Restoration on the Margins – the efficacy of using gravel augmentation to offset habitat loss in sediment-poor upland channels

Restauration des marges - efficacité des recharges en gravier pour compenser la perte d'habitat dans les chenaux d'altitude pauvres en sédiments

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RÉSUMÉ

Dans les cours d'eau d'altitude, la perte des habitats aquatiques pour la fraie et l'élevage des salmonidés est souvent compensée par une recharge en gravier, mais on en sait peu sur la dynamique du transfert de ces sédiments réinjectés et la réponse de l'habitat dans un tel substrat mixant granulométrie alluvial et fonds rocheux. Pour tenter de résoudre ces problèmes, la recharge en gravier dans la rivière Avon (Devon, UK) a été suivie en utilisant des plaques d'impact sismique, des particules équipées de RFID et une cartographie détaillée des lits pour caractériser la mobilité des particules, les distances de dispersion et les sites de sédimentation. Les résultats suggèrent que les particules sont fortement, et également mobiles, avec un mouvement du volume sédimentaire de la recharge corrélé de façon non linéaire à l'énergie d'écoulement. Les distances de déplacement médianes suggèrent un panache de dispersion à longue queue avec des facteurs de contrôles supplémentaires tels que la courbure du chenal, la présence de rocher et la puissance locale des écoulements. La cartographie indique la formation de patches de sédiments autour des rochers, de bois flottés, au niveau de zones abritées en bas de berges, mais également perchées en marge du chenal. Les résultats suggèrent que le succès de recharges en gravier pour améliorer l'habitat aquatique est nécessairement lié à la présence d'éléments grossiers créant une rugosité qui favorise la rétention des sédiments, limite leur transport mais permet aussi le développement de conditions de mobilité minimale.

ABSTRACT

In upland channels, loss of aquatic habitat for salmonid spawning and rearing is often countered using gravel augmentation, even though little is known about the dynamics of sediment transfer and habitat response in such steep, mixed alluvial-bedrock channel settings. Attempting to address these issues, gravel augmentation in the River Avon (Devon, UK) has been monitored using seismic impact plates, RFID-tagged particles and detailed channel bed mapping to establish the particle mobility, dispersal distances and settling locations relative to the flows received. Results suggest that particles are highly, and equally mobile, with volumetric movement non-linearly correlated to flow energy. Median travel distances suggest a long-tailed fan of dispersal with supplemental controls including channel curvature, boulder presence and stream power. Mapping indicates the formation of sediment patches around boulders or large wood and in sheltered river margins, but also perched above the low-flow channel. The results suggest that the success of gravel augmentation to improve aquatic habitat in supply-limited upland channels is inexorably bound up with the presence of large roughness elements that allow sediment retention to dominate over transport such that conditions of 'minimum mobility' exist.

KEYWORDS

Bedload transport, gravel augmentation, habitat loss, passive sensing, upland channels

1 INTRODUCTION

In upland channels, loss of aquatic habitat for salmonid spawning and rearing is often related to fragmented river networks, modified channels morphologies and channel beds depleted of alluvial sediment. Options for restoration include dam removal, which comprehensively reverses network fragmentation issues but is rarely feasible, and restoring channel form to provide ‘space for the river’, but this option is seldom practicable in narrow valleys. A third option, the addition of gravel to augment the alluvial sediment component of the channel bed to prompt recovery, is thus frequently practiced even though little is known about the dynamics of sediment transfer and habitat response in such steep, mixed alluvial-bedrock channel settings. Attempting to address these issues, gravel augmentation in the River Avon (Devon, UK) has been monitored using seismic impact plates, RFID-tagged particles and detailed channel bed mapping to establish the particle mobility, dispersal distances and settling locations relative to the flows received.

2 STUDY AREA

The Devon River Avon rises 460 m above sea level and flows approximately 40 km to the sea. Situated on the edge of a granite massif, the upper catchment produces naturally low rates of coarse sediment supply while mainstem flows are regulated by the 33-m high Avon Dam (built 1957). The focal study reach, situated 4 km below the dam, is characterized by a patchy matrix of coarse gravel and cobble deposits interspersed by a framework of large boulders and areas of exposed bedrock. The gradient of the focal reach is highly variable but averages 0.036 and the current channel is approximately 12 m-wide, having been subject to channel capacity contraction following building of the dam. Morphologically, the reach is most closely associated to the ‘cascade’ reach type, with the high relative roughness of the immobile boulder bed creating a chaotic pattern of energy expenditure: gravels and sands congregate in the stoss and lee of boulders and in the channel margins where they are often deposited above low flow elevations. Patchy sediment storage and mild imbrication of gravels and cobbles suggests a supply-limited reach in which transport thresholds are characteristically bi-modals. Limits to the availability and suitability of habitat for brown trout, sea trout and Atlantic salmon is assumed to link, at least in part, to the existence of the dam, leading to the initiation of periodic gravel augmentation in 2014.

3 METHODS AND RESULTS

Baseline sediment conditions were established using a high-resolution channel mapping protocol (as the canopy restricts remote survey) in combination with Wolman surface sediment characterization and baseflow velocity profiling to characterize habitat conditions in depositional areas. Native channel surface sediments were compared to those of the augmented gravel and sediment from upstream of the dam. Process ‘forcing’ was related to fifteen-minute flow elevations obtained from an agency-run stage gauge situated within the study reach – there is no rating curve for converting the flow elevations to discharge. Sediment dynamics were established using a combination of Radio Frequency Identification (RFID) tags and a seismic impact plate. The central 50 particles from a 100-200 sample of each sediment cohort were fitted with RFID tags ahead of Water Year (WY) 2015, and 200 of the augmented particles (only) were tagged for monitoring in WY2017. The study used 23mm Half-Duplex WMD Passive Integrated Transponder (PIT) tags attached to particles using dry curing epoxy-concrete and aligned with natural grooves in the sub-angular to angular granite particles to minimize hydrodynamic impact. Particle detection was achieved during low flow conditions using a hand-held reader in conjunction with a Trimble Geo7X Global Navigation Satellite System (GNSS) that allows for post-processing to improve positional accuracy. Searches were concentrated into a reach of approximately 200 m downstream of the point of augmentation. A ‘Benson type’ seismic impact plate mounted flush to the channel bed was used to establish the initiation, cessation and relative intensity of particle mobility, logging particle counts at 2.5-minute intervals. The plate was located approximately 10 m downstream of the augmentation location and positioned according field judgment to coincide with the track of greatest sediment transport - it was dislodged by a large flow event in November 2016 thus limiting mobility information during WY2017. A broader understanding of augmented sediment dispersion was achieved using periodic mapping of sediment over far greater distances, characterizing observed sediment (highly visible on the channel bed) into five size classes of deposition.

4 RESULTS

The native gravel surface sediment in the study reach had a median b-axis diameter (D_{50}) of 55 mm in 2014, with median diameters for the RFID tagged particles of 58 mm (native bed) and 55 mm (above dam sediments). The augmented material was, by design, finer, with a tagged sample D_{50} of 42 mm. By 2016, the native channel bed in the study reach had become finer (D_{50} = 50 mm) and the year's augmentation material had a D_{50} of 35 mm. Comparison of the larger daily means flows (0-20% flow exceedance) recorded at Didworthy stage gauge suggested that WY2015 possessed very few higher flows whereas WYs 2016 and 2017 were more 'average' in comparison. Despite the lack of truly high flows, the unconsolidated hummock of augmented materials was highly mobile with, in each year, a large proportion of the material mobilized by the first post-augmentation rainfall event emanating from the unregulated tributaries. RFID tag recovery rates in the focal reach was relatively low in each year, with 50% of tracers recovered in the first survey in WY2015 (four months after augmentation), and 53% in WY2017 (three months). Recovery rates were minimal in both cases after one year. The discovery of further tracers in an extended survey (180-410m downstream) in 2016 suggested that unrecovered tracers were likely transported beyond the focal reach rather than having been missed by the surveyors or subject to deep burial. Corroborating these results, the impact plate recorded an estimated 58% of augmented particles travelling across it during WY2015, and 40% of the finer augmentation material in just 2.5 months in WY2017, up until the plate was dislodged by a high flow event. As this result refers to a single impact plate, we should assume these statistics are a bare minimum. In WY2017, some particles had travelled up to 300 m in a 3-month period that included a two-year flood event. Evidence thus suggested that the augmented particles are highly mobile, confirming the supply-limited, bi-model transport character of a cascading reach type.

Consistent with the result above, in WY2015 there was almost no size-selectivity in particle transport distances with either size (range 30–90 mm) or mass (range 80–1000 g): the strongest result of 10% explained variance with size in the first re-survey in January 2015 fell to 3% the following summer. Comparisons of particles recovered per metre inversely with channel gradient and stream power fared little better (R^2 = 0.15 and 0.18, respectively). In conjunction with mapping surveys, it appears overall that travel distances (and thus retention) describe a long-tailed fan of dispersal from the point of origin with supplemental controls involving stream power but also the presence of large roughness elements (boulders, large wood), sheltered margins, and channel curvature (leading to lateral bars).

Analysis of event-based particle mobility during WY2015 (19 events) was highly convincing with a strong (R^2 = 0.77) and highly non-linear (power exponent of 3.95) relationship between total impacts recorded in individual events and 'peak stage over baseflow' as a metric of energy applied. The result was thus highly consistent with those found elsewhere indicating sediment transport reflects available energy. Further, outlying data points that recorded significantly more impacts than were expected occurred in the period immediately after augmentation, with the overpredictions occurring later in the year suggesting a volumetric waning of transport as the augmented material is 'exhausted', even during the dry WY of 2015. Of interest, a strong event-based mobility is not apparent (R^2 = 0.08) in the 8-events in the early part of WY2017 (*i.e.*, before the impact plate was dislodged). Other than the restricted period of the survey, these results may reflect the occurrence of a mobilizing event almost immediately after augmentation, allowing negligible 'sorting time', the impact of a finer augmented mass (D_{50} = 35 mm vs. 42 mm in WY2015) that is perhaps little affected by flow magnitude, or possibly that primary sediment track has moved relative to the impact plate that consequently records with a different efficiency than in WY2015.

5 PROSPECTS

The results to date appear to confirm that cascading river reaches are supply-limited, and have a bi-modal transport character wherein gravel particles are highly and equally mobile. Further though, the passive sensing techniques and high-resolution mapping are beginning to indicate empirically those factors, stream power, roughness elements and channel curvature, that combine with the intrinsic fan-like properties of coarse sediment dispersal, to result in patchy sediment deposition in steep, alluvial-bedrock channels. For gravel augmentation, the results indicate that in supply-limited upland channels, improvements to aquatic habitat are inexorably bound to the presence of features that allow sediment retention to dominate over transport and thus create reduced mobility conditions. Here, it seems that there is considerable short-term sediment loss from the focal augmentation reaches, and that deposits perched above the low-flow and in sheltered river margins may have limited short-term benefit to salmonid habitat, but such conclusions may change as the reach becomes increasingly 'gravel rich'.