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Review

Constructed wetlands to reduce metal pollution from industrial catchments in aquatic Mediterranean ecosystems: A review to overcome obstacles and suggest potential solutions

Anna Guittonny-Philippe [a,c], Véronique Masotti [a], Patrick Höhener [b], Jean-Luc Boudenne [b], Julien Viglione [c], Isabelle Laffont-Schwob [a,*]

[a] Aix-Marseille Université-CNRS, Institut Méditerranéen de Biodiversité et d'Ecologie marine et continentale UMR 7263/IRD 237 IMBE, 3 pl. Victor Hugo, Case 4, 13331 Marseille Cedex 3, France
[b] Aix-Marseille Université-CNRS, Laboratoire Chimie Environnement, FRE 3416, 3 pl. Victor Hugo, Case 29, 13331 Marseille Cedex 3, France
[c] ECO-MED SARL, Tour Méditerranée, 65 Avenue Jules Cantini, 13298 Marseille Cedex 20, France

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ABSTRACT

In the Mediterranean area, surface waters often have low discharge or renewal rates, hence metal contamination from industrialised catchments can have a high negative impact on the physico-chemical and biological water quality. In a context of climate and anthropological changes, it is necessary to provide an integrative approach for the prevention and control of metal pollution, in order to limit its impact on water resources, biodiversity, trophic network and human health. For this purpose, introduction of constructed wetlands (CWs) between natural aquatic ecosystems and industrialised zones or catchments is a promising strategy for eco-remediation. Analysis of the literature has shown that further research must be done to improve CW design, selection and management of wetland plant species and catchment organisation, in order to ensure the effectiveness of CWs in Mediterranean environments. Firstly, the parameters of basin design that have the greatest influence on metal removal processes must be identified, in order to better focus rhizospheric processes on specific purification objectives. We have summarised in a single diagram the relationships between the design parameters of a CW basin and the physico-chemical and biological processes of metal removal, on the basis of 21 mutually consistent papers. Secondly, in order to optimise the selection and distribution of helophytes in CWs, it is necessary to identify criteria of choice for the plant species that will best fit the remediation objectives and environmental and economic constraints. We have analysed the factors determining plant metal uptake efficiency in CWs on the basis of a qualitative meta-analysis of 13 studies with a view to determine whether the part played by metal uptake by plants is relevant in comparison with the other removal processes. Thirdly, we analysed the parameters to consider for establishing suitable management strategies for CWs and how they affect the whole CW design process. Finally, we propose monitoring and policy measures to facilitate the integration of CWs within Mediterranean industrialised catchments.

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* Corresponding author. Tel.: +33 4 13 55 12 30.
E-mail addresses: anna.philippe@imbe.fr (A. Guittonny-Philippe), veronique.masotti@imbe.fr (V. Masotti), patrick.hohener@univ-amu.fr (P. Höhener), jean-luc.boudenne@univ-amu.fr (J.-L. Boudenne), j.viglione@ecomed.fr (J. Viglione).

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1. Introduction

The Mediterranean basin has been identified as one of the most vulnerable regions of the world to climatic and anthropogenic changes (Milano et al., 2012). In the Mediterranean region, human pressure is very strong and occurs almost everywhere, while the biological diversity is remarkably high (Médail and Quézel, 1999). Thus conservation of biodiversity cannot be ensured by protected areas alone, but must depend on a balance between human activities and wildlife (Rhazi et al., 2001). Anthropogenic activity in industrialised zones generates wastes and pollutants on the catchment surfaces that may be washed out to water bodies during storm events (Barbosa et al., 2012). Even state-of-the-art treated industrial wastewaters that are discharged continuously may contribute to significant decline in aquatic faunal populations and biodiversity (Stalter et al., 2013). Drainage systems in catchments usually bring stormwaters and effluents to a point of discharge into the receiving water body, and thus pollution generated and accumulated over the whole catchment is transformed into a point source of pollution upon entry into the aquatic environment (Malaviya and Singh, 2012). In Mediterranean aquatic receiving environments, the pressure resulting from industrial contamination is particularly high (Köck-Schulmeyer et al., 2011). During summer, the natural sources of water may dry up, resulting in rivers and streams that are mainly fed with urban and industrial effluents containing metals[1]. Along the Mediterranean coast, there are many lagoons and associated wetlands with very low water renewal, which are all protected areas for biodiversity conservation (e.g. The Camargue in France, Chauvelon, 1998; The Ichkeul wetland in Tunisia, Casagranda et al., 2006). Anthropogenic activities also impose significant pressure on the groundwater quality and may consequently degrade Mediterranean wetland ecosystems that depend mostly on subsurface water flow (Dimitriou et al., 2008). Given the predicted climatic and anthropogenic changes in the Mediterranean basin in coming decades, with elevation of temperature, reduction of precipitation and population increase (Giannakopoulos et al., 2009; Milano et al., 2012), the contamination pressure on aquatic ecosystems is likely to increase in the medium term (Barbosa et al., 2012).

Among contaminants, metals are currently considered as the main toxic and genotoxic compounds present in hydrosoluble fractions (Maceda-Veiga et al., 2013; Omar et al., 2012). Unlike most of the organic pollutants, metals are not degraded through biological processes, and depending on their forms (complexed, adsorbed onto particles or dissolved), they may enter the trophic web or spread into the sediments where they remain stocked until the physical and chemical conditions change (Forstner and Wittmann, 1981; Devallois et al., 2008). Various industrial processes may induce the release of metals in aquatic environments (Yadav et al., 2012). Diffuse pollutions generated after rainfall in industrial catchments (root and road runoffs, leaching of waste incineration and industrial emissions deposited into river catchments,…) also contribute to high metal loads in rivers (Chon et al., 2012). Therefore, it is necessary to implement restoration measures with the aim of improving water quality (Stalter et al., 2013) and to develop new holistic strategies of management of industrialised catchments (Chon et al., 2012) in order to protect aquatic biodiversity from the impact of metals in Mediterranean environments. Solutions of water quality improvement have to be found at all levels: directly at industries' outfalls but also at the points of discharge of stormwaters into receiving bodies.

Constructed wetlands (CWs) are engineered systems that have been designed to exploit the natural processes involving wetland vegetation, soils and associated microbial assemblages for treating wastewaters. They are designed to take advantage of many of the processes that occur naturally in wetlands, by trying to optimise and speed them up (Vymazal, 2005). Worldwide, they have been increasingly used to successfully remove metals from many types of specific pre-treated industrial effluents (Marchand et al., 2010; Stottmeister et al., 2003). CWs are particularly efficient in warm climates and in areas with sufficiently long daytime periods in winter to support plant growth during all seasons, which is the case in the Mediterranean area. According to Ham et al. (2010), CWs are also a suitable approach for treating and controlling non-point source pollution. CWs are now widely used at catchment scale to attempt to reduce agricultural pollution in temperate environments worldwide (Maillard et al., 2011; Ockenden et al., 2012). These systems can be constructed near natural ecosystems, in particular if designed with notions of landscape-fit, as is the case for Integrated Constructed Wetlands (ICWs) (Everard et al., 2012; Harrington and McInnes, 2009). CWs are seen as an effective solution for wastewater processing for agriculture and rural communities (Babatunde et al., 2008) but, to our knowledge, they have never been used for the treatment of metal pollution from industrialised catchments or directly at industrial effluents outlets in Mediterranean environments. The introduction of CWs between industrialised zones or catchments and receiving water bodies could, however, be a suitable solution to restore or protect the endangered biodiversity of Mediterranean natural wetlands.

Depending on the thickness of the substrate layer, and of the level and direction of the water flow, CWs are classified into four categories, namely surface flow CWs, horizontal or vertical sub-surface flow CWs and hybrid CWs (Vymazal, 2005). In this review, we address more specifically the issue of hybrid CWs given that they enable better adaptation of the system to the wastewater and environmental context, which is a prerequisite for catchment pollution treatment. Moreover, we focused our study on rooted emergent macrophytes as they are the most widely used plants in CWs (Vymazal, 2005) and did not consider free-floating or submerged aquatic plants although they can also be used in treatment systems of this kind (Headley and Tanner, 2012). In this review, we aim to point out the different obstacles that may be overcome to promote the implementation of CWs in order to reduce metal pollution in Mediterranean natural ecosystems. With regard to some of the obstacles, we provide an insight into future prospects. In particular, we dwell on the lack of decision making tools and methodologies for wetland plant selection and we also argue in favour of the need to fit CW design to management strategies. Our review focuses on Mediterranean areas context and needs, but many of the aspects that we develop here may be suitable for other environmental contexts.

2. The Mediterranean context, expected changes and problematic linked to metal pollution

The Mediterranean basin is the region of lands around the Mediterranean Sea. It is defined as a biodiversity hot-spot and is one of the