FORUM

A Meeting of the Waters: Interdisciplinary Challenges and Opportunities in Tidal Rivers

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At the interface of estuarine tides and freshwater rivers lie wetland and aquatic ecosystems, which experience dramatic effects of sea level rise. There, nontidal channels and riparian floodplains are transforming into tidal ecosystems, and tidal freshwater ecosystems are receiving increasing salinity. These river-floodplain systems have both fluvial characteristics, including meandering channels and expansive floodplain forests, and estuarine characteristics, including tides and intertidal wetlands [see *Barendregt et al.*, 2009; *Conner et al.*, 2007, and references therein]. Because tidal rivers lie at the disciplinary divide between fluvial and estuarine science, a knowledge gap has developed in scientists' understanding of the geomorphic and biogeochemical response of these environments to sea level rise, climate change, and anthropogenically driven variations in watershed exports.

Knowledge of how tidal rivers respond to these perturbations is of increasing importance to three research questions. First, how do tidal rivers affect the flux of the elements carbon, nitrogen, and phosphorus between river networks and the ocean? Data on these processes within tidal rivers are limited, and improvement of regional- and global-scale models of elemental fluxes requires more information on the geomorphic and biogeochemical processes occurring in tidal rivers. Second, how will sea level rise and climate change influence the morphology of nontidal rivers, tidal rivers, and estuaries? Models of the geomorphic processes occurring in tidal rivers are not well developed, largely because the relative importance of various forcing factors has not been resolved. Third, how will the geomorphologic changes in these systems affect the ecosystem functions that are important to human, wildlife, and plant communities? In part due to their extensive wetlands, biogeochemical cycling and habitat provision are only a few of the many ecosystem functions performed by tidal rivers.

Addressing these questions requires understanding the relative importance of the fluvial and estuarine factors governing hydrologic, geomorphic, and biogeochemical processes. Existing empirical approaches from each discipline are inadequate to describe these processes in the tidal freshwater zone. For example, empirical models in both fluvial and estuarine science represent sediment transport as a function of temporal variability of flow, but the main factor governing this variation differs between rivers and estuaries. In rivers this variation occurs with watershed runoff, and a frequency distribution of river discharge can aid in determining the recurrence of the most geomorphically important discharge [*Wolman and Miller,* 1960]. In contrast, the variation in estuary flow velocity that affects sediment transport is related to tidal harmonics, which dictate flow regime and subsequent channel morphology [*Friedrichs and Aubrey,* 1988].

Similar differences occur between empirical models of biogeochemical process in rivers and estuaries. For example, empirical models of riverine nutrient flux are based on the balance among river discharge, nutrient uptake, and mineralization [see *Ensign and Doyle*, 2006, and references therein], whereas estuarine nutrient flux is a balance between tidal flushing and nutrient burial in benthic and intertidal areas [see *Tappin*, 2002, and references therein]. In the case of sediment transport and nutrient cycling, fluvial and estuarine empirical models cannot be applied to tidal rivers because neither fully encompasses both the stochastic variation in watershed runoff and regular tidal signal in tidal rivers.

Whereas empirical models are based on specific factors unique to either rivers or estuaries, conceptual models of rivers and estuaries share common ground in their dependence on feedbacks. In fluvial systems, evolution of channel morphology is driven by base level, channel gradient, and feedbacks between sediment flux, channel morphology, and vegetation [*Schumm et al.*, 1984; *Hupp and Simon*, 1991]. Channel evolution involves progressive shifts in the hydraulic channel parameters (e.g., channel gradient, width-to-depth ratio, and sinuosity) and their influence on sediment transport and deposition. As an example, the model used by *Hupp and Simon* [1991] of channel evolution following alteration (channelization) describes stages of channel and riparian vegetation conditions that result from initial channel incision and resultant bank instability and widening by bank erosion. Sediment deposition from upstream degradation eventually decreases channel gradient while widening processes eventually reduce bank slopes and erosion. As these degradation processes lessen, vegetation may establish and further enhance sediment deposition on both the bed and the banks through feedbacks between hydrology and channel morphology, leading to relatively stable channel configurations in both cross-section and plan aspects.

Estuaries exhibit similar patterns in evolution where sea level rise increases water depths in estuaries and river mouths, reducing bottom friction and dissipation of tidal energy [*Chernovtsy et al.*, 2010]. The tidal signal is therefore able to propagate farther upstream, augmenting the tidal prism (the volume of water in an estuary between low tide and high tide) and total flow [*Canestrelli et al.*, 2010]. Higher discharges can in turn rework bottom sediments, thus increasing water depths and facilitating tidal propagation. This positive feedback can amplify the effect of sea level rise in the shallow reaches of tidal rivers, where small variations in sea level have a high impact on water depths. A similar feedback can also occur when physical processes or human interventions (e.g., dredging for navigation) enlarge the cross section of estuaries and coastal plain rivers, thereby favoring tidal propagation and reduced energy dissipation [*Chernovtsy et al.,* 2010]. An increase in estuarine surface leads to an increase in tidal prism and related tidal discharges. The resulting faster flow can further enlarge the estuarine cross section in a positive feedback loop [*Canestrelli et al.*, 2010]. Increased tidal energy can also affect water and sediment exchange between the channel and freshwater or salt marshes, creating additional feedbacks by which wetland elevation adjusts within the tidal frame through vertical accretion [see *Fagherazzi et al.*, 2012, and references therein].

These conceptual models of fluvial and estuarine landform evolution share similar dependence on ecogeomorphic feedbacks, which indicate possibilities for synthesis across these environments and disciplines. We suggest that tidal river research may be advanced by developing conceptual frameworks focused on feedbacks; this is the agenda of an upcoming AGU Chapman Conference on tidal rivers (http://chapman.agu.org/tidalrivers/). Because feedbacks have a tendency to generate equilibria and the potential for alternative stable states, conceptual models of tidal rivers must also incorporate the sensitivity of these feedbacks to external drivers such as sea level rise, climate change, and anthropogenic inputs.

Can the empirical and conceptual models from fluvial and estuarine systems be extended into the tidal freshwater domain to predict the geomorphic alteration of rivers as they become tidal? Can the fate of tidal freshwater wetlands to rising sea levels and increased salinity be predicted? Conceptual, stratigraphic, and mathematical models of these processes have been developed for time scales spanning thousands of years, but models applicable to 10- to 100-year time scales are needed to predict how tidal rivers will change in the near term in response to sea level, climate change, and anthropogenic impacts. Addressing basic questions regarding elemental flux, geomorphology,

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and ecosystem functions in tidal rivers will also guide applied research on effective management actions (e.g., ecosystem restoration in tidal freshwater rivers and wetlands) and inform policy decisions in the coastal zone (e.g., regulations governing property rights based on rates of sea level rise).

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