Environmental Pollution 197 (2015) 256–261

Contents lists available at ScienceDirect

Environmental Pollution

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

Nitrogen and carbon export from urban areas through removal and export of litterfall

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ARTICLE INFO

Article history:
Received 10 July 2014
Received in revised form
27 October 2014
Accepted 15 November 2014
Available online 27 November 2014

Keywords:
Ecosystem model
Litter removal
Nutrient sources and sinks
Urban nutrient cycling

ABSTRACT

We found that up to 52 ± 17% of residential litterfall carbon (C) and nitrogen (N; 390.6 kg C and 6.5 kg N ha^{-1} yr^{-1}) is exported through yard waste removed from the City of Boston, which is equivalent to more than half of annual N outputs as gas loss (i.e. denitrification) or leaching. Our results show that removing yard waste results in a substantial decrease in N inputs to urban areas, which may offset excess N inputs from atmospheric deposition, fertilizer application and pet waste. However, export of C and N via yard waste removal may create nutrient limitation for some vegetation due to diminished recycling of nutrients. Removal of leaf litter from residential areas disrupts nutrient cycling and residential yard management practices are an important modification to urban biogeochemical cycling, which could contribute to spatial heterogeneity of ecosystems that are either N limited or saturated within urban ecosystems.

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1. Introduction

In northern temperate ecosystems, deciduous trees drop their leaves during the fall season in response to cooling temperatures to avoid damage caused by over-winter stress (Chabot and Hicks, 1982). In undisturbed rural areas, leaves decompose on the forest floor and nutrients are released, enabling efficient internal recycling of the majority of nutrients with only a small amount typically lost to nearby waterways or as gases to the atmosphere (Bormann and Likens, 1967; Likens and Bormann, 1995). In rural areas disturbed by humans, activities such as stem-cutting can reduce rates of litterfall (Gairola et al., 2009). In contrast, less is known about the controls on litterfall production and litter-derived nutrient cycling within urban areas (Michopoulos, 2011), including the influence of landscape management choices on these processes. In this study, we sought to determine how much C and N is exported via litter removal out of the City of Boston during the fall leaf litter collection period.

Several studies have examined biogeochemical processes in forest patches in urban environments (e.g., Groffman et al., 2006; Pouyat and Carreiro, 2003; Michopoulos, 2011), suggesting that complex and sometimes counter-balancing factors may control the patterns of leaf litter production in urban landscapes. For instance, while rates of litterfall production were shown to decrease with increased impervious area in Washington state (Roberts and Bilby, 2009), soil fertility was a more important predictor of litterfall production around Baltimore, Maryland (Groffman et al., 2006). To our knowledge, no study has examined litterfall in the developed portions of the urban landscape (e.g., highly urban residential areas), nor the effects on nutrient recycling that are caused by gathering of litterfall from trees by urban residents and landscapers. These activities represent a potentially large export of C, N and other nutrients from urban landscapes, which may disrupt ecosystem recycling of nutrients and carbon.

Urban areas around the world are growing in land area and population and their effect on ecological processes is being increasingly recognized (Pickett et al., 2011; Kaye et al., 2006; Gregg et al., 2003; Metson et al., 2012; Pouyat et al., 2006, 2008; UNDESA, 2008; Hutyra et al., 2014). New and existing urban areas will account for most of the world's population growth over the next 40 years (Seto et al., 2012). Within the United States the transformation of forests by urbanization will be most pronounced in the northeastern U.S., where four states (Rhode Island, New Jersey, Massachusetts and Connecticut) are projected to have more than 60% of their forestland converted to urban land use by the year

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http://dx.doi.org/10.1016/j.envpol.2014.11.016
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2050 relative to 1992 levels (Nowak and Walton, 2005). Urbanization often occurs at the expense of natural areas, but urban areas can still contain considerable tree canopy cover and biomass stocks. Raciti et al. (2012) found that mean biomass inside the Massachusetts portion of the Boston Metropolitan Statistical Area (MSA) was 72 Mg C ha^{-1}, compared to a Massachusetts statewide wide mean of 84 Mg C ha^{-1} and to rural forests with a mean of 117 Mg C ha^{-1}. Even the highly urbanized City of Boston, with a population density of almost 5000 people km^{-2}, contain 26% tree canopy cover and 29 Mg C ha^{-1} of tree biomass (Raciti et al., 2014).

Similar to other states in the U.S., Massachusetts mandates that yard waste be recycled. The Massachusetts Department of Environmental Protection (MassDEP) enacted a law in 1991 (310 CMR 190.017) banning incineration or transfer of yard waste (including leaves from trees, grass clippings, weeds, hedge clippings, garden materials and brush) to traditional landfill sites. Residents are encouraged to compost litter or place it in large paper bags or open barrels at their curb-side for pick-up. The City of Boston collects yard waste for six weeks in the fall (mid-October through November 30 each year) and four weeks in the spring of each year (typically end of April through end of May). Residents in the City of Boston recycled 8000 tons of yard waste in FY 2007 (City of Boston, 2007). Yard waste is transported to municipal compost piles and eventually applied to community gardens and/or sold for commercial use.

In this study, we sought to determine how much C and N is exported via litter removal out of the City of Boston during the fall leaf litter collection period and to relate N export from litterfall removal to other ecosystem N fluxes. We examined three census block groups, each in a different neighborhood within the City of Boston, and measured canopy cover, total litterfall mass, litter C and N concentrations, as well as mass and proportion of C and N exported as yard waste.

2. Methods and materials

We monitored the number and mass of yard waste bags left at the curbside for collection in one census block group in each of three neighborhoods in the City of Boston, MA (Fig. 1) over one complete fall yard waste collection season (October 18 to Nov. 26, 2010). The neighborhood census block groups (hereafter referred to as "neighborhoods") in Allston, Mission Hill, and Jamaica Plain were predominantly residential (>80% by land area compared to City of Boston at 42% residential; Massachusetts Office of Geographic Information [MassGIS], http://www.mass.gov 2009) and contained 93, 112, and 122 individual parcels, respectively.

We visited each parcel weekly, just prior to yard waste collection, and recorded the number of yard waste bags placed at the curbside and the approximate proportion that each bag was filled with leaves (e.g., 25, 50, 75, or 100% by volume). To convert bag counts to total dry mass of leaf litter, we collected three loosely packed and three tightly packed yard waste bags (all considered 100% full) and determined that the mean dry mass of litter in these "full" bags was 3.01 ± 0.48 kg. Partially filled bags were presumed to have a dry mass that was directly proportional to their fullness. The total dry mass of leaf litter exported from each parcel was estimated based on the total number and fullness of bags placed at the curb for collection over the course of the fall season.

We collected samples of litter from a subset of yard waste bags in each neighborhood (n = 24, 12, and 13 parcels for Allston, Mission Hill, and Jamaica Plain, respectively) to determine the average concentration of C and N in leaf litter across the three neighborhoods. We limited our litter analysis to Norway maple

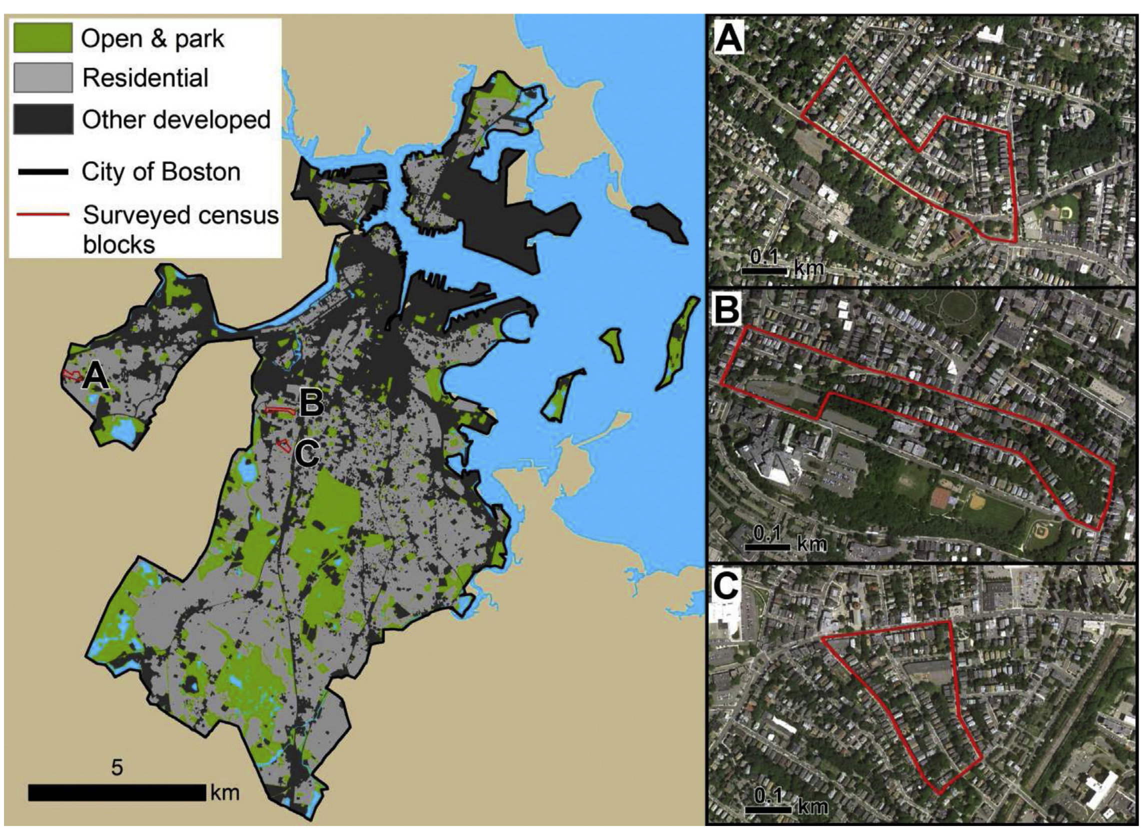

Fig. 1. Map of the City of Boston. Insets include census block groups surveyed within the neighborhoods of (A) Allston, (B) Mission Hill and (C) Jamaica Plain.

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