Hydropeaking effects on habitat dynamics at patch-scale: implications for aquatic invertebrates

Impacts des éclusées sur les dynamiques des micro-habitats : implications pour les invertébrés aquatiques

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RÉSUMÉ

Les éclusées, caractérisées par des fluctuations abruptes du débit à l'échelle sub-journalière, perturbent les écosystèmes aquatiques en provoquant des changements rapides dans les conditions des habitats. Les invertébrés aquatiques sont particulièrement sensibles aux modifications de la dynamique et de la persistance des habitats. Ici, nous nous concentrons sur les perturbations opérant à l'échelle des micro-habitats (taille <1m). Nous avons d'abord identifié cinq impacts principaux des éclusées affectant les micro-habitats des invertébrés : i) l'augmentation des contraintes hydrauliques ; ii) la réduction du mouillage persistant ; iii) l'altération de la dynamique sédimentaire ; iv) la diminution de la rétention de matière organique ; et v) l'intensification des fluctuations de température. Pour démontrer que les impacts des éclusées varient à l'échelle des micro-habitats, nous avons testé, à l'aide d'un chenal expérimental portatif, comment les augmentations des contraintes hydrauliques influencent la dérive des invertébrés. Nos résultats montrent que les habitats à courant lent (< 0,5 m/s) présentent des taux de dérive plus élevés que ceux à courant rapide (> 0,5 m/s). Enfin, nous avons évalué le potentiel de mesures morphologiques ponctuelles, telles que les blocs/pierres empilés, le bois mort et la création d'anses, pour atténuer les impacts des éclusées. Ces résultats soulignent l'importance des processus à l'échelle des micro-habitats dans la modulation des impacts des éclusées. Ils mettent également en évidence la nécessité d'une approche de gestion des habitats à l'échelle des micro-habitats, permettant une prise en compte plus explicite de la distribution spatiale des caractéristiques et dynamiques de chaque habitat.

ABSTRACT

Hydropeaking, characterized by abrupt and sub-daily flow fluctuations, disrupts river ecosystems by causing rapid shifts in habitat conditions. Aquatic invertebrates are particularly sensitive to such changes in habitat dynamics. Here we focus on disturbance occurring at the scale of individual habitat patches. We first review five key impacts of hydropeaking disturbance affecting invertebrate habitats at the patch scale (size <1m): i) increases in hydraulic forces; ii) reduction in persistent wetting; iii) alteration of the sediment dynamics; iv) reduction of the organic matter retention; and v) increase in temperature fluctuations. To demonstrate that impacts of hydropeaking vary at the patch scale, we tested with a portable flume how increases in hydraulic forces affect patch-specific invertebrate drift. We demonstrate that habitats with slow current experience higher invertebrate drift rates compared to habitats with fast current. Finally, we evaluate the potential of small-scale structural-morphological measures, such as boulder clusters, deadwood accumulations, and lateral shelters, to mitigate hydropeaking impacts. Our findings underscore the critical role of patch-scale processes in modulating hydropeaking impacts on invertebrate communities. They also underscore the need for a patch-scale management approach that allows for a more spatially explicit consideration of the habitat characteristics and their associated dynamics.

KEYWORDS

Biodiversity, flow alteration, habitat management, instream measures, invertebrate drift

Biodiversité, modifications du régime hydrologique, gestion d'habitat, aménagement hydraulique, dérive des invertébrés

1 IMPACTS OF HYDROPEAKING ON AQUATIC INVERTEBRATES

Human activities, particularly flow regulation, significantly alter natural river flows, disrupting ecosystem functioning and biodiversity. Hydropeaking, caused by intermittent hydropower generation, introduces artificial sub-daily flow fluctuations with frequencies exceeding natural variability. These abrupt fluctuations cause rapid shifts in habitat conditions and increase overall habitat dynamics (Bätz et al. 2023, 2024). Aquatic invertebrates are particularly sensitive to increased habitat dynamics, as their habitats are impacted by a combination of direct and indirect impacts operating primarily at the patch scale (Figure 1). Direct impacts include frequent wetting and drying of shallow habitats, leading to the desiccation of eggs and larvae (stranding), and increased hydraulic forces, which cause the involuntary dislodgment of individuals (drift). Indirect impacts involve altered sediment dynamics (e.g., colmation, erosion of gravel) that degrade habitat quality, flushing of organic materials that reduces food availability and habitat structures, and temperature fluctuations that impair egg development. Together, these impacts degrade habitat quality and, due to the frequent recurrence of hydropeaking events, lead to cumulative impacts that threaten invertebrate biodiversity.

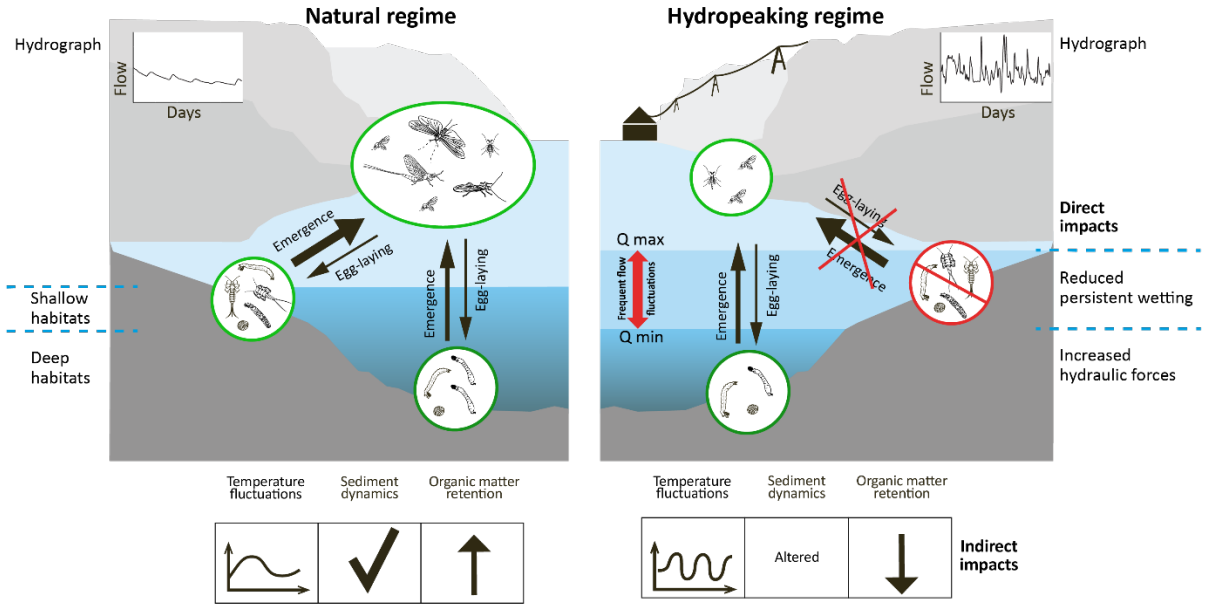


Figure 1: Direct and indirect impacts from hydropeaking on invertebrate habitats at the patch-scale (figure adapted from Friese et al., 2022).

2 QUANTIFYING PATCH-SCALE SPECIFIC IMPACTS

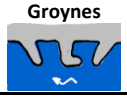
By deploying a portable flume, we simulated increases in hydraulic forces as they occur during hydropeaking on selected patches within a river reach hosting a macroinvertebrate community that is unimpacted by hydropeaking (Friese et al. 2024). The patches were characterized by either slow current (< 0.5 m/s) or fast current (> 0.5 m/s). The results show that flow fluctuations significantly trigger invertebrate drift at the patch scale, with impacts varying based on habitat type and its associated invertebrate community. Current velocity emerged as a key driver of drift in habitats with slow current. In contrast, in habitats with fast current, the velocity ratio between base and peak flow was more influential. Furthermore, the velocity ratio also shaped drift composition in habitats with slow current. These findings highlight the habitat-specific nature of hydropeaking impacts, underscoring the need for patch-scale management strategies tailored to habitat-specific hydraulic and ecological conditions to mitigate hydropeaking effects effectively.

3 STRUCTURAL-MORPHOLOGICAL MITIGATION MEASURES

Small-scale structural-morphological measures, such as engineered boulder clusters, groynes, woody debris and

lateral shelters, have the potential to mitigate hydropeaking impacts on patch-scale invertebrate habitats (Table 1; Friese et al., 2022). However, the feasibility and long-term functionality of these measures depend on interactions between large-scale processes (e.g., sediment regime) and local dynamics. Sediment deficits can erode valuable habitat, while excess fine sediment may clog the measures. To be effective, the measures must be adapted to the specific habitat requirements of the (expected) invertebrate community. In addition, invertebrate dispersal capabilities may be a limiting factor, restricting natural recolonization. Complementary, operational measures, such as seasonally adjusted flows, can address some limitations of these measures. Despite their potential, studies assessing the long-term impacts of structural-morphological measures at both small and larger scales remain scarce. Further research is needed to integrate structural-morphological measures into hydropeaking mitigation to enhance invertebrate habitat resilience.

Table 1: Examples of small-scale structural-morphological measures and their potential to counteract the five key impacts (see Figure 1) of hydropeaking on invertebrate habitats at patch scale. The blue intensity represents the expected effectiveness (table adapted from Friese et al., 2022).

In-stream measures	Reduce hydraulic forces	Increase persistent wetting	Reduce temperature fluctuations	Promote natural sediment dynamics	Increase organic matter retention
Boulder cluster 	Local reduction	No effect	No effect	Increased sediment sorting	Local retention
Groynes 	Local reduction	Possible dewatering	Possible (depending on size and design)	Increased sediment sorting, possible decolmation	Possible (depending on size and design)
Deadwood 	Local reduction	No effect	No effect	Increased sediment sorting, possible decolmation	Retention and habitat (depending on the wood type)
Lateral shelter 	Local reduction	Possible dewatering	Possible (depending on size and design)	Increased sediment sorting, possible colmation	Possible (depending on size and design)

4 CONCLUSION

Our findings underscore the critical role of patch-scale processes in modulating the impacts of hydropeaking on aquatic invertebrates. These impacts vary at patch scale, depending on the habitat type and associated invertebrate communities. For instance, habitats with slow current (< 0.5 m/s) experience higher drift rates compared to habitats with fast current (> 0.5 m/s). Small-scale structural-morphological measures can help mitigate the impacts of hydropeaking. However, to do so, these measures need to be adapted to the specific requirements of the invertebrate species expected within each habitat type. Adopting a patch-scale management approach would allow a spatially more explicit view of the impacts of hydropeaking on aquatic invertebrates, enabling a more effective and targeted management through the consideration of specific habitat characteristics.

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