Environmental Pollution xxx (2013) 1–8

Contents lists available at SciVerse ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Phytoremediative urban design: Transforming a derelict and polluted harbour area into a green and productive neighbourhood

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ARTICLE INFO

Article history:
Received 11 January 2013
Accepted 27 January 2013

Keywords:
Phytoremediation
Post-industrial
Research by design
Urban transformation

ABSTRACT

Many urban areas are polluted by industrial activities and waste disposal in landfills. Since conventional soil remediation techniques are costly and unsustainable, phytoremediation might offer an alternative. In this article, we explore how phytoremediation can be integrated into the transformation of urban post-industrial areas, while improving public space. Buiksloterham, a polluted and deprived industrial area in Amsterdam, serves as case study. Buiksloterham is polluted with heavy metals, with Zinc (Zn) concentrations being the highest. A regression-model for Alpine Pennycress (*Thlaspi caerulescens*) is used to estimate the time needed to remediate the site. This reveals a conflict in time between remediation and urban development. A research by design experiment shows how to overcome this conflict by dealing with polluted soil innovatively while emphasizing spatial and aesthetic qualities of the phytoremediation plant species. The resulting landscape framework integrates phytoremediation with biomass production and gives new ecological, economic and social value to Buiksloterham.

1. Introduction

Urbanisation and industrialisation have had a negative effect on the soil quality, resulting in 3.5 billion potentially polluted sites in the European Union (European Commission, 2006). Accumulation of pollutants can hamper the different soil functions and can become a risk to plant, animal and human health. Remediation of polluted sites is needed to prevent pollutants from leaching into the groundwater or pollutant uptake by food and or feed crops. Conventional remediation techniques are engineering-based and include excavation and disposal of polluted soil into a landfill, excavation and off-site treatments, on-site treatments and containment of polluted soils by plastic, pavement, or a layer of clean soil preventing contact with the polluted soil layer. Remediation by excavation, transportation and treatment are expensive, while containment has negative environmental effects (Scalenghe and Marsan, 2009). Phytoremediation, a technique in which plants are used to remediate polluted sites, might offer a good alternative to the conventional engineering-based remediation techniques. Phytoremediation is the use of plants and their associated microbes for remediation of polluted environments. The technique is based on naturally occurring processes within the plant itself or in its microbial rhizosphere to extract, degrade and/or stabilize organic and inorganic pollutants (Pilon-Smits, 2005).

The feasibility of phytoremediation was tested in Buiksloterham, a polluted and deprived industrial area in Amsterdam-North (Fig. 1). Buiksloterham used to be a part of the IJ-lake and was used as a landfill for polluted dredge out of the canals. In 1850 it was reclaimed as agricultural land. Since 1900 industrialisation led to the formation of the docks and settlement of harbour industries, later being replaced by road-oriented industries. Harbour industries as ship wharfs like ‘Ceuvel de Volharding’ have been replaced by metal processing industries, concrete cement industries such as the ‘Hollandse Beton Groep’ and chemical industries such as ‘Shell’. Since these industrial activities have decreased the last decades, vacant, polluted and abandoned parcels are now abundant in Buiksloterham. The municipality of Amsterdam wants to transform the area into a mixed residential-commercial area, which implies redevelopment of public space and infrastructure, development of the urban program and remediation of the polluted soil. Given the current economic situation no fixed master plan for the transformation is made, but instead a set of rules for a gradual transformation in time is set up. As a result the transformation is highly uncertain, leaving vacant and polluted parcels abandoned, waiting for future investments and costly remediation. Therefore the objective of this research is to explore how phytoremediation techniques can be introduced into the

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http://dx.doi.org/10.1016/j.envpol.2013.01.033

Fig. 1. Buiksloterham a deprived and polluted industrial area in Amsterdam-North along the IJ-lake (Theuws and Wilschut, 2009).

transformation of Buiksloterham and how these techniques can be combined with biomass production to create a (temporal) productive and attractive public space. In order to do so, we used a landscape design approach to translate scientific knowledge on phytoremediation into a spatial composition. The use of phytoremediative plant species in an aesthetic pleasing composition can also improve both the ecological and spatial qualities of Buiksloterham. The presented spatial composition for Buiksloterham can contribute to what Nassauer and Opdam (2008) call knowledge innovation. The results of this research will provide a link between science and practice and can serve as an example for a possible common base for future scientific and socio-economic research and discussion on phytoremediation.

2. Material and methods

2.1. Literature study on phytoremediation

To gain insight in the concept of phytoremediation a literature study was done. Compared to conventional remediation techniques phytoremediation has low capital and operating costs, the plant biomass can serve as bio-energy resource, it can serve as temporal or permanent treatment solution, it is applicable for a variety of pollutants and is aesthetically pleasing. The most important disadvantages are the parameter of time, the limiting applicability for a mix of pollutants, possible toxic effects to plant species due to high concentrations of pollutants and its limitation to the root zone of the plant species. Also limited economic and performance data as well as unfamiliarity of the concept by governmental institutions hamper the practical implication of phytoremediation (McCutcheon and Schnoor, 2003, Raskin and Ensley, 2000). The term phytoremediation describes a range of naturally occurring physical and biological processes in the plant and its rhizosphere. It is based on stabilization strategies to prevent migration of pollutants due to absorption on or in the root zone of a plant (phyto-stabilisation), prevention of infiltration of rainwater due to a vegetative cap with a high transpiration rate (phyto-cap) or the creation of an upward groundwater flow due to uptake of large amounts of groundwater using plants (hydraulic buffer). Degradation strategies are based on breakdown of organic pollutants by microbes in the root zone of the plant (rhizo-degradation), absorption of pollutants onto the root zone of a plant by microbiological activities (rhizofiltration) and precipitation of pollutants into plant roots in an aquatic environment (rhizofiltration/constructed wetlands). Degradation strategies are based on internal or external breakdown of pollutants by metabolic processes by enzymes produced by the plant (phyto-degradation), uptake of pollutants by plants and transpiration of those pollutants in volatile form (phyto-volatilization) and the uptake of pollutants by the plant roots and translocation of those pollutants into plant tissue above ground. Pollutants are removed by harvesting plant material (phyto-extraction) (Pilon-Smits, 2005, Schmidt, 2003). In reality these different processes occur simultaneously dependant on the plant species. However in the context of Buiksloterham the applicability to stabilize pollutants by creating hydraulic buffers, to degrade pollutants in an aquatic environment by constructing wetlands and to remove metal pollutants by phyto-extraction will be further studied in a research by design process.

2.2. Pollution levels and duration of phytoremediation

The municipality of Amsterdam provided soil quality reports of several parcels in Buiksloterham. From these reports soil characteristics (organic matter content, clay content, pH, density and porosity) and pollution characteristics (type of pollution and amount of pollution) were derived. The topsoil layer (0–0.5 m below ground level) is characterised as a sandy, slightly silty soil containing 4.8% clay and 3.7% organic mater. The average groundwater level fluctuates between 0.9 m and 1.5 m below ground level, due to an impervious dredge layer (Syneria, 2007). The soil quality reports indicated a mixture of pollutants and a variation in both the concentration as the spatial distribution of pollutants. Locally high concentrations of lead (Pb) (12,068 mg kg^{-1}), zinc (Zn) (10,952 mg kg^{-1}) and copper (Cu) (7729 mg kg^{-1}) were reported, probably as a result of former industrial activities. These activities also contributed to the pollution by PAK (polycyclic aromatic hydrocarbons up to 1188 mg kg^{-1}) and mineral oils (locally up to 240,000 mg kg^{-1}). Most reports however indicated relatively high concentrations of zinc, probably as a result of Buiksloterham being a former landfill.

Since soil quality reports were not available for all parcels in Buiksloterham and the available reports showed a great difference in the concentrations and spatial distribution of pollutants, we decided to base the estimation of the duration of phytoremediation on the average pollution concentrations. This assumption was supported by the soil-expert of the municipality of Amsterdam. This implied that zinc-concentrations (Zn) were assumed to be the main pollutant in Buiksloterham, since average zinc concentrations are highest (743 mg kg^{-1}), followed by lead (323 mg kg^{-1}) and copper (212 mg kg^{-1}) (Gemeente Amsterdam, 2012). For Buiksloterham to transform into a mixed residential-commercial area the concentrations of these heavy metals have to drop to 200 mg kg^{-1} (Zn), 210 mg kg^{-1} (Pb) and 54 mg kg^{-1} (Cu) (Gemeente Amsterdam, 2012).

To estimate the time to remediate Buiksloterham by phytoremediation *Thlaspi caerulescens*, a zinc-hyper accumulator was chosen as indicator species to lower the pollution in Buiksloterham. A regression model, used in previous studies (Koopmans et al., 2007) served as a practical tool to obtain an estimate of time *Thlaspi caerulescens* would need to lower zinc-concentration due to the process of accumulation towards the regulatory threshold set by the municipality of Amsterdam. Based on this time estimate an evaluation on the applicability of phytoremediation in Buiksloterham was done. Since the regression model only served to give an estimate of time, possible toxic effects of high concentrations of pollutants and the possible difficulty of removing a mixture of pollutants were not taken into account. The evaluation of the applicability of phytoremediation in Buiksloterham will serve as input for further process of research by design.

2.3. Research by design

In order to translate the results from the literature study and the feasibility study for phytoremediation into a spatial, site-specific, plan for the transformation of Buiksloterham a landscape-based research by design method is used. Research by design is an umbrella term for ways to link research and design (Duchhart, 2011). In this method, design is both a product and a process of deciding on the components and their spatial relations that form a spatial composition (Nassauer and Opdam, 2008). The process of design is an iterative process using mixed methods, in which, knowledge on phytoremediation, specific site characteristics and future programme are creatively integrated into a specific design. An analysis of present and future environmental quality regulations and land-use for Buiksloterham as set by the municipality, were mapped and combined with an analysis of the present spatial structure, context and visual perception of current site itself.

These results were overlaid with the results of the literature study and feasibility study for phytoremediation. This layered approach gave insight in possible conflicts and relations, but also exposed hidden qualities and potentials for future development (Theuws and Wilschut, 2009). In the process of design alternative concepts to integrate possible relations and to overcome the conflicts were explored in a cyclical manner. The different concepts were reflected onto the theoretical notions on future sustainable landscapes and urban environments (why should we do this) and, where possible, quantitative calculations or assessments were made (will it work). As such, the process of design can be positioned in the domain of applied sciences (Klaasen, 2007). The process aimed at producing innovative design strategies or concepts, which need further testing in practice. The design product can thus be seen as the accumulation of objective

Please cite this article in press as: Wilschut, M., et al., Phytoremediative urban design: Transforming a derelict and polluted harbour area into a green and productive neighbourhood, Environmental Pollution (2013), http://dx.doi.org/10.1016/j.envpol.2013.01.033