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An evolving research agenda for human–coastal systems

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ABSTRACT

Within the broad discourses of environmental change, sustainability science, and anthropogenic Earth-surface systems, a focused body of work involves the coupled economic and physical dynamics of developed shorelines. Rapid rates of change in coastal environments, from wetlands and deltas to inlets and dune systems, help researchers recognize, observe, and investigate coupling in natural (non-human) morphodynamics and biomorphodynamics. This same intrinsic quality of fast-paced change also makes developed coastal zones exemplars of observable coupling between physical processes and human activities. In many coastal communities, beach erosion is a natural hazard with economic costs that coastal management counters through a variety of mitigation strategies, including beach replenishment, groynes, revetments, and seawalls. As cycles of erosion and mitigation iterate, coastline change and economically driven interventions become mutually linked. Emergent dynamics of two-way economic–physical coupling is a recent research discovery. Having established a strong theoretical basis, research into coupled human–coastal systems has passed its early proof-of-concept phase. This paper frames three major challenges that need resolving in order to advance theoretical and empirical treatments of human–coastal systems: (1) codifying salient individual and social behaviors of decision-making in ways that capture societal actions across a range of scales (thus engaging economics, social science, and policy disciplines); (2) quantifying anthropogenic effects on alongshore and cross-shore sediment pathways and long-term landscape evolution in coastal zones through time, including direct measurement of cumulative changes to sediment cells resulting from coastal development and management practices (e.g., construction of buildings and artificial dunes, bulldozer removal of overwash after major storms); and (3) reciprocal knowledge and data exchange between researchers in coastal morphodynamics and practitioners of coastal management. Future research into human–coastal systems can benefit from decades of interdisciplinary work on the complex dynamics of common-pool resources, from computational efficiency and new techniques in numerical modeling, and from the growing catalog of high-resolution geospatial data for natural and developed coastlines around the world.

1. Introduction

Research recognizing humans as a geomorphic force has entered a new phase of intensification since its early precedents (Marsh, 1869, 1882; Phillips, 1991; Hooke, 1994, 2000; Vitousek et al., 1997; Haff, 2003, 2010, 2012; Foley et al., 2005; Wilkinson, 2005; Wilkinson and McElroy, 2007; Syvitski and Kettner, 2011; Zalasiewicz et al., 2011; Hooke et al., 2012; Brown et al., 2013; Ellis et al., 2013; Harden et al., 2014; Lazarus, 2014a). Physical and social insight into links and feedbacks between Earth-surface systems and human activities is a grand challenge shared across the many disciplines that study environmental change (NRC, 2001, 2002, 2010). Human activities related to agriculture, mining, and construction of physical infrastructure, from houses to highways, move more earth material than do natural geomorphic processes related to rivers, glaciers, wind, and waves (Hooke, 1994). The means by which humans redistribute soil and rock mass comprise novel sediment-transport mechanisms unto themselves (Haff, 2010, 2012). Moreover, human alterations to natural sediment-transport pathways, and the physical legacies of those alterations (McNeill and Winiwarter, 2004; Remondo et al., 2005; Montgomery, 2007; Neff et al., 2008; Syvitski and Kettner, 2011; Brown et al., 2013; Dotterweich, 2013), are now well established for river systems (Criss and Shock, 2001; Syvitski et al., 2005; Walter and Merritts, 2008; Hoffman et al., 2010; Di Baldassarre et al., 2013), deltas (Syvitski et al., 2009; Xing et al., 2014), marshes and estuaries (Kirwan et al., 2011; Kirwan and Megonigal, 2013; Ma et al., 2014), and coastlines (Dolan and Lins, 1986; Nordstrom, 1994, 2000; Willis and Griggs, 2003; Long et al., 2006) around the world.

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Current research in geomorphology is "employing a rapidly expanding, interdisciplinary set of tools that are revolutionizing how we understand Earth-surface processes", and benefiting from the conceptual and quantitative approaches of complexity science (Murray et al., 2009, p. 497). Geomorphology is also "becoming more concerned with human social and economic values,…conservation ethics, with the human impact on environment, and with issues of social justice and equity" (Church, 2010, p. 265). Exploring human and natural landscape change in an analytical context of integrated systems combines these diverse characteristics of modern geomorphology, and can reveal feedbacks and emergent phenomena that less holistic perspectives might not (Nordstrom, 1994; Haff, 2003; Werner and McNamara, 2007). In a seminal paper on the dynamics of human–landscape systems, Werner and McNamara (2007, p. 399) argue that "…human–landscape coupling should be strongest where fluvial, oceanic or atmospheric processes render significant stretches of human-occupied land vulnerable to large changes and damage, and where market processes assign value to the land and drive measures to protect it from damage. These processes typically operate over the (human) medium scale of perhaps many years to decades over which landscapes become vulnerable to change and over which markets drive investment in structures, evaluate profits from those investments and respond to changes in conditions." As coastal zones worldwide are increasingly vulnerable to natural hazards (Fig. 1) (NRC, 1995, 2014; Nordstrom, 2000; Nicholls and Cazenave, 2010; Gall et al., 2011; Hoagland et al., 2012; Lazarus, 2014b), research on coupled economic and physical dynamics of developed coastlines demonstrates the kind of insights that such an integrated systems approach can yield (Figs. 2 and 3) (McNamara and Werner, 2008a, 2008b; Slott et al., 2008, 2010; Lazarus et al., 2011a; McNamara et al., 2011, 2015; Ells and Murray, 2012; Jin et al., 2013; McNamara and Keeler, 2013; Murray et al., 2013; Williams et al., 2013). For example, although coastal engineering has long grappled with the fact that local interventions against coastal erosion have updrift and downdrift consequences, recent morphodynamical work suggests the spatial and temporal scales of those distributed effects may be surprisingly large. Long-distance nonlocality can derive from not only the cumulative effects of deliberately altering sediment budgets over the long term (Fig. 4) (McNamara and Werner, 2008a, 2008b; Lazarus et al., 2011a) but also the compounding – and confounding – effects that complex coastline shapes (Coco and Murray, 2007; Murray and Ashton, 2013) can exert on shoreline behavior through wave shadowing and net gradients in alongshore sediment flux (Fig. 5) (Slott et al., 2008, 2010; McNamara et al., 2011; Ells and Murray, 2012; Murray et al., 2013; Williams et al., 2013; Barkwith et al., 2014a).

Coastal coupled-systems research is pushing past its initial proof-of-concept phase, and in this paper we contribute to its progression in the following ways. First, we suggest that as coastal change becomes a combined function of economically driven human actions and natural physical processes (Nordstrom, 1994, 2000; Werner and McNamara, 2007; Smith et al., 2009; Gopalakrishnan et al., 2011; Lazarus et al., 2011a), developed coastlines are beginning to exemplify what economists describe as an asymmetrical commons (Ostrom et al., 1999; Dietz et al., 2003) – an especially problematic kind of common-pool resource system in which distribution of a resource, and user access to it, is non-uniform, and the spatial boundaries that define where the system begins and ends are vague. This conceptualization of developed coastlines as coupled systems functionally integrated over large spatial and temporal scales has major implications for coastal management and the liability insurance sector (Stone and Kaufman, 1988; NRC, 2014; McNamara et al., 2015). Second, we pose three major challenges that need resolving in order to advance theoretical and empirical treatments of human–coastal systems. Thematically, these challenges involve (1) social dynamics of coastal decision-making; (2) quantifying anthropogenic effects on coastal sediment pathways in space and time; and (3) reciprocal exchange of knowledge and data between researchers and practitioners. These challenges also extend in general ways to other human–environmental systems (Liu et al., 2007; Werner and McNamara, 2007; Harden et al., 2014). We suggest possible approaches to engage each challenge. Pursuing them will require adopting or adapting strategies and lessons from perspectives and research methods formalized in other disciplines.

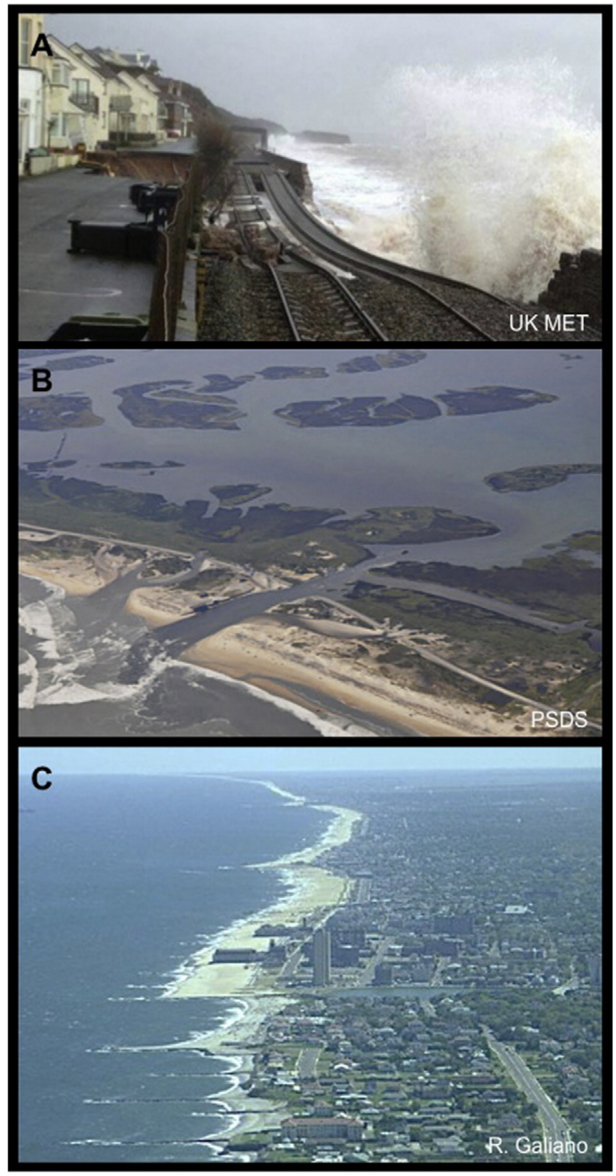

Fig. 1. (a) View east along rail line in Dawlish, UK, damaged during winter storms in February, 2014. (Photo: UK MET Office.) (b) Breach in Highway 12 between Duck and Rodanthe on the North Carolina Outer Banks, USA, following Hurricane Irene in August, 2011. (Photo: A. Coburn, Program for the Study of Developed Shorelines.) (c) View south along shoreline from Deal (foreground, no beach) to Asbury Park (middle ground, wide beach), New Jersey, USA. Prevailing direction of sediment transport in this region is from south to north. (Photo by R. Galiano.).

2. Local actions, nonlocal consequences

2.1. Common-pool resource asymmetry on developed coastlines

A groyne field that traps beach sand in front of one town tends to exacerbate erosion problems for neighbors downdrift (Pilkey and Dixon, 1996). But coastal engineering repercussions are not always so self-evident. Some systemic interdependencies may only become apparent when a major storm finds a localized weakness in hazard protection that disrupts a larger, more diffuse infrastructural network. In 2005,