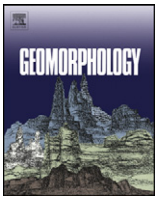
Geomorphology 253 (2016) 83–93

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph



Bed disturbance via foraging fish increases bedload transport during subsequent high flows and is controlled by fish size and species

A.G. Pledger *, S.P. Rice, J. Millett

Loughborough University, Leicestershire LE11 3TU, UK

A R T I C L E   I N F O

Article history:
Received 17 February 2015
Received in revised form 25 September 2015
Accepted 26 September 2015
Available online 30 September 2015

Keywords:
Ecosystem engineering
Barbel
Chub
Imbrication
Bedload transport
Zoogeomorphology

A B S T R A C T

Benthic foraging by fish can modify the nature and rates of fine sediment accrual and the structure and topography of coarse-grained fluvial substrates, with the potential to alter bed material characteristics, particle entrainment thresholds, and bedload transport fluxes. However, knowledge of what controls the nature, extent, and intensity of benthic foraging and the consequent influence of these controls on geomorphic impact remain rudimentary. An ex-situ experiment utilising Barbel *Barbus barbus* and Chub *Leuciscus cephalus* extended previous work by considering the role of fish size and species as controls of sediment disturbance by foraging and the implications for bed material characteristics and bedload transport. In a laboratory flume, changes in bed microtopography and structure were measured when a water-worked bed of 5.6–22.6 mm gravels was exposed to four size classes of Barbel (4–5″, 5–6″, 6–8″, 8–10″ in length) and a single size class of Chub (8–10″). In line with other studies that have investigated animal size as a control of zoogeomorphic agency, increasing the size of Barbel had a significant effect on measured disturbance and transport metrics. Specifically, the area of disturbed substrate, foraging depth, and the fish's impact on microtopographic roughness and imbrication all increased as a function of fish size. In a comparison of the foraging effects of like-sized Barbel and Chub, 8–10″ in length, Barbel foraged a larger area of the test bed and had a greater impact on microtopographic roughness and sediment structure. Relative to water-worked beds that were not foraged, bed conditioning by both species was associated with increased bedload transport during the subsequent application of high flows. However, the bedload flux after foraging by Barbel, which is a specialist benthivore, was 150% higher than that following foraging by Chub, which feed opportunistically from the bed, and the total transported mass of sediment was 98% greater. An interesting implication of these results, given the abundance and widespread distribution of foraging fish, is that numerous fish species belonging to a variety of functional groups may be acting as zoogeomorphic agents in rivers, directly affecting bed material conditions and sediment transport fluxes in proportion to their body size and feeding traits.

1. Introduction

Our understanding is growing of how animals, plants, fungi, and microorganisms can affect the nature and rates of geomorphological processes (Viles, 1988; Butler, 1995; Naiman et al., 2000; Reinhardt et al., 2010) and in doing so, act as ecosystem engineers (Jones et al., 1994). With regard to fluvial systems, reviews by Statzner (2011); Rice et al. (2012), and Albertson and Allen (2014) highlight the geomorphic capabilities of fish and macroinvertebrate fauna; but the number of studies is small and limited to a few species and impact mechanisms. The majority of research has focused on bed bioturbation during spawning by Salmonids (Field-Dodgson, 1987; Kondolf et al., 1993; Montgomery et al., 1996; Hassan et al., 2008), bed and bank bioturbation by crayfish (Statzner et al., 2003a; Zhang et al., 2004; Johnson et al., 2011; Harvey et al., 2014; Rice et al., 2014) and substrate consolidation through silk secretion by hydropsychid caddisflies (Cardinale et al., 2004; Johnson et al., 2009; Albertson et al., 2014).

Rice et al. (2012, their Figure 19.6) highlight a range of additional mechanisms by which fish and invertebrates might affect bed material conditions and thence sediment transport in gravel-bed rivers. Amongst these, foraging by fish is a potentially widespread and effective zoogeomorphic activity, but very little work has explored this possibility. Some work has considered the impact of detrivorous, tropical fish on fine sediment accrual within lotic systems (Flecker, 1996, 1997; Flecker and Taylor, 2004), finding that foraging reduced sediment accrual (Bowen et al., 1984; Lopez and Levington, 1987; Vari, 1989; Flecker, 1992) and that the effect increased with species density (Bowen, 1983; Goulding et al., 1988). European Cyprinid species reduce fine sediment accrual within lotic and lentic environments. Specifically, Carp *Cyprinus carpio* have been found to resuspend fine sediment when foraging for food (Breukelaar et al., 1994; Parkos et al., 2003; Chumchal et al., 2005; Miller and Crowl, 2006; Roozen et al., 2007; Matsuzaki et al., 2009); and other benthic feeders such as Bream *Abramis brama*, Tench

---

* Corresponding author at: Reaseheath College, Nantwich, Cheshire CW5 6DF, UK.
E-mail address: andrew.pledger@reaseheath.ac.uk (A.G. Pledger).

http://dx.doi.org/10.1016/j.geomorph.2015.09.021

Tinca tinca, and Ruffe *Gymnocephalus cernus* modify fine sediment accrual rates and increase turbidity (Persson and Svensson, 2006) whilst foraging.

Three further studies have considered the zoogeomorphic impact of benthic foraging fish on coarse fluvial sediments. First, Statzner et al. (2003b) used ex-situ experiments in small (0.2-m–wide) outdoor channels to investigate the impact of juvenile Barbel *Barbus barbus* on unstructured, fine gravel beds. They measured a decrease in the critical shear stress (for gravel entrainment) of ~45% as the number of fish that were allowed to forage the bed was increased from zero to eight (Statzner et al., 2003b). Significant increases in mean bed elevation and the authors' observation that the fish heaped gravel into piles led them to suggest that increased mobility was caused by the fish loosening the bed and increasing particle elevations. Second, Statzner and Sagnes (2008) investigated the joint effects of Barbel, Gudgeon (*Gobio gobio*), and the spiny-cheek Crayfish (*Orconectes limosus*) and found that their net joint effects on sediment mobility were generally less than the sum of the impacts of the individual species. These findings emphasise the role of biotic factors in controlling geomorphic impact. Third, Pledger et al. (2014) found that foraging juvenile Barbel modified water-worked surface gravels, undoing stable imbricate structures and increasing microtopographic roughness. These changes coincided with an average increase in initial bedload flux and overall sediment yield of 60% and 82%, respectively, under entrainment flows. Collectively, results from these three studies suggest that benthic foraging can have a significant impact on fluvial sediment characteristics, thereby influencing sediment transport processes under laboratory conditions and justifying the need for further study to gain greater understanding of benthic foraging as a geomorphic activity.

Understanding the geomorphological importance of animals requires an understanding of how abiotic and biotic factors mediate zoogeomorphic impact (e.g., Fig. 7b in Johnson et al., 2011). With regard to foraging, Statzner et al. (2003b) and Statzner and Sagnes (2008) have shown that biotic controls (specifically between-species interactions and shoaling, respectively) are relevant in this regard. Many other potentially important factors (biotic or abiotic), however, could influence foraging behaviour and therefore geomorphic impact in rivers. Temperature (Lemons and Crawshaw, 1985; Nerici et al., 2012), predator presence (Fraser and Huntingford, 1986; Ibrahim and Huntingford, 1989), and shoal feeding (Pitcher and Parrish, 1993), for example, have been shown to significantly influence the nature, duration, and frequency of feeding; but their effect on foraging behaviour, and thence geomorphic impact, is poorly understood.

An additional, potentially important, factor is body size because large animals could have a greater impact and modify sediment composition differently relative to smaller specimens. Indeed, Moore (2006) proposed that the most effective ecosystem engineers are likely to be those that have greater body mass. This is supported by studies showing that (i) the geomorphic effects of spawning fish increase with the size of individuals (cf. Burner, 1951) and (ii) physiological and anatomical differences associated with fish size could explain differences in their geomorphic impact when spawning (cf. Barber et al., 2001). Another, potentially important, factor that might control geomorphic impact whilst foraging is feeding habit, which varies between species and reflects a multitude of biological, physiological, and behavioural differences and adaptations.

The effects of fish size and species on bed disturbance by benthic foraging fish and the consequent impacts on bedload transport under subsequent high flows are therefore the focus of this paper. An ex-situ flume experiment was undertaken with two components. To investigate the role of fish size, the foraging effects of four size classes of a single species, Barbel (4–5″, 5–6″, 6–8″ and 8–10″ in length), on bed material disturbance and subsequent transport were compared (component 1). To investigate the role of species, the foraging effects of like-sized Barbel and Chub, 8–10″ in length, on bed material disturbance and subsequent transport were compared (component 2). Barbel and Chub were chosen for comparison in component 2 because they are two common, benthic-feeding fish that occupy similar habitats but have different physiologies and specific feeding habits, as illustrated by Pledger et al. (2014; their Table IV), and therefore potentially different zoogeomorphic capabilities and impacts. Expectations are that larger fish will have a greater impact and that Barbel being a benthic foraging *specialist* will have a greater geomorphic impact than Chub, a renowned *opportunistic* forager. The specific aim of this experiment was to test the following hypotheses:

Hypotheses pertaining to component 1:

(1) Foraging Barbel alter the arrangement and organisation of gravel-bed substrates as measured by imbrication and microtopography, and this effect increases with fish size.
(2) Structural and compositional changes to the bed as a function of foraging by Barbel significantly increase (a) grain entrainment, (b) bedload flux, and (c) total transported mass during subsequent high flows. The magnitude of this effect increases with fish size.

Hypotheses pertaining to component 2:

(3) Foraging Barbel and Chub alter the arrangement and organisation of gravel-bed substrates as measured by imbrication and microtopography. Because of their preference for benthic foraging and unique physiology, the impact of Barbel is greater than that of Chub.
(4) Structural and compositional changes to the bed as a function of foraging by Barbel and Chub significantly increase (a) grain entrainment, (b) bedload flux and (c) total transported mass during subsequent high flows. Because of their preference for benthic foraging and unique physiology, the impact of Barbel is greater than that of Chub.

2. Methodology

2.1. Fish husbandry

The experiment utilised four size classes of Barbel and a single size class of Chub (Table 1) that were hatchery-raised and born of captivity-reared broodstock at Hampshire Carp Hatcheries, UK. Fish lengths in metres are provided in Table 1 for the reader but are presented hereafter in imperial units to be consistent with those supplied by the hatchery.

The protocol pertaining to fish husbandry was consistent with that described in Pledger et al. (2014, p. 1501), with two modifications. First, water in two 1000-l holding tanks was cooled and maintained at a constant temperature of 16.70 °C ± 0.003 (±1 standard deviation). Second, during experiments and the intervening periods between experimental runs, a Teco TR120 water cooler was permanently installed to cool the water in the flume storage tanks. Given that fish metabolism and the amount a fish is required to eat to sustain body mass is sensitive to temperature, limiting the effect of temperature during the experiment was appropriate.

Table 1
Mean total length and mass values (±SD) of fish, utilised during the experiment.

Species	Size (inch)	Age (years)	Mean total length (m)	Mean mass (kg)	Replicates
Barbel	4–5	2–2.5	0.124 ± 0.0006	0.014 ± 0	4
Barbel	5–6	2.5–3	0.135 ± 0.002	0.019 ± 0.001	16
Barbel	6–8	3–3.5	0.179 ± 0.004	0.044 ± 0.004	13
Barbel	8–10	3.5–4	0.233 ± 0.008	0.095 ± 0.008	15
Chub	8–10	3.5–4	0.233 ± 0.049	0.13 ± 0.008	12