Role of benthic macro-invertebrate bioturbation on uranium biogeochemistry in freshwater sediments

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INTRODUCTION

During the last decades, numerous studies have demonstrated the strong influence of macrofauna bioturbation (food foraging, respiring, burrowing, defecating) on biogeochemical functioning of sediments, leading to the current consensual consideration of benthic organisms as 'ecological engineers'(Mermillod-Blondin and Rosenberg, 2006). Fluxes of solutes and mixing of solids are enhanced by bioirrigation of burrows/galleries dug into the sediments and by bioconveying of sediment particles. In combination with physical modifications as higher porosity or granulometric reworking, these activities directly influence microbial communities. Among the most relevant ecological consequences, the impact of bioturbation on distribution, speciation and (im)mobilisation processes of metallic pollutants accumulated in sediments is of first importance and has received lot of attention (Michaud *et al.*, 2005).

In this context, two objectives were drawn: (i) evaluate the effects of uranium on benthic macro-invertebrates, particularly on their bioturbation activity; and inversely, (ii) estimate the influence of bioturbation on sediment biogeochemistry and then on uranium distribution and transfers within benthic ecosystem. To aim these objectives, several laboratory studies were performed under controlled conditions. Microcosms were filled with natural sediment and water, sediment was artificially contaminated with uranium and two ubiquist and abundant freshwater invertebrate species were added (Chironomids larvae: *Chironomus riparius*, and Oligochaeata worms: *Tubifex tubifex*). *C. riparius* and *T. tubifex* were chosen as biological models because they belong to two distinct bioturbation functional groups. *C. riparius* larvae are surface deposit-feeders with a low burrowing activity mainly dependant of oxygen, organic matter availability and presence of predators in the water column (Hölker and Stief 2005). *T. tubifex* worms are 'conveyer-belt' deposit-feeders, living head-down oriented and partially submerged in the sediment, with the posterior section of the body free in the overlying water so as to ensure cutaneous respiration.

As to choice of uranium as contaminant in this study, it was motivated by the scarcity of ecotoxicological data involving benthic macroinvertebrates. Uranium is a natural radioactive heavy metal whose content in the environment has increased due to human activities, particularly in freshwater ecosystems (Saari *et al.*, 2007) where it can accumulate in sediments. Natural uranium concentrations considered as the 'background level' in freshwater sediments, are lower than 10 µg U g^{-1} dry wt (Kurnaz *et al.*, 2007), but concentrations higher than several hundreds to several thousands of µg U g^{-1} dry wt have been registered in rivers and lakes closed to mining sites, as in Spain (Lozano *et al.*, 2002) or in Canada (Neame *et al.*, 1982).

RESULTS AND CONCLUSIONS

Effects of uranium on *Tubifex tubifex*

After 12-day exposure to contaminated sediment (0 to 5980 µg U g^{-1} dry wt), at high concentrations of uranium (> 599 µg U g^{-1} dry wt), malformations were observed and survival

(Fig. 1A), biomass (Fig. 1B) and burrowing activity were all reduced. Nonetheless, although uranium toxicity has not been thoroughly assessed and comparison of the data from different studies remains troublesome, this species appears less sensitive to uranium than other invertebrates. This strong resistance in polluted environments can be explained mainly by the implementation of several processes that we observed directly: a high autotomy rate at very high concentrations of uranium, regeneration ability, increased production of mucus, a hormetic effect on biomass, and a probable strategy for avoiding the contaminated sediment.
Lastly, up to concentrations of 599 µg U g^{-1} dry wt, the activity displayed by these organisms led to a significant release of uranium from the contaminated sediment into the water column (Fig. 2). This study thus confirms the ability of *T. tubifex* to tolerate environmental pollution and demonstrates their crucial role in the functioning of ecosystems, particularly in the biogeochemical cycle of metals.

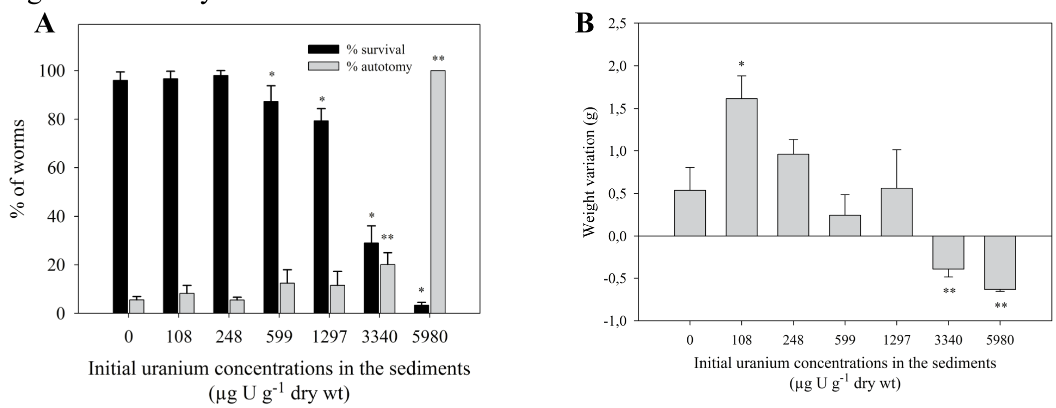

Figure 1 - After 12-day exposure to the seven experimental treatments (initial uranium concentrations in the sediments): A) Percentage of surviving and autotomized *Tubifex tubifex* worms. B) Evolution of biomass (ΔW) of *Tubifex tubifex*. Means±SD (*N*=3). Stars correspond to significant differences with the control group (*P*<0.05).

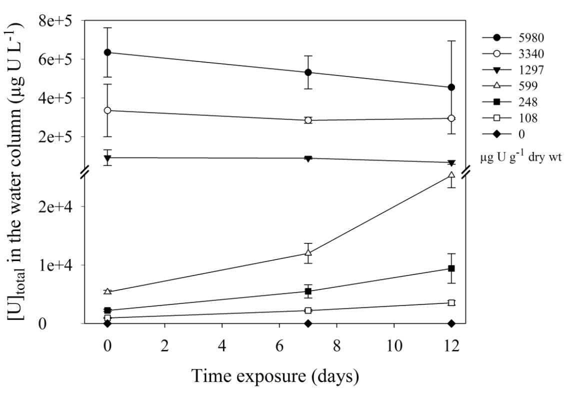

Figure 2 - Evolution of total uranium concentrations in the water column during the 12-day experiment for the seven experimental treatments (initial uranium concentrations in the sediments). Means±SD (N=3). Analysis of the data shows significant uranium release factors between day0 and day12 for 108, 248 and 599 µg U g^{-1} dry wt treatments (*P*<0.001).

Effects of uranium on the bioturbation of *Chironomus riparius* larvae and *Tubifex tubifex*

By quantifying the burial and the redistribution of fluorescent particulate tracers (microspheres), the sedimentary reworking induced by these macro-invertebrates was measured after twelve days of exposure. Biodiffusion D_b and bioadvection W rates, as well as several other parameters were estimated to assess and compare the bioturbation of the two species, separately and all together, between uncontaminated and uranium-spiked sediments (0, 150, 300 and 600 µg U g^{-1} dry wt). The results show that particle mixing was mainly induced by *T. tubifex* worms which were only affected by uranium for high concentrations into the sediments. *C. riparius* larvae were more sensitive to uranium but their bioturbation had few effects on sediment reworking (Fig. 3). Finally, the bioturbation of *T. tubifex* lead to a high uranium release from the sediments to the overlying water that highlighted the crucial role of this mostly dominant species on uranium biogeochemical cycle, at concentrations existing in natural contaminated sites.

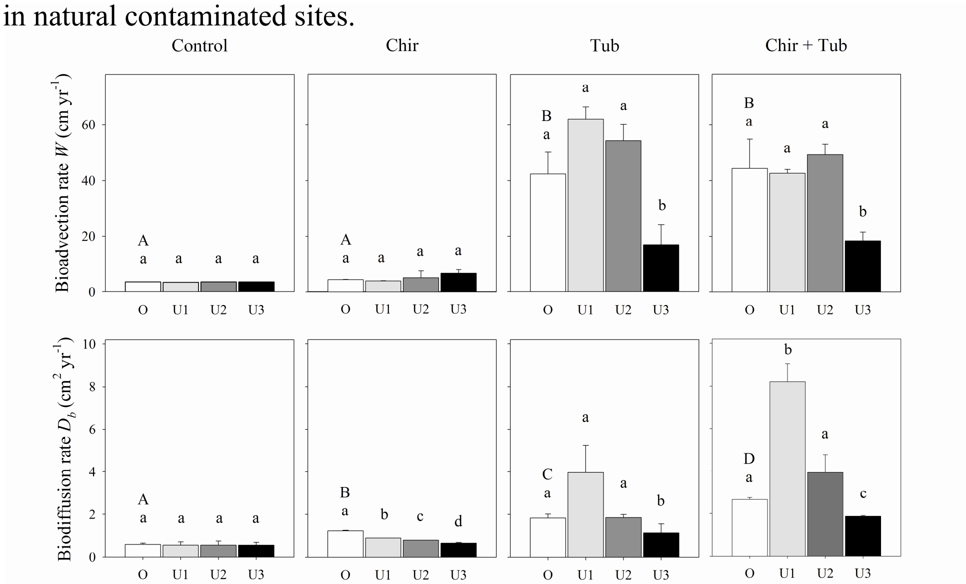

Figure 3 – Bioadvection and biodiffusion rates as a function of the initial uranium concentrations in the sediments (0=uncontaminated, U1=150, U2=300, U3=600 µg U g^{-1} wt) for each treatment. Means ± SD (*N=3*). Different letters correspond to significant differences between O, U1, U2 and U3 (small letters) and between bioturbation treatments in uncontaminated sediments (capital letters).

Influence of bioturbation on biogeochemical processes occurring in sediment

The oxygen uptake of sediments inhabited by *Chironomus riparius* larvae and *Tubifex tubifex* worms was investigated during a 12-day laboratory experiment using a planar oxygen optode device. Additional experiments were carried out within uranium-contaminated sediment to assess the impact of a metallic pollutant on these processes. As expected, both the two invertebrate species significantly increased the oxygen uptake of sediments (Fig. 4). After 72 hours, this enhancement reached 13 and 14% for sediments inhabited by *Chironomus riparius* and *Tubifex tubifex*, respectively, and no temporal variation occurred afterwards. The oxygen uptake rate enhancement in microcosms inhabited by *C. riparius* and *T. tubifex* can be related both to their own respiration and to the effects of their bioturbation activities on the oxygen fluxes within the sediment (oxygen pore water diffusion, bacterial respiration). In the case of contaminated sediments, the oxygen uptake rate was already 24% higher from the beginning of the experiment, suggesting that uranium directly influenced the sediment biogeochemistry. Two assumptions can be proposed: the oxidation of uranium into the sediment consumed oxygen and/or uranium modified the microbial community by directly or indirectly stimulating aerobic organisms.

As a consequence of lower bioturbation activity within uranium-contaminated sediments, the oxygen uptake was not modified in presence of *C. riparius* larvae. However, it was surprisingly higher (+18%) in presence of *T. tubifex* worms. The combined effects of uranium and *T. tubifex* into the sediments lead to an increase of 53% of the oxygen uptake. These results confirmed the ecological importance of Chironomid larvae and Tubificid worms in freshwater sediments and highlight the necessity of further investigations in order to take into account the interactions existing between bioturbation, microbial metabolism and metallic pollutants.

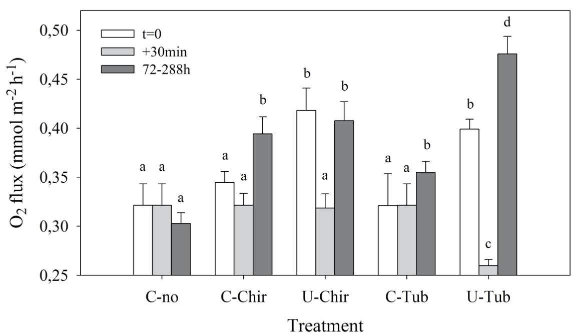

Figure 4 – Oxygen fluxes at the sediment/water interface in the different treatments (C: uncontaminated, U: contaminated, Chir: presence of *Chironomus riparius*, Tub: presence of *Tubifex tubifex*, no: no organism) before the introduction of organisms (white bars), after 30 min (grey bars), and after 72 hours to the end (black bars). Means ± SD (*N=4*). Different letters indicate significant differences.

Thanks to DET (*Diffusive Equilibrium in Thin films*) gel probes inserted in sediment, high-resolution vertical profiles of main chemical species concentrations in porewater were obtained and uranium fluxes at the sediment-water interface were then calculated. It appears clearly that the bioturbation of Tubificidae exert a strong influence on biochemical sediment properties (e.g. stimulation of digenetic processes, distribution of solutes). The activity of *T. tubifex* worms implied an important release of uranium from the sediments to the overlying water, as usually observed with this mode of bioturbation (*e.g.* Ciutat *et al.*, 2007). Indeed, upward bioconveyers are known to favour the removal of reduced metals from bottom sediments to the interface where the conditions favour their reoxidation and most often their mobility through the water column.

ACKNOWLEDGMENTS

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REFERENCES

Ciutat, A., M. Gerino and A. Boudou, 2007. Remobilization and bioavailability of cadmium from historically contaminated sediments: Influence of bioturbation by tubificids. Ecotoxicology and Environmental Safety, 68: 108-117.

Hölker, F. and P. Stief P, 2005. Adaptive behaviour of chironomid larvae (*Chironomus riparius*) in response to chemical stimuli from predators and resource density. Behavioral Ecology and Sociobiology, 58: 256-263.

Kurnaz, A., B. Küçükömeroglu, R. Keser, N.T. Okumusoglu, F. Korkmaz, G. Karahan and U. Cevik, 2007. Determination of radioactivity levels and hazards of soil and sediment samples in Firtina Valley (Rize, Turkey). Applied Radiation and Isotopes, 65: 1281-1289.

Lozano, J.C., P. Blanco Rodríguez and F. Vera Tomé, 2002. Distribution of long-lived radionuclides of the ^{238}U series in the sediments of a small river in a uranium mineralized region of Spain. Journal of Environmental Radioactivity, 63: 153-171.

Mermillod-Blondin, F. and R. Rosenberg, 2006. Ecosystem engineering: The impact of bioturbation on biogeochemical processes in marine and freshwater benthic habitats. Aquatic Sciences, 68: 434-442.

Michaud, A.L., L. Hare and P.G.C. Campbell, 2005. Exchange rates of cadmium between a burrowing mayfly and its surroundings in nature. Limnology and Oceanography, 50: 1707-1717.

Neame, P.A., J.R. Dean and B.G. Zytaruk, 1982. Distribution and concentrations of naturally-occurring radionuclides in sediments in a uranium mining area of northern Saskatchewan, Canada. Hydrobiologia, 91-92: 355-361.

Saari, H-K., S. Schmidt, A. Coynel, S. Huguet, J. Schaëfer and G. Blanc, 2007. Potential impact of former Zn ore extraction activities on dissolved uranium distribution in the Riou-Mort watershed (France). Science of the Total Environment, 382: 304-310.