Ecological Engineering 64 (2014) 385–390

Contents lists available at ScienceDirect

Ecological Engineering

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

Distribution patterns of spontaneous vegetation and pollution at a former decantation basin in southern Québec, Canada

Dominic Desjardins[a,*], Werther Guidi Nissim[a], Frédéric E. Pitre[a], Alexandre Naud[b], Michel Labrecque[a]

[a] Institut de recherche en biologie végétale, Université de Montréal and Montreal Botanical Garden, Montréal, QC, Canada
[b] Centre de recherche du centre hospitalier de l'Université de Montréal, Montréal, QC, Canada

ARTICLE INFO

Article history:
Received 11 June 2013
Received in revised form
20 December 2013
Accepted 1 January 2014
Available online 1 February 2014

Keywords:
Pollution
Spontaneous vegetation
Distribution patterns
Partial redundancy analysis
Site-specific
Remediation

ABSTRACT

After industrial activities shut down, the brownfields remaining on abandoned sites are often left to revegetate naturally, a process that reflects the site's biotic and abiotic characteristics, including spatial pollutant distribution. The soil of a former decantation basin in Varennes (southern Québec, Canada) was systematically sampled and described in terms of concentration of PAHs (polycyclic aromatic hydrocarbons), PHs (petroleum hydrocarbons C_{10}–C_{50}), various trace metals as well as ruderal plant abundance and diversity. Partial redundancy analysis was used to investigate the effect of heterogeneous pollution on the plant community's spatial distribution. Up to 61% of variance in spontaneous plant distribution was explained by the pollutant dispersion pattern on the study site. These findings provide guidelines for the design of site-specific and within-site remediation or rehabilitation promoting natural processes that are already in progress. They also suggest using local vegetation and a greater diversity of plant species when conditions are conducive as this may have many associated benefits. The resulting design, which promotes development of the local plant community, can be a more cost effective and environmentally sustainable alternative to traditional plant-based remediation approaches.

1. Introduction

Industrial activities are a vital economic sector, valuable to local populations and governments around the globe. Industrial development is often associated with negative impacts such as the discharge of pollutants into the environment, partly due to inadequate sustainable development policies. Long after industrial activities on a site have ceased, a variety of heterogeneously distributed pollutants can remain (French et al., 2006). Commonly-found contaminants include complex organic compounds such as polycyclic aromatic hydrocarbons (PAHs) and petroleum hydrocarbons (PHs), as well as inorganics (trace elements). PAHs and PHs, characterized by fused benzene rings and long carbon chains, are generally highly lipophilic, although to varying degrees, and consequently have the potential to bioaccumulate in the food chain (Jones and de Voogt, 1999), resulting in human health issues even at low concentrations (Qing Li et al., 2006) to the point that some are classified as carcinogenic (Brady and Weil, 2010). Trace elements, unlike organic compounds, do not decay and may persist in the environment for an extended period (Järup, 2003).

When industrial activities are shut down, brownfields on the site are often left to revegetate spontaneously. Patterns of plant distribution resulting from this process reflect plant interactions with site characteristics, as plants seek out vacant and suitable niches (Treshow, 1980). Ruderal vegetation will therefore appear distributed in a spatial pattern corresponding to variation of the site's specific attributes, including water conditions, pH, soil structure and associated biotic and abiotic stresses (Osmond et al., 1987). It has also been observed that vegetation assemblages can reflect anthropogenic metalliferous soil contamination (Gallagher et al., 2008). Eventually, vegetation will spread to cover most of the area, contributing to soil rehabilitation (Gao and Zhu, 2003).

Observations regarding natural revegetation patterns on former industrial sites as well as precise information on pollutant distribution should be taken into account when determining an ecologically responsible and site-specific rehabilitation approach (Danh et al., 2009). Several, possibly native, plant species should be favored, according to the contamination of the site. Addressing degraded land issues in this way would maintain greater local biodiversity, in contrast to more common phytoremediation practices (which have traditionally used high-maintenance, short-term intensive

* Corresponding author. Tel.: +1 514 343 6111 #82352.
E-mail address: dominic.desjardins.1@umontreal.ca (D. Desjardins).

0925-8574/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ecoleng.2014.01.003

agricultural techniques including planting selected species) and hence provide ecological services adapted to site specificity. The use of a greater number of plant species would also lead to a greater diversity of associated soil microorganisms (Eisenhauer et al., 2010), resulting in possible more effective degradation of organic pollutants. The literature suggests that the interaction between plant and microbial communities within the rhizosphere is critical to remediation success and the use of diverse communities may further enhance this potential, but a specific understanding of function within the community is required before this can be achieved (Batty and Dolan, 2011).

Unstable heterogeneous environments (e.g. polluted sites) can be remediated in two main ways: imposed or self-organized (Mitsch and Jørgensen, 2003). The first, typical of many "conventional" phytoremediation approaches, may result in rigid plant assemblages with little potential for adaptation to changing conditions. Self-organization, which can be achieved by keeping the system open and allowing self-introduction of locally-present species, provides higher potential for adaptation (and resilience) to new situations (Mitsch, 1998). In addition, this approach fosters maintenance of native biodiversity and hence the ecological functions naturally performed on the site.

The aims of this study were to describe a former decantation basin in southern Québec (Canada) in terms of spontaneous vegetation distribution as well as organic compounds and trace elements in soil, and to evaluate whether pollutant distribution could explain variation in the distribution of spontaneous plant communities. Since plant tolerance to specific pollutants can vary by species, we hypothesized that distribution patterns of spontaneous vegetation in a former decantation basin could be partially explained by the distribution of contaminants in the soil. Information on conjoint variation in pollution and vegetation distributions could subsequently be used to develop a rehabilitation plan for a site such as the one we studied. Promoting presence of ruderal species within on-site zones where they appear to have found a suitable niche would enhance natural remediation processes already in progress towards an ecological and sustainable site rehabilitation. The originality of our research lies in the use of a statistical tool to produce a spatial distribution model of the site's pollution and vegetation. Such a model provides relevant information that can be used to not only enhance the cost-effectiveness and ecological character of traditional phytoremediation approaches, but also render them infinitely adaptable to varying site conditions and requirements.

2. Methods

2.1. Study area

The study area was located in the industrial zone of Varennes, few kilometres south of Montréal, Québec, Canada (45°40′N; 73°25′W). The site lies on the shores of the St-Lawrence River, the primary drainage conveyor of the Great Lakes Basin. It is flat land with a temperate climate (annual average temperature: 6.2 °C; annual precipitation: 978.9 mm (www.stat.gouv.qc.ca). While the chemistry and ecology of the site have been previously described in detail (Guidi et al., 2011), it is important to note that it once hosted primarily petrochemical activities, but was also used for ethanol and titanium dioxide pigment production. Currently, the industrial zone is surrounded mainly by agricultural activities.

Subsequent to industrial use, parts of the zone served as a sedimentation basins for various industrial wastes that had been generated on-site. Industrial activities ceased in 2008. One sedimentation basin was emptied and left opened to spontaneous revegetation (Fig. 1).

Fig. 1. Decantation basin area in Varennes, Canada. Quadrats for ruderal vegetation and soil sampling (0–30 cm depth) are located inside a former decantation basin (zone marked in red, 20 m × 22 m). Basins still in operation are visible. The surrounding area is characterized mostly by industrial activities. Image was taken before the beginning of the study while colonization of the former basin by ruderal plants was already ongoing.

2.2. Data sampling

In the summer of 2012, the basin's vascular plants were sampled systematically. Twenty (20) quadrats, each 1 m^2, were staked out on the site in order to represent the range of conditions observed. For each quadrat, the number of species and percentage of canopy coverage per species were recorded. A *Braun-Blanquet* (Braun-Blanquet and Springer-Verlag, 1951) canopy cover index was calculated for each species. Rare species (<5% cover) were excluded from data analysis. Each individual of the 23 species found on the site was identified to the species level, except those either missing reproductive parts essential to clear identification due to the season or poorly developed, probably as a result of poor soil quality (Table 1). The soil of each quadrat was sampled (0–30 cm depth) and analyzed by GC–MS for organics and ICP–MS for trace elements. We determined that a depth of 0–30 cm was appropriate, based on our investigation of root length of individuals outside the sampling quadrats. Data regarding organic compounds in soil was regrouped into petroleum hydrocarbons C_{10}–C_{50} (PHs) and polycyclic aromatic hydrocarbons (PAHs). PAHs were considered as a group rather than individually, for reasons explained below. The presence of 10 trace elements (Al, B, Cu, Cr, Fe, Mg, Mn, Ni, Pb, Zn) and basic soil properties was also recorded (Table 2).

2.3. Statistical analysis

We divided vegetation data into two sets in order to perform two analyses. First, to obtain an estimate of general plant distribution on the site, three parameters were considered for each quadrat i.e. species richness, percent canopy cover and α-diversity using Shannon's (H) index. The latter takes into account species richness and equitability (Peet, 1974). According to a previous study (Mouillot and Leprêtre, 1999), Shannon's index has been shown to have a lower root-mean-squared error (RMSE) for assemblages containing 10 or 25 species, which makes it an appropriate measurement tool for our study. We obtained the Shannon index with the *diversity* function of the *Vegan* R software package (http://vegan.r-forge.r-project.org/). A second data set contained abundance of each species separately.