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Terrestrial sediment flux: the importance of timescale of observation and drainage-basin size

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Accurate measurements of sediment flux are critical for determining rates of landscape evolution, understanding the evolution of sedimentary basins and carbon burial, and assessing hazards in heavily populated areas. Historic measurements of sediment fluxes through rivers, that is, since the 20th century, are influenced by anthropogenic perturbations to the environment and landscape, and do not necessarily represent the natural flux of sediment from source to basin outlet. Such short-term measurements also might not be representative of sediment flux over longer timescales, during which alternations between sediment transport and quiescence might differ from one decade, century, or millennium to another. However, cosmogenic radionuclide abundances in river sand samples can be used to calculate denudation rates within drainage basins integrated over millennia.

We compiled 800 measurements of historic sediment flux from literature and the U.S. Geological Survey National Water Information System and 626 published measurements of drainage basin-integrated denudation rates from cosmogenic 10Be to assess the importance of timescale of observation and drainage-basin size in terrestrial sediment routing. Our compilations show that sediment flux increases with basin area according to a power-law relation for both historic and millennial sediment budgets. However, historic sediment fluxes and yields exhibit orders of magnitude greater variability per basin area than millennial rates. For basins between ∼100-10000 sq. km (482 data points), average historic fluxes are up to 15 times larger than millennial fluxes and average historic yields are up to 14 times larger than millennial yields. For smaller (<100 sq. km; 638 data points) and larger (>10000 sq. km; 306 data points) basins, average millennial fluxes and yields are larger than average historic fluxes and yields by a factor of <3 for a given drainage area.

We interpret that smaller drainage basins (<100 sq. km) facilitate rapid transfer of sediment from source to outlet, with little sequestered in route; thus, rates of sediment flux and yield measured over vastly different timescales can be similar or longer-term rates can be larger as a result of integrating more episodes of sediment transfer relative to historic rates. Medium-sized basins (100-10000 sq. km) are characterized by more accommodation for sediment sequestration in route to basin outlets. As a result, longer-term rates of sediment flux and yield integrate more of this "trap-door" sediment sequestration effect, whereas historic rates reflect the last major episode of reworking and dispersal of sediment from sediment-routing segments to the basin outlet. Larger drainage basins (>10000 sq. km) include greater area for denudation and sediment production, and historic and millennial rates of sediment flux and yield can be similar. For basin areas >550 sq. km, there might be sufficient area available for denudation and sediment production that the "trap-door" sediment sequestration effect is progressively less influential in determining longer-term rates of sediment flux and yield. Agreement of rates measured over different timescales might also be a result of the buffering capacity of large floodplains. The amount of sediment stored in floodplains is large relative to the sediment flux to the basin outlet, allowing streams to maintain certain sediment loads from transportable debris stored in the floodplain. Therefore, historic rates of sediment flux and yield do not necessarily reflect the rate at which mountains denude over millennia, and rates integrated over millennia do not necessarily reflect hazards of large magnitude, infrequent sediment transport events. The timescale of observation and drainage-basin area interact to produce a rate of sediment flux or yield. Relationships documented herein can be employed to enhance timescale-dependent hydrologic-sedimentologic-climatic models and predictions that will improve analysis of Anthropocene landscape change, understanding of source-to-sink sediment routing, budgets of carbon burial, and hazards imposed by catastrophic sediment-routing events.