A trajectory-based BACI framework to assess the effects of gravel augmentation on thermal functions in gravel-bed rivers

Un cadre conceptuel 'BACI' basé sur la trajectoire pour évaluer les effets de la recharge sédimentaire sur les fonctions thermiques des rivières à galets

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RÉSUMÉ

La recharge sédimentaire est devenue une pratique courante pour pallier au déclin des apports grossiers depuis l'amont sur les rivières à galets. En revanche, les aspects fonctionnels sont souvent ignorés dans des suivis post-restauration. Bien que la température soit un paramètre fondamental pour la santé générale des hydrosystèmes, peu d'études ont testé dans quelle mesure la recharge sédimentaire peut participer à la restauration de fonctions thermiques. En utilisant l'infrarouge thermique aéroporté (IRT-a), ce travail explore ces questions en suivant 3 projets de recharge sédimentaire en France. Pour compenser le manque de données pré-restauration, nous avons utilisé des indicateurs hydromorphologiques au sein d'une approche 'Avant-Après-Contrôle-Traitement' (BACI) basée sur la trajectoire des systèmes pour évaluer le succès de ces actions de restauration sur les fonctions thermiques. Ce cadre conceptuel, qui combine l'évaluation de la trajectoire géomorphologique avec une stratégie 'Contrôle-Traitement' sur les images IRT-a, a permis de montrer que la restauration des formes n'était pas suffisant pour restaurer les processus thermiques. Néanmoins, les indices hydromorphologiques ont permis de d'évaluer l'évolution sur le long terme des échanges nappe-rivière. Les résultats démontrent les bénéfices de l'approche proposée pour évaluer les conditions actuelles, comprendre les dynamiques passées et ajuster le cadre au sein duquel la restauration peut être évaluée de manière objective.

ABSTRACT

Gravel augmentation has become common practice to mitigate the effects of decline in upstream sediment supply in gravel-bed rivers. However, the functional aspects of river systems are often left out of rehabilitation monitoring programmes. Despite temperature being a fundamental parameter determining the general health of rivers, a limited number of studies have tested whether gravel augmentation can aid restoring thermal functions. Using airborne thermal infrared (TIR) imagery, this paper explores potential feedbacks through the monitoring of gravel augmentation on 3 rivers in France. To overcome the lack of pre-rehabilitation data, we used hydro-morphological indicators within a trajectory-based Before-After-Control-Impact (BACI) framework to assess the success of rehabilitation on thermal functions. This design, combining long-term geomorphic evolution with TIR-based CI strategy, indicated that restoring forms was not sufficient to restore thermal functions. Nonetheless, hydromorphological indices can be used to estimate long-term evolution of groundwater-surface water interactions. We emphasise the benefits of trajectory-based BACI assessment to identify current conditions, understand the past evolution (trajectory) of the system to define the framework within which rehabilitation can objectively be assessed.

KEYWORDS

BACI, gravel augmentation, river rehabilitation, TIR remote sensing, water temperature.

1 INTRODUCTION

Gravel augmentation has become a widespread and common practice to mitigate the effects of decline in upstream sediment supply and usually aims at restoring habitat for aquatic organisms and notably fish species. As such, the success of such “restoration” initiative is usually judged primarily on its ‘ecological’ success but is likely to miss on other fundamental functions. Hydromorphology is known to influence the distribution of thermal habitats at multiple scales, so gravel augmentation may act on their distribution. But since few of these initiatives are primarily designed to restore or improve functions, little is known about whether physical rehabilitation actually translates into such recovery. With temperature being arguably one of the most important parameters controlling habitat conditions and the general health of rivers, this study focusses on the assessment of the effects of gravel augmentation on river functions through the eye of the spatial distribution of water temperature. Focussed on three gravel-bed rivers from south-eastern France, the study is based on the three following hypotheses: (1) rehabilitation, which affects rivers’ morphology, is reflected in hydrological processes and notably thermal functions, (2) some hydromorphological indices can be used to assess thermal functions over longer periods (i.e. trajectory framework), and (3) some lessons can be learned from both a methodological and technical perspectives to stress the need for wider monitoring of temperature and related functions in river rehabilitation schemes. The objectives of the work are thus: (1) to design a specific framework to assess rehabilitation success considering dynamic and relative space-time references, and (2) to answer whether gravel augmentation has improved the thermal regime of the three studied river reaches (i.e. thermal gradients, cold-water patch distribution and temperature behaviour comparable to control), while (3) building on the drawbacks of these experiences to advocate the need for designing a priori comprehensive monitoring programme.

2 MATERIAL & METHODS

2.1 Study sites

The rivers analysed in this study are the Ouvèze, Buëch and Drac Rivers, all located in SE France and part of the Rhône River catchment. They were historically braided rivers and represent different contexts and a gradient of gravel augmentation scenarios, from local mitigation (Ouvèze) to targeted gravel augmentation downstream from a dam (Buëch) and large-scale rehabilitation aimed at recreating braiding patterns (Drac). From a geomorphic perspective, all three actions were considered rather successful with the re-creation for geomorphic features (Ouvèze, Drac) and/or some bedload transport (Buëch) (see notably Brousse et al., 2021).

2.2 Assessment of thermal functions using thermal infrared imaging

Aerial images were collected using an ultralight trike equipped with thermal camera (standard 30 mm) lens, and a DSLR camera (35 mm lens) to collect photographs. The surveys were carried out in mid-afternoon (around 15:00 CET) on warm and sunny summer days with rather low flows, i.e. when water temperature is at its highest and thermal contrasts are the strongest. Images were mosaicked using Structure-from-Motion photogrammetry and exported at a ground resolution of 30 or 40 cm·pixel^{-1} to ensure orthogonality with the RGB orthophotos (10 cm·pixel^{-1}). Longitudinal temperature profiles were extracted and cold-water habitats were identified, characterised and classified based on their origin and location within the floodplain.

2.3 Monitoring design to assess rehabilitation success

Following the work of Dufour and Piégay (2009) we proposed to implement a Before-After-Control-Impact (BACI) approach within a broader trajectory-based framework, i.e. re-placing today’s results along the path of changes structured by catchment-scale and human-induced alterations, and thus relying on the multi-scalar juxtaposition of two evaluation strategies to estimate the potential thermal effects of gravel augmentation. Archived aerial photograph were used to determine the geomorphic properties of both selected ‘control’ and ‘impact’ sections (trajectory-based BACI framework), and to explore evidence of thermal interactions between surficial flows and groundwater based on hydromorphological indicators. This was combined with a more classical CI strategy on reaches where a control site is chosen, informed with the observations made at the trajectory-based BACI stage. Hydromorphological indicators chosen were ‘total braiding index’ (Pttw), the ratio of non-flowing vs. total length of channels (NFI) and active width (AW), which were found in the literature to reflect a potentially higher number of secondary channels or lateral cold channels (Pttw), non-superficial flows (NFI) or bedload activity (AW) which, if limited, may cause disconnection of the groundwater table.

3 KEY RESULTS & DISCUSSION

3.1 Restoring forms does not mean restoring thermal functions

The TIR surveys were carried out between 2 and 8 years post-rehabilitation, and although the results were different for each project, none appeared to have positively affected the temperature regime within rehabilitated sections. When sediment deficit is localised, e.g. below a dam (Buëch) or caused by local factors such as gravel mining (Drac), gravel augmentation can restore some fluvial forms, as observed in changes in AW and Pttw. But when sediment starvation is systemic (e.g. Ouvèze River), the effects are minor. NFI score was found to be the index that best represents cold-water patches characteristics. A theoretical threshold of NFI > 0.2 was observed in this study (considering the limitations due to differences in hydrological conditions), threshold above which sit all control sections and which is associated with higher patch density and diversity. AW and Pttw failed to differentiate between control and impact sections; they are useful indices to capture changes in forms, but not to identify temperature-related hydrological patterns.

3.2 The advantages of a trajectory-based BACI strategy

No 'unaltered' section was found in the Ouvèze River because the entire river suffers from sediment starvation. The trajectory of the system shows that the rehabilitated section today actually resembles its upstream neighbouring section, chosen as control, which was large and braided in the past but is now narrow with closed canopy; it responded to decreased mobility by allowing vegetation to colonise, limiting mobility of gravel bars (and associated functional properties) but providing shade capable of preventing warming. This example illustrates the critical need, when evaluating the success of rehabilitation, to consider a geographical reference (i.e. 'control' state), a historical reference (i.e. 'before' state), as well as a series of states to assess the trajectory of change through time. Sometimes, control section upstream from the source of alteration can be found and downstream reach is chosen instead (i.e. Buëch River). Data collected from historical photographs have confirmed that the dam only moderately affected this lower reach, supporting its selection as a control. On other occasions, the obvious choice of a control site may be questioned when observed as part of a longer-term trajectory assessment. The widening of the Drac river led to the creation of a highly braided system, which resembles today's conditions in the control reach (Pttw >4.0) but can be considered as artificial when looking at the history of the system (highest Pttw was 2.9, 1961). Trajectory is then crucial to define suitable rehabilitation objectives.

3.3 The usefulness of using TIR as a diagnostic tool

TIR offers the possibility to rapidly map surface temperature with a high resolution and over increasingly large scales, making it useful to assess the thermal response of rivers to rehabilitation. Airborne TIR is often combined with optical imagery, offering measurement of the key parameter of interest (i.e. temperature) as well as data for a precise analysis of the river geomorphology and its riverscape organisation.

4 CONCLUSIONS

Comparison of control and impact reaches has revealed that gravel augmentation has failed to significantly improve the thermal regime of rehabilitated sections in the rivers reported here. The absence or slow pace of recovery of biota observed in many rehabilitation projects, despite the return of physical habitats, can sometimes be explained by the lack of functional properties of such habitats, e.g. non-removal of pollutants or absence of thermal habitats. In other cases, the short-lived benefits of rehabilitation measures can be understood, and perhaps anticipated, by looking at the long-term trajectory of the system and the limited effects in time and space that can be expected from one-shot gravel augmentation. In gravel-bed rivers, perhaps more than others, the shape and characteristics of these rivers are intrinsically driven by processes and so process-based rehabilitation should be advocated.

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