Global sediment fluxes to the Earth's coastal ocean

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There are many reasons why geoscientists are interested in the loads rivers deliver to the coastal ocean, including: stability and function of deltas and estuaries, harbor maintenance, coastal fisheries, benthic ecology, water quality, and geomorphic and geochemical flux studies. Interest extends from knowing longer-term averages of loads, to the natural variability in annual and seasonal load, and to event loads. Sediment load data is also discussed in terms of upstream sediment yield (e.g. for landscape evolution) or suspended sediment concentration (e.g. for stream habitat). Geoscientists also search for information on a load's particle characteristics (e.g. size distribution in both flocculated and unflocculated state), but this is not a well-developed field of research.

Milliman and Syvitski (1992) highlighted the importance of scaling drainage basin properties, demonstrating strong correlation between long-term sediment load, drainage area, and basin relief. This led to a multitude of scaling applications, with many studies emphasizing the important role of the world's numerous small mountainous rivers. Basin area and relief often reflect global tectonics and a river's position on an active versus passive margin. Scaling provides for an opportunity to view rivers regardless of size, where subtler influences such as the impact of climate on a river's sediment discharge could be studied (Syvitski et al., 2003). Dimensional analysis allowed Syvitski and Morehead (1999) to recast the problem in terms of dimensionless super-variables. The analysis allowed Syvitski et al. (2005) to predict for the first time, the global distribution of sediment delivery to the coastal ocean under pre-Anthropocene conditions.

These and other scaling studies culminated in the development of a complex multi-parameter model BQART (Syvitski and Milliman, 2007), able to scale for the influence of geology, geography and human disturbance. *BQART* includes factors related to: 1) the chemical breakdown of the rocks and thus soil formation, 2) mechanical-based erosion (frozen soils and river beds, freeze-thaw cycles, precipitation intensity, vegetation influences), 3) latitudinal variation in lapse rate, 4) storage or release of melt water, 5) flood-wave dynamics associated with different forms of rainfall (frontal vs. convective, monsoons, typhoons), 6) glacial influences, 7) basin lithology, 8) sediment trapping by lakes and reservoirs, 9) human accelerated soil erosion, and 10) soil conservation practices. The *BQART* predictions fall within 38% of the measured loads on average for the 488 global rivers that drain 63% of the global land surface (Syvitski and Kettner, in press). *BQART* captures the wash load of a river; bedload algorithms suggest a river's total load should be increased by another 1% to 20%, for locations near a river's mouth. *BQART* has since been successfully applied o within-basin predictions of loads (Kettner et al., 2010), leading to a new effort to develop distributed global predictions.

With the main scaling relationships developed, research continues to understand the driving forces. For example the BQART shows us that sediment yield decreases with increasing size of the basin. There are many reasons, e.g.: 1) hypsometry suggests that ever larger basins offer greater proportional areas with low relief and thus less sediment production, all other factors held constant, 2) there is more trapping of sediment on large floodplains as rivers traverse tectonic depressions. Other factors are both influential and highly variable, e.g.: 1) while mountains often receive a greater proportion of a basin's precipitation, many environments, such as the Niger River, experience most of the rainfall and runoff across their lowland plains; and 2) often softer lithologies are located in lower elevations, yet for the Mackenzie River, hard Precambrian granites occupy the lowest elevations. River mouth fluxes are the great integrators of these kinds of spatially variable factors throughout a drainage basin.

Scaling relationships also allow for estimating the seasonality of global sediment discharge (Syvitski et al., 2005). The PSI model scales for the variability in a river's sediment discharge, useful in studying high-intensity low-frequency events (Syvitski et al., 2000; Kettner et al., 2007). However precise predictions of a river's load for any single event remains a distant goal. Such predictions will require highly refined spatial information and routing models that include preconditioning or setup of past events that still hold influence on a river's load.

One of the most spatially variable influences on a river's load is from the impact of humans. This is witnessed where a river crosses a political boundary and the change in socio-economic conditions. For example, it is China that has developed most of the reservoirs along the Mekong, impacting the river's load as it passes through downstream countries. Human influences also push from both directions. The enhanced sediment load of the upstream Yellow River due to deforestation and poor farming practices is presently being offset by sediment retention behind downstream dams.

Human activities also magnify climate events. A proliferation of small farms employing poor tilling practice on top of a prolonged drought in the central U.S. Great Plains in the early 1930's, led to one of the world's largest erosion events where 23,500,000 acres lost 12.5 Gt of topsoil (Syvitski and Kettner, in press). In Taiwan, much of the sediment is released through the intense precipitation events associated with a typhoon. How much of the associated sediment discharge relates to the weather event, versus the preconditioning by deforestation and farming on steep mountainous slopes that can subsequently trigger landslides during the precipitation event. The global impact on human alteration of river sediment loads is huge ranging from accelerated delta subsidence, to changes in coastal fisheries, the health of coastal reefs, or even how most water and sediment enters the coastal ocean. Hyperpycnal flow events have become more common for some rivers, and less common for other rivers (Syvitski and Kettner, in press).

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