Using phytoremediation technologies as a nature-based solution to improve and recover impacted estuarine environments

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Abstract. Research carried out by group is focus on the development of biotechnology tools for ecosystems recover, taking into consideration the several anthropogenic impacts and the ecosystem functionality. Results obtained in the past 12 years have clearly shown the potentialities of applying native salt marsh plants for the remediation of pollutants (namely metals hydrocarbons and pollutants of emerging concern) in moderately impacted estuarine environments, which can contribute for its recovery. Present results (Ribeiro *et al*. 2013, Silva *et al*. 2014; Oliveira *et al*. 2014, Fernandes *et al*. 2015, Montenegro *et al*. 2016) show phytoremediation as a suitable cleaning technology and enable the generalization of these techniques to everyday life.

Keywords: phytoremediation; salt marshes; metals; hydrocarbons; pollutants of emerging concern

1. Introduction

Our present research aims at investigating the mutual interactions between organisms and the involving medium in estuarine areas, focusing on the chemical and biological factors that influence the biological remediation of different inorganic and organic pollutants, namely metals, petroleum hydrocarbons and, more recently, pollutants of emerging concern (nanoparticles and pharmaceuticals). In fact, our research is focused on the development of biotechnology tools for ecosystems recovering, taking into consideration the several anthropogenic impacts and the ecosystem functionality. Most importantly, this research is focused on the use of native organisms, either salt marsh plants or rhizosphere microorganisms, already present in the impacted areas. By understanding and stimulating their capabilities for recovering impacted ecosystems, one can ensure biodiversity equilibrium without the introduction of exogenous species. Moreover, one can work with organisms already adapted to the impacted area, overcoming adaption problems that non-native species normally used in phytoremediation biotechnological tools generally suffer.

2. Results

Results obtained in the past 12 years have clearly shown the potentialities of applying native salt marsh plants for the remediation of pollutants (metals and hydrocarbons) in moderately impacted estuarine environments, which can contribute for the recovery of these ecosystems. For instance, salt marsh plants (e.g. *Phragmites australis*, *Scirpus maritimus*, *Juncus maritimus*, *Halimione portulacoides*) have the ability to uptake metals (e.g., Cd, Cu, Pb, Zn), concentrating them in their tissues (enrichment factor (EF) > 1, Table 1), or immobilize them in their rhizosphere zone (e.g. Almeida *et al*. 2004, 2006a, 2008a, 2011), reducing metal availability to other estuarine organisms. Pollutants bioavailability has shown to be a key factor in the success of phytoremediation application that needs to be taken in consideration. This bioavailability has shown to be affected by sediment characteristics, namely sandy versus muddy sediments. For instance, muddy sediment, in general with higher organic matter content and low grain size particles, can decrease pollutants' bioavailability, both of metals and hydrocarbons (Almeida *et al*. 2006b, Ribeiro *et al*. 2015). The presence of more than one type of pollutant affects also pollutants' bioavailability. For example, estuarine sediment contamination with both metals and hydrocarbons increased Cu uptake by *J. maritimus* (Almeida *et al*. 2008b; Montenegro *et al*. 2016). Regarding metals, the form in which the metal is introduced in the system, e.g., metal in ionic and in nanoparticle (NP) form, showed different metal uptake patterns by salt marsh plants (Andreotti *et al*. 2015) (Fig. 1). Obtained results have also highlighted the potential of combining salt marsh plants and their rhizosphere microbial communities, the so-called rhizoremediation. For instance, salt marsh plants, *P. australis* and *J. maritimus*, have shown to clearly improve the potential of rhizosphere microorganisms for the degradation of hydrocarbons in estuarine sediments (Ribeiro *et al*. 2013). In fact, hydrocarbons removal was higher in the presence of plants than in non-vegetated sediments. And recently, our studies have shown that *P. australis* and its associated microorganisms have a potential for removal of the antibiotic enrofloxacin, a pollutant of emerging concern (Fernandes *et al*. 2015). However, attempts to increase the abundance of indigenous microorganisms resistant to a pollutant, namely petroleum hydrocarbons in plants rhizosphere, through biostimulation (addition of nutrients) and bioaugmentation (inoculation of hydrocarbon degrading microorganisms) were not successful in the tested conditions in the increase of hydrocarbon removal rates (Ribeiro *et al*. 2014). So, the improvement of rhizoremediation for increasing organic.

Table 1. Enrichment factors[a] observed for different salt marsh plants and sites (mean and standard deviation, n=3) at Lima River estuary, Portugal. Results from Almeida *et al*. (2011).

Plant	*Site*	*Cd*	*Cr*	*Cu*	*Fe*	*Mn*	*Ni*	*Pb*	*Zn*
J. maritimus	*1*	4.0±0.2	0.33±0.08	1.7±0.1	1.0±0.6	0.8±0.2	0.58±0.06	0.5±0.1	1.6±0.4
	2	2.1±0.5	0.3±0.1	1.0±0.2	1.6±0.9	1.1±0.2	0.5±0.2	0.9±0.4	1.4±0.2
	3	3.7±0.7	0.3±0.2	1.19±0.08	1.6±0.9	0.60±0.04	0.4±0.1	1.1±0.6	2.5±0.6
	4	17±1	0.7±0.3	4±2	0.4±0.3	0.6±0.3	0.7±0.3	0.7±0.6	2.6±0.5
T. striata	*3*	2.4±0.3	0.38±0.06	1.8±0.2	0.15±0.06	0.56±0.07	0.3±0.1	1.4±0.1	1.5±0.2
P. australis	*3*	3±1	0.23±0.08	3.2±0.6	0.14±0.02	0.36±0.04	0.30±0.08	1.2±0.3	2.0±0.6
S. patens	*4*	4±3	0.3±0.2	3±1	0.22±0.05	0.9±0.5	0.2±0.2	0.8±0.5	2.5±0.7

a: EF = $[M]_{belowground\ tissues}/[M]_{non\ vegetated\ sediment}$. Belowground tissues include plants' roots and rhizomes.

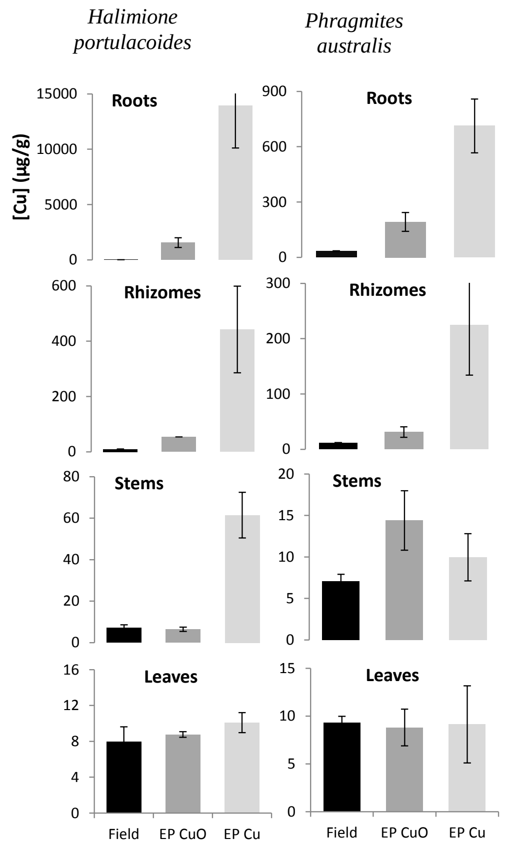

Figure 1. Cu concentrations (n=3) in plants structures. Not exposed plants (Field), exposed to NP (EP CuO) or to ionic Cu (EP Cu). Adapted from Andreotti *et al*. (2015).

contaminants degradation/removal is a challenge that in the future needs to be addressed. However, autochthonous bioaugmentation with addition of indigenous metal-resistant microorganisms into the salt marsh plants rhizosphere has shown to be a valuable strategy for metal phytoremediation. For example, addition of native microorganisms resistant to metals (previously stimulated in the laboratory to metals presence) increased the potential of two salt marsh plants, *P. australis* and *J. maritimus*, to phytoremediate Cd and/or Cu contaminated estuarine sediments, by increasing metal uptake by the plants, namely in aboveground (stems) plant tissues (Silva *et al*. 2014; Oliveira *et al*. 2014) (Fig 2 and 3).

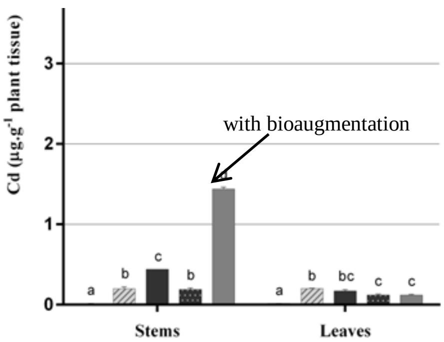

Figure 2. Cd concentrations (n=3) in *Phragmites australis* aboveground tissues (stems and leaves) without and with bioaugmentation. Adapted from Silva *et al*. (2014).

The combination of autochthonous bioaugmentation with phytoremediation opens, therefore, new perspectives for the enhancement of metals phytoremediation rates, the challenge being now its application in the field.

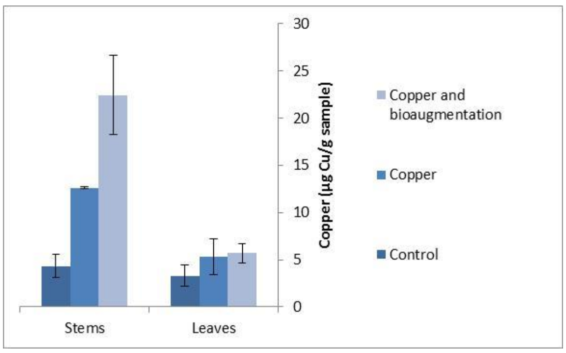

Figure 3. Cu concentrations (n=3) in *Phragmites australis* aboveground tissues (stems and leaves) without and with bioaugmentation. Adapted from Oliveira *et al*. (2014).

3. Conclusions

The results obtained so far with this research line enable the choice of environmentally friendly and nature-based technologies as the first option, by key role players in the recovering of impacted environments, or when dealing with sources of contaminants, which will ultimately benefit the human health. Present results show phytoremediation as a suitable cleaning technology and enable the generalization of these techniques to everyday life.

References

Almeida C.M.R., Mucha A.P., Vasconcelos M.T.S.D. (2004), Influence of the sea rush *Juncus maritimus* on metal concentration and speciation in estuarine sediment colonized by the plant, *Environmental Science and Technology*, **38**, 3112-3118.

Almeida C.M.R., Mucha A.P., Vasconcelos M.T.S.D. (2006a), Comparison of the role of the sea club-rush *Scirpus maritimus* and the sea rush *Juncus maritimus* in terms of concentration, speciation and bioaccumulation of metals in the estuarine sediment, *Environmental Pollution*, **142**, 151-159.

Almeida C. M. R., Mucha A. P., Vasconcelos M.T.S.D. (2006b), Variability of metal contents in the sea rush *Juncus maritimus*-estuarine sediment system through one year of plant's life, *Marine Environmental Research*, **61**, 424-438.

Almeida C.M.R., Mucha A.P., Bordalo A., Vasconcelos M.T.S.D. (2008a), Influence of a salt marsh plant (*Halimione portulacoides*) on the concentrations and potential mobility of metals in sediments, *Science of the Total Environment*, **403**, 188-195.

Almeida C.M.R., Mucha A.P., Delgado M.F.C., Caçador I.M., Bordalo A., Vasconcelos M.T.S.D. (2008b), Can PAHs influence Cu accumulation by salt marsh plants?, *Marine Environmental Research*, **66**, 311-318

Almeida C.M.R., Mucha A.P., Vasconcelos M.T.S.D. (2011), Role of different salt marsh plants on metal retention in an urban estuary (Lima estuary, NW Portugal), *Estuarine Coastal and Shelf Science*, **91**, 243-249.

Andreotti F., Mucha A.P., Caetano C., Rodrigues P., Gomes C.R., Almeida C.M R. (2015), Interactions between salt marsh plants and Cu nanoparticles - effects on metal uptake and phytoremediation processes, *Ecotoxicology and Environmental Safety*, **120**, 303-309.

Fernandes J., Almeida C.M.R., Basto M.C.P., A. P. Mucha (2015), Response of a salt marsh microbial community to antibiotic contamination, *Science of the Total Environment*, **532**, 301-308.

Montenegro I.P.F.M., Mucha A.P., Reis I., Rodrigues P., Almeida C.M.R. (2016), Effect of petroleum hydrocarbons in copper phytoremediation by a saltmarsh plant (*Juncus maritimus*) and the role of autochthonous bioaugmentation, *Environmental Science and Pollution Research*, **23**, 19471-19480.

Oliveira T., Mucha A.P., Reis I., Rodrigues P., Gomes C.R., Almeida C.M.R. (2014), Copper phytoremediation by a salt marsh plant (*Phragmites australis*) enhanced by autochthonous bioaugmentation, *Marine Pollution Bulletin*, **88**, 231-238.

Ribeiro H., Almeida C.M.R., Mucha A.P., Bordalo A.A. (2013), Influence of different salt marsh plants on hydrocarbon degrading microorganisms abundance throughout a phenological cycle, *International Journal of Phytoremediation*, **15**, 715-728.

Ribeiro H., Mucha A.P., Almeida C.M.R., Bordalo A.A. (2014) Potential of phytoremediation for the removal of petroleum hydrocarbons in contaminated salt marsh sediments, *Journal of Environmental Management*, **137**, 10-15.

Ribeiro H., Almeida C.M.R., Magalhães C., Bordalo A.A., Mucha A.P. (2015), Salt marsh sediment characteristics as key regulators on the efficiency of hydrocarbons bioremediation by *Juncus maritimus* rhizospheric bacterial community, *Environmental Science and Pollution Research*, **22**, 450-462.

Silva M.N., Mucha A.P., Rocha A.C., Teixeira C., Gomes C.R., Almeida C.M.R. (2014), A strategy to potentiate Cd phytoremediation by saltmarsh plants - autochthonous bioaugmentation, *Journal of Environmental Management*, **134**, 136-144.