Chapter 12

Lawns as Common Ground for Society and the Flux of Water and Nutrients.

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In Brief

- Lawns and residential lands are an important and increasing land cover and land use type, and there is great concern about its ecological value and environmental performance.
- Long-term integrated social-ecological studies show that the socio-ecology of lawns and residential land use are much more complex than originally thought.
- Lawns are less intensively managed, and have produced less nitrogen pollution of water and air than originally expected by BES investigators.
- Long-term studies of lawns and residential lands have facilitated integration between biophysical and social science research within the BES.
- Long-term studies of lawns and residential lands have produced results that can improve the environmental performance of urban ecosystems and landscapes.
- Novel methods have been required to examine social-ecological dynamics of residential land uses because of the fine-scale, spatial heterogeneity of urban areas. These methods include: hi-resolution characterization of landcover; integration with demographic, social, economic, and built data; and characterizing individual property parcels with these physical, biological, social, and built data.

Introduction

Lawns and residential lands are two of the most obvious components of urban ecosystems. While urban ecosystems are a heterogeneous and variable mix of paved surfaces, trees, shrubs, and grass, grass itself is a dominant land cover, representing 20 – 30 % of typical residential parcels. There are over 150,000 km^2 of lawns in the U.S. This is larger than the area of any irrigated crop in the U.S. and is roughly equal to the area of the "northern forest" of northern Maine, New Hampshire, Vermont and New York.

Early ideas about lawns in the Baltimore Ecosystem Study were rooted in theory and data relevant to highly disturbed, heavily managed ecosystems with significant inputs and outputs to surrounding environments such as agricultural ecosystems. Early ecological analyses of lawns focused on concerns about their environmental performance, especially outputs of nutrients and pesticides and intensive use of energy and water. These analyses also addressed some of the social-ecological aspects of lawns and residential lands with ideas about the benefits (ecosystem services) that people derive from lawns and some of the philosophical, emotional, social, and political motivations behind the establishment and maintenance of lawns.

More recently, we have attempted to use theories and concepts from grasslands and rangelands in our studies of lawns, developing the term "urban grasslands" which we define as "ecosystems dominated by turf-forming species created and maintained by humans for aesthetic and recreational (not grazing) purposes." We use this term to indicate that urban grassland ecosystems cover significant areas and have coherent patterns of ecosystem processes that can be evaluated with the same approaches used to study other ecosystem types e.g., forests, rangelands, prairies.

While ecologists have paid some attention to lawns over the past 50 years, other disciplines have paid much greater academic and commercial attention to lawns. Turfgrass science research and management programs are active at most land grant universities in the U.S. and there is a multi-billion dollar industry associated with the production, establishment and management of lawns. The focus of these efforts has primarily been on aesthetics and practical uses of lawns, but there has also been extensive analysis of environmental performance, driven by concerns identified by ecologists and others that have noted the potential for high inputs of fertilizer, pesticides and water on lawns. Many of these analyses have suggested that the environmental performance of lawns is better than expected, with less runoff of water and contaminants and less leaching of contaminants to groundwater than expected given the amount of fertilizer applied. Thus two very different threads of theory and practice, one from basic ecology and one from applied turfgrass science, have provided a foundation for lawn research in BES.

We have taken multiple approaches to study lawns in BES. Our first effort was to establish a network of long-term biogeochemical study plots so that we could compare the soil carbon and nitrogen cycles in lawns with forests, the dominant natural ecosystem type in the region, and with agriculture, the other dominant human land use in the region over the past 300 years. These plots have provided long-term data on hydrologic and gaseous outputs of nitrogen, a great environmental concern in the region. We also established an early focus on lawn management practices, and how they varied within our study watersheds. These early efforts were driven initially by the need for detailed input data for watershed nitrogen budget analyses (Chapter 9), but rapidly developed into a key platform for integrated social-ecological research. These early studies have led to a series of efforts to conduct integrated research with a focus on practices on actual lawns across socio-demographic gradients within Baltimore and across the U.S. In the sections below, we trace the evolution of this research and develop the idea that lawn research is an ideal platform, or a common ground - for social-ecological research addressing society and the flux of water and nutrients.

Long-term Biogeochemical Research Plots

One of the earliest efforts in BES was the establishment of long-term plots for comparative analysis of soil biogeochemical variables in lawns and forests. We established eight plots in urban (Leakin and Hillsdale Parks) and rural (Oregon Ridge Park) forested parks and four grassland plots on two school campuses (McDonogh School; University of Maryland Baltimore County (UMBC)). The forest plots provided two contrasts; urban versus rural atmospheric conditions, and soils, as they encompassed the two most common soil types in the region. The lawn plots provided a gradient of management intensity, with the McDonogh plots receiving no fertilizer or pesticides, one of the UMBC plots receiving moderate fertilizer (~100 kg N ha^{-1} y^{-1}) and occasional herbicide applications and the other UMBC plot receiving more intensive management with higher fertilizer (~ 200 kg N ha^{-1} y^{-1}) and more regular pesticide application. This network of plots is clearly not an ideal experimental design providing controlled contrasts of multiple factors in representative components of the urban environment. Rather, these were plots that we considered to be representative of the major ecosystem types in our study region where we could have access and control for long-term studies. The limitations of these plots have driven us to constantly compare them with a wider range of lawns in the region to ensure that the information that they produce is relevant.

The long-term study plots were instrumented with lysimeters (tension and zero tension) to sample water that percolates through the soil profile, with chambers that allow for quantification of fluxes of gases (carbon dioxide - CO_2, nitrous oxide - N_2O, methane - CH_4) from soil to the atmosphere, and probes for measurements of soil temperature and moisture. This instrumentation has produced some interesting and surprising results. First, leaching of nitrate (NO_3^-), the most mobile form of nitrogen, was not as high as expected. Lawns had higher leaching than forests (Figure 12.1), but the differences were not as large as expected given the differences in input. Even more interestingly, there were no systematic relationships between inputs and outputs. While the McDonogh grass plots received less fertilizer than the UMBC plots, they had higher NO_3^- leaching. And although the two UMBC plots differed markedly in fertilizer input, they had similar leaching. These data, as well as results from studies conducted by other investigators, signaled to us that the nitrogen cycle in these urban grasslands was more complex and retentive than we had originally thought.

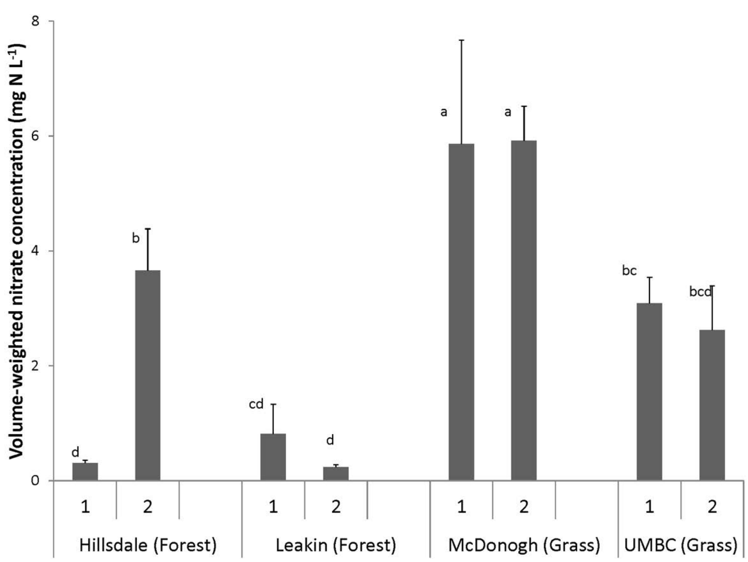

FIGURE 12.1 Volume-weighted nitrate concentration in leachate collected in zero tension lysimeters in four forest and four grass plots in the Baltimore metropolitan area. Values are mean (standard error) of three water years (2002-4). Bars with different superscripts are significantly different at $p < 0.05$.

It is important to note that the lawns still had significant hydrologic losses of NO_3^-. If the concentration data from Figure 12.1 are combined with estimates of water flow, the forest plots consistently yielded less than 3 kg N ha^{-1} y^{-1} of leaching, which is considerably less than estimates of atmospheric deposition in the region (8 – 12 kg N ha^{-1} y^{-1}). The lawns produced from 1.4 (in a very dry year) to 25 kg N ha^{-1} y^{-1}. So even though the differences between lawns and forests were not as big as expected, and there was evidence for significant retention of nitrogen in the lawns, they are still important sources of reactive nitrogen to the environment.

Surprising results were also evident in our soil to atmosphere gas flux data. We had expected to find high fluxes of N_2O, a potent greenhouse gas, from the grass plots as fertilizer input is a strong driver of these fluxes. Studies in other areas, especially irrigated lawns in the arid U.S. West, have found very high N_2O fluxes from lawns. Instead, we found that N_2O fluxes were generally lower in lawns than in forests (Figure 12.2). And as with the leaching data, there was no systematic response to fertilizer input, i.e. the McDonogh plots which received less fertilizer than the UMBC plots had higher N_2O fluxes and the two UMBC plots that had very different fertilizer input had very similar (and low) N_2O fluxes.

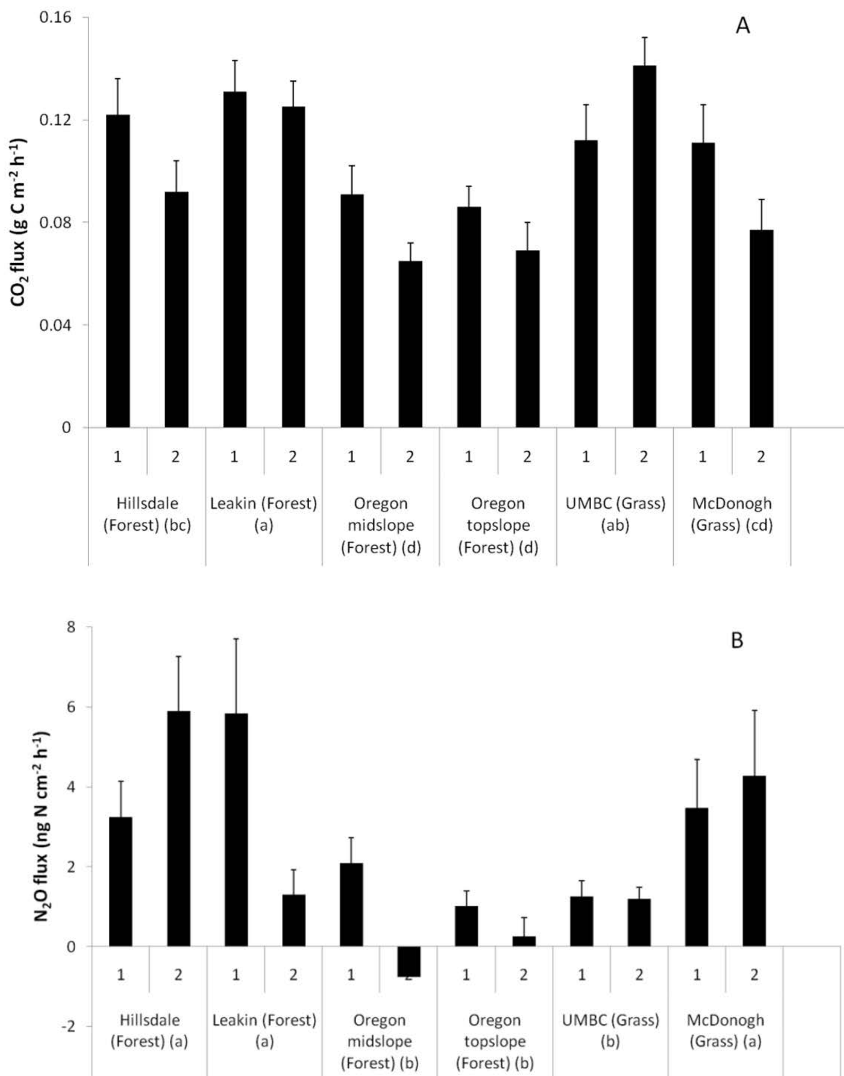

FIGURE 12.2 Soil to atmosphere fluxes of N_2O (top) and CO_2 (bottom) from forest and grass plots in the Baltimore metropolitan area. Values are means of all fluxes measure in three chambers per plot from June 2001 through May 2004. Sites followed by different letters parenthetically in the site labels are significantly different at $p < 0.05$.

The long-term data series of N_2O flux was also interesting and surprising. We observed an increase in flux in 2003 and 2004 (Figure 12.3), which were wet years with very dynamic nitrogen cycling and loss in our study watersheds. However, the increase was much more marked in the forest plots than the grass plots, suggesting the nitrogen cycle in lawns may be less susceptible to hydro-climatic disruption than in forests.

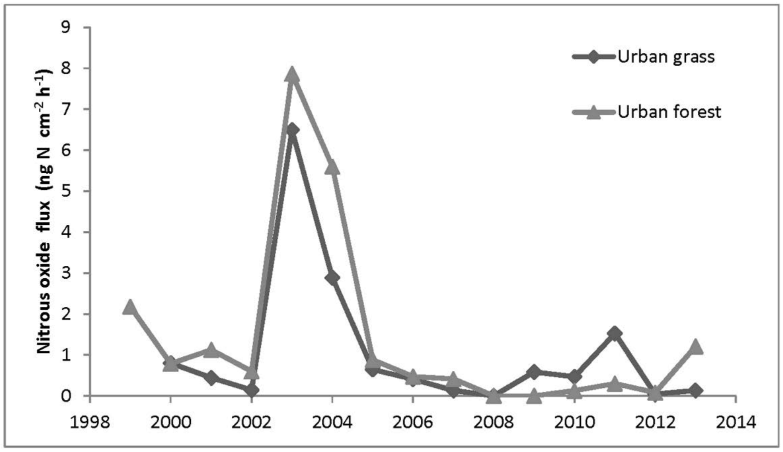

FIGURE 12.3 Mean annual soil to atmosphere N_2O flux from two urban forests (1998-2014) and two urban lawns (2001-14) in the Baltimore metropolitan area.

A major factor underlying the complexity of nitrogen cycling and retention in the lawn plots is likely high flux of carbon from the atmosphere into plants and then into soil microbial populations. High carbon flux in lawns is evident from the long-term patterns of soil to atmosphere CO_2 flux (Figure 12.2b), i.e. this flux was consistently higher from lawns than forests, suggesting that there are high rates of both carbon and nitrogen cycling in lawn soils. High carbon cycling is also likely driven by the higher temperatures in lawns than in forest, i.e. mean annual average temperature at 10 cm depth ranged from 13.5 to 15.0^{o} C in lawns and 12.2 to 12.6^{o} C in forests over an 8 year period.

The major data stream that behaved as expected in our long-term study plots was soil to atmosphere CH_4 flux. Upland soils are known to have the capacity to remove CH_4, a potent greenhouse gas, from the atmosphere. However, this capacity is known to be susceptible to inhibition by soil disturbance and especially by nitrogen inputs. We found that CH_4 uptake was reduced by approximately 50% in the urban forest plots compared to the rural forest plots and was completely eliminated in the lawn plots (Figure 12.4). Subsequent studies determined that this inhibition was linked to long-term increases in nitrogen enrichment and cycling in the urban forest and lawn soils.

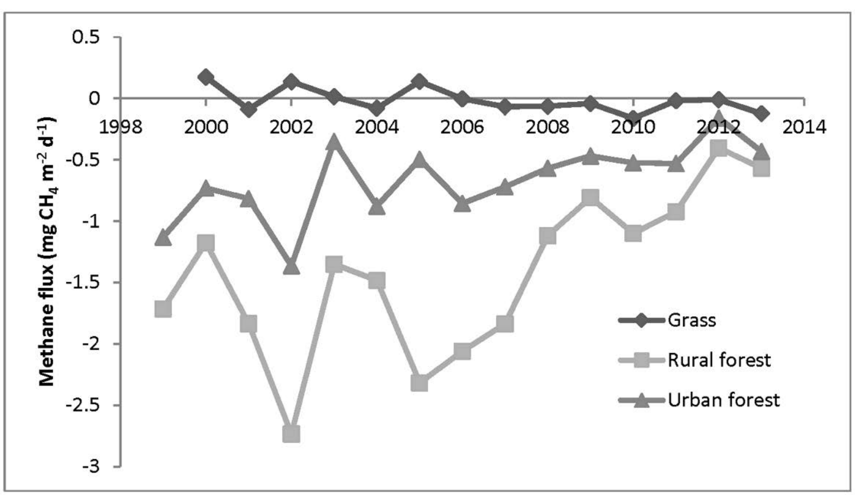

FIGURE 12.4 Mean annual soil to atmosphere CH_4 flux from two urban and two rural forests (1998-2010) and two urban lawns (2001-10) in the Baltimore metropolitan area.

Process Studies

As is common in long-term ecological research projects, the long-term study plots were an effective platform for more detailed process-level research. The surprisingly high nitrogen retention that we observed motivated an isotope tracer study, where small amounts of fertilizer enriched with the stable isotope 15N were added to a series of forest and lawn plots and the movement of this tracer was followed into aboveground and belowground plant material and detritus, soil microbial biomass and soil organic matter. These studies confirmed that lawns have a high potential for nitrogen retention. After one year, we were able to recover more of the tracer in the grass plots than in the forest plots suggesting that more of the N that we added was lost to the environment from the forests than from the lawns.

We were also keen to make measurements in actual residential parcels to determine whether our long-term study plots were relevant to "real world" conditions. A first step in this effort was an assessment of homeowner practices through a detailed door-to-door survey in two of the main BES long-term study watersheds; one exurban area with large lots and expensive homes and one suburban area with older, smaller, less expensive homes. This survey produced surprising results in that fertilization was less common than we expected, ranging from approximately 50 – 75% and was higher in the older, denser, less wealthy neighborhood (Law et al. 2004).

The survey results motivated a more comprehensive analysis of variation in lawn carbon and nitrogen cycling. The High Ecological Resolution Classification for Urban Landscapes and Environmental Systems (HERCULES) system was used to produce an experimental design comparing 32 actual residential parcels with different tree density (driven largely by previous land use, i.e., forest versus agriculture) and structure density (i.e. larger versus smaller lawns). These studies, which included comparison with the 8 forested long-term study plots confirmed that lawns in the Baltimore region have high capacity for nitrogen retention, driven by active carbon cycling and that our long-term study plots are generally representative of lawns in the region.

These studies on actual residential parcels also produced some surprising mechanistic insights into lawn biogeochemistry. First, we were surprised that residential soil profiles were largely intact, as we had expected lawn soil profiles to be highly compacted and to show evidence of imported or altered soil materials. Second, residential soils had higher carbon and nitrogen content than soils from the forested reference plots (6.95 vs. 5.44 kg C/m2 and 552 versus 403 g N/m2), which was unanticipated given the much higher aboveground biomass and lack of disturbance in the forested plots. It was particularly notable that much of the carbon and nitrogen accumulation in the residential soils occurred at depth (30 – 100 cm) in the soil profile. We also observed strong relationships among carbon and nitrogen content and lawn age, but only at sites that were previously in agriculture. Rates of N accumulation at these sites were roughly equal to estimated fertilizer N inputs at the sites, confirming a high capacity for N retention.

Detailed nitrogen cycle process results from the actual residential parcels also confirmed results from the long-term study plots and increased our understanding of lawn biogeochemistry. Consistent with the surprisingly low NO3- leaching that we observed in the long-term study plots, soil NO3- pools and internal NO3- production by nitrification were higher in residential parcels than in forested reference plots but they were not as high as expected, i.e. they were comparable to deciduous forest stands in other studies. Also consistent with results from the long-term study plots was the observation that homeowner management practices—fertilization and irrigation—were not predictive of NO3- availability or production suggesting that active carbon and nitrogen cycling are key drivers of the environmental performance of lawns.

The Social-ecology of Lawns and Residential Lands

Novel methods have been required in BES to examine the social-ecological dynamics of lawns and residential lands because of the fine-scale, spatial heterogeneity of urban areas. These methods have included a combination of intensive surveys of household perceptions, attitudes, and behaviors; improving the characterization of urban heterogeneity patterns using remote sensing and geographic information systems and integration with existing administrative and marketing data.

Our survey of approximately 500 households across Baltimore found that only 50% of households applied fertilizer (Figure 12.5) and that the amount of fertilizer varied widely; from 10 to 679 kg N ha^{-1} y^{-1}, with a mean of 116 kg N ha^{-1} y^{-1}. The high variation in the amount of fertilizer applied was likely driven by the large percentage of households that carried out their own fertilization. We assume that individual practices vary much more than commercial practices and of the households who applied fertilizer, more than 60% of those applications were performed by the homeowner.

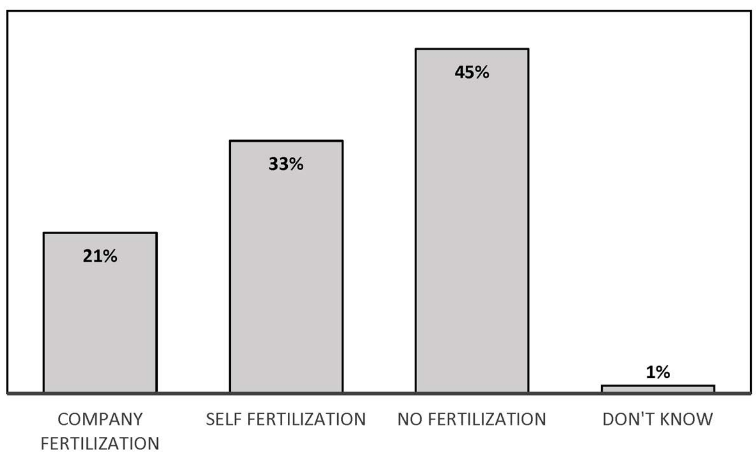

FIGURE 12.5 Fertilization practices of 496 homeowners in the Baltimore metropolitan region surveyed in summer 2008.

The most challenging result from the lawn care practice survey was the lack of relationships between fertilization rate and a variety of potential explanations including lawn area, lot size, house size, house age, house value and lawn greenness as indicated by normalized difference vegetation index (Figure 12.6). None of these factors was significantly related to the amount of fertilizer applied, raising fundamental questions about the social-ecological factors influencing fertilizer use.

The uncertainty in the factors influencing fertilizer use led us to consider alternative explanations and formulate new theories of lawncare behaviors in residential lands. We developed the idea that a household's land management decisions are influenced by its desire to uphold the prestige of its community and outwardly express its membership in a given lifestyle group. From this perspective, housing and yard styles, green grass, and tree and shrub plantings are status symbols, reflecting the different types of neighborhoods to which people belong and that people often use their yard to express their belonging in a certain social group or class. We called this explanation an "Ecology of Prestige" theory, drawing from classic reference group behavior theory from sociology.

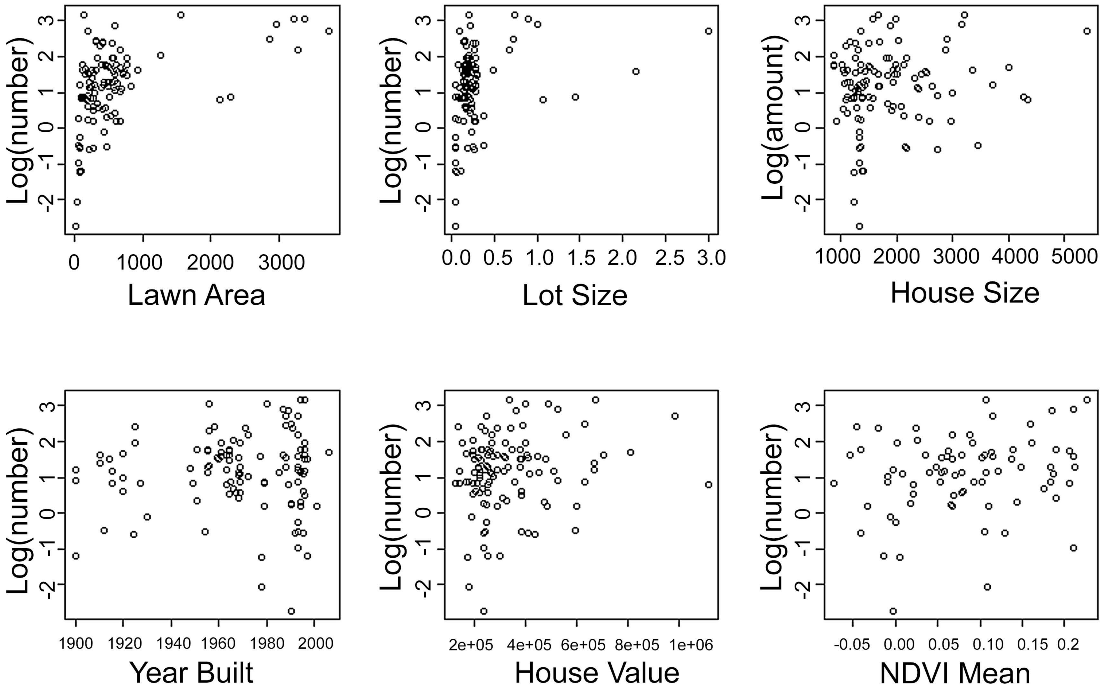

FIGURE 12.6 Relationships between the amount of fertilizer applied and lawn area, lot size, house size, year built, house value, and normalized difference vegetation index (NDVI).

To test our ecology of prestige theory, we developed detailed studies that focused on specific household and neighborhood socioeconomic characteristics as predictors of residential lawn-care expenditures and lawn greenness. These studies examined relationships between population, social stratification (income, education and race), lifestyle behavior, and housing age as predictors of lawn-care expenditures and lawn greenness. Lifestyle behavior was indexed using Claritas, Inc.'s PRIZM™ (Potential Rating Index for Zipcode Markets; hereafter referred to as "PRIZM") marketing categorization system. Despite the name, PRIZM is also a block group-level product, which is a much smaller spatial unit, more socially homogenous than zipcodes, and allows for linkages to other US Census data. This system segments the American population and their urban, suburban, and rural neighborhoods into clusters using Census data related to household education, income, occupation, race/ancestry, family composition, and housing and classifies neighborhoods by social rank (e.g. income, education), household (e.g. life stage, size), mobility (e.g. length of residence), ethnicity (e.g. race, foreign versus U.S. born), urbanization (e.g. population, housing density), and housing (e.g. owner and renter status, home values). The second objective of the PRIZM classification system is to associate these clusters with consumer spending patterns and household tastes and attitudes using additional data such as market research surveys, public opinion polls, and point-of-purchase receipts.

In our analysis, the PRIZM lifestyle segmentation was a useful predictor of both lawn extent, lawncare expenditures, and lawn greenness. The ecology of prestige theory has provided a basis for understanding the variation in lawn management within cities and may be key to understanding how this management can be altered to achieve social and environmental objectives.

While we have found the ecology of prestige to be important for understanding lawncare behaviors, it is also important to recognize that management of residential lands is a multi-scale process. For instance, neighborhood-level factors such as homeowner's associations (HOAs) may influence yard care decisions such as fertilization. For example, we found in Baltimore that households in neighborhoods with HOAs were associated with a higher probability of higher rates of fertilizer application than households in neighborhoods with Neighborhood Associations, which did not have legally binding rules. Further, the probability of applying lawn fertilizers was higher in neighborhoods with higher neighborhood social cohesion, suggesting that social norms and expectations affect lawncare practices.

Our production and use of high resolution landcover data (<1 m) and integration with high resolution, parcel-based data on land ownership, has enabled us to analyze how landcover varies among land use types and, within residential lands, among different neighborhood types. Using these methods, one of our initial findings was that most of the existing canopy cover and opportunities for increasing canopy cover are found in residential lands, a finding in BES that has since been supported in many other cities. Further, using our ecology of prestige theory and PRIZM marketing data, we found that lifestyle factors such as family size and life stage, and ethnicity appear to be stronger predictors of variations in residential canopy cover than population density or socioeconomic status. Second, different social groups' needs for status and group identity produce neighborhood-based and geographically coherent differences in ecological structures and functions. Finally, there are important temporal lags and legacies associated with the distribution of residential canopy cover because trees can live for long periods of time, while the neighborhood characteristics of residential land uses may change over shorter periods. For example, neighborhood lifestyle characteristics in the 1960s were the best predictors of canopy cover existing in the 2000s. These results suggest the need for understanding the heterogeneous legacies of past housing markets and land management on the current spatial heterogeneity of ecological structures and functions, and to make predictions about changes in the future. For instance, because the data on the 1960s improve our understanding the present distribution of trees in Baltimore, the 2000s will matter for city managers as they attempt to green the city over the next 40 years.

The distribution of vegetation structure and land management practices on residential lands has important implications for social processes such as social cohesion, neighborhood satisfaction, and social order (crime), and ecological processes such as the urban heat island. By combining our landcover data, parcel data, and household telephone survey data, we found that differences in neighborhood desirability, environmental satisfaction, quality of life, and social cohesion were positively associated with variations in canopy cover. Our research relating residential vegetation and social order found that while a ~10% increase in canopy cover reduced crime by ~11% (controlling for other factors such as income and race), residential land management had significant effects, supporting Joan Iverson Nassauer's theory of "cues to care" (Chapter 6). Factors that were negatively associated with crime included: the presence of yard trees, garden hoses/sprinklers, and lawns, in addition to the percentage of pervious area in a yard, while factors positively associated with crime included presence of litter, desiccation of the lawn, and lack of lawn cutting. The presence of trees also has a significant effect on the urban heat island and household exposure to heat stress with a variation of ~30^{o} F from the coolest neighborhoods (76^{o} F) and the hottest (106^{o} F) on a summer day.

The Ongoing Challenge of Lawns and Residential Lands

Lawns and residential lands will continue to be an important topic of research in BES for at least the next 10 – 20 years. A major concern is whether our past and current studies, which have painted a surprisingly optimistic picture of the environmental performance and social value of lawns are complete and accurate. We are now initiating studies to determine whether we have missed lawns with poor environmental performance, especially those developed on disturbed and compacted subsoils that might have much less active carbon cycling and nitrogen retention than the lawns that we have studied so far, which overwhelmingly have relatively intact soil profiles.

We are also keen to resolve ongoing biogeochemical and social-ecological mysteries that have emerged from our past and current studies. There is great uncertainty about why carbon is accumulating at depth in the soils beneath lawns and whether this is driven by root production, decomposition, or translocation of dissolved organic carbon. There is great interest in determining the limits of nitrogen retention. As lawns age and/or fertilization rates are sustained or increased, will lawn soils become nitrogen saturated, leading to increases in hydrologic and/or gaseous losses? Gaseous losses are a particular uncertainty, and there is a great need to reconcile our results showing low N2O fluxes in lawns relative to forests with studies from other (mostly arid) regions that have shown higher fluxes in lawns relative to the native ecosystems that they replaced.

There is a great need to develop landscape, regional, and continental scale contexts for studies of lawns and residential lands. While most of our research has focused on the parcel scale, each parcel is hydrologically connected to other parcels and to natural and/or anthropogenic drainage systems. In future studies, we hope to understand the nature and extent of these connections and determine how they influence the environmental performance of neighborhoods and watersheds. A key questions is whether interventions at the parcel (e.g., apply less fertilizer) or neighborhood (e.g., engineer nitrogen sinks in drainage swales) scale are more or less efficient for achieving environmental objectives.

At larger scales, there is interest in determining whether the biogeochemical and social patterns that we observe in Baltimore occur in other cities in the region, in the U.S., and across the globe. A current project is comparing biogeochemical and social variables in six cities across the U.S. (Boston, Baltimore, Miami, Minneapolis-St. Paul, Phoenix, Los Angeles) to determine whether residential land use change is homogenizing the continent by creating ecosystems that are more similar to each other than the native ecosystems that they replaced. A major component of this research is to test whether our ideas about lifestyle as a driver of lawn management are robust at larger scales by determining whether practices in similar neighborhoods in different cities are more similar than practices in different neighborhoods in the same city. This research also includes detailed interviews with a set of homeowners in each city, allowing us to explore their values and motivations related to lawn management more intensively. Lawns and residential lands are likely to continue to be an important platform for theoretical and practical advances in social-ecological science.

Chapter 12 Key Terms

Biogeochemistry: The study of how biological, chemical, and geological factors interact to control the fluxes of energy, water, and matter across the surface of the Earth.

Carbon dioxide (CO_2): A gas present in the atmosphere, presently at ~400ppm, produced by biological respiration and consumed by photosynthesis. It play an important role in absorbing infrared radiation in the atmosphere, i.e., the greenhouse effect.

Lysimeters: Devices used to sample water that percolates through the soil profile. These can involve suction that pulls water out of the soil (tension lysimeters) or passive devices that sample water percolating by gravity (zero tension lysimeters).

Methane (CH_4): A gas present in the atmosphere at ~1.7ppm produced by anaerobic respiration and consumed by a specialized group of aerobic bacteria in the soil. It plays an important role in absorbing infrared radiation in the atmosphere, i.e., the greenhouse effect.

Nitrogen retention: The ability of ecosystems to absorb nitrogen added from the atmosphere, fertilizer, or hydrologic sources.

Nitrous oxide (N_2O): A gas present in the atmosphere at ~300ppb produced and consumed by several nitrogen cycling processes in soil. It plays an important role in absorbing infrared radiation in the atmosphere, i.e., the greenhouse effect.

Soil to atmosphere gas flux: The ability of soil to produce and consume greenhouse gases (CO_2, CH_4, N_2O) is an important ecosystem function and service.

Urban grasslands: Ecosystems dominated by turf-forming species created and maintained by humans for aesthetic and recreational (not grazing) purposes.