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Assessing anthropogenic pressure in the St. Lawrence River using traits of benthic macroinvertebrates

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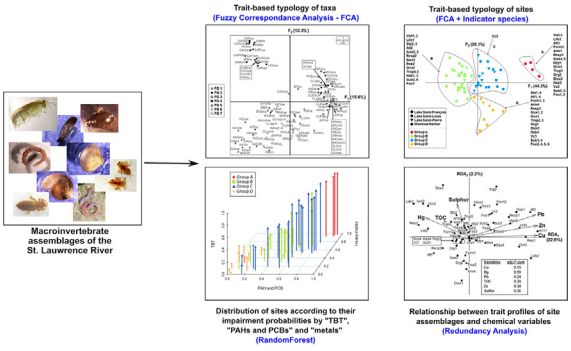
HIGHLIGHTS

- 17 functional traits of invertebrate taxa were coded in a large river.
- Indicator traits were related to the most heavily polluted sites (Pb, Zn and Cu).
- 3 pressure-models have been built based on the RF model (metals, BPC and PAH, TBT).
- Trait-based pressure-specific models can assess sediment quality in a large river.

GRAPHICAL ABSTRACT



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ABSTRACT

This study aims to evaluate the anthropogenic pressure in the St. Lawrence River by assessing the relationships between chemical contamination of sediments and benthic community structure with the trait-based approach. Organic and inorganic contaminants as well as other sediment variables (sediment grain size, total organic carbon, nutrients, etc.) and benthic invertebrate assemblages were determined in 59 sites along the river. Biological and ecological traits of taxa were coded, taking into account regional climate and ecosystem conditions. The aims of this study were to (1) describe the relationships between traits and macroinvertebrate taxa and identify homogeneous clusters of taxa with the same combinations of functional traits, (2) describe spatial patterns in traits of macroinvertebrates in the St. Lawrence River, (3) link trait-based metrics and site groups to sediment quality and (4) define a trait-based strategy for diagnosing the ecological quality of the St. Lawrence River. Seven groups of taxa sharing similar trait-category attributes were defined. Moreover, four groups of sites were identified using the 'K-mean' non-hierarchical clustering approach. The 'IndVal' method enabled us to specifically defined trait categories corresponding to site groups on the basis of their indicator value. The relative abundances of taxa from five functional groups significantly varied among site groups. For example, some indicator traits such as multivoltine cycle, long life span, fixed clutches, tegumental respiration, asexual reproduction, and collector/

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gatherer feeding habit were associated to the most heavily polluted sites located in the Montreal harbour which showed the highest sediment concentrations in Pb, Zn and Cu. Three trait-based pressure-specific models were built, based on the random forest approach, for respectively (1) heavy metals, (2) BPCs and PAHs, and (3) TBTs occurring in the environment. These models could be applied to assess sediment quality using macroinvertebrate assemblages in a large Canadian river.

1. Introduction

For decades, human pressure such as fisheries, industrial activities, recreation and transport have altered the ecological integrity of large rivers (Jungwirth et al., 2002; Tockner et al., 2009). Consequently, in order to evaluate the ecological condition and recovery of freshwater ecosystems, new approaches were developed (Bailey et al., 2004; Hering et al., 2010; Reynoldson et al., 1997; Reynoldson et al., 2001). Two major approaches to evaluate water and sediment quality use bioindicators and metrics based on benthic macroinvertebrates (Li et al., 2010; Menezes et al., 2010). The taxonomic approach is traditionally used to estimate the impacts of environmental conditions and human disturbances in lakes, rivers and streams by comparing macroinvertebrate species assemblages in impaired and near-natural undisturbed sites (Bailey et al., 2004; Reynoldson et al., 1997; Tall et al., 2008). Over the last three decades, interest for the functional approach has increased because it helps to understand the relationships between community structure and functioning of aquatic ecosystems facing multiple stressors (Dolédec et al., 1999; Hering et al., 2015; Navarro-Ortega et al., 2015; Resh et al., 1994; Statzner et al., 2001; Usseglio-Polatera et al., 2001; Verberk et al., 2013). The functional trait approach implies that environmental filters select taxa with suitable traits to coexist under similar environmental conditions or types of disturbances (Poff, 1997; Townsend and Hildrew, 1994). More recently, experts in Ecological Risk Assessment (ERA) have used the trait-based approaches because taxonomic-based methodologies limit our ability to describe and generalize ecological responses to stressors (Artigas et al., 2012; Reyjol et al., 2014; Van den Brink et al., 2011a, b). In comparison, trait-based approaches that rely on taxon-free metrics (i.e. biological and ecological traits) better allow the evaluation and comparison of evolutionary responses of organisms to various types of disturbances across broad geographical gradients (Dolédec and Statzner, 2008).

In Europe, macroinvertebrate functional traits were successfully applied to describe biological reference status, and to determine the impacts of multiple stressors. This approach is more often used in streams and rivers (Archaimbault et al., 2005; Mondy and Usseglio-Polatera, 2013; Statzner and Bêche, 2010; Statzner et al., 2001) than in lakes (Heino, 2008). In large rivers, macroinvertebrate traits were used to assess the impacts of pollution and cargo-ship navigation (Bady et al., 2005; Dolédec and Statzner, 2008; Gayraud et al., 2003). However, integration of functional approaches for biomonitoring the ecological integrity of large rivers facing multiple environmental changes and human disturbances is still in progress (Bonada et al., 2006; Menezes et al., 2010; Mondy and Usseglio-Polatera, 2013). Application of macroinvertebrate functional traits represents a relevant approach for the assessment of ecological integrity of complex large rivers in North America.

This study is the first attempt to apply the functional trait approach to evaluate the ecological quality of a large Canadian river and explore the relationships between sediment quality and macroinvertebrate communities. The study was carried out in the St. Lawrence River, a major waterway in North America exposed to multiple stressors due to commercial navigation and dredging activities in the maritime channel and harbour (D'Arcy and Bibeault, 2004; Desrosiers et al., 2010), sediment contamination (Carignan et al., 1994; Desrosiers et al., 2010), and watershed disturbances such as urbanization, industrialisation and intensive agriculture (Desrosiers et al., 2010; Hudon and Carignan, 2008). We focused on the fluvial section of the St. Lawrence River including the fluvial lakes Saint-François, Saint-Louis, and Saint-Pierre, and the harbour area of Montreal that represent the major features of the riverine landscape. Based on functional traits defined for the macroinvertebrates collected in the St. Lawrence River along a sediment contamination gradient, we tested the hypothesis that trait-based community structure of macroinvertebrates differs significantly among sites having different sediment quality. We aimed to: (1) describe the relationships between functional traits and macroinvertebrate taxa and identify homogeneous groups with similar functional attributes, (2) describe spatial patterns in functional traits of macroinvertebrates in the St. Lawrence River; (3) link macroinvertebrate functional traits and groups to sediment quality, (4) define a combination of 83 trait-based metrics as potential candidates to a multimetric tool for evaluating the ecological quality of the St. Lawrence River and (5) propose a strategy for the construction of such a bioassessment tool. Performance of macroinvertebrate traits and their links with sediment quality were compared to previous results obtained using the taxonomic approach on the same macroinvertebrate data set (Masson et al., 2010) as an indicator of the adequacy of the functional approach.

2. Methods

2.1. Study sites and analysis of sediment quality

This study was carried out on the fluvial portion of the St. Lawrence River (Canada) that flows over 240 km from the inlet of Lake Saint-François to the Lake Saint-Pierre outlet (Fig. 1). Sampling sites were mainly located in sedimentation areas (fluvial lakes, harbour and river plumes) characterized by past or present point sources of anthropogenic contamination, fine particle deposition, and potential dredged areas.

A Shipek grab sampler (400 cm^2) was used to collect sediments during the fall of 2004 and 2005 at 59 sampling sites in the fluvial lakes and the Montreal harbour area along the St. Lawrence River continuum. All samples were retrieved and treated in a similar way. Between twenty and twenty-five litres of sediments were collected at each sampling point and transferred in clear polyethylene bags (Desrosiers et al., 2008). Sediment samples were transported on ice and kept for 24 to 30 h before being stored in the laboratory at 4 °C. Twenty-four to 48-h after sampling, each sediment sample was manually homogenized and sieved through 2-mm mesh for chemical analyses. Analyses of sediments met the standardized protocols of Quality Assurance and Quality Control (QA/QC) (Desrosiers et al., 2010; Desrosiers et al., 2008; Masson et al., 2010) (see Appendix S1 for specific methods and detection limits).

We observed a wide range in grain size composition, organic matter content, as well as in concentrations of nutrients, metalloid, metals and organic chemicals. The highest chemical concentrations were observed in the Montreal harbour area (Table 1; see also Desrosiers et al., 2010; Desrosiers et al., 2008; Masson et al., 2010).

2.2. Sampling and analyses of macroinvertebrates

Three samples of macroinvertebrates (=3 replicates) were collected at each site using a Shipek grab (400 cm^2) and placed into a polyethylene bag. Samples were fixed on site with formaldehyde (10%) and coloured with Rose Bengal in order to reduce sorting time. Each