A multi-proxy approach for assessing the downstream impact of dams on upland river systems ahead of gravel augmentation

Une approche multi-proxy pour évaluer l'impact des barrages sur les systèmes fluviaux de montagne dans une perspective de recharge sédimentaire

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RÉSUMÉ

Les opérations durables de recharge sédimentaire en aval de barrages nécessitent d'analyser les changements morphologiques et la dynamique des lits fluviaux afin de quantifier les altérations des habitats pour des espèces cibles. Les données historiques et les mesures en temps réel sont rares sur les petits systèmes fluviaux. Un cadre de recherche est proposé sur la rivière Haddeo (58 km²), combinant des observations de terrain, des métriques du déficit sédimentaire et des changements d'habitat, et une estimation des débits de mise en mouvement des particules et des volumes transportés à partir de simulations hydro-sédimentaires. L'analyse révèle une augmentation de la largeur du chenal post-barrage et une augmentation de la taille des sédiments sur le fond du lit, causant une réduction significative de la disponibilité des zones de frai pour le Saumon Atlantique. Les lâchers d'eau au barrage et la contribution d'un affluent favorisent la mobilité des sédiments grossiers et aggravent ces impacts. L'analyse hydro-sédimentaire indique une diminution des volumes d'alluvions transportées. Les volumes et calibres des sédiments nécessaires aux recharges sont estimés par tronçons. La robustesse de l'approche multi-proxy est confirmée en corroborant les résultats. Les secteurs de frai pourraient bénéficier d'une rugosité additionnelle du chenal apportée par la mise en place de bois et de blocs. Les simulations numériques permettent de tester des scénarios de recharge et sont utiles pour mettre en œuvre et évaluer les opérations, selon une gestion adaptative.

ABSTRACT

Sustainable approaches to gravel augmentation are critically dependent on analysis of changes to channel morphology and sediment dynamics to quantify the magnitude of habitat alteration for valued species. As historical data and direct monitoring are rare in small river systems, a framework is advanced for the upland River Haddeo (58 km^2) that combines field evidence, surveys, and metrics of sediment deficit and habitat changes with estimates of sediment transport competency and volume achieved using hydrological and sediment transport simulation. Comparisons of bankfull capacity indicate channel enlargement and measures of sediment deficit indicate a coarsening bed with significant reductions in spawning habitat availability for smaller Atlantic salmon. Tributary inflows and reservoir overtopping enable coarse bed sediment mobility, compounding the impact. Sediment transport analyses quantify the post-dam volumetric reduction in alluvium and permit reach-scale estimates of a feasible volume and calibre of sediment for augmentation. The framework seeks to achieve robustness through corroboration and indicates that, here, spawning habitats would benefit from additional channel roughness. Because the numerical simulations permit scenario testing, the approach is suitable for implementation and evaluation under an adaptive management framework.

KEYWORDS

Gravel augmentation, rehabilitation, multi-proxy framework, sediment transport, scenario testing

INTRODUCTION

Rehabilitation measures such as gravel augmentation attempt to offset the deleterious impacts of dams on downstream fluvial ecosystems. Impact severity is conditioned by the interplay between the lifecycle requirements of valued species and the magnitude of habitat alteration, thus rehabilitation is critically dependent on analysis of reach-scale changes to channel morphology and sediment supply and transport dynamics. As historical data and direct monitoring are rare in small river systems, surrogate approaches should use multiple lines of evidence to provide a robust interpretation of field conditions. Building on earlier studies, a multi-proxy framework is advanced combining field reconnaissance of channel conditions, surveys of morphological adjustment in relation to the prevailing and past hydrology, metrics of the extent of sediment deficit and the likely impact on spawning suitability, and estimates of the competency of flows to transport channel bed sediments and the volume of sediment transported under past, present and potential future scenarios.

The River Haddeo drains 58 km^2 on the edge of Exmoor National Park, Somerset, UK, before discharging into the River Exe. It was split into two near-equal parts by the construction of the 49-m water supply Wimbleball Dam in 1978. The 'lower' Haddeo possesses channel gradients ranging from about 0.0160–0.0060 as the river flows 6.5 km through a narrow valley before entering a more extensive floodplain near to its confluence with the Exe. A major unregulated tributary (20km^2) enters approximately 0.8 km downstream of the dam. Geology consists of slates and sandstones providing coarse bed sediments. There is no long-term record of flows for the lower river below the unregulated tributary confluence but area-based estimates of discharge pre- and post-dam are aided by gauging records measuring upstream inflows to the reservoir and records of flow releases and spills immediately below the dam. Little archival evidence exists of channel conditions prior to dam construction and canopy cover obscures channel bank edge details.

METHODS AND RESULTS

Reconnaissance surveys indicate a paucity of alluvial material and a morphological response presumably conditioned by a combination of shallow depths to bedrock, coarse sediments, reduced discharges and reduced sediment supply relative to transport capacity: the overall channel response is visually subtle but indicates some widening and limited incision. Hydrological analyses of peak flows indicate that the current Q1.5 is ~50–65% of pre-dam magnitude. Comparison to surveyed bankfull indicators confirms the erosional morphological response of the channel but indicates that impacts are specific according to three reach types (1) below the dam to the unregulated tributary confluence, (2) in the narrow valley mid-reaches, and (3) in the wider alluvial valley of the lower reaches. Morphological response appears to have been maximised in the mid-reaches where the bankfull channel can convey flows with a recurrence interval in excess of 40 years whereas the channel downstream can convey only ~Q2–Q4. Not surprisingly, Schmidt and Wilcock's (2008) metrics of dam impact indicate maximum sediment deficit in the reach below the dam whereas the ability for channel incision is limited throughout the river by coarse channel bed sediments. However, because the reservoir holds only 75% of average annual runoff, dam spills are frequent in wet years and shear stress-based competency estimates based on peak discharges indicate that current median bed sediments (D50 = 57–68 mm) are mobile under even moderate contemporary flood events (*e.g.*, Q1.5). This corroborates field evidence that bed sediments have coarsened since dam closure (D50 sediment above the dam = 48 mm) and suggests that further bed coarsening should be expected. Surface-based sediment transport equations using flow duration statistics (BAGS software: Pitlick *et al*., 2009) suggest that the potential volume of sediment transported prior to dam closure was some 5–8–times higher than present day conditions and that, below the dam and in the lowest reaches, the volumetric potential for transport is negligible under current conditions suggesting a largely static bed armour except during peak flows of moderate floods and larger. Confirming the implied impact of these changes for salmonids, the useable spawning area of the channel bed for small spawning Atlantic salmon may have been reduced from approximately 75% to 50% since dam closure using Riebe *et al.'s* (2014) metrics.

PROSPECT AND IMPLICATIONS

The use of multiple methods to simulate the impact of the Wimbleball Dam on the lower River Haddeo provides a corroboratory account of progressive downstream channel impacts that may have significantly affected habitat for native salmonids. Further, the sediment transport equations also provide the facility for scenario testing of augmentation sediment mixtures relative to (1) salmonid spawning preferences, (2) the estimated volumetric loss of sediment since dam closure, and (3) economically and logistically feasible volumes of annual augmentation (50–100 t a^{-1}). Sensitivity tests indicated that mixtures with a D50 of 48, 36 and 29 mm are the most feasible for augmentation below the dam, in mid-valley and the lower reaches, respectively, but that large wood and boulder emplacement is also required below the dam and in mid-valley to roughen the channel and assist in retaining the augmented material. The approach thus provides a framework for gravel augmentation and habitat modification that can be implemented and evaluated under an adaptive management framework and that exploits the scientific notion of dams as 'natural experiments' in fluvial system manipulation. Empirically, the availability of reach-differentiated hydrological information is paramount to permit comparative analyses and is probably the element most difficult to achieve with accuracy in small upland channel settings. Analytically, the approach relies on the relevance of the applied metrics but should achieve at least a relative comparability between reaches.

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