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Editorial

Geomorphology of the Anthropocene: Understanding the surficial legacy of past and present human activities

Landscapes around the world are extensively altered by agriculture, forestry, mining, water storage and diversion, and urbanization. Human activities have modified more than half of Earth's land area in both the form and sediment fluxes of landscapes (Hooke et al., 2012); less than 25% of Earth's ice-free area can be considered wild (Ellis and Ramankutty, 2008). Earlier human alterations, though often forgotten, exacted significant impacts that may persist to the present day. For example, in the eastern United States, post-European land "management" activities in the 1700s and 1800s resulted in large volumes of upland soil erosion and floodplain aggradation behind thousands of milldams (Walter and Merritts, 2008). Today, the geomorphic effects of ongoing urban and suburban development in the same areas can only be understood in the context of the legacy of historical human activities (Bain et al., 2012; Voli et al., 2013).

A strong tradition in geomorphology centers on studying human effects on river systems and other landscape processes (Thomas, 1956). The effects of dams on channel geometry (e.g., Williams and Wolman, 1984), the impact of forest harvest on sediment fluxes (e.g., Grant and Wolff, 1991), and the consequence of agricultural practices on erosion and sedimentation (e.g., Happ et al., 1940) are but a few of the examples of studies seeking to understand humans as geomorphic agents. Nonetheless, many geomorphic studies are still set in or referenced to areas perceived to be undisturbed by human activities. In a period in which human alteration is increasingly ubiquitous and often multi-layered, we require an invigorated focus on the geomorphology of human activity. Such a discipline, which has been called anthropogenic geomorphology (Szabó, 2010) and anthropogeomorphology (Cuff, 2008), must encompass both direct and indirect consequences of human activity in the past and the present. It must investigate not only the ways that humans modify geomorphic forms and processes, but the way the alterations impact subsequent human activities and resource use through positive and negative feedbacks (Chin et al., 2013a). The discipline must recognize not only the effects of individual human alterations, but also their heterogeneity and cumulative effects across both time and space (Kondolf and Podolak, 2013). Such investigations can benefit from approaches in both empirical data collection and numerical modeling. The discipline should aim to develop concepts and theory that do not require reference to unaltered "natural" forms and that can be used to guide management and restoration activities. Finally, in addressing these complex issues and developing new concepts and theories, the discipline must expand and deepen linkages with other fields (Chin et al., 2013b; Harden et al., 2013; Wohl et al., 2013).

Charlotte, North Carolina, where active urban expansion obliterates forests that grew on abandoned cotton fields, and urban stream syndrome alters channel patterns and substrates previously affected by mill dams and gold mining, seemed an appropriate setting for a convergence of researchers interested in human interaction with geomorphic systems. In November 2012, in Charlotte, we convened a session on "Geomorphology of the Anthropocene: the surficial legacy of past and present human activities" as part of the 124th meeting of the Geological Society of America. That session and the journal *Anthropocene* shared the goal of understanding how Earth's surface is evolving under increasing human interactions by soliciting empirical studies and synthetic, theory-developing reviews across multiple spatial and temporal scales.

This special issue of *Anthropocene* contains a selection of papers primarily based on contributions to the Geomorphology of the Anthropocene session. The papers draw on the tradition of studying human effects on geomorphological form and process, while also emphasizing cumulative effects in time and space, and implications for the future of managed landscapes. The papers demonstrate a timely direction for anthropogenic geomorphological research. They highlight the need for such research as an emerging, important field of study.

Emphasizing the importance of anthropogenic geomorphology, Wohl draws attention to the pervasive geomorphic influence of humans that exists even in landscapes that we tend to think of as unaltered and protected, like national parks and forestlands. Drawing on the hydrological assertion that "stationarity is dead" in a time of anthropogenic climate change, Wohl asserts that "wilderness is dead" when direct human manipulation has affected half of the Earth's land surface and even remote polar regions are experiencing altered geomorphic processes as a result of climate change. To move forward, Wohl synthesizes concepts from geomorphology and ecology that might help guide critical zone and geomorphic research in the future. These concepts include physical and biotic integrity and resilience, connectivity, and thresholds where form or process fundamentally changes, and are themes that appear amongst the other papers in this issue.

James also points us to the ubiquity of historical landscape manipulation and its implications for future trajectories in his

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review and definition of "legacy sediment." This episodically produced wave of sediment can manifest itself across many parts of the landscape as a time-transgressive signal that is capable of recording lags in the geomorphic system. Legacy sediment demonstrates the ways that humans alter sediment flux, but also connectivity between different landscape pieces in both space and time. Florsheim et al. illustrate how river processes and climate variation increasingly interact with human activity to cause channel incision. Results from their field study in northern California enabled development of a dimensionless metric "relative incision," to aide in quantifying thresholds of stability in incised alluvial channels. Incision also leads to changes in channel-floodplain hydrologic connectivity. An influx of sediment can serve as an important stratigraphic marker of human activity. For example, Stinchcomb et al. studied the distribution of coal alluvium along river valleys of eastern Pennsylvania using an event stratigraphy approach along with specific examples of complex and cascading spatial effects of human activities. As coal alluvium from mining activities silted up channels, flooding increased, resulting in further distribution of coal alluvium across the floodplains.

With over half of the world's large rivers and virtually all of the rivers in the United States affected by dams (Graf, 2001; Nilsson et al., 2005), devoting several papers in this issue to investigations of the effects of dams on fluvial forms and processes is appropriate. Yet, each of these papers goes beyond investigating the effects of a single dam on a river, instead examining the cumulative effects of multiple human interactions over space and time. Skalak et al. studied the Upper Missouri River as a case of the effects of successive dams on fluvial geomorphology, where the downstream effects of one dam are not dissipated before the upstream effects of the next dam occur. The morphology of the reach affected by the interacting dams is distinct from either the typical upstream or downstream effects of singular dams. Skalak and colleagues estimate that 80% of large rivers in the U.S. may have reaches affected by such interactions. Interacting dams are an example of human manipulations occurring in different places having a cumulative effect on a river or landscape. Freyer and Jefferson consider the temporal cumulative effects of 150 years of river engineering and dams on the islands and emergent land of the Upper Mississippi River. While eroding islands is the dominant trend in engineered rivers, Freyer and Jefferson examined the patterns and processes of land emergence in a river reach where islands have grown for the last 40 years. They contrast this reach to others where land emergence has not occurred. This analysis of an unusually resilient landscape patch provides one model for guiding restoration designs where unaltered reference conditions no longer exist or where climatic, hydrologic, of geomorphic processes have crossed a threshold and the historical range of variability is no longer applicable.

Dammed streams and rivers also provide environmental archives that allow investigation of the geomorphic impacts of land use change in the surrounding watershed. Mann et al. use sediment cores and bathymetric changes in a reservoir on Ohio's Cuyahoga River to assess how urban land use patterns in the watershed affected sediment quantity and quality. The sediments in the reservoir record the multiple ways that urban activity can alter fluxes. Lower sedimentation rates and higher sediment-bound metals concentrated early in the record when industrial activity was more prevalent in the watershed; higher sedimentation rates and lower metals registered in more recent times when population in the watershed increased and industrial activities and power generation declined. The reservoir sediment record, coupled with modeling of modern watershed sediment fluxes, is also useful for guiding management and predicting geomorphic changes that may occur when the old dams are removed and channel connectivity is restored. At a much smaller scale, Mattheus and Norton employ sediment records and erosion modeling to examine sediment generation in urban forests. Their results suggest that urban forests, which cover nearly 30% of US urban areas (Nowak et al., 2001), have unexpectedly high erosion rates relative to other forested landscapes. The authors suggest that these high erosion rates may result from upslope impervious surfaces generating erosive stormwater, or a legacy of forest harvest reducing the ecological complexity and erosion resistance of forested slopes. The contributions by Mann and colleagues and Mattheus and Norton emphasize the importance of quantifying the heterogeneous impacts of human activities over time, even under relatively static land cover conditions. These studies also highlight important insights that can be gained by coupling sediment flux models with empirical data collection. Such multiple method approaches are an important way forward for anthropogenic geomorphology studies to not only explain past and present impacts, but to make predictions of future forms and processes given increasing interactions between humans and the Earth surface.

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