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Research article

Decision-making criteria for plant-species selection for phytostabilization: Issues of biodiversity and functionality

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ABSTRACT

In polluted protected areas, using phytoremediation raises the question of the choice of the plant species to select. As an example, *Atriplex halimus* has been identified as a proliferative plant species that needs to be eradicated in the Calanques National Park (PNCal). Since it has been proven that the spontaneous populations of this plant species could phytostabilize shore waste deposits generated by past industrial activities within the PNCal territory, its status seems controversial, presenting a dilemma between biodiversity management of a protected area and ecological solutions for pollution management. To address this issue, we assessed the ability of *A. halimus* to grow on different soils from this territory, in order to estimate the potential invasiveness of this plant in this territory. Petri dish germinations and pot-growth experiments showed 50% germination of seeds collected on local individuals from the most polluted PNCal soil and 20% growth reduction of seedlings. Soil analysis showed that limitation of growth was caused by high pH value and sparsely available micronutrients as well as metal and metalloid contamination. Our results suggested that local populations of *A. halimus* may stabilize the highly metal and metalloid polluted salt-affected soils of the PNCal, with low seed germination potential lowering the eventuality of a propagation over the PNCal territory. As a consequence of this study, the administration of the PNCal decided not to remove *A. halimus* populations along the polluted coastline until another solution to prevent pollution dispersal had been found. This laboratory approach may be extended to other similar situations where plant species may be evaluated not only in term of phytoremediation potential but also in term of biodiversity preservation.

1. Introduction

1.1. Problem statement

Most of the papers dealing with *in-situ* soil phytoremediation examine persistence of selected agronomic plant species in polluted sites and mainly use efficiency of the pollution management as the major criteria of success (Vangrosveld et al., 2009; Kidd et al., 2015). Apart from this mainstream approach, the use in phytoremediation of native plants to avoid introduction of non-native and potentially invasive species that may result in decreasing regional plant diversity has been discussed (Mendez and Maier, 2008) and pilot assays using local plant assemblages for phytostabilization in polluted protected areas have been incremented (Heckenroth et al., 2016). However in certain cases, the status of invasiveness or even more of indigeneity is still controversial for some plant species and new criteria of evaluation of the compliance of these plants for phytoremediation of protected polluted areas have to be investigated. Moreover, although the great majority of invasive species are introduced, occasionally native plant species may become invasive, spreading rapidly into previously unoccupied habitats according to Simberloff (2011), these new habitats may correspond to recently polluted habitats. In

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France, many national parks host polluted soils in their territory (Desrousseaux and Ugo, 2016) and worldwide this situation occurs regularly (Mazurek et al., 2017; Armendáriz-Villegas et al., 2015). Amongst invasive plant species, some of them are really good candidates for phytoremediation such as *Miscanthus* X *giganteus* or alimurgic species (Bandiera et al., 2016). However, in protected areas, phytoremediation approach favour phytostabilization i.e. use of plant cover to reduce pollutant mobility in soils rather than phytoextraction i.e. use of the ability of some plants for metal translocation in their aerial parts involving the removal of the aerial parts. Thus, determining the benefit of ecological services vs the proliferation risk of these controversial plant species in polluted protected areas is important to assess and also better understanding the local parameters and specially soil characteristics that enable or not their proliferation and their ability for metal phytostabilization.

Atriplex halimus: example of a controversial species in a protected area.

To illustrate this situation, the plant species *Atriplex halimus* (Amaranthaceae), a xerohalophyte that mainly grows in salt-affected nitrophilous and/or degraded soils with a high tolerance to drought (Walker et al., 2014), may be an expressive case study in the Mediterranean area. This plant species has a high tolerance to metal and metalloid elements (MM) and numerous papers dealing with its potential use for phytoremediation have recently been published, showing the growing interest in this plant species (Caçador and Duarte, 2015; El-Bakatoushi et al., 2015; Manousaki and Kalogerakis, 2009; Márquez-García et al., 2013; Pardo et al., 2014; Pérez-Esteban et al., 2013; see reviews by Lutts and Lefèvre, 2015; Walker et al., 2014). *Atriplex halimus* has been widely cultivated as forage or wind barrier in much of the world (Otal et al., 2010; Walker et al., 2014), although it originated in the Mediterranean Basin (Ortíz-Dorda et al., 2005; Walker et al., 2014). In South East France (Mediterranean coast), spontaneous populations of *A. halimus* are found in polluted coastal soils of a protected area i.e. the Calanques National Park (PNCal). Though part of the populations present on the site may be native of Ibero-Provençal origin, according to Ortíz-Dorda et al. (2005), the Mediterranean National Botanical Conservatory (MNBC), a French authority for plant conservation, considers that many ornamental individuals of this species planted as hedges near housing might have escaped from neighbouring gardens and originated most of the populations currently occurring along the coast of the PNCal on the basis of phytosociological criteria. Therefore the MNBC suggested the eradication of *A. halimus* from the territory of the PNCal in the same way as the notorious invasive species *Carpobrotus edulis* in Mediterranean (Affre et al., 2010). However, the composition of the soil near the coastal road in the PNCal was definitely altered by slag deposits from past industrial activities from the 19th to the mid-20th century (Laffont-Schwob et al., 2011; Daumalin and Laffont-Schwob, 2016), and it has been demonstrated that stands of spontaneous *A. halimus* phytostabilize these polluted soils, preventing soil erosion, diffuse pollution and contamination of the food web (Rabier et al., 2014).

This turns to a cornelian dilemma for the PNCal between plant conservation including invasive plant eradication and maintaining pollution management to prevent pollutant transfer to terrestrial and sea biocoenosis. Therefore, a set of effective parameters has been examined to provide decisional criteria for the PNCal.

1.2. Methodological approach

A genetic approach for the study of the PNCal *A. halimus* populations would be too expensive, time-consuming and probably not effective for determining the autochthonous status or not of these populations. In addition to showing high genetic variability (Abbad et al., 2004; Ortíz-Dorda et al., 2005), local populations may have been subject to microevolution processes due to the driving force of high MM pollution, as has been recently proven for another pseudo-metallophyte (Słomka et al., 2011).

An ecological approach on life traits may be more accurate to evaluate the potential of invasiveness of this species on a specific territory. *A. halimus* mainly spreads via seeds that may be transported by animals, air or water and, to a lesser extent, can propagate vegetatively (Walker et al., 2014). A potential spread of this species at the expense of other native plant species, especially rare ones, needs to be taken into account. Therefore the invasiveness potential may be evaluated as the ability of this species to germinate and grow in soil conditions differing from those in which its currently develop. While the tolerance of *A. halimus* to MM in coastal areas has been demonstrated previously on older *in situ* individuals, no information is available on its capacity to establish on the more or less polluted soils of this territory. More scientific information on the ecological preferendum of *A. halimus* is thus necessary. As a first step, the ability of local *A. halimus* populations to germinate and grow on various soils from the PNCal territory needs to be assessed. Therefore, an *ex-situ* experiment was conducted in laboratory on the germination, seedling growth and MM accumulation capacities and on chemical and ecological traits of *A. halimus* in various PNCal soils. The results are discussed in a global perspective to propose a methodological approach for the selection or keep up of non-native or potentially invasive plant species in polluted protected areas.

2. Materials and methods

2.1. Study area and soil sampling

The current PNCal territory was the site of metallurgical and chemical industrial activities from the mid-19th century until the beginning of the 20th century. Silver–galena ore was treated by pyrometallurgical processes during this period (Daumalin and Raveux, 2016). The former Escalette factory (in operation from 1851 to 1924) was the one that had the most intensive activity in the area. The factory, located on the lower slopes of a hill, was characterized by a horizontal smelter chimney as the condensing system. The ruins of this chimney are still present today. In well-constructed flues, the deposit could yield from 2% to 3%, while loss dispersed in the smoke could amount to around 10% of the lead produced in the ore, depending on its quality (Percy, 1870). Slag was deposited on the old factory site, but was also scattered along the coast in several main deposits and as roadfill. Six sites were selected for this study (supp. data 1), located in the peri-urban area of Marseille, south-east France, i.e. Calanque de Saména (SA, 43°13.749′ N; 5°20.960′ E) and Calanque des Trous (TR, 43°13.233′ N; 5°20.766′ E), corresponding to soils from moderately polluted seashore sites where *A. halimus* grows spontaneously; Escalette Chimney (E.C, 43°13.584′ N; 5°21.320′ E) and Escalette Slagheap (E.S, 43°13.454′ N; 5°21.126′ E), corresponding to soils from the former Escalette smelter heavily polluted by two different steps of the smelting process; Cap Croisette (CC, 43°12.812′ N; 5°20.899′ E), a site exposed to very low pollution and seaspray; Sormiou (SO, 43°12.806′ N; 5° 24.964′ E), a site exposed to very low pollution and no seaspray; and in order to have a reference condition, was chosen as a control substrate a loamy horticultural soil (CN, mixture of peat moss, sphagnum peat moss, wood fiber and plant cultivation support composted with NPK 8-2-7, Botanic®). The areas were chosen on the basis of previously published data on metal and metalloid contamination in the PNCal area (Laffont-Schwob et al., 2016) and according to similar physico-chemical characteristics of the soils (except level of MM contamination). All soils are pooled samples of