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Assessing potential abiotic and biotic complications of crayfish-induced gravel transport in experimental streams

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Abstract

Biogeomorphology adds the element "biological dynamics" (of populations or communities) to chemical and physical geomorphic factors and thus complicates the framework of geomorphic processes. Such biological complications of the animal-induced transport of solids in streams should be particularly important in crayfish, as crayfish affect this transport through their overall activity and intraspecific aggression levels, which could be modified by shelter availability or the establishment of dominance hierarchies among individuals not knowing each other. Using experimental streams, we tested these hypotheses by measuring how shelter availability or residential crayfish group invasion by unknown individuals affected the impact of the crayfish *Orconectes limosus* on the (i) transport of gravel at baseflow (during 12 experimental days); (ii) sediment surface characteristics (after 12 days); and (iii) critical shear stress causing incipient gravel motion during simulated floods (after 12 days). The two potentially important factors shelter availability or residential group invasion negligibly affected the crayfish impact on gravel sediments, suggesting that habitat unfamiliarity (a third potentially important factor affecting crayfish activity) should increase the crayfish-induced sediment transport. Because habitat unfamiliarity is associated with sporadic long-distance migrations of a few crayfish individuals, this third factor should play a minor role in real streams, where crayfish biomass should be a key factor in relations with crayfish effects on sediments. Therefore, we combined the results of this study with those of previous crayfish experiments to assess how crayfish biomass could serve in modelling the gravel transport. Crayfish biomass explained 47% of the variability in the baseflow gravel transport and, in combination with the coefficient of variation of the bed elevation and algal cover, 72% of the variability in the critical gravel shear stress. These results encourage more research on the topic, as an increasing number of eliminations of abiotic and biotic factors that could complicate the animal-induced sediment transport in streams would facilitate the use of biological variables (e.g., bioturbator biomass) in future modelling of the transport of solids.

Keywords: Biogeomorphology; Bioerosion; Benthos; Gravel-bed river

1. Introduction

Biogeomorphology addresses the role of plants or animals in geomorphic processes as a complement to chemical or physical factors that shape earth surface systems (Naylor et al., 2002). Apparently, the importance of biogeomorphic processes in comparison to that of chemical or physical geomorphic processes is viewed equivocally (acknowledged or ignored) among geomorphologists (Butler, 1995; Viles and Naylor, 2002), and it seems that this view is influenced by the size or the abundance of the involved organisms.

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That larger but less abundant terrestrial plants, either alive or as large woody debris, can have significant effects on the erosion in river catchments (Phillips, 1995), river floodplains (Jeffries et al., 2003), and river channels (Montgomery and Piégay, 2003) is undisputed. Likewise, larger but less abundant terrestrial mammals can have clear effects on soil erosion (Trimble and Mendel, 1995; Govers and Poesen, 1998; Hall and Lamont, 2003). Finally, very small but very abundant aquatic animals, such as reef corals, obviously have effects on landforms (Butler, 1995). In comparison, more arguments and data are required to convince geomorphologists that organisms of intermediate size and abundance, such as benthic fish or invertebrates, play potentially a role as geomorphic agents in marine or freshwater systems (see Butler, 1995; Montgomery et al., 1996; Statzner et al., 1999, 2003b; Murray et al., 2002).

For running waters, predictions of the transport of solids are difficult (e.g., Buffington and Montgomery, 1997; Martin, 2003; Rathburn and Wohl, 2003); and a steadily increasing number of physical processes complicating such predictions have been discovered in the recent past (e.g., Billi et al., 1992; Lisle, 1995; Church et al., 1998; Wilcock, 1998; Marion and Weirich, 2003; Pyrce and Ashmore, 2003). Thus, adding biogeomorphic factors to this already complicated physical framework makes sense only if stream organisms indeed play an important role in geomorphic processes. Statzner et al. (2003b) synthesized the so far available results (and these are not numerous) in a conceptual framework that outlined the contribution of benthic animals of intermediate size and abundance to the spatio-temporal dynamics of the gravel and sand transport in real streams. First estimates in this synthesis illustrate that stream animals may modify the discharge required to mobilize gravel and/or sand at a given moment (period of activity) and a given location (used habitat type) by factors ranging from ~0.1 to 9. When discharge is assessed in a purely physical context, discharge differences of almost two orders of magnitude can have significant effects on the bed load transport in streams and rivers (e.g., Marion and Weirich, 2003; Martin, 2003; Hassan and Woodsmith, 2004). Thus, stream animals seemingly can play an important role in the transport of gravel and sand. However, Statzner et al. (2003b) also discussed a disturbingly great number of abiotic and biotic factors that could interfere with the animal-induced sediment transport in streams and called for assessments of the relative importance of these abiotic and biotic factors for the sediment transport.

Equivocal views about the importance of biota in geomorphic processes signify that the relatively young, interdisciplinary field of biogeomorphology has to focus its future research on goals that assess this importance and that prepare the use of biological variables in the modelling of geomorphic processes. Defining such future research goals, Naylor et al. (2002) called for (i) representative and replicated experimental designs to study biogeomorphic processes; (ii) extension of biogeomorphology research to organisms and environments beyond studies of notable and obvious examples, including assessments of the effects of other environmental variables on biogeomorphic processes; and (iii) studies of abundance effects of species that act as geomorphic agents. Corresponding to this call, this study (i) used a representative and replicated design of artificial stream experiments to assess (ii) how an organism of intermediate size and abundance, a benthic crayfish, affects the transport of gravel across a gradient of an abiotic and a biotic factor that potentially affect crayfish behaviour, and in turn could complicate the crayfish-induced gravel transport; and (iii) assesses how crayfish abundance in terms of their biomass affects the gravel transport across a variety of experimental conditions.

2. Potential complications of the crayfish-induced transport of solids and hypotheses

In general, biogeomorphology adds the element “biological dynamics” (of populations or communities) to the chemical and physical framework of geomorphic processes (Naylor et al., 2002). For streams, the currently available evidence suggests that the effects of lotic animals on sediment mobilization are particularly complicated trough interspecific variation of (i) their mechanistic impacts on the bottom sediments, and (ii) environmental factors that affect these mechanistic impacts (Statzner et al., 2003b). Such complications should be particularly important in bioturbating crayfish, as their population dynamics depend largely on intra- or interspecific aggressive interactions that are affected by shelter and food availability (Lodge and Hill, 1994; Gherardi, 2002). The obvious bioturbation of bottom sediments through crayfish relates to the behaviour of many species to burrow shelters in soft substrates (Gherardi, 2002; Barbaresi et al., 2004b). In addition, crayfish bioturbate sediments in less obvious ways: (i) the third and fourth pair of the walking legs provide most of the propulsion during walking (Pond, 1975), i.e., the friction between the tip of these legs and sediment particles should be relatively high; (ii) fright-