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Active biomonitoring for assessing effects of metal polluted sediment resuspension on gammarid amphipods during fluvial traffic☆

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ABSTRACT

The resuspension of polluted sediments by boat traffic could release substantial amounts of metals to the water column, affecting at the same time their bioavailability. In order to characterize the impact of sediment resuspensions on biota, caged amphipods have been deployed on three different channelized watercourses in Northern France. Firstly, the biological responses of transplanted freshwater gammarid amphipods, *Gammarus fossarum*, described by trace metal accumulation, feeding and reproduction activities were quite similar for the three water courses despite the differences of metal contamination and navigability. Secondly, the concentrations of metals accumulated in gammarids never exceeded the contamination thresholds previously defined for Co, Cu, Cr and Zn. Values were in the same order of magnitude whatever the studied site despite: (i) large differences noticed in the sediment quality and (ii) some concentrations in the overlying waters exceeding the Environmental Quality Standards (EQS) defined by the Water Framework Directive. Conversely, Pb was highly bioaccumulated with values systematically exceeding the threshold value whatever the site. Therefore, the impact of navigation cannot be proved and the difference between the 3 monitoring periods is rather attributed to environmental variability, probably linked to the seasonality. Moreover, this study also confirms that organisms sampled from a local population in the vicinity of the three studied watercourses could be used as test organisms, leading to similar results than the ones obtained with reference gammarids initially used for developing all the biological responses. This would simplify and then promote the development of studies based on gammarid amphipod, *G. fossarum*, as bioindicators.

1. Introduction

In Northern France, watercourses present some characteristics inherent to the geographical and to the former socio economical contexts. Because of a low relief, rivers are small with limited flow rates (*e.g.* average flow of 8 $m^3 s^{-1}$ for the Deûle River). The intense steel sector and coal mining development from the 19th century resulted in the channelization of main rivers with the aim to transport ores, coal, and manufactured products by boat between the factories and the seaports. As environmental issues were not considered during the first industrial revolution, some part of rivers, especially those located in the vicinity of the factories, have been heavily contaminated, especially by metals and polycyclic aromatic hydrocarbons (Lourino-Cabana et al., 2011; Net et al., 2015). Nowadays, despite that most of these activities have ceased, the sediments are still highly polluted, partly because they are exported only very slowly downstream with time.

When buried in sediments, metals such as Cd, Cu, Pb and Zn are known to be relatively well trapped by several host phases, particularly sulphides and particulate organic matter (Zhang et al., 2014; Besser et al., 2015). However, when fluvial traffic occurs regularly with barges, the surface sediment is recurrently resuspended (Rapaglia et al., 2011, 2015; Ji et al., 2014), resulting in the oxygenation of anoxic sediment, and a possible remobilization of a metal fraction in the water column as dissolved species and/or

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colloids. Additionally, the construction of a new channelled watercourse in France (Canal Seine Nord-Europe) to link Paris (the Seine River) with the Benelux (via the Scheldt River) has begun. It aims at encouraging the intensification of merchandise transport by boat, in consequence, sediment resuspension events would increase significantly.

Recently, resuspension events have been closely examined on a strictly chemical point of view in the Deûle River that is strongly polluted by Cd, Pb and Zn. According to these studies, the resuspension of sediments result in an increase of Pb and Zn electrochemically labile concentrations in the water (Superville et al., 2014, 2015), which may impact directly the aquatic organisms. It was also clearly shown that the potential bioavailability of metals is strongly increased with the contents of polluted suspended particles in the overlying water. Note that this relationship is also dependent on the seasons (Superville et al., 2015). By contrast, another approach combining data from both the overlying water and surface sediment sampled from 3 rivers showed that sediments act as an efficient trap for metals, the latter being poorly present in the water column, even in the case of daily resuspensions of these highly polluted sediments by boat traffic (Prygiel et al., 2015). Finally, the methodology recommended by the Water Framework Directive (WFD) appears to be not relevant to evaluate the quality of such channelized river and complex systems that evolve very quickly (at the hour scale). Therefore additional assessments must be carried out, and for this purpose, experiments performed with organisms enable to bring complementary information on the metal mobility and the impact of degraded ecosystems on biota.

I Recently, a new approach, based on the use of caged standard organisms (*in situ* experiment) was proposed to monitor the water quality. This approach allows: (i) reducing the sources of variability related to biotic factors (Crane et al., 2007) by using standard organisms (surrogate species), presenting similar physiological characteristics (Liber et al., 2007); (ii) providing an environmental realist exposure and thus integrate the effect of many factors (temperature, pH, conductivity, contamination changes over the time) that may influence the toxicity of aquatic systems; and (iii) using life history traits related to population dynamics (survival, growth, reproduction and feeding rate) as toxicity markers, what is not achievable with harvested native organisms. Among test organisms, amphipods, fishes, chironomids have been studied in details at different biological levels, from the molecular (acetylcholinesterase activity, bioaccumulation) to the population scale (survival, feeding rates, reproduction cycles) (Mousavi et al., 2003; Xuereb et al., 2009a; Coulaud et al., 2011, 2014; Ferrari et al., 2014; Charron et al., 2015; Hackenberger et al., 2015; Gagnaire et al., 2015). For the study, the target organism is one crustacean amphipod, the gammarid species *Gammarus fossarum,* key component of freshwater ecosystems. This amphipod is involved in litter decomposition and microbial turnover, and constitutes an important source of food for birds, amphibians and fishes (Lebrun et al., 2015). It is also largely used because it has been proved to be widely widespread, robust, and relatively easy to grow and to deploy i*n situ*.. Moreover, this organism should be used for establishing a new methodology for chemical contamination survey of freshwater systems, applicable to various river typologies including channels (Besse et al., 2012, 2013).

This paper is the second one dedicated to the comparison of three channelled rivers (Deûle, Sensée and Scarpe) that tackles the impact of navigation and polluted sediment resuspension on the water quality. The first one (Prygiel et al., 2015) was exclusively focused on chemical and geochemical parameters and the main conclusions will be reminded briefly (see discussion section). The present work investigates the biological responses of caged gammarid amphipods during three campaigns of deployment to complete our view on the water quality in such complex aquatic systems that are frequently met in Northern France and Europe (with 630 km of channelled rivers in this Euro-region). Additionally, comparisons between the reference gammarid population (sampled in the Bourbre River, near Lyon, France) initially used to propos*e in situ* experiments, and a local population sampled in the Rhônelle River (Northern France) were undertaken to investigate the possibility of generalizing the use of this organism at a broader scale.

2. Material and methods

2.1. Location of the study sites

Three sites were selected for this study (Fig. 1), according to two main criteria: the concentrations of metal contamination in the sediments (mainly Cd, Pb and Zn), and the boating pressure on the channels. The first river to be considered was the Deûle River with a monitoring station located at Courcelles-lès-Lens. This station was selected for its intense navigation and its severe pollution of sediments owing to the presence of Zn and Pb smelting plant Metaleurop (closed in 2003). The second station was on the Sensée River at Goeulzin. The fluvial traffic was very similar to that on the Deûle River but the sediments are much less contaminated. The last site was located at Râches on the Scarpe River that exhibits a strong sediment contamination towards metals and an absence of navigation activities (Prygiel et al., 2015). Navigation data on the Deûle and the Sensée rivers were obtained from Voies Navigables de France at the locks of Douai and Goeulzin respectively and the main features were detailed in a previous paper (Prygiel et al., 2015). Globally, the daily traffic for the Deûle and the Sensée rivers was similar, with a mean of 30 ± 10 boats per day and remained stable according to the sampling periods.

The monitoring of the sites has been performed 3 times during 2 years as follows: sediment cores (approximately 20–30 cm depth) were sampled on each site in May 2011 and in April 2012. . As for water, samplings were performed manually through 3 monitoring periods of 6 weeks in May–June 2011, September–November 2011 and April–May 2012. When available, the mobile monitoring stations belonging to the French Water Agency have also been deployed to record at high frequency (1 measurement every 10 min) data related to physico-chemical and chemical water quality (such as O_2, temperature, conductivity, turbidity, nitrates, phosphates, dissolved organic carbon, etc.). This important (geo) chemical monitoring has already been treated and published recently (Prygiel, 2013; Prygiel et al., 2015) and the main results in relation with the present study are briefly presented in the discussion section and more informations are available in Supplementary Informations.

2.2. Organisms exposures

2.2.1. Source of test organisms

Three sets of gammarid amphipods (*G. fossarum*) were sampled (approximately 2–3 weeks before the monitoring campaigns) in the Bourbre River (Fig. 1). The location was at the head of the watershed, known to be uncontaminated by metals and to display good physicochemical water quality (Geffard et al., 2010a; Lebrun et al., 2015). Adult amphipods were selected according to their body size using a series of sieves (2–2.5 mm). Back at the laboratory (IRSTEA, Lyon), the organisms were introduced into small aquariums (20 L) where they were acclimated for 2 weeks under the following conditions: T = 12 °C; conductivity = 600 µS cm^{-1}; photoperiod (14 h day/10 h night); oxygen saturation = 100%. In addition, the organisms were fed *ad libitum* with leaves (*Alnus*