ESEX Commentary

Biogeomorphology: diverse, integrative and useful

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Abstract

Biogeomorphology is an umbrella term given to a highly-active research area within geomorphology that focusses on the many and varied interactions and feedbacks between organisms and the physical Earth. In the last 25 years this interest has developed and diversified to include the direct and indirect influences of microorganisms, plants, animals and humans on earth surface processes and landform dynamics, and the roles of geomorphology in ecological functioning, resilience and evolution. This Commentary introduces a virtual special issue of 16 research papers and 3 'State of Science' pieces, illustrating the diversity of the field, its continued theoretical and conceptual progression, and the applied relevance of biogeomorphological science in tackling environmental problems. Collectively, these papers demonstrate the merits of—and opportunities for—biogeomorphology as an inherently integrative science in understanding and managing the complexity of living landscapes.

KEYWORDS: biogeomorphology; ecosystem engineering; ecogeomorphology zoogeomorphology; ecological engineering

The study of organisms' roles in earth surface processes is nothing new. One need only look to the works of Darwin for exemplary evidence of this (Darwin, 1881). Yet it is only over the last 25 years or so that biogeomorphology has become established as a subfield of geomorphology explicitly focussed on the interactions and feedbacks between life and landscape (Viles, 1988). This is reflected by an increase in publications identifying themselves as 'biogeomorphological' in scope, particularly over the last 10 years (Figure 1). In reality there is an additional (an undoubtedly substantial) body of work that falls under the umbrella of biogeomorphology but which is not explicitly identified as such, perhaps being more immediately aligned with (and produced within) other allied disciplines including ecology, engineering and materials science. Collectively, this body of work encompasses a vast and ever-growing range of biogeomorphological interactions involving microorganisms, plants, animals and humans. Within geomorphology, such a broad approach to the study of landscapes means that biogeomorphology is very often multidisciplinary (and at its best interdisciplinary) and multi-scalar (Naylor, et al., 2002), offering a useful framework for holistic and increasingly applied geomorphological science.

[FIGURE 1 NEAR HERE]

In the last five years journal special issues have emerged that focus on particular aspects of biogeomorphology. These include ecogeomorphology (Wheaton, et al., 2011), zoogeomorphology (Butler and Sawyer, 2012), vegetation and disturbance regimes (Stoffel, et al., 2013), biopedturbation (Whitesides and Butler, 2015) and fluvial ecosystem engineering (Harvey and Bertoldi, 2015). With a few exceptions (e.g., Renschler, et al., 2007; Etienne, 2010) volumes drawing from the field as a whole have, nevertheless, been relatively few since Viles and Naylor (2002). This Virtual Special Issue stems from a session held at the European Geosciences Union

(EGU) General Assembly in 2014 convened by Martin Coombes, Larissa Naylor, Heather Viles, Thorsten Balke, David Eldridge and Paul Richards. The session sought to draw together examples of contemporary research in biogeomorphology and thus illustrate the diversity, interdisciplinarity, and utility of the field as a whole. Many of the nineteen papers included here derive from that session and others have been incorporated since. Accepting some inevitable overlap, the papers are loosely grouped into four themes: (1) those engaging with and extending theoretical frameworks and concepts in biogeomorphology, (2) fluvial, estuarine and coastal systems, (3) soils and hillslopes, and (4) applied biogeomorphology.

Theory and concepts in biogeomorphology

One characteristic of biogeomorphology as an area of study is the rapidity at which underpinning theory and concepts have developed. This includes important discussions devoted to scale-linkages (Phillips, 1995), complexity (Stallins, 2006), disturbance regimes (Viles, et al., 2008) and contingency (Phillips, 2016a) among others. Perhaps most notably, the progressive integration of parallel ideas that emerged from the ecological and evolutionary sciences has done much to shape the way we think about what organisms 'do' in landscapes and, in-turn, how landform- and landscape-forming processes influence ecological functioning. Ecosystem engineering and associated concepts (see Cuddington, 2007; Corenblit, 2011; Jones, 2012) are proving particularly valuable in exploring how the physical (and often geomorphological) impacts of organisms have significant ecological and evolutionary feedbacks (Corenblit, et al., 2008). In the first 'State of Science' paper of this special issue Phillips (2016b) builds on these ideas by introducing the notion of landforms as extended composite phenotypes – physical expressions of organisms' activities that act to perpetuate (select for) genes. In this context Phillips provides a fascinating discussion with reference to a range of biogenic landforms including stromatolites, coral reefs, salt marshes and mangrove swamps, and ultimately concludes that the toposphere (encompassing Earth's landforms) is, at least partly, a biotic construct.

Complementing ideas arising from the study of mangrove systems (Balke, et al., 2014), Eichel et al. (2016) develop the concept of a 'biogeomorphic feedback window' in their assessment of vegetation dynamics and geomorphic disturbance on lateral moraines of the Turtmann Glacier, Switzerland. In doing so they demonstrate how the occurrence and nature of biogeomorphological interactions may be temporally contingent. Lane et al. (2016) also present a conceptual model that links geomorphic disturbance and plant community development, this time for alluvial fan surfaces. Their model is illustrated using detailed field and aerial surveys of a subalpine fan in the Vallon de Nant, southwest Switzerland, successfully linking spatial and temporal patterns of disturbance, edaphic factors and floristics. These papers demonstrate how biogeomorphology can contribute to understanding of fundamental ecological processes (i.e., plant community succession) in physically-dynamic landscapes.

Fluvial, estuarine and coastal biogeomorphology

Biogeomorphological research in water-sediment driven systems has proved particularly productive in recent years, as demonstrated by a recent special issue of this journal (Harvey and Bertoldi, 2015). Building on this, Corenblit et al., (2016) explore how the establishment of black poplar (*Populus nigra*) and its influence on hydrogeomorphic processes controls the formation and development of in-channel landforms of the River Garonne, France. Using a combination of GIS, photogrammetry and *in situ* measurement, gravel point bars in this system are shown to be rapidly colonised and stabilised by poplar, facilitating sediment trapping, landform accretion and subsequent colonisation. Linked to the ideas discussed by Phillips (2016b), the authors suggest that these landforms may be considered as functional (from an ecological perspective) by improving conditions for growth and reproduction. The photogrammetric techniques employed in their study are described by Vautier et al. (2016), who illustrate the exciting potential of both recent and historical aerial photography for reconstructing biogeomorphological dynamics.

At the coast, Swales et al. (2015) explore the development of mangrove (*Avicennia marina*) forests on the Firth of Thames coast, New Zealand, using a detailed analysis of sedimentary records. They find that development of these systems is multi-phased, primarily controlled by physical processes and mudflat elevation. Baptiste et al. (2016) examine saltmarsh development on Texel in the Wadden Sea, the Netherlands, over a 30-year period. Their findings illustrate the potential sensitivity of marshes to external forcing, revealing how changes to local hydrology and human activity (dredging) have had knock-on consequences for sediment supply and marsh dynamics. In a second 'State of Science' paper, Vacchi et al. (2016) review the biogeomorphology of coastal seagrass (*Posidonia oceanica*) meadows. Drawing on a range of studies the authors examine the influence of substratum properties on the establishment and distribution of meadows in the Mediterranean, and their influence on nearshore hydrodynamics and erosional-depositional processes. Lastly, in a different coastal setting, Gowell et al. (2015) examine the roles of vegetation on temperate rocky shores. Using a laboratory simulation they identify the mechanisms through which macroalgae (seaweed) may limit mechanical rock breakdown. Their results imply that shading and water-retention by vegetation canopies probably reduces rates of weathering via a reduction in the frequency of salt crystallisation.

Biogeomorphology of soils and hillslopes

Vegetation on land is of equal biogeomorphological interest. Pawlik et al. (2016), for example, provide a detailed assessment of tree-uprooting in the Sudeten Mountains, Poland, combining primary and secondary data sources of tree-throw occurrence and wind patterns, and *in situ* monitoring of root-plate degradation. Their paper illustrates the opportunities and challenges for up-scaling from the local to the regional scale, revealing the complexity and context-dependency of uprooting as a mechanism of downslope sediment transfer and topographic evolution.

In the first of two zoogeomorphological papers, Travers and Eldridge (2016) use litter bags to compare decomposition rates between foraging pits of native mammals (echidnas, bilbies and bettongs) in Australia. They find that initial differences measured over a period of months were obscured at the annual scale. These temporal patterns were further complicated by a significant effect of litter substrate type on decomposition rates as well as—to a lesser extent—soil detritivore activity (fungi and termites). In the USA, Whitesides and Butler (2016) examine bioturbation by pocket gophers (*Thomomys talpoides*) and marmots (*Marmota olympus*) in two national parks. In identifying distinct physical and chemical signals at digging sites, they suggest that bioturbated soils may act as nursery sites for conifer seed germination and establishment, with the potential to influence alpine treeline dynamics.

In comparison to animals and plants, biogeomorphological research at the microbial scale is still comparatively lacking in output and application, although Viles (2012) suggests this is likely to change in the future as more sophisticated techniques are added to the biogeomorphologist's toolbox. Liu et al. (2016) quantify the significant role of microbial communities in regulating erosion of soils from the Loess Plateau, China, by overland flow. Their flume experiments show marked reductions in soil detachment rates and rill erodibility in the presence of biological soil crusts (BSCs) dominated by cyanobacteria and mosses. A similar bioprotective role, this time for higher plants, is demonstrated by Seitz et al. (2015) in subtropical forests. Their study in Southeast China shows that the presence and activity of meso- and macrofauna moderate the protective function of leaf litter, by loosening soils and accelerating litter decomposition. This provides an important example of how interactions between different organism groups can have distinct geomorphological consequences; organisms rarely live in isolation and studies attempting to elucidate the geomorphological importance of ecological interactions (at the individual, population and community level) are likely to reveal emergent—and potentially quite different—impacts.

Applied biogeomorphology

There is an increasing body of work that demonstrates the utility of biogeomorphology in tackling management problems arising from environmental change and human disturbance (Viles et al., 2008). In their discussion of intertidal mangrove forests, Balke & Friess (2016) offer a compelling argument for the application of geomorphological knowledge for successful restoration and conservation, and for improving coastal resilience against extreme storms in the tropics. Similarly, Spencer et al. (2016) demonstrate how European saltmarsh communities show high resilience with respect to sediment erosion under true-to-scale simulated storm surge conditions. Their study further demonstrates how species' morphological traits moderate the nature and efficacy of biogeomorphological processes. Smith et al. (2016) build on laboratory simulations of wave dissipation over wetlands, using numerical modelling, to up-scale over larger areas. They also highlight the importance of vegetation traits (such as plant density, diameter and degree of submergence) and further emphasise opportunities for using nature-based solutions to improve the resilience of coastal communities against storms.

In fluvial systems, Wohl & Scott's (2016) 'State of Science' paper examines the influence of large wood (including dispersed pieces, logjams and beaver dams) in sediment storage and dynamics. They hypothesise that the positive relationship between wood load and sediment storage is conditioned by drainage area, and that the form of sediment storage is closely linked to channel gradient. From an applied perspective, the authors suggest that re-introducing wood and beavers offers opportunities for restoring the natural dynamics of fluvial systems. These last four papers aptly illustrate how a growing emphasis on 'nature-based solutions', 'working with nature' and ecological engineering approaches in environmental management has important implications for biogeomorphology; much of this work essentially involves the conservation, restoration and/or manipulation of biogeomorphological processes and systems. Biogeomorphologists clearly have a role to play here.

Another area requiring biogeomorphological input is assessing and predicting the impacts of invasive species, given that they may often have a high physical ecosystem engineering capacity (Ehrenfeld, 2010; Fei, et al., 2014). This is demonstrated by Schwarz et al. (2016) who discuss the roles of the invasive cordgrass *Spartina alterniflora* in altering the geomorphological functioning of tidal wetlands in the Yangtze Estuary, China. They provide evidence that the nature and dynamics of biogeomorphic feedbacks can be significantly altered following invasion, in part due to very different morphological and physiological traits of the invader compared to native species. Thanks to an ever-more connected world, current rates of species introductions present a major concern for global biodiversity conservation (Simberloff, et al., 2013) and biogeomorphologists are well placed to contribute to assessments of their nature and scale of impact.

Some future directions

Several areas can be identified as being ripe for further study. First, the critical control of organism traits (morphological, physiological and behavioural) on the occurrence, efficacy and dynamics of biogeomorphological processes could be explored in a range of contexts. Such an approach should prove valuable in explaining and predicting the spatial and temporal patterning and resilience of biogeomorphological phenomena. Second, more population- and community-level studies are needed to up-scale from individual and single-species impacts. Several papers in this issue illustrate how, at higher levels of ecological organisation, all manner of potentially interesting biogeomorphological interactions may occur. These may be both positive (facilitatory) and negative (inhibitory). Possible tools here include existing ecological datasets (e.g., Coombes and Viles, 2015), modern observation techniques and remote sensing (including UAVs and satellite imagery, e.g., Zangerlé, et al., 2016) and computer modelling (e.g., Smith, et al., 2016). Thirdly, biogeomorphology can continue to strengthen its contribution to tackling environmental problems. This includes further consideration of how ecological responses to climate change will impact upon geomorphological dynamics and vice versa (e.g., Butler, 2012; Viles and Cutler, 2012) and, as is well-illustrated by papers in this special issue, how biogeomorphological processes and systems may be best conserved and employed to maximise regulatory (and other) ecosystem services.

The range of topics included in this Special Issue is testament not only to the variety of biogeomorphological research currently being undertaken internationally but also its utility. Especially encouraging is the number of studies that align our field very firmly with dominant paradigms in other allied sciences, including biodiversity conservation, ecological functioning, ecosystem service provision and valuation, and environmental resilience in the face of the Anthropocene (e.g., Brown, et al., 2016). The drive within Earth System Science for holistic understanding of the environment marries well with an area of research ultimately tasked with understanding the complexity of living landscapes. In these respects, biogeomorphology offers great potential for impactful and useful academic research.

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Figure Captions:

Figure 1. Numbers of publications identifying themselves as ‘biogeomorphological’ since 1990. Data are unfiltered counts from Web of Science (as of August 2016) using the search terms ‘biogeomorph*’ ‘zoogeomorph*’ ‘phytogeomorph*’ and ‘ecogeomorph*’. Studies that are inherently biogeomorphological in scope but which are not explicitly identified as such (either in their title, abstract or keywords) are not included.

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