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Preface: Multiscale Feedbacks in Ecogeomorphology☆

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1. Introduction

Geomorphic systems are known to exhibit nonlinear responses to physical–biological feedbacks (Thornes, 1985; Baas, 2002; Reinhardt et al., 2010). These responses make understanding and/or predicting system response to change highly challenging. With growing concerns over ecosystem health, a pressing need exists for research that tries to elucidate these feedbacks (Jerolmack, 2008; Darby, 2010; National Research Council, 2010). A session was convened at the Fall 2008 meeting of the American Geophysical Union (AGU) to provide an outlet for some of this truly interdisciplinary and original research, which is central to understanding geomorphic and ecological dynamics. The session attracted over 39 contributions, which were divided into two well-attended oral sessions and a very busy poster session.

This special issue presents new research from the AGU session, which highlights clear physical–biological feedbacks. The aim is to bring together contrasting perspectives on biological and geomorphic feedbacks in a diversity of physiographic settings, ranging from wetlands and estuaries, through rivers, to uplands. These papers highlight biological and physical feedbacks which involve the modulation or amplification of geomorphic processes. These papers will be of interest to a core geomorphology audience, and should also draw attention from the fields of ecohydraulics, hydroecology, ecohydrology, ecomorphology, biogeochemistry and biogeography, and biogeomorphology as well as the more traditional fields of hydrology, ecology and biology.

In this preface to the special issue, we a) review past contributions to the emerging field of ecogeomorphology and related disciplines, b) provide some context for how this topical special issue came to fruition, and c) summarize the contributions to this special issue.

2. What is ecogeomorphology?

Examples of studies explicitly integrating ecology and geomorphology date back to at least the late 1800s (e.g. Cowles, 1899), with more examples appearing in the 1950s (e.g. Olson, 1958) and 1960s (e.g. Hack and Goodlet, 1960). Terms such as ecogeomorphology and biogeomorphology only became popular in the 1990s (Osterkamp and Hupp, 2010). The 1990 British Geomorphology Research Group Annual Meeting (Thornes, 1990) and the 1995 Binghamton Symposium on Biogeomorphology (Hupp et al., 1995b) were two of the first symposiums to emphasize the theme of biogeomorphology. Ecogeomorphology and biogeomorphology are generally considered synonyms (Hupp et al., 1995a), but they do sprout from slightly different research interests. Both are part of a larger family of terms that researchers have used somewhat inconsistently to describe research at the interface between some combination of hydrology, geomorphology and/or ecology/biology (Fig. 1). Unlike some of the other eco-geo-hydro combinations in Fig. 1, the eco- or bio-root is an adjective modifying the noun geomorphology. Based on the types of research published under these two banners, the biogeomorphology community has generally focused more on how chemical and physical weathering are amplified and modulated with biological feedbacks; ecogeomorphology is commonly used to describe studies that focus more on the amplification and modulation of erosion and deposition processes. Both are fundamentally concerned with the bidirectional influences of biota and landscapes on each other. Biogeomorphology is concerned with both the influence of landforms on plants, animals and micro-organisms distribution and development; as well as the influence of those plants, animals and micro-organisms on earth surface processes and the landforms shaped by those processes (Viles, 1988). Naylor et al. (2002: p. 4) loosely define biogeomorphology as involving 'the cooperation between ecology and geomorphology' to study two-way linkages between ecological and geomorphological processes. Murray et al. (2008) argue that biomorphodynamics is a more restrictive term than biogeomorphology or ecogeomorphology, and that it highlights landscape dynamics in which an explicit two way coupling (i.e. feedback) occurs between biotic and physical processes. The related zoogeomorphology (e.g. Butler, 1995) term has received less play, but it is worth mentioning that research under this banner focuses on examples of animals influencing geomorphic processes and landforms (e.g. beaver, salmon, burrowing animals, etc.).

The term biogeomorphology has been more widely used since Viles (1988) first attempted to provide a comprehensive overview of what was, at that time, an emerging discipline. A review of Web of

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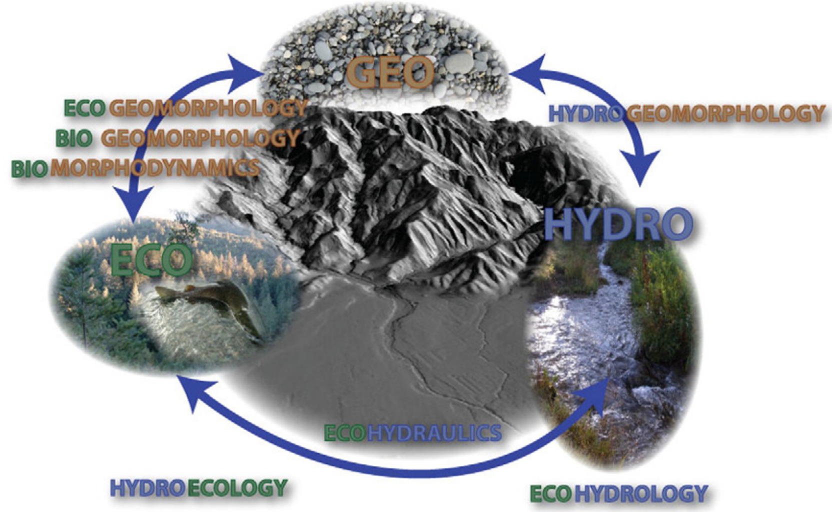

Fig. 1. The 'Eco-Geo-Hydro Mess'. Interdisciplinary scientists at the interface of physical and biological sciences have struggled with what to call their disciplines. These seven combinations of geo-, hydro-, and eco-roots represent invented terms scattered throughout the literature, which represent different sub-disciplines. In this special issue, we focus on feedbacks between ecological and geomorphic processes and adopt the 'ecogeomorphic' term from ecogeomorphology.

Science articles using various search terms (Table 1) reveals only thirteen papers on ecogeomorphology, with five of them published in 2010 alone and six between 2005 and 2009. By contrast, biogeomorphology or biogeomorphic returns eighty-four articles with a longer history of publication. Although this may be the first special issue focused specifically on ecogeomorphology, if we broaden our definition to include other related approaches, then this is not the first special issue spanning ecogeomorphic research. Two of the first special issues on biogeomorphology, edited by Hupp et al. (1995b) and Viles and Naylor (2002), were also published in *Geomorphology*. Although terms such as ecohydraulics (Leclerc, 2005; Rice et al., 2010), hydroecology (Gilvear et al., 2008) and ecohydrology do not emphasize the geomorphology, they are frequently used loosely to include the geomorphic implicitly (Hannah et al., 2004). Thus, by expanding our definitions we find special issues covering the 'eco-geo' realm in *Geomorphology* (e.g. Hupp et al., 1995b; Osterkamp and Hupp, 1996; Viles and Naylor, 2002; Hession et al., 2010), *Earth Surface Processes and Landforms* (e.g. Darby, 2010), and *River Research and Applications* (e.g. Gilvear et al., 2008; Rice et al., 2010) over the past decade, with most of the activity in the last 3–4 years. Finally, as past literature has shown, attempts to clarify nomenclature are unlikely to really change the inconsistent use of these terms (similar to the 'restoration definition' debate). Nonetheless, the above history provides some context for what is clearly a growing area of interest (National Research Council, 2010).

Table 1
Number of peer-reviewed articles found for different search terms from a Web of Science search. The total number of articles returned from all the above searches was 815, but due to the use of multiple search terms, the above represents 482 unique articles.

Search term(s)	Total	Pre 2000	2000–2005	2005–2009	2010
Biogeomorphology or biogeomorphic	84	17	15	35	17
Biomorphodynamics	2	0	0	2	0
Ecogeomorphology	13	0	2	6	5
Ecohydraulics	46	1	8	26	11
Ecohydrology	316	7	86	173	50
Hydroecology or hydroecologic	124	21	31	59	13
Hydrogeomorphology or hydrogeomorphic	230	48	56	101	25

3. Path to the special issue

After the Fall AGU 2007 meeting, many delegates noted the lack of sessions highlighting research at the interface of geomorphology and ecology (or 'life and its landscape' as Jerolmack (2008) referred to it). Based on the meetings, conference sessions and special issues that have followed in the three years since 2007, an audience for ecogeomorphic research clearly exists and a vibrant community of individual researchers is actively engaged in cutting edge research, with an appetite for appropriate places to disseminate their work (National Research Council, 2010).

For example, in the summer of 2008, two meetings explicitly focusing on ecogeomorphology took place, organized by completely different international groups of researchers. In May of 2008, a group of 77 competitively-selected early-career researchers met in New Orleans at the Meeting of Young Researchers in Earth Sciences (MYRES III), under the meeting theme of 'Dynamic Interactions of Life and its Landscape'. The main findings of that meeting were summarized in an agenda-setting National Academy of Sciences report (Jerolmack, 2008), and a 'State of Science' paper in *Earth Surface Processes and Landforms* (Reinhardt et al., 2010). In June of 2008, the British Hydrological Society (BHS) sponsored a national meeting at Loughborough University, UK on 'Ecohydraulics at Scales Relevant to Organisms', attended by over 100 researchers from the UK and abroad. Papers from the meeting were published in a special issue of *River Research and Applications* (Rice et al., 2010). Another recent special issue appeared in *Geomorphology* titled 'Geomorphology and vegetation: Interactions, dependencies, and feedback loops' (Hession et al., 2010). Papers were drawn from contributions to the 40th Binghamton Geomorphology Symposium held at Virginia Tech in the Fall of 2009 which used the same title as the special issue. Synthesizing eighteen articles published in *Earth Surface Processes and Landforms* from 2007 to 2009, Darby (2010) edited a thematic Virtual Special Issue on 'Reappraising the geomorphology–ecology link'.

As already mentioned, this special issue is a selection of papers from three sessions convened at the Fall 2008 American Geophysical Union meeting on 'Multi-scale Feedbacks in Ecogeomorphology'. The sessions were the culmination of seven independent session proposals by fourteen researchers. Four of these session proposals were combined in a pre-proposal round from February to June of 2008. The original four proposals were 1) 'Ecohydrological Feedbacks Affecting

Aquatic Ecosystem Restoration' (Larsen and O'Connor), 2) 'Measuring and modeling the effect of vegetation on river geomorphology (Yager and Lightbody), 3) 'Geomorphic Dynamics and Ecohdyraulics' (Gibbins, Rice, Vericat and Wheaton), and 4) 'Interactions between vegetation, geomorphic processes, and landforms (Hession and Pizzuto). At the conclusion of the pre-proposal vetting, AGU meeting organizers suggested combining the four into one proposal on 'Feedbacks between Ecological, Geomorphic and Hydrologic Systems in Fluvial & Estuarine Landscapes' (to be led by Larsen, Gibbins and Wheaton). At the conclusion of the session proposal stage, the AGU meeting organizers combined the above proposal with another session proposal on 'Multiple Scales of Boundary Roughness' (Wohl and Papanicolao) and called it 'Feedbacks Between Ecological, Geomorphic, and Hydrologic Systems Across Multiple Scales'. After abstracts were submitted, the AGU meeting organizers were surprised by the level of interest in this and one other session titled 'Timescales and Feedbacks in Ecogeomorphology' (McElroy, Wainwright and Parsons). To capitalize on this collective interest, the seven original session proposals were combined into a series of two oral sessions and one large poster session all under the heading of 'Multi-scale Feedbacks in Ecogeomorphology'. Thus, from the success of the session this special issue was prepared to highlight and disseminate some of the key contributions to an even broader audience.

4. Review of contributions

The special issue consists of nine contributions, which have been selected and organized based on their physiographic setting, including wetlands, fluvial environments, and upland environments. The contributions are summarized briefly below.

4.1. Wetland feedbacks

The special issue begins its exploration of ecogeomorphic feedbacks on the brackish side of wetlands with D'Alapos (2011-this issue) studying how marsh biological processes dictate different morphological evolutionary regimes. Using a two-dimensional numerical morphodynamic model that explicitly represents biotic and geomorphic processes, the authors show that vegetation is critical in defining salt-marsh resilience to sea-level rise and how topographic heterogeneity of the marsh surfaces is strongly correlated with sediment supply.

With a contribution from Larsen and Harvey (2011-this issue), we move from salt-marshes to freshwater wetlands but continue to look at the role of feedbacks using morphodynamic modeling. Larsen and Harvey (2011-this issue) present a new, quasi-3D cellular automata, wetland morphodynamic model (RASCAL), which they use to explore how ecogeomorphic feedbacks influence landscape patterns in wetlands and floodplains. Through a case study in the Florida Everglades, they show that, in contrast to some river systems, knowledge of the flow and sediment supply is inadequate to predict channel form, and the antecedent vegetation patterns and vegetation dynamics (i.e. feedbacks between vegetation and hydraulic and geomorphic processes) must be known to reliably predict channel patterns. Their work highlights the fundamental importance of ecogeomorphic feedbacks in predicting channel form, and is also critical in evaluating restoration alternatives. They explain how the loss of ridge and slough wetlands in the Everglades over the past century has primarily been driven by declining water levels (from diversions), but that restoring the water levels alone without thinning slough vegetation and increasing water-surface slopes will not be able to halt ridge expansion.

In a related study also in the Everglades, Harvey et al. (2011-this issue) present findings from deploying a novel, in-situ, field flume to quantify the interactions of flow with aquatic vegetation and the feedback on sediment transport and nutrient redistribution. Their work is among the first to recognize the importance of sediment entrainment from epiphyton in shallow vegetated aquatic ecosystems. They show how this understanding is critical to protecting and restoring ecosystem functions and services because of its implications for the redistribution of organic carbon and phosphorous, as well as its control on habitat diversity.

4.2. Fluvial feedbacks

Taking us from wetlands to rivers, Fuller et al. (2011-this issue) take advantage of a dam removal on Fossil Creek, Arizona, to explore ecogeomorphic feedbacks between travertine-growth and step-pool morphology. With the removal of the dam, a $CaCO_3$-rich baseflow was restored, which led to significant travertine growth in the channel. Their findings suggest a positive feedback between flow hydraulics and travertine growth, whereby particular hydraulic conditions combined with abiotic precipitation, algal growth, trapping of organic material, and in-situ plant growth produce a self-reinforcing positive feedback loop that alters the hydraulics to further promote travertine growth. They found algal growth to be the dominant mechanism of modulating hydraulics and amplifying rates of travertine accrual. They conclude that the combination of these abiotic–biotic feedbacks with broader beneficial effects of travertine steps on ecosystem dynamics is an excellent example of a positive feedback between biology and geomorphology.

Keeping a focus on in-channel feedbacks, Salant (2011-this issue) explores the 'sticky business' of periphyton growth on streambeds and its role in modulating hydraulics and amplifying rates of particle deposition and modulating particle infiltration. Using a gravel-bedded flume, she shows that periphyton assemblages significantly changed the nature of suspended sediment deposition and infiltration through a variety of mechanisms including shear stress modification, increased surface adhesion and bed clogging. When comparing the flume data with field studies, she highlights that because particle loss from deposition is a function of surface deposition and subsurface infiltration, the combined feedbacks can sometimes be positive, sometimes negative and other times neutral.

Shifting our focus from sticky stream beds to a broader view of morphological channel changes over the past century, Dean and Schmidt (2011-this issue) explain progressive channel narrowing in the Big Bend region of the lower Rio Grande as a function of a variety of feedbacks across multiple scales. They show that prior to the 1940s, frequent floods imposed a negative feedback on extensive riparian vegetation growth and helped to maintain a wide, sandy, multi-threaded river. Because of water extractions in the upper basin, the peak and mean flows have been dramatically reduced since this time, and led to progressive channel narrowing, less frequently interrupted by large floods. This coincides with the introduction of non-native riparian vegetation (*Tamarix* spp., *Arundo donax*), which has created a positive feedback on channel narrowing by promoting rapid vertical accretion of the floodplain (upwards of 2.75 to 3.5 m over just 15 years).

Continuing with the theme of anthropogenically induced changes to channel morphology, Loheide and Booth (2011-this issue) present the effects of incised and over-widened channel morphologies on riparian and floodplain vegetation with a feed-forward model that links geomorphic, hydrologic and ecological responses. They show how the distribution of floodplain and riparian vegetation is highly contingent on the morphological channel state, which in turn controls groundwater and soil moisture patterns and species response. Their model is a significant step toward being able to fully couple bi-directional feedbacks between the vegetative and geomorphic responses.

4.3. Upland feedbacks

D'Amore et al. (2011-this issue) help gradually take this special issue up and out of the channels and into uplands with a link between salmon and soil development in southeast Alaska. Although salmon-derived nutrients are known to be an important component of aquatic and terrestrial ecosystem productivity in North American Coastal rainforests, the relative roles of nutrient loading in uplands from salmon-derived nutrients versus soil formation are not well understood. They focus on soils and landforms that formed over the Holocene along salmon spawning Channels of Prince of Wales Island, and use a soil-geomorphic model to test whether the types of soils closer to the channel have a distinctive isotopic nitrogen signature indicative of ocean (salmon-derived) nutrients. Their study highlights how long-term geomorphic and soil development processes, which help determine the productivity of later ecosystems are, in this case, amplified because of the presence of salmon.

Concluding the special issue, Wainwright et al. (2011-this issue) walk us through the contrasts between structural and functional connectivity with case studies ranging from the hyporheos of a temperate UK stream, through upland agricultural settings, to a degrading semi-arid landscape in the Southwest US. They use an improved distinction between structural and functional connectivity to lay out a conceptual framework that aids in more clearly elucidating feedbacks between ecologic, geomorphic and hydrologic systems. Thus, this paper helps conceptualize and link together some of the empirical evidence of feedbacks detailed in previous papers in the special issue.

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