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The need for river management and stream restoration practices to integrate hydrogeomorphology

Pascale M. Biron
Department of Geography, Planning and Environment, Concordia University

Thomas Buffin-Bélanger
Département de biologie, chimie et géographie, Université du Québec à Rimouski

Simon Massé
Département de biologie, chimie et géographie, Université du Québec à Rimouski

Key Messages

- Fish habitat restoration needs to consider hydrogeomorphic concepts, which is not always the case as several misconceptions exist in river restoration guidelines.
- There is a major gap in the transfer of knowledge between academics and decision makers involved in stream restoration for fish habitat in Quebec.
- Adopting a freedom space for river management approach, where possible, would be a wise and much-needed change in stream restoration for fish habitat.

There is growing support amongst scientists worldwide about the need for a shift in river management approaches to include hydrogeomorphic processes. However, the degree to which these concepts are transferred to governmental agencies and practitioners varies widely. In Quebec, for example, many stream restoration projects are based on the (incorrect) assumption that river mobility and its inevitable consequences (bank erosion of meanders, presence of woody debris in the channel) are problematic for salmonids. This paper presents examples drawn from current guidelines on stream restoration for fish habitat in Quebec to demonstrate the need to improve the knowledge exchange among scientists and decision makers about the positive impact of river mobility and large wood dynamics on biodiversity. Our observations reveal that existing guidelines for stream restoration in Quebec need to be revised to better integrate hydrogeomorphic concepts and to no longer assume that maintaining rivers in a static state is beneficial for fish. Adopting the "freedom space for rivers" approach would likely result in improved habitat as it combines natural processes related to mobility, flooding, and riparian wetland connectivity to determine the minimal space around rivers where development should not be allowed, thus allowing river processes to be restored.

Keywords: river management, freedom space, hydrogeomorphology, fish habitat, beaver dams

La nécessité d'intégrer l'hydrogéomorphologie pour la gestion des rivières et les pratiques de restauration des cours d'eau

Il existe un consensus croissant parmi les scientifiques du monde entier qu'il est nécessaire de changer les approches de gestion des rivières pour inclure les processus hydrogéomorphologiques. Cependant, la mesure

Correspondence to / Adresse de correspondance: Pascale M. Biron, Department of Geography, Planning and Environment, Concordia University, 1455 de Maisonneuve Blvd. W., Montreal, QC H3G 1M8. Email/Courriel: pascale.biron@concordia.ca

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dans laquelle ces concepts sont transférés aux agences et praticiens gouvernementaux varie considérablement. Au Québec par exemple, plusieurs projets de restauration des cours d'eau sont basés sur l'hypothèse (incorrecte) que la mobilité des rivières et leurs conséquences inévitables (érosion de berge des méandres, présence de débris ligneux dans le chenal) sont problématiques pour les salmonidés. Cet article présente des exemples tirés des lignes directrices actuelles sur la restauration de l'habitat du poisson au Québec pour démontrer la nécessité d'améliorer le transfert de connaissances entre scientifiques et décideurs sur l'impact positif de la mobilité des rivières et de la dynamique des bois morts sur la biodiversité. Nos observations révèlent que les lignes directrices existantes pour la restauration des cours d'eau au Québec doivent être révisées afin de mieux intégrer les concepts hydrogéomorphologiques et de ne plus supposer que le maintien des rivières dans un état statique soit bénéfique pour les poissons. Adopter l'approche de gestion par « espace de liberté des cours d'eau » entraînerait probablement une amélioration de l'habitat, car elle associe des processus naturels liés à la mobilité, aux inondations et à la connectivité des milieux humides riverains pour déterminer l'espace minimal autour des rivières où le développement ne devrait pas être autorisé, permettant ainsi de restaurer les processus fluviaux.

Mots clés : gestion des rivières, espace de liberté, hydrogéomorphologie, habitat de poissons, barrages de castors

Introduction

Traditional river management has relied on hydraulic experts trained to maintain or constrain natural river processes within a limited space (Piégay et al. 2005; Kondolf 2011; Roni et al. 2014). Since the early 1990s, there is growing support amongst scientists for a paradigm shift in river management approaches to include more natural processes (Beechie et al. 2010; Kline and Cahoon 2010) and to embrace collaborative practices (Medema et al. 2015). However, the degree to which these concepts are transferred to governmental agencies and practitioners varies widely.

In river restoration, the contrasting perspectives of academic experts versus practitioners and of engineers versus biologists or geomorphologists have often led to gaps between science and policy or management (Adams et al. 2004; Lave 2012; Bracken and Oughton 2013). Although there is an increasing expectation that policymakers should be using the best available evidence from research when making decisions (Campbell et al. 2011; Bracken and Oughton 2013), this viewpoint sheds light on the lack of scientific evidence in some governmental fish habitat guidelines.

Including more natural processes in river management and restoration requires letting rivers flow free, that is, freeing up areas near streams when possible to allow for natural processes such as floodplain inundation and bank erosion. This approach is now promoted in several countries-particularly in Europe due to the *EU Water Framework Directive* and the *EU Floods Directive* (Piégay et al. 2005; Ollero 2010; Verkerk and Van Buuren 2013), but also in the state of Vermont (Kline and Cahoon 2010) and in the province of Ontario with the meander belt width (Parish Geomorphic Ltd. 2004). Providing more space for fluvial processes is seen as a means to reduce flood and bank erosion hazards, but also to provide better aquatic habitats (Beechie et al. 2010; Hauer et al. 2016).

In the province of Quebec, the current legislation is based on a very narrow protected riparian zone of 3 m in agricultural zones, which can widen up to 15 m in some non-agricultural areas with steep channel banks. The Regional County Municipalities have the responsibility to carry out the maintenance of waterways which includes bank stabilization works and the removal of obstructions like sediment accumulations and in-stream large wood (LW) that cause, or are perceived to cause, an imminent danger to infrastructure and populations.

Recently, an alternative management approach that relies on a better consideration of hydrogeomorphic processes was proposed in Quebec (Biron et al. 2014; Buffin-Bélanger et al. 2015). This approach, called "freedom space for rivers" (FSR) following the French expression "espace de liberté," relies on a delineation method that combines two levels of mobility space and three levels of flood space with riparian wetlands to determine two main levels of freedom space—minimal and functional—with a third (rare) level representing very small zones where exceptional floods can occur, with low mobility (Biron et al. 2014; Figure 1). Within the minimal freedom space, stream maintenance operations such as the removal of LW or destruction of beaver dams should be avoided, unless there is a serious risk to infrastructure or populations.

Although hydrogeomorphic concepts are now better understood by decision makers involved with river management and policies in Quebec, there seems to be a major gap in the transfer of this knowledge in stream restoration projects for fish habitat, which are often led by watershed agencies. This viewpoint highlights several misconceptions in current guidelines, which lack key fundamental fluvial geomorphology concepts about the role of river dynamics and its benefits for fish. This is particularly the case with regard to the presence of LW in river channels and problems of implementing fixed in-stream structures within a dynamic alluvial channel. This viewpoint argues that long-term objectives of fish restoration projects would be more efficiently reached by the implementation of river management frameworks that promote a holistic and science-based knowledge of rivers. It also attempts to situate the lack of knowledge transfer in fish habitat restoration in Quebec with regard to the local context, including the very limited expertise in hydrogeomorphology within ministries and local environmental agencies.

Integrating natural processes in stream restoration for fish habitat

The desirable attributes of bank erosion and overall river mobility in floodplain habitat diversity are increasingly recognized (Florsheim et al. 2008; Kondolf 2011; Choné and Biron 2016). Channel migration creates channel complexity—for example, deep pools near the outside banks of meanders, or undercut banks providing cover habitat for large fish and thermal refugia during hot weather (Kondolf 2011). Active migration and floodplain lateral connection also result in an abundance of LW in the channel (Hickin 1984). LW has always played a central role in river dynamics and is known to improve habitat quality by creating pools and providing cover, particularly for salmonid fishes (Whiteway et al. 2010; Roni et al. 2014). In addition, wood in streams helps trap sediments, increase

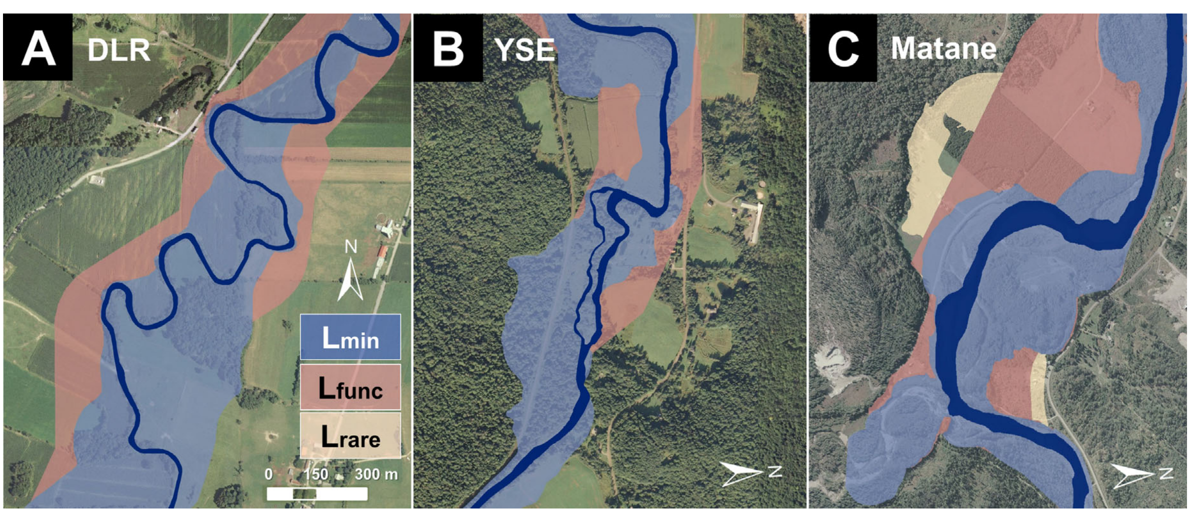

Figure 1
Examples of freedom space maps for selected reaches of A) de la Roche (DLR), B) Yamaska Sud-Est (YSE), and C) Matane rivers, all located in Quebec. The blue, brown, and beige zones correspond to the minimum, functional, and rare freedom space, respectively.

nutrient retention (Opperman et al. 2006; Roni et al. 2014), and increase channel roughness, resulting in increased bed and bank stability (Davidson and Eaton 2013).

There are several examples of fish restoration projects in various countries which have incorporated these scientific concepts related to vegetation and river dynamics. For example, the Staffordshire Wildlife Trust in the United Kingdom (UK) recognizes that the presence of LW provides a low-cost form of stream restoration and acts as a flood defence (Mott 2010). In the United States (US), habitat improvement projects that add wood to streams are ubiquitous (e.g., in the Columbia River Basin alone, there have been more than 2,000 projects since 1980), and the National Oceanic and Atmospheric Administration Fisheries recommends using wood as an effective restoration measure for fish (Milstein and Roni 2015). However, several misconceptions remain about the role of LW in rivers, leading to removal of wood from streams in error (Opperman et al. 2006). For example, many people see wood as a barrier to fish migration, and believe that pulling out wood actually facilitates migration.

This misconception also includes beaver dams, which are sometimes removed as a "restoration" measure (e.g., in Northern Wisconsin; Randolph 2011), despite overwhelming evidence of their positive impacts on fish habitat and fish diversity (Kemp et al. 2012; Smith and Mather 2013; Bouwes et al. 2016). The misconceptions about beaver dams impeding the movement of fish, and salmonids in particular, have been dismissed by scientific evidence. For example, the meta-analysis of Kemp et al. (2012) reveals that the majority (78%) of studies mentioning the potential barrier effect of beaver dams are speculative. Indeed, Lokteff et al. (2013, 1124) conclude: "Our results refute the largely speculative concerns about beaver dams acting as migration barriers." Since beavers and salmonids have coexisted without human intervention in far greater numbers than occur today—the beaver population in North America prior to the European's arrival was an estimated 60 to 400 million (Naiman et al. 1988)—it is difficult to understand why we should worry about this coexistence today (Bouwes et al. 2016).

The negative impression about LW and beaver dams seems more present in Canadian non-governmental organizations (NGOs) and ministries than in other countries. For example, in New Brunswick, the Miramichi Salmon Association indicates on their website that each fall, it "increases the spawning habitat available to adult salmon by removing beaver dams on tributary streams" (MSA n.d.). It further states that "beaver dams can impede the upstream progress of adult salmon and can prevent them from reaching headwater spawning areas, especially in years of low flow conditions" (MSA n.d.). These statements are in contrast with the scientific literature and with those of several American wildlife services—for example, "Along the West Coast of North America, interest in protecting beaver-modified habitat is growing because of the habitat's potential to benefit anadromous fish populations" (Pollock et al. 2017, 18).

Environmental groups often have very limited resources to keep up with the scientific literature on fish diversity, rivers, and wood dynamics, so perhaps it is not surprising that the roles of LW and beaver dams are not always well understood. However, it is more worrying to see that guidelines emanating from provincial or federal ministries also promote restoration approaches based on misperceptions of rivers as static entities. For example, the Mont-Joli (Quebec) regional branch of Fisheries and Oceans Canada (DFO) has published recommendations for brook trout habitat restoration, in the form of a *Canadian Technical Report of Fisheries and Aquatic Sciences* (Fleury and Boula 2012). According to the DFO, this series of technical reports contains scientific and technical information that contributes to existing knowledge that is not normally appropriate for primary literature; they are directed primarily towards a worldwide audience and have an international distribution. The Mont-Joli report, which contains no scientific references, states that: "Stream-cleaning operations to improve brook trout habitat is a widespread activity in Quebec. It consists primarily in removing part of riparian vegetation, woody debris, log jams or old beaver dams which contribute to reducing the overall quality of brook trout habitat" (Fleury and Boula 2012, 22). Figure 2 illustrates how the DFO guidelines on fish habitat restoration differ from another scientific report published the same year, the *Stream Habitat Restoration Guidelines* outlining aquatic habitat guidelines in Washington state (Cramer 2012). DFO guidelines also promote construction of log or

Figure 2
Stream restoration examples for fish habitat improvement: A) stream cleaning recommended in DFO guidelines (Fleury and Boula 2012); B) adding LW to create a log jam following Washington state aquatic habitat guidelines program (Cramer 2012).

rock weirs perpendicular to the banks to create pools needed for trout. Two DFO aquatic habitat rehabilitation guides—from the Gulf region (Melanson et al. 2006) and the Central and Arctic region (Kavanagh and Hoggarth 2015)—promote bank stabilization, removal of beaver dams, and construction of instream structures such as deflectors or rock cross vanes (e.g., Kavanagh and Hoggarth 2015, Table 2). However, doubts about the benefits of traditional in-stream structures for channel restoration for fish communities have been raised for many years, and the ability of these structures to increase fish populations should not be presumed (Thompson 2006). Also, such fixed structures assume channels remain immobile, and are incompatible with more recent concepts on the need to restore river processes (Beechie et al. 2010). Furthermore, the various failure mechanisms common to engineered structures, such as weirs, have led many designers away from this technique since the early 1990s (Roni et al. 2014), as they can become inappropriate or even harmful to habitat as conditions change (Cramer 2012; Salant et al. 2013).

The Fondation de la Faune du Québec (FFQ), which provides funding for several stream restoration projects for fish habitat in Quebec, follows the DFO recommendations and indicates that funding for restoration projects will be attributed "based on expected results, for example number of metres of stream cleaned [removing vegetation], number of dismantled beaver dams or log jams, number of weirs, deflectors, cover or artificial spawning grounds" (FFQ 2015). The DFO and FFQ guidelines have resulted in a very large number of "restoration" projects in Quebec, often led by watershed agencies (e.g., Comité de bassin versant Rivage de la rivière du Moulin et Organisme de bassin versant du Saguenay 2015), promoting the construction of artificial weirs and removing wood and/or beaver dams from streams. These projects do not consider hydrogeomorphic concepts and appear to be in contradiction with the current scientific knowledge on river restoration.

Knowledge transfer and environmental decision making in fish habitat restoration

The above examples reveal profound gaps in the knowledge exchange between academic experts and scientists in ministries and watershed agencies and environmental NGOs. The challenge of knowledge transfer in environmental decision making was noted in other fields, for example in the adaptive governance of marine resources (Cvitanovic et al. 2015). In river restoration, there are well-known tensions between academic researchers and practitioners; one example is the Natural Channel Design and Rosgen's stream classification in the US (Lave 2012). A common problem reported in countries such as the United Kingdom is the inertia of engineers, mainly because of their fear of a decline in flood protection if hard-engineering structures are no longer used (Adams et al. 2004). However, in Quebec (and to some extent the rest of Canada), inertia seems to arise from biologists rather than engineers.

One possible explanation is the pressure put by anglers on governmental agencies. Indeed, anglers are usually the most vocal opponents of beaver reintroduction, and those who believe beaver dams will impede migrating salmonids (Collen 1997; MacDonald et al. 2002). The trout lobby is believed to be at least partially responsible for the massive program of beaver dam removal that was put in place by the Wisconsin Department of Natural Resources (WDNR) in 1985 to "restore" the trout habitat (Brown 2012). This program is now increasingly criticized as one lacking scientific evidence, as its justification appears to be based on only two studies: one from a former WDNR employee (Avery 2002), and one on the thermal effects of beaver ponds (McRae and Edwards 1994). Interestingly, unlike the argument used by Canadian NGOs and ministries that beaver dams can impede the upstream progress of salmonids, WDNR used the premise that beavers warm the water too much for trout to survive (Avery 2002; Randolph 2011; Brown 2012). However, stable cold-water groundwater inputs combined with vegetative stream shading were able to maintain downstream water temperatures in northern Wisconsin, despite the presence of beaver dams (McRae and Edwards 1994; Ribic et al. 2017).

It is generally believed that restoration has become increasingly "science-led" since the 1990s because of the past successes of such approaches (Gross 2002; Eden and Tunstall 2006; Bracken and Oughton 2013). It is also widely accepted that the science required for river restoration is highly multidisciplinary (Eden and Tunstall 2006). The lack of scientific evidence and the absence of hydrogeomorphic concepts in the current fish habitat restoration guidelines in Quebec therefore appear as an anomaly, particularly since hydrogeomorphology is a central component of the *EU Water Framework Directive* (e.g., Dany 2016), and multidisciplinary teams consisting of engineers, biologists, and geomorphologists are very common in the US (e.g., Cramer 2012). Part of the explanation for the lack of inclusion of current scientific knowledge in Quebec could come from a limited access to the (mostly) English scientific literature, although several up-to-date scientific documents on stream restoration are increasingly available in French (e.g., Dany 2016), yet are nevertheless not cited in ministry or NGO reports. The problem may be due in part to the lack of trained staff in hydrogeomorphology, but also to a culture of in-house training, with very limited contacts with academic scientists. The role of anglers should also be investigated, as it is possible that they are loudly voicing concerns that often lack a more holistic perspective on natural river processes, such as the key role of beaver dams in the fluvial ecosystem as observed in Wisconsin (Brown 2012).

Concluding remarks

As both river mobility and floodplain connectivity have been shown to be beneficial for aquatic species (Florsheim et al. 2008; Tockner et al. 2010; Choné and Biron 2016; Hauer et al. 2016), managing rivers using hydrogeomorphic concepts such as the FSR will contribute to stream restoration in a way that is more likely to be successful in the long term than constructing artificial weirs and spawning sites or dismantling beaver dams. In our view, it is essential that holistic management frameworks like the FSR are seriously considered by agencies funding fish habitat restoration projects. The implementation of the minimum freedom space, using easements or other means to compensate for financial loss for riparian owners, represents a more perennial alternative for long-term fish habitat restoration than in-stream interventions that require periodic replacement and are not always well-aligned with scientific knowledge on river dynamics.

Since there is overwhelming evidence that the presence of wood is beneficial for fish (Roni et al. 2014), and a lack of evidence that the costs of adding in-stream structures such as weirs are offset by biological recovery (Palmer et al. 2010), we believe it is urgent to perform a thorough re-assessment of stream restoration guidelines—in Quebec as well as in other Canadian provinces. As Palmer et al. (2014) noted, higher biological success rates will likely result from projects with a primary focus on enhancing the riparian zone as the restoration action. Applying FSR concepts where possible would thus be a wise and much-needed change in the stream restoration paradigm in Quebec and elsewhere.

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