousand years. In contrast, significant human impact on the Upper Mississippi River is significantly younger. It started only 200

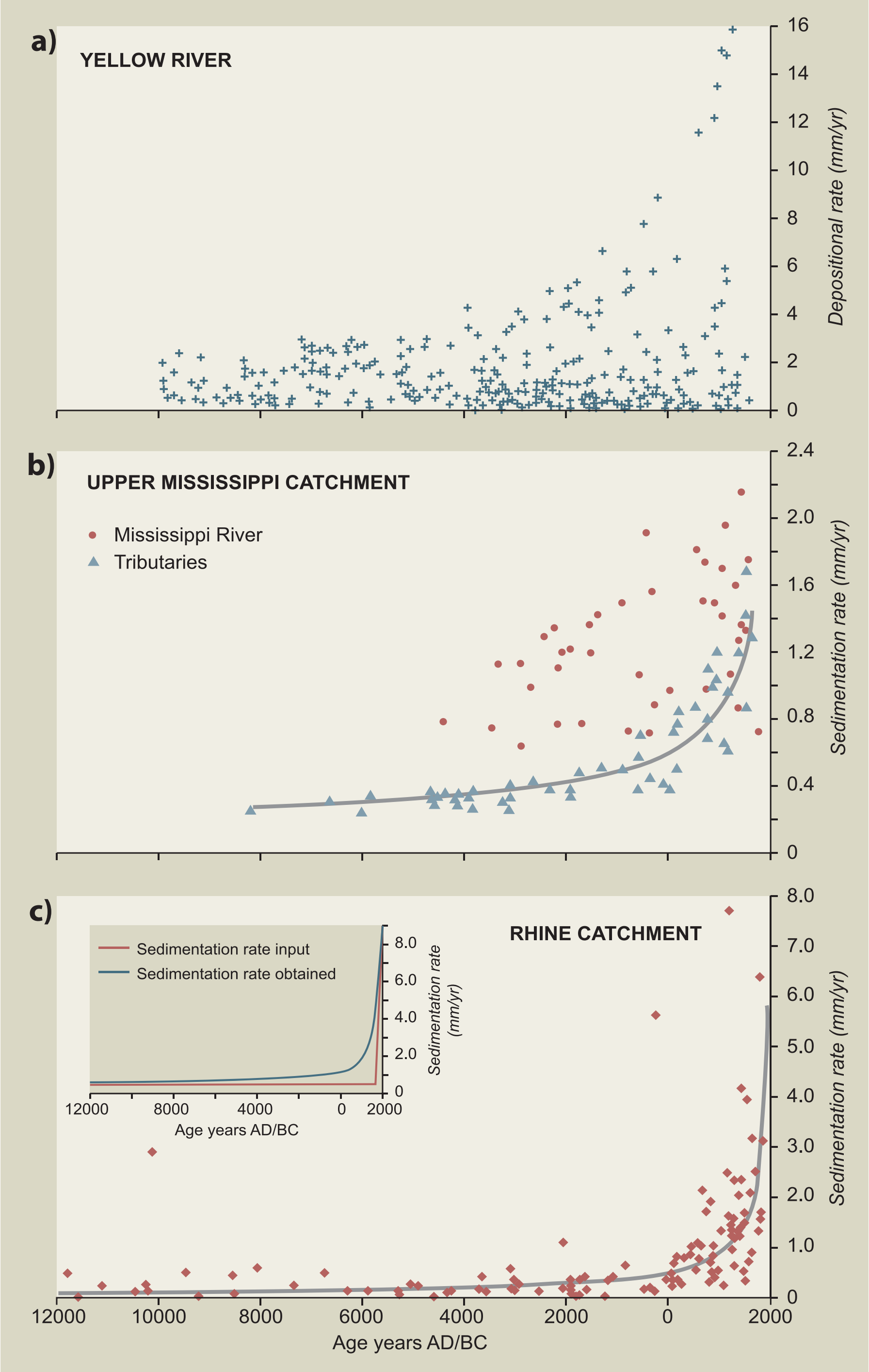

Figure 1: Averaged sedimentation rates derived from depth of burial and radiocarbon ages of objects embedded in floodplain sediments. Trend-lines are given. Figure ***1a*** *from Shi (2002), figure* ***1b*** *from Knox (2006), and figure* ***1c*** *from Hoffmann (2007). The effect of averaging inherent to this approach is depicted in* ***1c inset****: a constant sedimentation rate of 0.5 mm yr^{-1} with a linear increase to 9 mm yr^{-1} during the last 200 years, the 'sedimentation rate input' (red line) is smoothed out resulting in the 'sedimentation rate obtained' (blue line). Due to the smoothing effect, 'sedimentation rates obtained' suggest a much earlier increase of sedimentation rates than happened in reality.*

years ago when the Euro-American settlers transformed the natural mosaic of prairie and woodland to cropland and pasture (Knox, 2006). Long-term pre-agricultural rates of floodplain accretion in the smaller tributaries average about 0.2 mm yr^{-1} and in the case of the trunk river about 0.9 mm yr^{-1} (Fig. 1b). During the last 200 years, the Euro-American impact increased pre-agricultural accretion rates by an order of magnitude, with averages between 2 and 20 mm yr^{-1}. According to Knox (2006), this represents the most dramatic change in fluvial activity of the Mississippi and its tributaries during the Holocene. As Figure 1b shows this can clearly be seen for the smaller tributaries, which are characterized by a recent increase of sedimentation rates. The pattern for the Mississippi trunk stream are less clear and show a rather gradual increase of sedimentation rates since 6 kyr BP, without any break in system trajectory due to Euro-American impact.

The first agricultural activities in the Rhine catchment (Germany) date back to the Neolithic ~5,500 BC. Large-scale deforestation and land use changes and significant impacts on the fluvial sediment flux occurred during the Bronze Age ~2,200 BC (Lang et al., 2003; Hoffmann et al., 2007). Floodplain sedimentation in the Rhine catchment was calculated based on the database established by Hoffmann (2006) and is shown in Figure 1c. Similar to the Yellow and the Upper Mississippi River, the results reveal a strong increase of floodplain accretion rates during the last 2,000 years. While natural long-term sedimentation rates range between 0.1 and 1 mm yr^{-1}, human induced sedimentation rates increase up to 9 mm yr^{-1}. The majority of data used for this analysis, is derived from floodplains of smaller tributaries within the Rhine catchment.

Catchment size usually acts as a buffer to the effects of human impact: Small catchments show a dramatic increase in sedimentation rate after human impact, suggesting distinct forcing-response mechanisms, whereas in larger drainage basins, the forcing–response mechanisms are less clear and there is evidence to propose that values for fluxes in continental-scale catchments after human impacts lie close to long-term averages (Dearing and Jones, 2003).

The results from the Upper Mississippi River confirm the importance of catchment size as suggested by Dearing and Jones (2003). In this catchment human impacts result in strongly increasing floodplain sedimentation in the smaller tributaries, while the impact on the main trunk is less clear. Similarly, increasing sedimentation rates in the Rhine catchment (Fig. 1c) mainly result from data obtained for smaller tributaries and support the high sensitivity of small system to environmental changes during the last 2,000 years. While it is generally accepted that increasing sedimentation during the last 2,000 years results from increasing agricultural activities at local scales, climate impacts cannot be neglected as a major factor at the regional scale. In the case of the Yellow River, significant accelerated sedimentation rates are shown despite its large catchment. The increased rates are caused by the direct impact of the artificial levee constructions that reduce deposition space on the floodplain (Xu, 1998). The steep topography and the large amounts of highly erodable sediments at the Loess plateau also render the Yellow River highly sensitive to human impact, resulting in a good correlation between sediment yield and population density (Shi et al., 2002).

All three case studies show an unprecedented increase in sedimentation rates, which illustrates the importance of human interference for increasing riverine sediment fluxes. Due to the large scatter, which results from the spatial lumping at the regional scale, the exact timing of the increase is difficult to assess and smaller climate driven variations are not detectable. Additionally, floodplains are only a part of the river sediment system—and in most cases only accretion rates have been determined. More detailed reconstructions of past sediment flux will be possible as database build-up proceeds.

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A meta-database for recent paleolimnological studies

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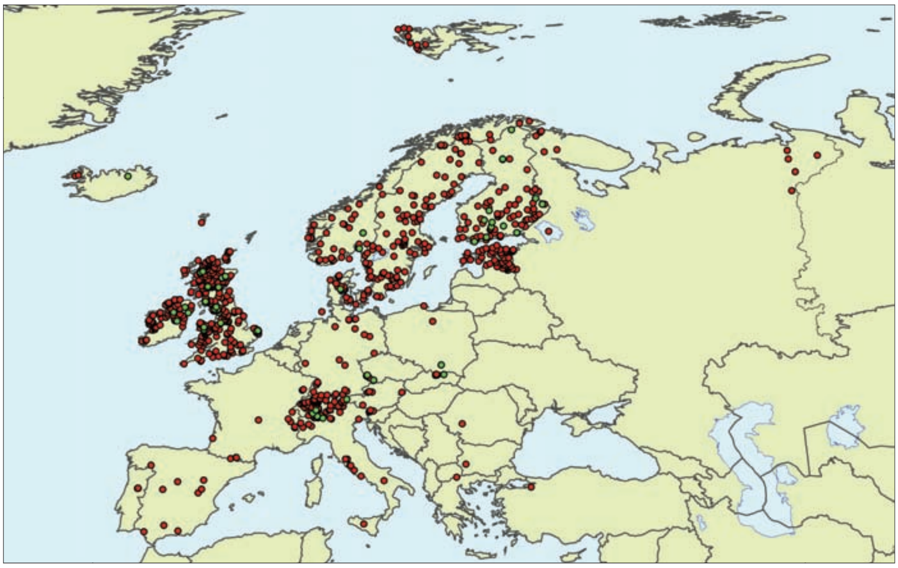

Figure 1: Distribution of sites across Europe in the Euro-limpacs paleo meta-database. Red circles indicate sites in the database where recent paleolimnological data are available, green circles indicate sites where both paleolimnological and monitoring time-series data are available.

Assessing how the status of lakes, or any ecosystem, changes through time and space requires an awareness and understanding of key processes acting and interacting on different scales. By combining observational and paleolimnological datasets (Battarbee, 2000, Battarbee et al., 2005) it is becoming increasingly possible to identify processes occurring on a continuum of time-scales. This includes seasonal and inter-annual variability related to short-term climate variability or internal food chain dynamics, decadal-scale processes associated with pollution pressures from human activity, and centennial and millennial scale processes related to catchment evolution and lake ontogeny.

Placing these temporal patterns across space at the regional, continental and global scales is, however, currently impossible, restricted by: (i) the rarity of multi-decadal instrumental time-series; (ii) the rarity of millennial scale paleolimnological records; and (iii) the lack of any central public domain database for either instrumental or paleolimnological records. So far spatial upscaling has only been attempted at the regional level using data owned by individual laboratories or by a project consortium (e.g. Cumming et al., 1992; Curtis et al., submitted).

However, not all paleolimnological records are rare. Indeed those that cover recent lake history (i.e. the last 100-200 years) are quite abundant, principally as a result of the close attention given by paleolimnologists over recent decades to problems of 19th and 20th century pollution (cf. Smol, 2002). Using such datasets we can begin to explore the spatial upscaling of paleolimnological data, starting by building a meta-database that lists geo-referenced information availability site by site.

The meta-database described here is being developed under the auspices of the EU project Euro-limpacs ("Global Change Impacts on European Freshwater Ecosystems"). We have so far only included sites where cores have been taken with an intact mud-water interface, have been dated and, ideally, extend in time back to the early nineteenth century. Data fields include site geography (location, altitude etc), climate (temperature, precipitation), water chemistry (pH, alkalinity, Total Phosphorus (TP)), core information (length, age, sample, year, etc), core analyses (diatoms, metals etc) and associated literature. Currently there are records for 954 lake sites across Europe (Fig. 1) derived from our own studies and from a review of the literature (published and unpublished).

As a separate initiative we are also compiling a meta-database for sites in Europe where long-term monitoring programs are underway. We define these as sites with 10 or more years of annual or more frequent observations. The two databases together enable us to identify sites (i) where both long-term data-sets and recent sediment records are co-located (Fig. 1); (ii) where ecological trends and variability on different time-scales for individual sites can be defined; and (iii) where observational time-series data-sets can be used to verify or calibrate sediment records.

So far we have used the paleo meta-database to define, on the basis of transfer functions, reference values of pH and (TP) for lakes suffering from acidification and eutrophication respectively in Europe (Fig. 2), and to identify the approximate date (decade) at which the first evidence for