Environ Sci Pollut Res (2018) 25:970–974
https://doi.org/10.1007/s11356-017-0620-z

CONFERENCE REPORT

Looking at biological community level to improve ecotoxicological assessment of freshwater sediments: report on a first French-Swiss workshop

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Received: 3 October 2017 / Accepted: 25 October 2017 / Published online: 31 October 2017

Abstract The first French-Swiss workshop on ecotoxicology of freshwater sediment communities was co-organized by the French Research Institute of Science and Technology for Environment and Agriculture (Irstea) and the Swiss Centre for Applied Ecotoxicology (Ecotox Centre EAWAG-EPFL) in Villié-Morgon (Beaujolais Region, France) on April 27–28, 2017. The workshop brought together scientists working in different fields of expertise (ecotoxicologists, ecologists, environmental chemists…), environmental stakeholder groups and managers, as well as economic players (start-ups and consultancies) to better connect research needs of potential end-users with research outputs. The objectives of this workshop were (i) to establish the state of the art of research in the characterization of sediment contamination and in the evaluation of the effects on sediment-associated biological communities and ecosystem functioning and (ii) to give an overview of the French and Swiss regulations dealing with the assessment of contaminated sediments in freshwater ecosystems. The ultimate goal was to collectively identify research needs and knowledge gaps, as well as to highlight ways to improve the ecotoxicological assessment of sediments in freshwater environments by further considering the structure and functions of associated microbial and invertebrate communities.

Keywords Sediment ecotoxicity · Environmental risk assessment · Structural and functional effects · Sediment exposure · Bioavailability · Microbial ecotoxicology · Invertebrates

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Context

Among the different compartments of aquatic habitats, sediments play a critical role in biogeochemical cycling and in the maintenance of the biodiversity, and benthic processes often support the base of aquatic food chains. However, sediments are often polluted with contaminants introduced into surface waters as these latter bind predominantly to fine particulate matter settling in "storage habitats," i.e., the porous matrix and fine deposits, along the river continuum or in lakes and reservoirs. The subsequent accumulation of contaminated sediment can represent a risk for benthic communities of micro- and macro-organisms and thereby disturb the functioning of the ecosystem, even if no signs of pollution are apparent in the water column (Lafont et al. 2010). Moreover, sediments can also act as a source of contaminants which can be transferred to higher trophic levels via the food chain, or be remobilized during sediment resuspension episodes or by re-dissolution from sediment and diffusion from pore water following changes in redox conditions. It is therefore crucial that this complex compartment is evaluated properly following an

appropriate methodological framework in order to identify its impact on aquatic ecosystem health.

At the European level, the sediment compartment has, until recently, been neglected in the Water Framework Directive (DCE 2000/60/EC). However, several successive amendments to that directive have permitted the progressive consideration of sediments in this piece of legislation essential for the protection of aquatic environments (Förstner 2009). These include the amendment of the 16th December, 2008 (2008/105/EC), defining the need to "monitor sediment […] at an adequate frequency to provide sufficient data for a reliable long-term trend analysis of those priority substances that tend to accumulate in sediment," or the publication of the guidance document on chemical monitoring of sediment (European Commission 2010) in line with the above amendment. However, and as reported several years ago (de Deckere et al. 2011; Flück et al. 2012), there is still a lack of adequate recommendations on the strategies and methods to better evaluate the ecotoxicological impact of chemical substances which accumulate in sediments on associated benthic communities and the resulting effects on ecosystem functioning. Such questions remain meaningful, both in France and in Switzerland, emphasizing the need to facilitate the dialogue between researchers and environmental stakeholders and managers from these two countries in order to implement joint research actions and monitoring programs.

One way to integrate an ecological dimension into ecotoxicological approaches is to perform studies at the community level, applying community ecology concepts (Clements and Rohr 2009; Gessner and Tlili 2016). Indeed, the propagation of ecotoxicological effects along the successive levels of biological organization (from cells to communities) does not follow a linear trend thus limiting the extrapolation from results obtained at cellular, individual or population levels to the community level (Segner 2007). Communities represent the intermediate level between populations and ecosystems. Assessing ecotoxicological effects on communities, which are composed of several species, gives the opportunity to consider the notion of specific and functional biodiversity in ecotoxicology, thus offering the possibility to further develop innovative approaches to assess the impact of toxicants on the biological and functional integrity of ecosystems (Ghiglione et al. 2016).

In this context, it is therefore necessary to strengthen the existing methodological framework for sediment quality assessment and to develop new tools and approaches to better take into account benthic communities (especially microorganisms and invertebrates) in sediment ecotoxicology. These scientific developments should allow the design and the implementation of improved procedures for assessing the quality of aquatic environments through the study of the ecotoxicological impacts of toxicants in contaminated sediments (following the accumulation of toxicants) and/or the ecological gain resulting from the improvement of sediment chemical quality (following a decrease in toxicant concentrations).

Objectives

The first French-Swiss workshop on ecotoxicology of freshwater sediment communities (SediCommuTOX), which was co-organized and co-chaired by Drs. Stéphane Pesce (leader of the Aquatic Microbial Ecotoxicology research group of the French Research Institute of Science and Technology for Environment and Agriculture, Irstea) and Benoît Ferrari (leader of the Soil and Sediment Ecotoxicology group of the Swiss Centre for Applied Ecotoxicology, Ecotox Centre EAWAG-EPFL) took place on 27th–28th April, 2017 in Villié-Morgon (Beaujolais Region, France). The primary aim of the meeting was to encourage fruitful discussions in different sessions between scientists (ecotoxicologists, ecologists, environmental chemists…), environmental stakeholders, and managers, as well as economic players.

Forty-five participants attended the workshop (Fig. 1). About two thirds of them were researchers, lecturers, and professors from various research laboratories and universities in the Auvergne-Rhône-Alpes region (e.g., Irstea Lyon-Villeurbanne Center, University Savoie Mont Blanc, INRA CARRTEL joint research Unit, and Grenoble Alps University) and in Switzerland (e.g., EPFL, University of Geneva, EAWAG). Numerous scientific disciplines were thus represented, including, but not limited to, ecology, ecotoxicology, hydrobiology, environmental chemistry, microbiology, genetic and molecular biology, geochemistry, modeling…. The French Agency for Biodiversity (AFB) and the Swiss Federal Office for the Environment (OFEV), as well as several Swiss cantons (e.g., Vaud, Fribourg) were also represented to promote the dialogue between scientists and environmental stakeholders and managers during the meeting. Given its pivotal and unifying role in the field of environmental toxicology and ecotoxicology, the Rovaltain Foundation took part in the discussions. Finally, it seemed important for us to complete the panel of participants by also involving representatives of French and Swiss private sectors including start-ups in environmental and molecular diagnostics (e.g., Enoveo, ID-Genes) and environmental consulting firms (e.g., Burgeap, Soluval Santiago, and Biol'Eau) as well as public technical platforms for environmental analysis (AnaEE France Biochem-Env and GenoSol platforms).

The objectives of the different sessions were to present the state of the art of research in exposure assessment of contaminated sediments and in the evaluation of the impact of such contamination on associated biological communities as well as to give an overview of the French and Swiss regulations dealing with those questions. The ultimate goal of the

Fig. 1 Group picture of most of the participants of the first French-Swiss workshop on ecotoxicology of freshwater sediment communities (SediCommuTOX)

workshop was to collectively identify the main needs and barriers as well as to highlight ways to improve the ecotoxicological assessment of the quality of sediments in freshwater environments by developing approaches at biological community level.

Workshop sessions: highlights and outcomes

On the first day, after a brief introduction by the main organizers to recall the objectives of the workshop and to give an overview of the tools and methods that are currently used to assess the sediment quality, four plenary sessions followed.

In the first session, representatives from the AFB and the OFEV presented an overview of the French and Swiss regulations dealing with the chemical and ecotoxicological assessment of sediment quality and described current practices regarding the management of polluted sediments in force in these two countries. Another presentation was given by the Ecotox Centre Eawag-EPFL to describe the MODSED project which aims at providing a new module for the sediment compartment within the modular stepwise procedure for quality assessment of surface water bodies in Switzerland. Altogether, these three talks clearly highlighted the specificities of the strategies and approaches developed in France and Switzerland, which are highly influenced by their respective regulatory frameworks. In addition, specific issues at both practical (e.g., how to define an optimal sampling technique to characterize sediment contamination?) and theoretical (e.g., how to define quality criteria for the sediment compartment?) levels were pointed out by environmental stakeholders and managers. A discussion was also initiated concerning the pivotal role of institutions such as the Ecotox Centre Eawag-EPFL in Switzerland and the AFB in France. They play a leading role in narrowing the gap between water science, policy and management in the field of ecotoxicology, by facilitating knowledge and technology transfers and providing expertise to governmental bodies and academic groups.

The second session focused on environmental chemistry with presentations on innovative tools and technologies recently developed to (i) identify the source and origin of contaminants which are detected in freshwater sediments (by using geochemical and isotopic signatures) and to (ii) better estimate the potential availability of organic and inorganic contaminants in the sediment compartment (using passive samplers) and predict the bioaccumulation of these contaminants in benthic organisms (by using modeling approaches based on biodynamic and trait-based models). The first question is of primary interest to distinguish between natural inputs and anthropogenic pollution and then to contribute to the implementation of environmental measures to reduce anthropogenic sources of emission and/or contaminants transfers to the sediment compartment. Characterizing and predicting the potential availability of the various classes of contaminants in sediments is also an issue in community ecotoxicology and environmental risk assessment, as shown by the progressive inclusion of the concept of bioavailability in regulatory frameworks. The development of the described innovative analytical tools and modeling approaches should thus facilitate the assessment of sediment communities' exposure levels to contaminants to better establish the causality link between sediment contamination and community responses.

The third session was dedicated to the methods that are specifically used to evaluate the effects of contaminants on microbial and macro-invertebrate communities in aquatic ecosystems. The first talk illustrated the relevance of studying microbial adaptation to contaminants (e.g., pollution induced community tolerance or increase in biodegradation potential following in situ chronic exposure) as an ecological indicator to monitor contamination in water and sediment and for assessing consequent ecological effects. The second presentation showed that among the potential indicators of biodiversity, oligochaete indices as well as those based on the functional traits of invertebrates could be particularly adapted to assess the ecotoxicological effects of contaminants on sediment invertebrate communities. Recent results also demonstrated that the generalization of such approaches, which currently require

a high level of morphological and taxonomical expertise, should be enhanced by the development of molecular barcoding methods. Finally, the last talk pleaded for the development and implementation of functional approaches to appraise the effects of contaminants on the main ecological functions supported by the sediment communities, such as organic matter consumption and decomposition, biodegradation or nutrient cycling. This session also highlighted current limits in understanding how structural and functional ecotoxicological effects observed at community level can inform about the biological and functional integrity of ecosystems, preventing for the moment the generalization of community responses at ecosystem scale.

In the fourth session, innovative tools and approaches that could be used to implement biomonitoring surveys in sediments at large spatio-temporal scales were presented. Indeed, the two first presentations introduced molecular methods, which offer the possibility to analyze many biological samples simultaneously. Some of these methods aim at assessing biological diversity, using next-generation sequencing to perform molecular diagnostics. This was notably illustrated by the presentation of the French-Swiss Interreg project SYNAQUA, which proposes to develop genetic tools based on the recognition of bio-indicator species (focusing on diatoms and oligochaetes) that are present in the aquatic environment directly from their DNA. Molecular functional approaches used to detect and quantify the occurrence of functional genes or their expression level, were also described and the potential of such approaches to establish a causal relationship between microbial community exposure to chemicals and the molecular response was exemplified by several successful studies performed in different contaminated ecosystems. The last presentation focused on the soil quality monitoring network for French soils (RMQS; Ranjard et al. 2010) in order to initiate a reflection on the possible development of joint integrated chemical and biomonitoring strategies in sediments from different French and Swiss aquatic ecosystems. The implementation of such monitoring programs could be technically supported by the involvement of platforms such as those proposed by the infrastructure for the analysis and experimentation on ecosystems (AnaEE; http://www.anaee.com/).

Finally, a half-day workshop session was organized to collectively identify the main needs and perspectives to improve the ecotoxicological assessment of sediment quality in freshwater ecosystems. First of all, all participants were invited to write down (on post-it notes) both needs and suggestions to better characterize (i) the exposure of natural benthic communities to contaminants in sediments and (ii) the resulting ecotoxicological effects on those communities and on the ecological quality of sediments. These notes initiated a productive discussion allowing to identify relevant actions to be supported and/or implemented in order to contribute to a better evaluation of the ecotoxicological quality of sediments.

The main outcomes and recommendations from these discussions are covered by the points below:

- Better adapt the sampling strategy according to the addressed question and the ecosystem assessed:

- Which kind of sediment should be considered? This choice should be made according to various factors such as the depth, the grain size distribution and the organic matter content
- Which temporal and/or geographical scale? The question needs to take into account the hydrology and the associated sediment dynamics.

- Better consider the various modes of exposure of organisms to toxicants in the sediment compartment as well as the diversity of contaminants, including metabolites (notion of "exposome").
- Develop modeling and predicting tools to evaluate the exposure risks according, among others, to the source and origin of contaminants and their dispersion and distribution in aquatic environments and in the trophic chain.
- Evaluate the relevance of existing ecotoxicological tools at sediment community level to be used as in situ diagnostic tools and develop new approaches based on the structural and functional study of microbial and invertebrate sediment communities.
- Initiate transfer of knowledges to environmental managers by proposing operational guidelines, including standardized protocols and threshold values allowing a relevant and easy interpretation of ecotoxicological effects.

These points underline the necessity to develop pluridisciplinary approaches to better explore the relationship between contaminant exposure and ecological effects in sediments and to propose models and operational tools that could be used to improve the chemical and ecotoxicological assessment of the quality of freshwater sediments in France and Switzerland.

Main conclusions

The presentations and discussions carried out during the SediCommuTOX workshop highlighted the relevance of bringing together actors from different spheres (scientific, operational, economic…) and representing different disciplines. It was also particularly interesting to present, compare and discuss the specific features of each regulatory framework and the different approaches implemented in France and in Switzerland for the management of polluted sediments. The sharing of ideas and of experiences and knowledge made it

possible to collectively propose a wide range of possible actions to improve the ecotoxicological assessment of the quality of sediments in freshwater environments. These actions are characterized by variable operational levels, from fundamental research to large-scale implementation.

Based on the conclusions of the SediCommuTOX workshop, we aim at mobilizing stakeholders (involved in the monitoring and management of the chemical, ecological and ecotoxicological quality of aquatic environments) around the main issues identified. To this end, a first step will be the drafting of a technical article, intended for both environmental managers and scientists, describing the main needs and perspectives in sediment ecotoxicology and the resulting proposed strategies to improve the quality assessment of sediment in freshwater ecosystems.

Acknowledgments We would like to thank the Municipality of Villié-Morgon for granting us the space to host our workshop and our colleagues from Irstea who were closely involved in the workshop organization: Vanessa Aburegaiba, Catherine Ambroise-Rendu, Anaïs Charton, and Bernard Motte. We are also grateful to Dr. Inge Werner for her careful reading of and valuable comments on the manuscript.

Funding Information This workshop benefited from funding from the Auvergne-Rhône-Alpes Region, the French Research Institute of Science and Technology for Environment and Agriculture (Irstea) and the Swiss Centre for Applied Ecotoxicology (Ecotox Centre Eawag-EPFL).

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