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Altered vegetative assemblage trajectories within an urban brownfield

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High concentrationsof soil metals, impact the trajectory of vegetative assemblages in an urban brownfield leading to the speculation of an alternate stable state.

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ABSTRACT

Recognizing the growing importance of both structure (maintenance of biodiversity) and function (fostering natural cycles) of urban ecologies, we examine coarse scale (herbaceous, shrub and forest) beta guild trajectory in an urban brownfield. The distribution of the pioneer forest assemblage dominated by *Betula populifolia* Marsh. and *Populus* spp. could be correlated positively with total soil metal load (arsenic, cadmium, chromium, copper, lead, zinc, lead and vanadium),whereas herbaceous and shrub guilds were negatively correlated. Distinct assemblage development trajectories above and below a critical soil metal threshold are demonstrated. In addition, we postulate that the translocation of metals into the plant tissue of several dominant species may provide a positive feedback loop, maintaining relatively high concentrations of metals in the litter and soil. Therefore assembly theory, which allows for the development of alternate stable states, may provide a better model for the establishment of restoration objectives on degraded urban sites.

1. Introduction

Many post-industrial urban landscapes present the opportunity to convert brownfields into future open green spaces. However, before such restoration initiatives can be undertaken and reasonable objectives established, a clear understanding of urban ecology and a corresponding philosophy of restoration must be developed. In addition to typical competitive and facilitative biological interactions, assemblage development on degraded sites is often subject to the following three strong filters; a) the ability of plant diaspores to reach these isolated urban areas is reduced; b) the soil resources needed to establish and sustain plant growth are often limited; and c) toxic substances within the soil often exceed the tolerance threshold of many plant species (Wagner, 2004). This paper focuses on the latter of these filters and the resulting implications for assemblage development and the potential for alternate stable states.

Brownfield soils often contain trace metals such as arsenic (As), cadmium (Cd), copper (Cu), zinc (Zn), lead (Pb) and others, in concentrations above regulatory screening criteria (Dudka et al., 1996). While these elements can be adsorbed or occluded by carbonates, organic matter, iron magnesium oxides and primary or secondary minerals their soluble fractions create an effective abiotic filter that "can limit the establishment, growth and/or reproduction" (Adriano, 1986; Ross, 1994), of sensitive plant species. Plants that respond passively to increasing soil metal concentrations tend to allow accumulation of metals in the plant proportionate to the concentration in the external environment until, some threshold is reached, after which homeostasis or failure of growth ensues (Baker, 1981). Other species exclude metal ions from particular organs via active processes by sequestering metal ions in metallothioneins or phytochelatins (Vesk et al., 1999; MacFarlane and Burchett, 2000). In rare cases hyperaccumulation of metal ions is achieved through highly specialized physiological mechanisms that concentrate certain metals.

Under optimal growing conditions, when abiotic filters do not limit plant growth, it is probable that species interaction, specifically competition, contributes significantly to vegetative assemblage development (Lawton, 1987; Wilson and Gitay, 1995). However, the stress associated with polluted environments tends to favor species that exhibit resistance traits over species with strong competitive ability, relationships within these assemblages tend toward facilitation rather than competition (Wagner, 2004; Connell and Slatyer, 1977; Bertness and Callaway, 1994). Therefore under conditions of stress the corresponding vegetative assemblages may exhibit both structural and developmental differences.

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Ecological restrictions resulting in the presence, absence, or abundance of species can produce repeatable guild developmental patterns or trajectories (Wilson and Gitay, 1995). For example, Sanguer and Jetschke (2004) demonstrated that birch dominated the early colonization of a former uranium-mining dump. They argue that the early arrival of this metal-tolerant species alters the development sequence (i.e. birch – woodland vs. grass – herb assemblage) and that colonization by many other species may be delayed or totally inhibited. Such examples provide evidence for non-equilibrium or stochastic models of assemblage development where species transition is determined by both abiotic and biotic filters (Hobbs and Norton, 2004).

In this paper we describe the dynamics of coarse scale (i.e. beta guild) vegetation assemblages trajectory based on a sequence of aerial photographs of an urban brownfield known to have heterogeneous soil metal loading (Gallagher et al., 2008a). We hypothesized that assemblage trajectories had been influenced, if not directed, by soil metal contamination, which limited recruitment and or establishment of non-tolerant species from the regional species pool. We compared guild trajectories on soils with contrasting metal loads that had been isolated from human impacts for approximately 40 years. More specifically, we expected that beta guild trajectory would be distinctively different above and below a previously defined critical soil metal threshold (Gallagher et al., 2008b).

In addition, it may be possible for an ecological restriction to be reinforced through a feedback loop that is capable of operating on a large spatial scale (Belyea, 2004). Such feedback systems could result in an alternate stable steady state that is maintained for an unusually long period of time. In the Chihuahuan Desert, derelict agricultural fields exhibit soils with slow infiltration rates. The rainfall runs off rapidly and therefore the soils do not hydrate well. This results in drier conditions that produce sparse vegetation further decimating the soils, which results in increased evaporation from the soils (Suding et al., 2004). We postulate that such a feedback mechanism could exist in urban brownfield. Several metal tolerant plant species that exhibit passive or active uptake patterns are known to inhabit brownfields (Gallagher et al., 2008a; French et al., 2006). Should the resulting detritus maintain soil metals at concentrations that prohibit germination and/or growth of non-tolerant species the current metal induced ecological restriction could be reinforced.

2. Material and methods

2.1. Study area

The 251-acre (102 ha) study site is located within Liberty State Park on the west bank of Upper New York Bay at the Hudson Estuary (centered at 40°42′14″ N; 74°03′14″W). Prior to its development by the Central Rail Road of New Jersey (CRRNJ) the site was an intertidal mud flat and salt marsh. The area was filled using debris from construction projects and refuse from New York City and the surface was stabilized with cinder and ash typically used by the rail road. The industrial use of the site for commodity transport and storage, including coal, resulted in relatively high levels of soil metals. In 1967, the CRRNJ discontinued operations leaving the site isolated and undisturbed. Today the park consists of approximately 1100 acres, of which 251 remain undeveloped, fenced with limited access, which serves as the study site.

2.2. Soil sampling and spatial analysis

To determine the spatial distribution of metal contamination, soil samples were collected in triplicate from 32 sites representing the various vegetative assemblage types during the summer of 2005. Soil samples were collected with a hand spade or soil borer from the depth of the greatest root concentration. Depending on the vegetation type the samples were collected between 10 and 25 cm from the surface. The sites were also examined for depth of soil above the original rail yard fill by measurement of visual soil layering in the cores as contamination was associated with rail yard activity. In general, the bottom of the root zone correlated well with the top of the rail yard fill. The samples were examined for concentrations of arsenic (As), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), vanadium (V), and zinc (Zn) using Atomic Absorption Spectroscopy (AAS). Since all the metal data were positively skewed, 16 additional sites were sampled in 2006. In addition, to better define the site border areas, five sites were added to the eastern boarder of the study area. Finally, at the three sites with the highest metal load, four additional samples were taken (one in each compass direction at 20 m). Kriged maps with least mean error and root mean square error values were used to calculate area soil metal concentrations. The resulting contour maps were transformed into vector data and analyzed in ArcGIS environment. (see Gallagher et al., 2008a for details on soil sample analysis).

Individual soil data were kriged to estimate the distributions of soil metals. Block kriging was used to accommodate the considerable standard deviation found in the soil metal data (Stein, 1999). Since the metal data was highly skewed it was transformed before performing kriging. Logarithmic (McGrath et al., 2004) and rank order (Juang et al., 2001) transformations were used to normalize the data distribution and provide more stable variograms. The results were back-transformed using the reverse function of the linear regression between the original metal data and the ranks (Wu et al., 2006). To asses the performance of kriging on the differentially transformed data sets, the mean error (ME), rootmean square error (RMSE) and the coefficient of determination (r^2_p) were calculated and yielded acceptable results (see Gallagher et al., 2008a for details on performance evaluation).

Since the concentration of individual soil metals did not produce significant relationships when compared to either plant productivity or assemblage diversity the total soil metal load (TML) was determined by calculating the summation of the rank order transformation of the individual metal concentration as described by Juang et al. (2001). The spatial distribution of the data set was developed using the block kriging method and Surfer Surface Mapping Software (Release 8.0, Golden Software Inc., Colden, CO, USA), which compensates for the high standard deviation (Leenaers et al., 1990).

The resulting index provided a way to evaluate the cumulative soil metal load using a scale from 0–5 in 0.1 unit increments, with 5 indicating the highest cumulative soil metal concentrations. This metric was then used as a relative index of soil contamination. A critical TML threshold value of 3.0 was used as a benchmark for areas of high metal load as our previous work indicated that soil metals load above this level had a significant sublethal impact resulting in metal-induced stress on plant productivity, long-term growth and diversity (Gallagher et al., 2008b).

2.3. Soil metal distribution

The total soil metal load (TML) was unevenly distributed (Fig. 1a) and exhibited considerable local variation (Gallagher et al., 2008a). The concentration of As exceeded the Lowest Observed Effective Concentration (LOEC, Oak Ridge, 1997) at 20% and Pb at 16% of the sites. Cr exceeded the LOEC at most of the sites (80%). The other measured soil metals exceeded the LOEC at approximately half of the sites (Table 1).

2.4. Spatial vegetation classification

The variability in substrate materials combined with the undulating topography of the abandoned rail yard has created a patchy distribution of soils and cinders that has influenced plant colonization over the last 40 years. A unique mosaic of assemblage types exists within the study site (United States Army Corps of Engineers, 2004). The hardwood assemblage is composed primarily of Gray Birch (*Betula populifolia* Marsh.) (35% cover), Eastern Cottonwood (*Populus deltoids* Marsh.) (16% cover) and Quaking Aspen (*Populus. tremuloides* Michx.) (14% cover) (Gallagher et al., in press). Shrubs are dominated by three species of the genus *Rhus*; Staghorn Sumac (*R. typhina* L.), Smooth Sumac (*R. glabra* L.), and Winged Sumac (*R. copallinum* L.). Herb and grass assemblages are dominated by a mix of several native and non-native species: Goldenrod (*Solidago* spp.), Mugwort (*Artemisia vulgaris* L.), Switchgrass (*Panicum virgatum* L.), Chee Reedgrass (*Calamagrostis epigeios* L.) and Red Fescue (*Festuca rubra* L.) (all nomenclature after Gleason and Cronquist, 1991).

Historic true color aerial photographs from 1976, 1984, 1993, 1996, 2000, and a 1969 gray scale photograph, were scanned at 600 dpi and were geo-referenced in ArcGIS using a 2002 aerial photo (released by NJDEP, spatial resolution .3 m) as reference. The rectification resulted in less than 0.6 m RSM (root square mean) error for each of the photographs. In delineating the assemblages, three field-verified digital vegetation maps were used, the first from the 2003 United States Army Corp of Engineers (USACE) Liberty State Park Environmental Assessment (USACE, 2004) based on the 2002 NJDEP aerial photo, the second from a 1996 aerial photograph which was field verified during a park natural resource assessment (MacFarlane, 1996) and the third was the 2009 field survey. In addition, an early report (Texas Instruments, 1976) was also used to verify the 1976 digital vegetation map.

The 2003 vegetation map differentiated 12 alpha guilds based on species composition (Table 2). The alpha guilds were classified according to the Ecological Communities of New York State (Edinger et al., 2002). The identified assemblages ranged from successional northern hardwood to grasslands. Linear regressions between assemblage distribution (area ratios) and total soil metal load, indicate significant relationships within the successional northern hardwood ($r^2 = 0.62$, $p < 0.01$) and semi-emergent marsh ($r^2 = 0.49$, $p < 0.01$) (Gallagher et al., 2008a).