Variation in quality and decomposability of red oak leaf litter along an urban-rural gradient

Abstract  This study tested whether urban land use can affect the chemistry and decomposability of *Quercus rubra* L. (red oak) leaf litter in forests within and near a large metropolitan area. Cities may affect the quality of leaf litter directly through foliar uptake of atmospheric pollutants, and indirectly through alterations in local climate and changes in soil fertility caused by pollutant loads and altered nutrient cycling regimes. Using a microbial bioassay, we tested whether red oak leaf litter collected from urban and suburban forests in and near New York City differed in decomposability from litter of the same species collected from rural forests 130 km from the city. We found that oak litter from the urban forests decayed 25% more slowly and supported 50% less cumulative microbial biomass in a laboratory bioassay than rural litter. Rural litter contained less lignin and more labile material than urban litter, and the amounts of these chemical constituents were highly correlated with the decay rate coefficients and integrated microbial growth achieved on the litter. The specific causes of the variation in litter chemistry are not known. The results of this study suggest that decomposer activity and nutrient cycling in forests near large cities may be affected both by altered litter quality and by altered biotic, chemical and physical environments. The sensitivity of the microbial bioassay makes it useful for distinguishing differences in within-species litter quality that result from natural or anthropogenic variation in the environment.

Key words  Leaf litter quality 7 Forest litter decomposition 7 Urban land use 7 Microbial bioassay 7 *Quercus rubra*

Introduction

Plant litter is an important component of terrestrial ecosystems because it supports diverse decomposer food webs and because it is a reservoir for many nutrients needed to support primary production (Swift et al. 1979; Aber and Melillo 1991). The release rate of these nutrients during decay depends on three factors: climate, the species composition and activity levels of the decomposer community, and the physical and chemical quality of the litter. Cities may affect decomposition processes in natural systems within their boundaries by altering all of these factors. Urban and suburban land use may change the local climate (e.g. urban heat islands; Oke 1995), and may provide foci for the introduction of exotic plant and decomposer species into surrounding natural areas (Sukopp and Hejny 1990; Rapoport 1993; Steinberg et al. 1997). Moreover, urban areas are acknowledged sources of a diverse array of atmospheric pollutants that can affect decomposition and nutrient return rates by changing vegetation abundance and diversity, and by changing decomposer activity by direct pollutant deposition (Bewley and Parkinson 1984; Baath 1989; Francis 1989; Smith 1990). Fewer studies have explored whether air pollutants can also affect litter decay rates and growth of decomposer organisms indirectly by altering the properties of the living leaves that later enter the plant detritus pool (Prescott and Parkinson 1985; Garden and Davies 1988; Findlay et al. 1996). Such changes can occur through foliar uptake of pollutants (Constantinidou and Koz-
lowski 1979; Garten and Hanson 1990; Latus et al. 1990; Jordan et al. 1991), through altered patterns of soil-nutrient uptake (Flanagan and Van Cleve 1983; Haines and Carlson 1989) or through modifications of plant metabolism (Smith 1990).

Urban and suburban areas in the United States have been expanding rapidly since the 1950s (Richards 1990; Douglas 1994). Between 1960 and 1990, 31 million acres of cropland, forest, and pasture in the United States were converted to urban and suburban land use (Frey 1984; Dougherty 1992). This makes it important to evaluate the extent to which urban areas in the United States can affect ecosystem processes in natural systems within and near their boundaries and, where possible, to identify the mechanisms involved. New York City provides an excellent “natural laboratory” for studying the possible cumulative effects of urban environments on ecosystem processes like decomposition, since it has large remnant forests that have been subjected to altered land use, climate, and atmospheric chemistry over many decades. Recently forest stands in New York City have been studied and compared to similar forests in outlying suburban and rural areas to determine whether urban conditions can affect natural communities and ecosystem functions (Pouyat and McDonnell 1991; Pouyat et al. 1994; Pouyat et al. 1995; McDonnell et al. 1997).

The objective of the present study was to determine whether an urban environment can alter the leaf litter quality of a regionally abundant tree species, in this case Quercus rubra L. (red oak). We collected red oak leaf litter from forest stands located along an urban-to-rural land-use gradient in the New York City area and assayed the litter for specific chemical constituents known to influence decay rates (Melillo et al. 1982). We also used a microbial bioassay to detect whether differences in decomposability existed among the urban, suburban and rural litters. Microbial sensitivity to qualitative differences in the litters was assessed by measuring fungal and bacterial biomass responses to the leaf litter incubated in the laboratory, respiratory CO2 evolution from filtered inoculum and the litter discs were brought up to the same weight) of combined leaves was blended in 600 ml sterile deionized water, and large particles were removed by filtering through a 250-μm nylon mesh screen. Each vial received 0.5 ml of this pre-filtered inoculum and the litter discs were brought up to the same (300%) moisture level with sterile deionized water. The capped vials were placed in racks and covered with plastic bags that contained wet paper toweling to keep the air around the vials humid. The vials were incubated at 20°C in the dark for up to 150 days.

Litter chemistry

Indices of initial litter quality were obtained as follows. Lignin, cellulose, hemicellulose, neutral detergent fiber (NDF, which includes lignin and structural carbohydrates like cellulose and hemicellulose) and acid detergent fiber (ADF, which includes lignin and cellulose) were assayed using the method of Van Soest et al. (1991). Three one-grain replicates per site were used for these analyses. Percent C and N of the milled leaf litter samples (2–3 replicates per site) were determined using a Carlo-Erba CHN analyzer. Unbound and bound phenolics were assayed using Folin-Denis reagent as described in Findlay et al. (1996). Unbound and bound phenolics were defined as phenolics that were extracted from leaves after mild (5°C, 18 h) and more stringent (70°C, 2 h) extraction with 70% CH3OH, respectively. Tannin was quantified using the method of Dawra et al. (1988).

Materials and methods

Site descriptions

The forest stands selected for this study are located along a 130 km by 20 km belt transect extending from urban Bronx, New York, through suburban Westchester County, New York, and into rural Litchfield County, Connecticut. To minimize variation in site variables not related to surrounding land use, we used the following criteria to select 11 forest stands: (1) domination (40–80% of total basal area) by red oak and/or Quercus velutina Lam. (black oak), both in the subgenus Erythrobalaninus; (2) soils in either of two series (Hollos or Charlton), which are classified in the same soil family (Gonick et al. 1970); (3) stand age of at least 70 years; and (4) no evidence of recent natural or human disturbance (canopy gaps, insect infestations, fire, logging). The urban stands were located in the New York Botanical Garden (N2, N3), Van Cortland Park (V3) and Pelham Bay Park (P1). The suburban stands were located in Sauganash Woods Park, N.Y. (S1, S2) and Mountain Lakes Park, N.Y. (M3). The rural stands were located in Mohawk State Forest, Conn. (MF1, MF3) and Housatonic State Forest, Conn. (H1, H3). More information about the land-use gradient and these forest stands can be found in Pouyat et al. (1995), Medley et al. (1995) and McDonnell et al. (1997).

Litter collection and preparation for the bioassay

Leaves were collected in litter traps placed in each of the 11 plots along the urban-rural transect in autumn 1990. Leaves were collected within a few days of falling, air-dried and stored at room temperature. Red oak leaves were selected for this experiment. However, it is possible that some leaves of black oak may have been included in samples from three plots (P1, S1 and S2) where it was present. Leaves of black and red oak are difficult to distinguish, particularly since the two species are in the same subgenus and hybridize (Gleason and Cronquist 1963). As seen in subsequent analyses, where mixing may have occurred there was no tendency for these three plots to group together in any unexpected manner when foliar chemistry and decay parameters were plotted against distance from Central Park. However, data concerning relationships of litter chemistry and decomposability with distance from New York City have been analyzed and reported in two ways: using all 11 plots and using only 8 plots (i.e. excluding P1, S1 and S2).

Uniform leaf discs (6 mm diameter) were punched from the leaf blades. Leaf petioles and main veins were excluded from this experiment, and no more than 25 discs were cut from any single leaf collected from a stand. Two hundred discs were placed in each of 24 vials (100×23 mm) per stand, and their air-dry weights obtained to 0.01 mg. Other leaf discs were weighed to determine the air-dry weight to oven-dry weight correction factor for each stand. Additional leaf discs were ground in a Wiley mill and used for chemical analyses.

On the day before the start of the bioassay, oak leaf litter was collected from the forest floor of each plot in the land-use gradient. Equal fresh weights of leaf litter from each stand were combined as inoculum for the bioassay since microbial diversity in the litter might have differed among stands. A total of 8 g (fresh weight) of combined leaves was blended in 600 ml sterile deionized water, and large particles were removed by filtering through a 250-μm nylon mesh screen. Each vial received 0.5 ml of this pre-filtered inoculum and the litter discs were brought up to the same (300%) moisture level with sterile deionized water. The capped vials were placed in racks and covered with plastic bags that contained wet paper toweling to keep the air around the vials humid. The vials were incubated at 20°C in the dark for up to 150 days.