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Habitat structure influences below ground biocontrol services: A comparison between urban gardens and vacant lots

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ABSTRACT

Urban agriculture offers a framework for local self-reliance by provisioning food security, employment opportunities, and other community benefits. However, urban agriculture must rely on the supporting and regulating services of the soil food web. Hence, we quantified belowground biocontrol activity in urban gardens and vacant lots in two post-industrial cities using an in situ insect baiting technique. Due to the differences in habitat structure, we hypothesized that belowground biocontrol services will differ between gardens and vacant lots and the influence of habitat structure would differ with the type of biocontrol organism. Results revealed that biocontrol activity, as assessed by % mortality of baited insects, varied between 51% and 98% with higher activity often recorded in vacant lots than gardens. Major contributions to bait insect mortality were by ants, followed by microbial pathogens and entomopathogenic nematodes, respectively. Ants showed higher ($p < 0.0001$) % mortality in vacant lots (60% ± 33.4%) than in urban gardens (33.3% ± 22.2%) whereas microbial pathogens exhibited higher ($p < 0.0001$) mortality in gardens (27.8% ± 15%) than vacant lots (8.3% ± 16.7%). Ants caused higher ($p < 0.0001$) mortality when larger-mesh size cages were used compared with the smaller-mesh size cages, but mortality by microbial pathogens did not differ with cage type. The high biocontrol activity indicates the resilience of the soil food web in urban ecosystems and the differential effects of habitat structure on biocontrol activity can help guide landscape planning and vegetation management to enhance urban environments and boost local self-reliance.

1. Introduction

Urban agriculture offers a comprehensive framework for local self-reliance and resilience and a means to reducing the ecological footprint of cities (Grewal & Grewal, 2011). Interest in urban agriculture has escalated recently due to the accumulation of vacant land particularly in post-industrial U.S. cities (Callis & Cavanaugh, 2009) and motivation to address food insecurity and childhood obesity issues in disadvantaged urban neighborhoods. Urban agriculture can revitalize affected cities and neighborhoods by generating new employment opportunities, increasing access to healthy food and sustaining cities by forming closed-loop ecological systems with vacant spaces, waste water and solid waste as potential resources (Lorenz & Lal, 2009; Nugent, 1999). Indeed North American cities have the necessary resources to substantially increase their self-reliance in fresh produce and reduce local economic leakage (Grewal & Grewal, 2011). However, urban soils are highly disturbed due to anthropogenic activities such as compaction by heavy equipment, removal of top soil, atmospheric deposition of toxic compounds, heavy metal contamination, extensive fertilizer and chemical pesticide applications, de-icing salts, and other transport and industrial contaminants (Lohse, Hope, Sponseller, Allen, & Grimm, 2008; Pouyat et al., 2010) and pose a threat to biodiversity (Mcdonald, Kareiva, & Forman, 2008; Puppim de Oliveira et al., 2011). An important regulatory ecosystem service associated with biodiversity is natural pest control (Gurr, Wratten, & Luna, 2003) which can enable sustainable crop production (Naylor & Ehrlich, 1997; Ostman, Ekbom, & Bengtsson, 2003) without reliance on the use of toxic chemical pesticides. Hence, conserving natural pest and disease control services of the soil food web is crucial for minimizing human and environmental exposure to chemical pesticides and for enhancing local self-reliance through ecological design of urban ecosystems.

The natural enemy complex including predators, parasitoids, and pathogens have the potential to regulate pest populations and become a central part of integrated pest management strategy (Kogan, 1998). Enhancement of natural biological control has been suggested as a prime preventive tactic for pest management in recent literature (Isaacs, Tuell, Fiedler, Gardiner, & Landis, 2009;

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Letourneau & Bothwell, 2008; Schellhorn, Pierce, Bianchi, Williams, & Zalucki, 2008). However, studies on the occurrence of natural biological control agents and the extent of pest control services they render in urban soils are sparse. Additionally, due to differences in functional processes acting on fragmented landscapes (Byrne & Grewal, 2008; Pickett & Cadenasso, 2008), in depth ecological studies addressing small scale urban parcels/patches are needed.

We focused on belowground generalist biocontrol agents including ants, microbes and entomopathogenic nematodes which prey upon soil-dwelling stages of diverse insect pests affecting urban agriculture. Ant communities in urbanized ecosystems have been found to be vulnerable to urban development, fertilization and other vegetation management practices and occurrence of human/animal/vehicle traffic (Clarke, Fisher, & LeBuhn, 2008; Gotelli & Ellison, 2002; Lassau & Hochuli, 2004; Sanford, Manley, & Murphy, 2009). Though these studies have addressed species richness and abundance, the extent of biocontrol service provided has not been studied. Also few studies have addressed the effect of land use change on microbial communities. Diquelou, Roze, & Francez (1999) found that microbial activity tends to decline several years after establishment of agriculture. Scharenbroch, Lloyd, and Johnson-Maynard (2005) found that old residential landscapes had higher microbial biomass than new residential landscapes most likely due to greater time since disturbance. Similarly, Park, Cheng, McSpadden Gardener, and Grewal (2010) found that soil nematode food webs were relatively more structured in older parts of the cities than the more recently developed areas on the urban fringe. Though these studies show the influence of anthropogenic activities on the structure and diversity of invertebrate and microbial communities, enhanced understanding of pest regulation services they provide is critical for designing ecologically-based cultural practices for urban agriculture.

Therefore, the main aim of this study was to assess the extent of naturally occurring belowground biological pest control services in post-industrial cities which have accumulated substantial amounts of vacant land. We used an in situ baiting technique to quantify biocontrol activities in community gardens and vacant lots provided by the major groups of biocontrol agents known to provide belowground pest regulation services (Denno, Gruner, & Kaplan, 2008). As habitat structure, defined as the composition and arrangement of physical matter (Byrne, 2007), can regulate community structure by providing resources (shelter, nutrients, nesting sites) and mediating interactions (e.g. predation, competition) for a diverse array of organisms in many ecosystems (Bell, McCoy, & Mushinsky, 1990; Byrne, 2007; Tews et al., 2004), we tested if human modification of habitat structure would influence belowground biocontrol services rendered by invertebrate and microbial communities. Because habitat structure can differ considerably between urban gardens and vacant lots, we hypothesized that these two land covers would differ in the extent of belowground natural biocontrol services and the influence of habitat structure would differ with the type of biocontrol agent. Specifically, we hypothesized that vacant lots (which are left unmanaged following building demolition except for occasional mowing to keep the vegetation height short) would exhibit higher belowground biocontrol activity than urban gardens which possess heterogeneous, sparse, and relatively taller plant species and receive regular tillage, irrigation, weeding, and chemical fertilizer and pesticide inputs. The percentage mortality of the model bait insect was used as an index for biocontrol service/activity. We also hypothesized that ant predation would be more in vacant lots due to permanent ground cover with greater structural complexity, lower moisture content and minimal disturbance compared to gardens, whereas the reverse would be true for microbial pathogens which require high relative humidity and soil moisture for persistence and optimal activity.

2. Methods

2.1. Study sites

Twenty two urban gardens and twenty three vacant lots were studied for belowground biological insect control services provided by soil invertebrates and microorganisms over a two year period in two post-industrial Ohio cities, Akron (41 05′05″N, 81 30′56″W) and Cleveland (41 29′58″N, 81 41′37″W). The two cities have average monthly temperatures of −4 °C in January and 22 °C in July and average annual precipitation of 91.9–101.3 cm. We identified six community gardens and six nearby (within 1 mile) vacant lots in Akron and seven urban gardens and seven nearby vacant lots in Cleveland for sampling during July and August in 2009. Additionally, nine new community gardens and ten new vacant lots in Cleveland were studied in July and August in 2010. The community gardens in Akron were established only in 2009 (i.e. were only 3–4 months old), whereas those in Cleveland were much older (the majority being 15–30 years old). We used the word 'vacant lot' to represent the larger urban context for these spaces from which houses had been demolished and the building footprint had been re-colonized by natural and weedy species over time.

Site addresses, soil texture, soil pH and % organic matter for all gardens and vacant lots are given in Table 1. In general, soil texture and pH conditions varied substantially but randomly in urban gardens and vacant lots of Akron and Cleveland. Soil organic matter however, tended to be higher in urban garden sites as compared to vacant lots most likely due to compost amendments.

These community gardens and vacant lots differed in two key components of habitat structure: heterogeneity and complexity. The gardens were more heterogeneous with respect to composition and arrangement of vegetation than the vacant lots, whereas vacant lots had more complexity than gardens in the volume and numbers of distinct leaves of grassy and weedy species. The commonly planted species of vegetables and fruits in the community gardens were: *Solanum lycopersicum* (tomato), *Solanum tuberosum* (potato), *Daucus carota* (carrot), *Cucurbita pepo* (zucchini), *Cucurbita mixta* (pumpkin), *Lactuca sativa* var. *longifolia* (romaine lettuce), *Capsicum annuum* (bell pepper), *Cucurbita moschata* (squash), *Phaseolus vulgaris* (beans), *Brassica oleracea* (cabbage), *Brassica oleracea* (broccoli), *Rubus idaeus* (raspberry), *Vitis vinifera* (grape), *Spinacia oleracea* (spinach), *Pisum sativum* (pea), Brassica *oleracea* var. *acephala* (cole), *Citrullus lanatus* (watermelon), *Cucumis melo* (cantaloupe), *Mentha sachalinensis* (mint), *Brassica oleracea* (cauliflower), *Prunus avium* (cherry), *Raphanus sativus* (radish), *Zea mays* (maize), *Allium sativum* (garlic), *Helianthus annuus* (sunflower), *Solanum melongena* (eggplant), and *Ipomoea batatas* (sweet potato). Most of these species were found in most gardens except for raspberry, grape, cherry and mint being found in fewer gardens. As expected these annual species were planted in distinct patches with only a few sparsely planted individuals of a single species per patch. The gardens were also regularly tilled, weeded, and irrigated but had no pesticide inputs except for occasional fertilizer applications.

In contrast, the vacant lots were typically covered in grassy and weedy species and were occasionally mowed to look like urban lawns. Twenty of the 23 vacant lots were predominantly covered in turfgrass and associated weedy species such as *Poa annua* (annual bluegrass), *Digitaria ischaemum* (smooth crabgrass), *Festuca arundinacea* (tall fescue), and *Taraxacum officinale* (dandelion), and appeared to be mowed frequently. Two vacant lots in Akron were predominantly covered with weedy species, including *Trifolium pratense* (red clover), *Plantago lanceolata* (plantain), *Trifolium repens* (white clover), *Dactylis glomerata* (orchardgrass), *Daucus carota* (wild carrot), and *Cichorium intybus* (chicory), and also appeared to be mowed occasionally. Finally, one vacant lot