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# Green Roofs and Biodiversity

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## BOOK REVIEW

# Introduction: Green Roofs and Biodiversity

Until recently, the design of green roofs was based almost entirely on engineering considerations. Much has been written about how extensive green roofs—those that are grown on a shallow substrate and require little irrigation or other maintenance—affect building performance, especially energy consumption and storm-water retention. Although advocates have said repeatedly that green roofs can be a source of habitat for wildlife, there have been few studies and little data to back up these claims.

In the past few years, however, researchers have turned their attention to the role that green roofs can play in the conservation of biodiversity in towns and cities, where natural habitats are few and far between. They have produced a small but growing body of evidence suggesting that green roofs can indeed provide living space for plants and animals, at least mobile species such as invertebrates and birds. Six pioneering papers on the biological value of extensive green roofs are included here.

Some of the longest-term data come from Germany, where the first wave of green roof construction came at the end of the 19th century. In his paper, Manfred Köhler describes his studies of green roofs constructed in Berlin in the mid-1980s, representing the second boom in German green roof creation. Köhler concludes that a relatively diverse flora is possible on extensive green roofs in inner cities as well as rural areas. He also suggests that plant diversity can be even higher if varied microclimates, especially sunny and shady areas, are created, initial plantings are enhanced, and a minimal amount of irrigation and maintenance is provided.

Stephan Brenneisen discusses his work in Basel, Switzerland, where green roofs have become an important part of the city's biodiversity strategy. Based on research conducted at a 90-year-old green roof in Zurich, in which native soil was used and which has become an orchid meadow with high conservation value, the use of natural soil as well as different substrate thicknesses is stipulated in the design criteria for green roofs in Basel and other Swiss cities. On the most biodiverse of the Basel green roofs studied, a dense combination of microhabitats supports 79 beetle and 40 spider species; 13 of the beetles and 7 of the spiders are endangered species.

The work in Basel has been the inspiration for the creation of innovative replacement rooftop habitat in London. The redevelopment of derelict "brownfield" sites, which have become critical habitat for many species since World War II, has resulted in a squeeze on the city's biodiversity, leading biologists to look to buildings as potential habitat. In his paper, Gary Grant reviews the various types of green roofs that have been constructed in London during the past 15 years. Among the most interesting are the customized "brown roofs" constructed from recycled crushed concrete and brick aggregate specifically for the black redstart, a rare and protected bird threatened by the development of their brownfield refuges. Gyongyver Kadas discusses the results of her surveys of invertebrate diversity on green roofs in London, focusing on three groups: spiders, beetles, and aculeate Hymenoptera (wasps, bees, and ants). She has found a higher abundance of invertebrates on rooftops than at brownfield sites, and at least 10% of the species from the target groups are nationally rare.

Nathalie Baumann presents preliminary data from a long-term study of green roofs as potential bird habitat in Switzerland. Her research suggests that green roofs may be able to provide not only food habitat but also breeding habitat for ground-nesting birds such as the endangered little ringed plover and northern lapwing.

As several of the papers in this issue show, green roof design is becoming more sophisticated. Ecologists have begun looking for alternatives to widely used sedum mats that incorporate microhabitats customized for particular species and/or more closely mimic natural habitats, with varied microtopography (including hollows and "clifflets"), scattered rocks, rubble, dead wood, and more diverse vegetation. In fact, there is an increasingly nuanced understanding of creating entire plant communities on rooftops. In his paper, Jeremy Lundholm suggests that green roof designers should look to natural analogs of these manmade environments, especially rock outcrop habitats such as cliffs, scree slopes, and limestone pavements. These rare habitats include suites of species adapted to shallow substrates and extreme temperature and moisture conditions—the same characteristics of extensive green roofs—and therefore can be useful natural models. The natural rock barren ecosystems also typically include varied microtopography, increasing the diversity of the vegetation and providing a greater range of habitats for invertebrates.

These papers point to other promising areas of research. For example, what role can green roofs play in regional landscape and ecological planning? Can they function as green corridors, linking fragmented habitats and facilitating wildlife movement and dispersal?

Although the data presented in these papers are for the most part preliminary, they suggest that if suitable niches are provided on green roofs, plants and animals will move in rapidly and establish communities. Customized green roofs can even provide habitat for declining and endangered species, suggesting that they have the potential to be an essential tool in species conservation.

Urban habitats are often seen as too disturbed, too degraded, and too depauperate to serve as reservoirs of biodiversity. Even ecologists have been slow to acknowledge that cities offer biological benefits. Green roofs may prove them wrong.

**Janet Marinelli**
**Guest Editor**

# Long-Term Vegetation Research on Two Extensive Green Roofs in Berlin

### by Manfred Köhler

University of Applied Sciences Neubrandenburg, Brodaer Str. 2, 17041
Neubrandenburg, Germany

## Abstract

In this paper, I evaluated the long-term vegetation dynamics of two extensive green roof (EGR) installations in Berlin. The first, installed on two inner-city residential buildings in 1985, consisted of 10 sections ("sub-roofs") with a combined area of 650 square meters. The 10 sub-roofs differed in exposure and slope. Ten plant species were initially sown on the sub-roofs. Observations were made twice yearly (with a few exceptions) from 1985 to 2005. Altogether, 110 species were observed over the 20-year time period; however, only about 10 to 15 of these were dominant over the long term and could be considered typical EGR flora in Berlin. *Allium schoenoprasum* was the dominant plant species over the entire time period on all sub-roofs. *Festuca ovina*, *Poa compressa*, and *Bromus tectorum* were also typically present over the course of the study. Statistical tests revealed that weather-related factors such as temperature and rainfall distribution were the most important factors affecting floral diversity. The size, slope, and age of the sub-roofs had no significant statistical influence on plant species richness. This EGR installation was virtually free of technical problems after 20 years. The success of this low-maintenance green roof is a good argument for greater extension of green roof technology in urban areas. The EGR of the second study was installed in 1986, but investigation of the flora only began in 1992. Observations were again made twice yearly until 2005. The six roofs studied were on top of a cultural center located in a park area in the Berlin suburbs, and they were irrigated during the first few years to support plant establishment. These EGRs had a higher degree of species richness than the inner-city ones. These early German projects in urban ecology demonstrate that relatively diverse EGRs are possible on city buildings. They also show that species richness can be increased with a minimal amount of irrigation and maintenance. And they suggest that enhanced initial plantings, the creation of microclimates (shaded and sunny areas), and the presence of surrounding vegetation also increase plant diversity.

**Key words:** extensive green roofs; Germany; plant community dynamics; urban ecology; vegetation science

## Introduction

There are two types of green roof. The first, the "intensive green roof," or roof garden, generally features trees and other large plants and requires deep soils, intensive labor, and high maintenance, and its purpose is usually ornamental. Roof gardens can be designed in nearly every garden style; many examples from around the world are presented in Theodore Osmundson's book *Roof Gardens* (1999). The second type of green roof is the "extensive green roof" (EGR), as defined by the FLL (2002). It is characterized by drought-tolerant vegetation grown on a thin layer of growing medium, and it requires little maintenance and usually no irrigation. Most EGRs are constructed on flat roofs with slopes of about two degrees for drainage. Pitched EGRs are in the minority. In the long-term experiment reported here, roofs with pitches of up to 47 degrees were tested along with flat roofs (see Table 1).

In Germany, the first boom in green roof construction came at the end of the 19th century, when numerous apartments were built as low-cost rental housing for the families of industrial workers. A layer of gravel and sand with some sod was added to the roofs for protection against fire (Rueber, 1860). This type of green roof was installed all over Germany on less than 1% of buildings.

The vegetation dynamics of some of these early EGRs were described by Kreh (1945), Bornkamm (1961), and Darius and Drepper (1984). These studies showed that a vegetation type called Poetum compressae (mainly featuring the grass *Poa compressa* plus a lot of moss and annual plant species) dominates the roofs. Grasses are dominant on growing media 10 to 20 centimeters in depth; on media less than 10 centimeters in depth, the genus *Sedum* and mosses are most successful.

After 1980, many green roofs were constructed with the idea of bringing vegetation back into urban areas. Divided Berlin was a focus for EGR installation in Germany. The history of green roof development in Berlin is documented in Koehler and Keeley (2005).

Beginning in the 1980s, there was a change in urban planning in Germany. Neighborhoods with apartment buildings from the era of early industrialization were renovated. Citizens preferred to live in more mature neighborhoods in the center of town rather than in newly constructed multistory buildings in the suburbs. More apartments were integrated into existing urban properties. Additional apartments were also added to rooftops of existing buildings, so that typical four-story apartment buildings in the inner city got a fifth level with roof windows and terraces. At first these new apartments were uncomfortable due to insufficient insulation. However, as the decade progressed and the influence of urban ecologists increased, planners began to reconsider using green roof technology. A new building code was developed that required extensive green roofs to be constructed over roof apartments in central parts of the city. In addition, incentive programs were introduced to reduce the additional costs of installation. The program, which lasted from 1983 until 1996, supported the installation of about 63,500 square meters of green roofs (Köhler & Schmidt, 1997). It was terminated after German reunification. Currently, green roofs are legally required by the federal government for buildings on large construction projects, such as the recent ones in Potsdamer Platz (for a case study, see Earth Pledge, 2005).

## The Research Sites

### 1. Paul-Lincke-Ufer (PLU) Green Roofs

The Paul-Lincke-Ufer (PLU) project in the neighborhood of Kreuzberg was the first inner-city residential eco-project in Berlin, and one of the first in Germany. The project was conceived during studies carried out in the early 1980s to examine the potential of inner-city greening. Funding to execute the project was provided in 1984 by the federal government and the Berlin senate. A number of conservation ideas were incorporated into PLU buildings, including waste recycling and decentralized heating. The project was the first of its kind in the city to include a monitoring program evaluating the success of its different components. I was responsible for vegetation research and for measuring the urban climate. The official survey lasted 12 years, and a final report was published almost a decade ago (Köhler & Schmidt, 1997). Since then, I have continued the research without government funding.

For this paper, I observed the long-term vegetation dynamics of 10 EGRs (referred to here as "sub-roofs 1–10") on two buildings at the PLU site (see Figures 1a, 1b). Installed in autumn 1985, the green roofs are 24 meters above the ground and have a range of different exposures and slopes (Table 1). Their combined area is 650 square meters. Initially, erosion barriers were installed in the growing medium of the pitched roofs. The 10-centimeter-deep growing medium (consisting of a mixture of expanded clay, sand, and humus) had an average water-storage capacity (and water availability to plants) of 16.5 liters per square meter (author's measurement)—a relatively low capacity compared with other green roofs in Berlin (Köhler & Schmidt, 1997). To speed plant coverage on the roofs, precultivated vegetation mats were used. These mats included some popular EGR plant species (see Table 2, under column titled "seed"). Plants were selected on the grounds that they would not require additional maintenance or irrigation after installation. The mats were prototypes and were in and of themselves an experiment in green roof production, transport, and installation. In the following years, this technology came into widespread use for extensive roof greening.

#### Methods (PLU Site)

The study ran from 1986 to 2005. Data was collected twice a year, in May and in September, with a few exceptions. There are no data for 1988 and 1990 and only one observation per year for 1987 and 1989. Measurements included the number of vascular plants, percent coverage of each plant species, plant heights, and the percentage of "standing dead" (living plants with dead leaves and stems). Data analysis was conducted for the following categories: quantity of seeded species, life form of the plant species, and type of plant (i.e., annual or perennial). For more on the method of data collection used, see Kreeb (1983). Table 2 is an example of the reduced original data set for sub-roof 1. Multivariate analysis of variance (MANOVA) was performed on the data using the SPSS statistical package (SPSS Version 11; see Diehl & Staufenbiel, 2002).

### 2. Ufa-Fabrik (Ufa) Green Roofs

The second green roof site was the Ufa-Fabrik (Ufa) cultural center, located in a park area in suburban Berlin, in the Templehof neighborhood. The center is famous for its association with the golden age of German cinema in the 1920s and 1930s. Copies of Ufa films were stored here. These films were highly flammable, so the storehouse was built with a special vegetated covering to protect it against fire. After World War II, Berlin lost its status within the film industry, and the Ufa complex was abandoned. However, in the 1980s, a group of grassroots and cultural environmentalists occupied the area and started renovation work. The environmentalists were inspired by the storehouse (or Filmbunker, as it became known) to cover all the other buildings in the complex with extensive green cover.

The Ufa EGRs were built virtually at the same time as those of the PLU project, the main difference being that the Ufa activists conducted their work without the support of academic researchers. Between 1986 and 1990, during several green roof workshops, three EGRs were installed, with a total area of about 2,000 square meters. Various other green roofs were added in the following years. Today, every Ufa building features an EGR (see Figures 2a, 2b, and some of the roofs are augmented with photovoltaic (PV) panels. Indeed, one of the largest PV power plants in Berlin was erected on a green roof at the Ufa complex (Köhler, Schmidt, Laar, Wachsmann & Krauter, 2002).

The EGRs were planted with flowering meadow species seed-collected from the Alps. The 10-centimeter substrate consisted of sandy garden soil with about 10% expanded clay. During the first years, the green-roof meadows were irrigated by volunteers, and plant species richness was high. Since the mid-1990s, however, the water system for the Ufa buildings has changed, and irrigation of the EGRs on the Ufa roofs has stopped.

### Methods (Ufa Site)

Beginning in 1992, the EGRs of the Ufa complex were studied in the same manner as the PLU roofs. At the Ufa complex, six roofs are currently in the research program. Table 5 details plant community succession on the roof of the Ufa concert hall.

## Results

### 1. PLU Site

The vegetation of one EGR in the green roof complex (sub-roof 1) was examined and may be considered representative of the vegetation dynamics of the other EGRs studied. Further statistical surveys were done with the complete data set for all 10 sub-roofs and for all dates of investigation.

***Plant diversity on sub-roof 1.*** Table 2 details the succession of the plant community on sub-roof 1 over the years. In 1986, some annual pioneer plants and weeds from the seed bank of the growing medium grew for a short while (see double-lined box). These species disappeared after the first few years. The plant species introduced in the vegetation mat are marked with an "x" (see single-lined box). Over the length of the study, five plant species continued to be present each year: *Poa compressa*, *Festuca ovina*, *Sedum acre*, *Allium schoenoprasum*, and *Bromus tectorum*. The vegetation mat included *Lolium perenne*, but this plant was not successful over the long term. Other typical meadow plants, such as *Alopecurus geniculatus*, *Dactylis glomerata*, *Poa pratensis*, and *Festuca rubra*, did not persist over several years. *Koeleria pyramidata*, not typical in northern Germany, died back in the first few years. An interesting plant found colonizing sub-roof 1 was *Poa bulbosa*, which has a bulb that allows it to store nutrition and survive over dry periods. The lichen *Cladonia coniocrea* established spontaneously after 1995 and became a common species on all 10 sub-roofs. In Hamburg, vegetation stands containing this species are rare and protected by law.

The number of vascular plant species for each observation date varied from a minimum of 8 in June 1998 (a dry month), to 25 in June 1987 and 21 in May 2005 (both wet months). In total, 55 plant species were observed over the 20-year period on sub-roof 1.

***Overall plant diversity.*** The average number of vascular plant species over all 10 sub-roofs and dates was 15. The total number of vascular species observed on all 10 sub-roofs was 110. The absolute number of known vascular plants in Berlin and Brandenburg County is approximately 1,600 (Jedicke, 1997). Therefore, close to 7% of the total number of species in the region have been observed on this small roof over the years.

***The influence of climate.*** A calculation was made from general climate data (temperature, precipitation, and evaporation) in accordance with the Penman-Monteith equation (Köhler & Schmidt, 1997). Based on this calculation, the terms "dry" or "wet" were applied to each vegetation period (see Table 2). For example, the years 1986 and 2003 were characterized by summers with extremely low precipitation; all vegetation periods were described as dry. During 2004 and 2005, precipitation was higher and evenly distributed, so that the growing media were well supplied with water throughout the summer months; these vegetation periods were described as wet.

Nowadays, water-requirement measurements of EGR plants are made at the Green Roof Research Center, in Neubrandenburg, using roof lysimeters. Green roof systems have a daily requirement of approximately 2–2.5 millimeters (mm) evapotranspiration in summer and 0.1 mm in winter (Koehler, 2005). The daily water requirement and the duration of dry periods can be combined: If the growing medium is able to retain 16.5 mm of water, then the plants will undergo water stress about one week into a period without summer rain. Extensive green roofs face dry-stress situations almost every year during the growing season, and the vegetation must have survival strategies for these times. The dieback of plant species on green roofs is quite normal. Annual plant species can fill these gaps.

A regression analysis was carried out to see if there were differences between the number of plant species in "dry" and "wet" summer seasons. Table 3 shows that wet summer periods served to enrich the plant diversity. Annual and volunteer plant species invaded more during wet periods. This effect was evident by the appearance of species from the family Fabaceae, such as *Trifolium arvense*, *Medicago lupulina*, and others. Perennial plant species did not react so directly; there was no significant numerical difference. However, the percent coverage of the perennials varied: They did not die back completely during wet periods. For example, the grass *Festuca ovina* was well developed on the EGRs and flowered significantly during wet seasons. In dry years, only very small parts of individual plants survived.

***Roof size and plant diversity.*** There was a slight correlation between roof size and plant species richness. At 112 square meters, the northward-pitched sub-roof 10 (see Table 1) had the lowest number of plant species (44) over the years. The highest number of plant species (61) over the years was found on the almost-flat sub-roof 9, which had an area of 160 square meters. This roof differed from the others in that it was dominated by lichens, had a high cover value of *Poa bulbosa* and *Erodium cicutarium*, and contained many annual species. However, a regression analysis showed only a low dependence ($r^2$-value = 0.67); thus, the correlation between area and richness was not statistically significant.

***Roof angle and plant diversity.*** Vegetation periods and the various angles of the flat and pitched roofs were investigated using analysis of variance (ANOVA). No significant difference was found between plant species richness in flat and sloped roofs (f-value = 0.45).

***Roof age and plant diversity.*** In the early years of the project, weeds that had been brought in as seeds with the growing media were observed. After they declined, however, the number of plant species varied from year to year with no apparent significant tendency according to roof age.

***Effects of maintenance/erosion.*** The roofs received only minimal maintenance. Sub-roof 8, which had a southern aspect, received additional irrigation during the first few years because one of the apartment owners in the building was keen to green the area surrounding his terraces. A few years later, this individual mowed the green roof. As a result, the vegetation broke down on this sub-roof, but it regenerated some years later to match the other roof areas.

On the steeply sloped sub-roof 7, some erosion was detected five years after construction. *Sedum rupestre* and *S. album* were planted to patch the eroded area. The plants eventually spread to other parts of the roof. In this case, species richness was strongly influenced by human interference.

***Plant species dominance.*** Table 4 shows a list of the 15 most dominant plants present on all 10 sub-roofs. *Poa compressa*, *Festuca ovina*, and *Bromus tectorum* were present on nearly all sub-roofs on all dates. Some typical plant species in the first years were *Lolium perenne*, *Festuca rubra*, and *Poa pratensis*; these declined after some years. *Cerastium semidecandrum* and *Setaria viridis* were typically associated with the green roof plants over all the years of the survey. Other species, such as *Apera spica-venti*, were found during dry summer climate situations, but their presence became more apparent with increasing rainfall. *Poa annua* and *Senecio vulgaris*, typical garden weeds, were common on the green roofs but only had a low cover value. The final column in Table 4 indicates the dominance of the plant species according to the sum of cover values for all observation dates on all sub-roofs. *Allium schoenoprasum* didn't start growing on the roofs until some years after they were built, but its cover value increased rapidly. This plant was the most dominant species in terms of cover. The 110 plant species had a sum cover value of 35,142 over all the years, while *A. schoenoprasum* alone had 19,512—or 56% of the total. The 10 next most common species after *A. schoenoprasum* had a combined sum cover value of 9,143. The remaining 99 plant species had a combined sum cover value of 6,487. The cover values for these three groups of plants are shown in Figure 3.

***Species of conservation value.*** *Poa bulbosa* and *Petrorhagia saxifraga* are endangered plant species in some parts of Germany but not in Berlin. *Bromus tectorum* is endangered in the state of Schleswig-Holstein. The endangered *Vulpia myurus* volunteers on the EGR of the University of Applied Sciences in Neubrandenburg. However, the studies presented here did not focus on endangered species. The extreme conditions on green roofs differ considerably from conditions at ground level, and it is expected that rare plant species would have difficulty establishing, especially in urban areas.

### 2. Ufa-Fabrik Site

Data from one EGR at the Ufa site (the concert hall) are shown in Table 5 and are representative of the vegetation dynamics of the six EGRs studied. The concert hall was found to support 91 vascular plant species. In the table, perennial plants are marked with the letter "p" and seeded/planted species with an "x." There were 27 observation dates altogether. This EGR has a total size of about 200 square meters and is only 10 meters above ground level. The building is located in a green area in the suburban part of Berlin. Besides those marked with an "x," it is not known exactly which plant species were sown in 1986.

The years that the roof was irrigated are marked in the header of the table (1 = irrigation, 2 = well-saturated irrigation, 0 = no irrigation). Three groups of plant species are marked with single-lined boxes: *Sedum* species, attractive species, and annual species. The minimum number of species observed was 22 (May 1993) and the maximum was 64 (September 2005). Worth noting is the presence of *Anthyllnis vulneraria*, *Onobrychis montana*, and *Medicago sativa*—plants not native to Berlin but which have survived on this roof for two decades. Irrigation has helped these nonnative plants grow, but they would be able to survive and reproduce without it. The seeds of these plants are present in the roof seed bank and can regenerate.

Since irrigation was halted in 1997, *Sedum* species have begun to dominate the EGR. The cover layer of the perennial plants was sometimes more than 100%. The total number of plant species on each observation date was significantly higher than that on the PLU roofs.

It is also important to note that several tree saplings became established on the EGR. None, however, grew larger that 0.5 meters.

## Discussion

The PLU and Ufa projects in Berlin differ with regard to such variables as location in the city, size, and maintenance history. The PLU roofs are typical *Allium* roofs, while the Ufa roofs are *Sedum* roofs with unusually high species richness. In the inner city, hundreds of EGRs have been created since the 1980s. In many cases, precultivated vegetation mats were used. The technology is simple, though it does take several years before the vegetation is well developed. In order to reduce costs, *Sedum* cuttings have been used on some roofs in the last few years, and this has resulted in the domination of clonal *Sedum* species. The high species richness of the Ufa roof represents an experimental phase of green roof installation in Germany in the 1980s, when many plant species were tested. Several of these plants have survived on the roof.

To compare the project sites, I calculated a Jaccard index (Dierssen, 1990) evaluating the relationship between the full species list of each project and the species lists for each individual roof or sub-roof in the projects. The index ranged in value between 0 (no species in common) and 100 (all species in common). The average index of the PLU sub-roofs was about 60%, indicating that these plots were rather similar to each other. The Ufa plots were less similar to each other, at about 50%. A comparison between the total lists from the PLU and Ufa projects resulted in a similarity index of 34% and highlighted the different character of the roofs at each site.

The species richness of the Ufa project was higher than at PLU because the buildings are located in a greener area with higher potential for natural plant dispersal. Moreover, there are tall trees adjacent to the buildings that provide shade and thus a greater heterogeneity of habitat exposures (from full sun to semishade) on the roofs. As a result, shade plants such as *Geranium robertianum* are able to grow along with typical sun-loving EGR plants.

The influence of climatic factors, in particular water availability due to irrigation at Ufa, was a significant difference between both projects. During the first years of the Ufa project, the EGRs were maintained by a gardener. The

PLU sub-roofs, however, had virtually no maintenance.

On lower roofs, such as those of the Ufa buildings, many tree seedlings colonized and had to be removed frequently. Twenty years after installing the first green roofs at these sites, we have discarded the idea that green roofs are zero-maintenance systems. Further study is now being undertaken to determine the minimum amount of maintenance needed for the EGRs.

The tendency of the Ufa roofs is toward dominance by *Sedum* species. Under the climate conditions of northeastern Germany, this kind of roof has high species richness. Though again, a small amount of maintenance is needed to prevent colonizing weeds (such as *Melilotus*) from crowding out less competitive species (such as *Ononis*, *Medicago*, and *Scabiosa*).

The installation of precultivated vegetation mats at the PLU site was a suitable method for rapidly securing the growing medium. Once the plant roots penetrated the growing medium, the EGR was successfully established.

*Allium schoenoprasum* showed great success in covering the PLU roofs. However, both long-term experiments demonstrate that EGRs can be designed and maintained to support different plant species. These studies suggest that a full range of possible plant species should be explored.

The EGRs described in these two projects are typical of urban green roofs in Germany: They contain only a small selection of the wide range of plant species common on green roofs in rural areas. Vegetation studies have been conducted on other green roofs in Berlin by graduate students (see Koehler, 1994). Factors influencing diversity on these roofs include the initial vegetation planted, as well as propagate inputs from wind and animals. Significant differences have been found between roofs located in the city center and those in surrounding areas. (For example, inner-city plant species tend to be more adapted to dry conditions.) A remarkable green roof is at the old waterworks at Teufelssee, a lake located in the Grunewald forest on the edge of Berlin. In the 1920s, the old water reservoir at Teufelssee was covered with an EGR to keep the water cool while in storage. Not only *Calluna vulgaris* and *Deschampsia cespitosa* have grown on this roof, covered with sandy forest soil, but also interesting mosses and lichens (see Figure 4). Roofs in areas such as this are valuable for the conservation of endangered plant species.

The results of my research indicate that relatively diverse EGRs are possible on inner-city buildings as well as rural buildings. It also shows that a small amount of maintenance from a qualified gardener can enhance plant species richness on green roofs.

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## Glossary

**Analysis of variance (ANOVA)**: Statistical method that yields values that can be tested to determine whether a significant relation exists between variables.

**Evapotranspiration:** Moisture transfer from the earth to the atmosphere via evaporation of water from transpiring plants.

**Extensive Green Roof:** A low-management type of green roof that has soil depths ranging from three to seven inches. Due to the shallow soils and the extreme environment on many roofs, plants are typically low-growing groundcover species that are extremely sun and drought tolerant.

**Lysimeter:** An instrument that measures the amount of water-soluble matter in soil.

**Multivariate analysis of variance (MANOVA):** An extension of analysis of variance (ANOVA) covering cases where there is more than one dependent variable and where the dependent variables cannot be simply combined.

**Penman-Monteith equation:** A standard equation used to compute evapotranspiration rates (and thus water requirements) in crop plants. For more information, see http://www.fao.org/docrep/X0490E/x0490e06.htm.

**Regression analysis:** Any statistical method in which the mean of one or more random variables is predicted conditioned on other (measured) random variables (see http://en.wikipedia.org/wiki/Regression_analysis).

**Species richness:** The number of different species found in a particular habitat.

**Succession:** The sequential change in vegetation and the animals associated with it, either in response to an environmental change or induced by the intrinsic properties of the organisms themselves.

**Figure 1a: The PLU research site in Berlin-Kreuzberg. In the foreground is flat sub-roof 9, which had the highest plant diversity of all the 10 sub-roofs in this project. The north-pitched sub-roof 10 is visible in the background; it had the lowest plant diversity.**

**Figure 1b: The PLU research site in Berlin-Kreuzberg. In the foreground is a portion of flat sub-roof 1, with *Allium* species in fruit. In the background, the 47-degree pitched sub-roof 2 is visible.**

**Figure 2a: The Ufa project EGRs in Berlin-Templehof: concert hall roof, as described in Table 5.**

**Figure 2b: The Ufa project EGRs in Berlin-Templehof: concert hall roof, with measurement equipment. Photovoltaic panels are visible on the adjacent green roof in the background.**

**Figure 3**: **Cover values of all 110 roof plants over all dates and all sub-roofs at the PLU site.**

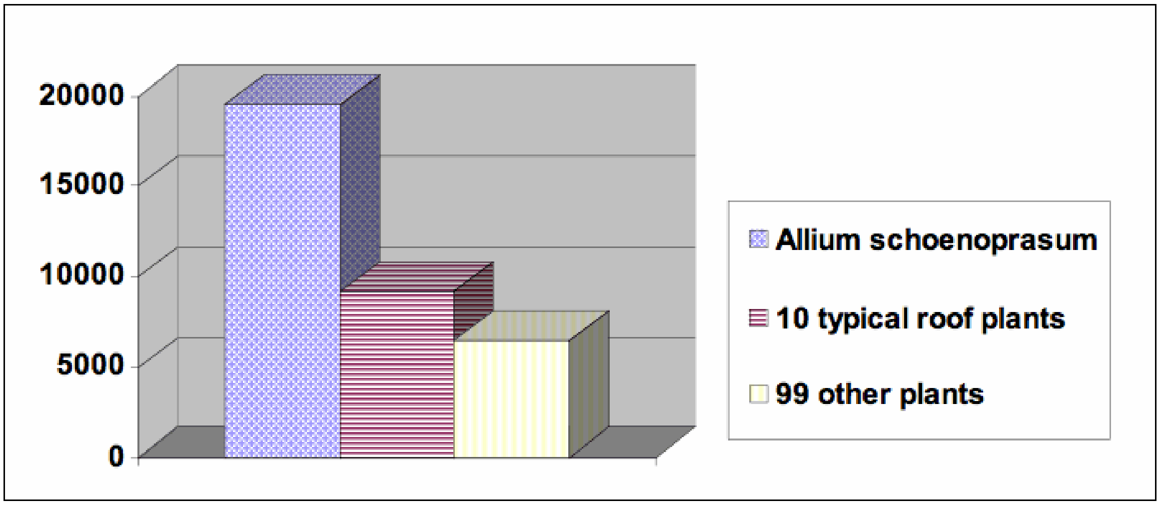

**Figure 4: Green roof at Teufelssee, Berlin-Grunewald.**

**Table 1. Descriptions of the 10 PLU sub-roofs.**

| Sub plot | Size ($m^2$) | Aspect | Angle (°) | Number of plant species over the time of investigation |
|---|---|---|---|---|
| 1 | 40 | Flat | 2 | 55 |
| 2 | 54 | West | 47 | 47 |
| 3 | 54 | North | 15 | 51 |
| 4 | 61 | North | 15 | 57 |
| 5 | 20 | North | 15 | 45 |
| 6 | 46 | Flat | 2 | 60 |
| 7 | 54 | East | 47 | 49 |
| 8 | 48 | South | 30 | 55 |
| 9 | 160 | Flat | 2 | 61 |
| 10 | 112 | North | 30 | 44 |

**Table 2. Plant community composition and succession of sub-roof 1 at the PLU project site from 1986 to 2005. This sub-roof is a flat EGR measuring about 40 square meters.**

| **Tab. 2: Roof 1<br>PLU 17.Oct 2005** | | | | **Coverage (%)** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | | | | | 1986 | 1986 | 1987 | 1989 | 1991 | 1991 | 1992 | 1992 | 1993 | 1993 | 1994 | 1994 | 1995 | 1995 | 1996 | 1996 | 1997 | 1997 | 1998 | 1998 | 1999 | 1999 | 2000 | 2000 | 2001 | 2001 | 2002 | 2002 | 2003 | 2003 | 2004 | 2004 | 2005 | 2005 | | |
| Month | | | | | May | Sep | June | May | May | Sep | May | Sep | May | Sep | May | Sep | May | Sep | Jun | Sep | Jun | Sep | Jun | Sep | May | Sep | Jun | Sep | Jul | Sep | June | Oct | Jun | Sep | Jul | Aug | May | Sep | | |
| Year t=dry f= wet | | | | | t | t | f | t | f | f | t | t | f | f | t | t | t | t | f | f | t | t | t | t | t | t | t | t | f | f | f | f | t | t | f | f | f | f | | |
| Flowering plant coverage (%) | | | | | 95 | 70 | 90 | 85 | 80 | 80 | 95 | 95 | 95 | 95 | 95 | 95 | 90 | 90 | 95 | 95 | 96 | 97 | 92 | 90 | 95 | 95 | 98 | 98 | 98 | 98 | 98 | 99 | 95 | 95 | 95 | 95 | 100 | 99 | | |
| Dead plant coverage (% or number?) | | | | | k.A. | k.A. | k.A. | 40 | 5 | 80 | 5 | 5 | 5 | 2 | 2 | 3 | 3 | 3 | 2 | 4 | 2 | 5 | 5 | 1 | 2 | 3 | 10 | 3 | 5 | 4 | 3 | 4 | 5 | 5 | 4 | 4 | 2 | 1 | | |
| Moss coverage (%) | | | | | 0 | 0 | 40 | 80 | 95 | 90 | 80 | 85 | 90 | 95 | 95 | 95 | 95 | 98 | 95 | 95 | 95 | 95 | 95 | 90 | 90 | 90 | 80 | 60 | 70 | 70 | 70 | 90 | 85 | 85 | 85 | 85 | 85 | 85 | | |
| Height of perennial? (m) | | | | | 0.3 | 0.1 | 0.2 | 0.3 | 0.2 | 0.4 | 0.2 | 0.3 | 0.3 | 0.2 | 0.3 | 0.3 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.3 | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.4 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | | |
| Number of vascular plants | | | | | 14 | 15 | 25 | 16 | 18 | 17 | 15 | 21 | 11 | 17 | 13 | 13 | 20 | 10 | 13 | 11 | 10 | 9 | 8 | 11 | 11 | 12 | 7 | 6 | 13 | 12 | 15 | 12 | 9 | 10 | 17 | 18 | 21 | 18 | | |
| Species from pre-cultivated vegetation mats | | | | | 7 | 9 | 8 | 8 | 6 | 7 | 7 | 6 | 5 | 5 | 5 | 5 | 5 | 5 | 6 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | | |
| Spontaneous plant species | | | | | 7 | 6 | 23 | 8 | 10 | 10 | 8 | 15 | 6 | 13 | 8 | 9 | 14 | 5 | 7 | 6 | 5 | 4 | 3 | 5 | 6 | 7 | 2 | 1 | 8 | 6 | 10 | 7 | 4 | 5 | 12 | 13 | 16 | 13 | | |
| Annual and biennial plant species | | | | | 5 | 6 | 18 | 10 | 11 | 10 | 8 | 14 | 6 | 13 | 7 | 6 | 13 | 6 | 8 | 7 | 5 | 5 | 4 | 5 | 6 | 7 | 3 | 3 | 8 | 6 | 10 | 6 | 4 | 4 | 12 | 12 | 15 | 12 | | |
| Perennial species | perennial | | | | 9 | 9 | 13 | 6 | 6 | 7 | 7 | 7 | 5 | 5 | 6 | 7 | 6 | 4 | 5 | 4 | 5 | 4 | 4 | 5 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 6 | 6 | 6 | 6 | 6 | 6 | | |
| Lifeform/ seeded / presence | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | occurrences | |
| | | seed | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | sum |
| **Flowering plant species** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Echinochloa crus-galli | | | | | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | 1 |
| Poa annua | | | | | 9 | 9 | 9 | 9 | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 5 | 37 |
| Alopecurus geniculatus | p | | | | 1 | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 2 | 2 |
| Plantago major | p | | | | 1 | 3 | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 3 | 5 |
| Dactylis glomerata | p | x | | | . | 2 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | 2 |
| Poa pratensis ssp angustifolia | p | x | | | 3 | 3 | . | 3 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 3 | 9 |
| Koeleria pyramidata | p | x | | | 2 | 2 | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 3 | 5 |
| Lolium perenne | p | x | | | 68 | 68 | 19 | 9 | 9 | 9 | 3 | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 8 | 186 |
| Festuca rubra | p | x | | | 4 | 1 | 1 | . | 2 | 3 | 1 | . | . | 1 | . | . | . | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 8 | 14 |
| Poa compressa | p | x | | | 9 | 9 | 38 | 19 | 5 | 9 | 9 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 1 | 1 | 2 | 1 | 3 | 3 | 3 | 3 | 9 | 9 | 5 | 4 | 4 | 8 | 34 | 183 |
| Festuca ovina s,str, | p | x | | | 4 | 3 | 9 | 9 | 9 | 9 | 9 | 3 | 3 | . | 3 | 3 | 3 | 1 | 2 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 5 | 3 | 1 | 3 | 5 | 8 | 5 | 5 | 5 | 5 | 4 | 5 | 33 | 137 |
| Allium schoenoprasum | p | x | | | . | 3 | 3 | 38 | 19 | 68 | 68 | 68 | 68 | 88 | 88 | 95 | 90 | 92 | 92 | 92 | 92 | 90 | 92 | 68 | 80 | 85 | 85 | 90 | 85 | 90 | 90 | 90 | 70 | 80 | 70 | 70 | 80 | 85 | 33 | 2464 |
| Sedum acre | p | x | | | . | . | 1 | 1 | 4 | 1 | 1 | 1 | 9 | 9 | 9 | 9 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 5 | 4 | 6 | 32 | 104 |
| Bromus tectorum | | x | | | 2 | 2 | 2 | 9 | 19 | 3 | 1 | 9 | 9 | 1 | 1 | 1 | 3 | 4 | 1 | 2 | 1 | 1 | 1 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 1 | 1 | 1 | 5 | 3 | 5 | 2 | 34 | 112 |
| Apera spica -venti | | | | | 1 | . | 3 | 3 | . | 1 | 3 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 5 | 11 |
| Tripleurospermum inodorum | | | | | 1 | . | 2 | . | 2 | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 4 | 6 |
| Polygonum aviculare | | | | | 9 | 3 | | . | . | . | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . | 4 | 14 |
| Spergula arvensis | | | | | 1 | 3 | | . | . | . | . | . | . | 1 | . | . | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 2 | 2 | . | . | 6 | 10 |
| Viola arvensis | | | | | . | 1 | 1 | . | 4 | . | 1 | 1 | . | 1 | . | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | . | . | . | 8 | 11 |
| Cerastium semidecandrum | | | | | . | . | 3 | 9 | 4 | . | 9 | 3 | 3 | 1 | . | . | . | 1 | 1 | 1 | . | . | . | . | 1 | 1 | 1 | . | . | . | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 21 | 47 |

| **Flowering plant species (Cont.)** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chenopodium album | | | | | . | . | 1 | 3 | . | 1 | . | 1 | . | . | . | 1 | 1 | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | . | . | 8 | 10 |
| Bromus hordeaceus ssp. hord. | | | | | . | . | 1 | 3 | . | . | . | 1 | 3 | . | 1 | . | 1 | 1 | 1 | 1 | 1 | 1 | . | . | . | . | . | . | . | . | . | . | . | . | 1 | 1 | 3 | 2 | 15 | 22 |
| Scleranthus annuus | | | | | . | . | 1 | . | 2 | 1 | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 4 | 5 |
| Myosotis arvensis | | | | | . | . | 1 | . | 4 | 1 | . | 1 | . | 1 | . | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | . | . | . | 1 | . | 1 | . | 9 | 12 |
| Vicia angustifolia | | | | | . | . | 1 | . | 2 | . | 3 | 1 | . | 1 | 1 | . | 1 | . | 1 | 1 | 1 | 1 | . | 1 | 1 | 1 | 1 | 1 | 1 | . | 1 | . | . | . | 2 | . | 2 | . | 20 | 25 |
| Sisymbrium loeselii | | | | | . | . | 1 | . | . | 1 | . | . | . | 1 | . | 1 | 3 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 5 | 7 |
| Medicago lupulina | | | | | . | . | 1 | . | . | . | 3 | . | 1 | 1 | 1 | . | . | . | 4 | 3 | 3 | 3 | 1 | . | . | 1 | . | . | 1 | 1 | 1 | 1 | . | . | 3 | 2 | 3 | 1 | 19 | 35 |
| Conyza canadensis | | | | | . | . | 1 | . | . | . | . | 1 | . | 1 | . | . | 1 | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | 1 | 1 | 8 | 8 |
| Vicia hirsuta | | | | | . | . | 1 | . | . | . | . | . | . | 1 | 1 | . | . | . | 1 | 1 | 1 | 1 | 1 | . | 1 | 1 | . | . | . | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 3 | 1 | 19 | 22 |
| Capsella bursa-pastoris | | | | | . | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | . | . | 1 | . | . | . | . | . | . | 3 | 3 |
| Veronica arvensis | | | | | . | . | . | 3 | 4 | . | 1 | . | 3 | . | . | . | 1 | . | . | . | . | . | . | . | 1 | . | . | . | . | . | . | . | . | . | . | . | 1 | . | 7 | 14 |
| Senecio vulgaris | | | | | . | . | . | 3 | 4 | 1 | . | 1 | . | . | . | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | . | 6 | 11 |
| Sonchus oleraceus | | | | | . | . | . | 1 | . | . | . | 3 | . | 1 | . | . | 1 | . | . | 1 | . | . | . | 1 | . | . | . | . | . | . | 1 | . | . | . | . | . | . | . | 7 | 9 |
| Bromus sterilis | | | | | . | . | . | 1 | . | . | . | . | . | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | 1 | . | . | . | . | 1 | 1 | 3 | 1 | 8 | 10 |
| Arenaria serpyllifolia | | | | | . | . | . | . | 4 | . | 3 | . | 1 | . | 1 | 1 | 1 | 1 | 1 | . | . | . | . | . | 1 | 1 | . | . | . | . | . | . | . | . | . | 1 | 3 | 1 | 13 | 20 |
| Arabidopsis thaliana | | | | | . | . | . | . | 2 | . | . | . | . | . | . | . | 1 | . | . | . | . | . | . | . | . | . | . | . | 1 | . | . | . | . | . | . | . | . | . | 3 | 4 |
| Galinsoga ciliata | | | | | . | | . | . | . | 1 | . | 1 | | | . | 1 | . | . | . | . | . | . | . | 2 | . | . | . | . | . | . | . | . | . | 1 | . | . | . | . | 5 | 6 |
| Setaria viridis | | | | | . | . | . | . | . | 1 | . | 1 | . | . | . | 1 | . | . | . | . | . | . | . | 2 | . | . | . | . | . | 1 | 1 | . | . | . | . | . | . | 2 | 7 | 9 |
| Poa bulbosa | p | | | | . | . | . | . | . | 1 | . | | . | . | 1 | 1 | 1 | . | . | . | . | . | . | | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 4 | 4 |
| Trifolium repens | p | | | | . | . | . | . | . | . | 1 | 1 | 1 | 1 | 1 | 1 | 1 | . | . | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 8 | 8 |
| Taraxacum officinale | p | | | | . | . | . | . | . | . | . | 1 | | | . | . | | . | . | . | . | . | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 2 | 2 |
| Vicia cracca | p | | | | . | . | . | . | . | . | . | . | . | 1 | . | 1 | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | 1 | . | . | 5 | 5 |
| Poa palustris | p | | | | | | | | | | | | | | | | | | | | | | | | | | | | 2 | 1 | . | . | . | . | . | . | . | . | 2 | 3 |
| Trifolium campestre | | | | | | | | | | | | | | | | | | | | | | | 1 | 3 | 9 | 1 | . | . | 2 | 1 | . | . | . | . | . | . | . | . | 6 | 17 |
| Trifolium arvense | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 2 | 2 | 1 | 1 | . | . | 15 | 15 | 5 | 5 | 8 | 46 |
| Sedum album | p | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 8 | 9 |
| Trifolium aureum | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 1 | . | | . | . | 2 | 1 | 4 | 5 |
| Sedum sexangulare | p | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 1 | . | 1 | 2 | 2 | 5 | 7 |
| Solanum nigrum | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 1 | 2 | 2 |
| **Moss species** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0 | 0 |
| Ceratodon purpureus | | | | | . | . | 38 | 68 | 88 | 68 | 68 | 88 | 88 | 85 | 85 | 85 | 85 | 88 | 88 | 88 | 88 | 88 | 88 | 80 | 80 | 80 | 80 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 32 | 2354 |
| Bryum argenteum | | | | | . | . | 2 | 3 | 5 | 5 | 3 | 5 | 5 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 32 | 151 |
| Brachythecium rutabulum | | | | | . | . | . | . | . | . | . | . | . | . | 3 | 3 | 3 | 3 | 5 | 5 | 5 | 5 | 5 | 3 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 24 | 108 |
| Cladonia coniocrea | | | | | . | . | . | . | . | . | . | . | . | . | . | . | . | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 21 | 78.5 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0 | 0 |
| Flowering plant coverage (%?) | | | | | 115 | 113 | 104 | 123 | 100 | 112 | 116 | 104 | 104 | 114 | 110 | 117 | 115 | 105 | 109 | 107 | 105 | 102 | 101 | 88 | 102 | 102 | 100 | 101 | 106 | 110 | 113 | 112 | 92 | 104 | 120 | 116 | 131 | 127 | 468 | 3700 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| m=perennial | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| x=seeded in pre-cultivated mat | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

The following were present only at one observation date (year, cover value):

Echinocloa crus galli (Sep1986; 2); Agrostis tenuis (June1987; 1); Phleum pratense ssp. nodosum (June 1987, 2); Dactylis glomerata (June 1987); Matricaria chamomilla (June 1987; 2); Veronica polita (June 1987, 2); Rumex thyrsiflorus (June 1987; 1); Polygonum dumentorum ( June 1987; 1).

**Table 3. Significance of climate factors ("dry" or "wet" season) on development of plant species on PLU roof, as determined by regression analysis.**

| **Question** | **Level of significance** | **Significance** |
|---|---|---|
| Number of vascular plant species | 0.01 | *yes: more in wet seasons |
| Only annual plant species | 0.02 | *yes: more in wet seasons |
| Volunteer plant species | 0.02 | *yes: more in wet seasons |
| Only perennial plant species | 0.5 | no: no differences between both types |

**Table 4. Occurrence of the dominant plant species. "Presence value" is the occurrence of a species on the 10 sub-roofs over the 34 observation periods; the maximum value would be 10 × 34 = 340. "Sum" is the product of the presence value of a species multiplied by its degree of coverage (average coverage across all dates); for example, *Allium* is 321 × 60 = 19,512. Species listed in bold letters remained dominant over the duration of the project.**

| | **Plant species, ordinal ordered** | **Presence value** | **Sum** |
|---|---|---|---|
| 1 | ***Poa compressa*** | 329 | 1548 |
| 2 | ***Festuca ovina*** | 313 | 1781 |
| 3 | ***Bromus tectorum*** | 325 | 1762 |
| 4 | ***Allium schoenoprasum*** | 321 | 19512 |
| 5 | ***Cerastium semidecandrum*** | 199 | 509 |
| 6 | *Chenopodium album* | 115 | 246 |
| 7 | *Lolium perenne* | 84 | 1946 |
| 8 | *Festuca rubra* | 95 | 606 |
| 9 | ***Setaria viridis*** | 87 | 215 |
| 10 | ***Conyza canadensis*** | 93 | 158 |
| 11 | *Poa annua* | 43 | 193 |
| 12 | *Senecio vulgaris* | 41 | 87 |
| 13 | *Apera spica venti* | 38 | 103 |
| 14 | *Galinsoga ciliata* | 40 | 109 |
| 15 | *Poa pratensis* | 20 | 69 |

## Table 5. Plant community composition and succession of the concert hall at the Ufa project site from 1992 to 2005.

| Tab. 5: Extensive green roof Ufa Audience Hall | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | May | May | Sep | May | Sep | May | Sep | June | Sep | June | Sep | June | Sep | May | Sep | June | Sep | July | Sep | June | Oct | June | Sep | July | Aug | May | Sep | |
| | | | 1992 | 1993 | 1993 | 1994 | 1994 | 1995 | 1995 | 1996 | 1996 | 1997 | 1997 | 1998 | 1998 | 1999 | 1999 | 2000 | 2000 | 2000 | 2001 | 2002 | 2002 | 2002 | 2003 | 2004 | 2004 | 2005 | 2005 | |
| Flowering plant covereage (%) | | | 95 | 95 | 98 | 98 | 99 | 95 | 105 | 98 | 99 | 99 | 98 | 95 | 98 | 99 | 99 | 95 | 95 | 97 | 97 | 97 | 105 | 98 | 95 | 98 | 98 | 98 | 98 | |
| Dead plant coverage | | | k.A. | 70 | 3 | 2 | 5 | 5 | 5 | 3 | 3 | 8 | 5 | 10 | 2 | 5 | 15 | 10 | 5 | 4 | 4 | 4 | 5 | 8 | 8 | 1 | 2 | 3 | 3 | |
| Max. high perennial plants in cm | | | 40 | 30 | 60 | 80 | 150 | 40 | 120 | 45 | 100 | 90 | 80 | 20 | 120 | 120 | 80 | 40 | 60 | 100 | 100 | 100 | 125 | 80 | 40 | 0.4 | 0.8 | 0.2 | 1 | |
| Average high perennial plants in cm | | | | | 20 | 20 | 35 | 20 | 20 | 30 | 20 | 30 | 30 | 15 | 0.2 | 20 | 10 | 20 | 20 | 15 | 15 | 15 | 50 | 20 | 20 | 0.05 | 0.2 | 0.1 | 0.2 | |
| Bryophyt coverage (%) | | | 95 | 95 | 98 | 98 | 98 | 98 | 98 | 98 | 50 | 50 | 80 | 98 | 60 | 90 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | |
| Irrigation | | | 1 | 1 | 0 | 2 | 2 | 0 | ? | ? | 1 | 1 | ? | 0 | ? | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Climate | | | t | f | f | t | t | t | t | f | f | ? | ? | ? | ? | | | | | f | f | f | f | t | t | f | f | f | f | |
| Number of flowering plant species | | | 27 | 22 | 30 | 39 | 42 | 32 | 32 | 46 | 39 | 40 | 34 | 43 | 47 | 34 | 27 | 34 | 45 | 46 | 40 | 56 | 56 | 46 | 28 | 46 | 51 | 41 | 64 | |
| Cover value, calculated | | | 92.5 | 91 | 107 | 107 | 115 | 102 | 103 | 104 | 101 | 102 | 100 | 102 | 102 | 101 | 97.5 | 96 | 101 | 99.2 | 100 | 143 | 140 | 130 | 112 | 161 | 170 | 124 | 163 | Counts |
| | **Seeded** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | **Lifeform** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Flowering plant species** | | | | | | | | | | | | | | | 22.5 | | | | | | | | | | | | | | | |
| Perennial plant coverage | | | 62.5 | 74 | 81 | 80 | 87.5 | 77.6 | 79.5 | 74 | 75 | 73.5 | 78.5 | 75 | 73 | 81 | 83 | 78.5 | 77.5 | 81.7 | 84.5 | 110 | 109 | 105 | 94 | 127 | 128 | 98 | 122 | |
| Annual plant coverage | | | 30 | 17 | 26 | 26.5 | 27 | 24 | 23 | 30 | 26 | 28.5 | 21.5 | 27 | 28.5 | 18.5 | 13 | 16.5 | 23 | 17.5 | 15.6 | 33 | 31 | 24.5 | 17.5 | 32.5 | 39.5 | 25 | 39 | |
| Sedum hybridum (yellow) | **x** | **p** | 12 | 12 | 12 | 10 | 10 | 12 | 12 | 12 | 12 | 12 | 22 | 22 | 22 | 28 | 28 | 29 | 30 | 15 | 15 | 15 | 15 | 25 | 25 | 35 | 40 | 25 | 25 | 27 |
| Sedum spurium (red) | | | | | | | | | | | | | | | | | | | | 15 | 15 | 15 | 15 | 10 | 10 | 15 | 4 | 5 | 5 | 10 |
| Sedum sexangulare | **x** | **p** | 15 | 20 | 20 | 22 | 22 | 20 | 20 | 20 | 15 | 15 | 15 | 7 | 7 | 8 | 8 | 8 | 8 | 8 | 10 | 15 | 15 | 15 | 15 | 20 | 20 | 15 | 15 | 27 |
| Sedum acre | | | | | | | | | | | | | | 3 | 3 | 3 | 4 | 3 | 3 | 4 | 5 | ? | ? | 4 | 5 | 5 | 4 | 5 | 5 | 14 |
| Sedum album | **x** | **p** | 15 | 15 | 16 | 16 | 12 | 12 | 12 | 7 | 7 | 8 | 5 | 5 | 5 | 6 | 10 | 11 | 10 | 10 | 10 | 15 | 15 | 12 | 12 | 15 | 20 | 20 | 20 | 27 |
| Sedum reflexum | **x** | **p** | 4 | 6 | 5 | 1 | 1 | 2 | 2 | 2 | 3 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 5 | 5 | 27 |
| Sedum rubrum | **x** | **p** | . | . | . | . | . | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 4 | 4 | 4 | 5 | 4 | 5 | 5 | 4 | 4 | 2 | 1 | 2 | 5 | 22 |
| Sedum hispanicum | **x** | | . | . | . | 0.5 | 0.5 | 1? | 1? | 1 | 0.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | . | . | 1 | 1 | 20 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0 |
| **Onobrychis montana** | **x** | **p** | 0.5 | 1 | 0.5 | 1 | 1 | 2 | 2 | | . | . | . | 5 | 2 | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | 10 |
| **Medicago sativa** | **x** | **p** | 2 | 3 | 5 | 6 | 8 | 10 | 10 | 6 | 3 | 3 | 4 | 2 | 3 | 3 | 4 | 1 | 1 | 1 | 3 | 5 | 3 | 3 | 2 | 3 | 3 | 2 | 3 | 27 |
| **Scabiosa atropururea** | **x** | **p** | 1 | . | 3 | . | . | . | . | . | 2 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 0.5 | 0.5 | . | 4 | 6 |
| **Coronilla varia** | **x** | **p** | . | . | 1 | 1 | 1 | 2 | . | 2 | 3 | . | 2 | . | . | . | . | . | . | 1 | 0.5 | 2 | 5 | 4 | 2 | 2 | 2 | 1 | 1 | 17 |
| **Trifolium repens** | **x** | **p** | . | . | . | 1 | 2 | 1 | 1 | . | 3 | 3 | . | . | . | 8 | . | . | . | . | . | 2 | 2 | 1 | 1 | 1 | 1 | . | 1 | 14 |
| **Anthyllis vulneraria** | **x** | **p** | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 2 | 0.5 | 1 | 2 | . | . | . | . | 1 | 1 | 2 | 4 | 2 | 1 | . | . | 2 | 1 | 21 |
| Festuca ovina | **x** | **p** | 5 | 5 | 5 | 5 | 6 | 6 | 6 | 6 | 4 | 4 | 5 | 8 | 4 | 3 | 4 | 2 | 2 | 2 | 2 | 4 | 4 | 5 | 5 | 4 | 5 | 2 | 5 | 27 |
| Poa compressa | **x** | **p** | 3 | 4 | 4 | 4 | 4 | 1 | 1 | 3 | 3 | 4 | 3 | 2 | 2 | 2 | 3 | 3 | 2 | 2 | 2 | 5 | 4 | 5 | 5 | 4 | 5 | 3 | 3 | 27 |
| Lolium perenne | **x** | **p** | . | 1 | . | . | 1 | . | . | . | . | 1 | 1 | 0.5 | 0.5 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 6 |
| Artemisia vulgaris | | **p** | 2 | 3 | 3 | 0.5 | 3 | 3 | 3 | 2 | 4 | 2 | 1 | 2 | 2 | 2 | 4 | 1 | 1 | 0.5 | 1 | 3 | 0.5 | 0.5 | . | 1 | 1 | . | 1 | 25 |
| Oenothera biennis | | **p** | 1 | . | 1 | 3 | 3 | 1 | 2 | 1 | 2 | 2 | 0.5 | . | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 0.1 | 0.1 | . | . | 0.5 | 1 | 0.5 | 1 | 23 |
| **Acer plat. K** | | **p** | 0.5 | 0.5 | . | 0.5 | 0.5 | . | . | 0.5 | 2 | . | . | 1 | 1 | 1 | . | . | . | . | . | 0.1 | 0.5 | . | . | 0.5 | 0.5 | 0.5 | 0.5 | 15 |
| **Prunus padus K** | | **p** | 0.5 | 0.5 | . | 0.5 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 0.5 | 0.5 | . | . | 0.5 | 0.5 | 0.5 | 0.5 | 9 |
| Hieracium pilosella | | **p** | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | 1 | . | . | . | . | 1 | 1 | 5 |
| Leucanthemum vulgare | | **p** | . | 1 | . | 0.5 | . | . | . | 0.5 | . | 2 | . | . | . | . | . | . | . | . | . | 1 | 1 | . | . | . | . | 1 | 1 | 8 |
| Melilotus officinalis | | | . | . | 0.5 | 0.5 | 0.5 | 0.5 | 2 | 2 | 1 | 2 | 3 | 2 | 2 | 2 | 2 | 3 | 2 | 1 | 1 | 2 | 4 | 1 | . | 1 | 2 | 0.5 | 2 | 24 |
| Erysimum cheiranthoides | | **p** | . | . | 1 | . | . | . | . | . | . | . | 1 | . | 0.5 | 1 | . | . | 0.5 | 0.5 | 0.5 | 2 | 1 | 1 | . | 1 | 1 | . | 1 | 13 |
| Agropyron repens | | **p** | . | . | 3 | . | . | . | . | . | . | . | . | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 2 |
| Taraxacum officinalis | | **p** | . | . | . | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | . | 1 | 1 | 1 | . | . | . | 0.5 | 0.5 | . | 0.1 | 0.5 | . | 0.5 | 0.5 | . | 1 | 17 |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Anthemis tinctoria | | | . | . | . | 0.5 | 2 | 0.1 | 0.5 | 1 | . | 1 | . | 1 | 0.5 | . | . | 2 | 1 | 1 | 1 | 1 | 1 | 1 | . | 4 | 2 | 1 | 1 | 19 |
| Sisymbrium loeselii | | **p** | . | . | . | 0.5 | 0.5 | . | . | 0.5 | 1 | 1 | 0.5 | 1 | 0.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.5 | 1 | . | 1 | 2 | 1 | 2 | 21 |
| **Trifolium pratense** | | **p** | . | . | . | 3 | 3 | 0.5 | . | 0.5 | . | 2 | . | 0.5 | . | . | . | . | . | . | . | 1 | 1 | 0.5 | . | 1 | . | 1 | 1 | 12 |
| Arenaria serpyllifolia | | **p** | . | . | . | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | . | 1 | . | . | . | 2 | 1 | 1 | 0.5 | 0.5 | . | 1 | 0.5 | 0.5 | 1 | 2 | 2 | 1 | 1 | 19 |
| Festuca rubra | | **p** | . | . | . | 0.5 | 0.5 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 2 |
| Silene alba | | **p** | . | . | . | 0.5 | 0.5 | . | . | . | . | . | . | . | . | . | . | 0.5 | 1 | 0.5 | . | . | . | . | . | . | . | . | . | 5 |
| Melilotus alba | | | . | . | . | . | 2 | 0.5 | 1 | 1 | 2 | . | 2 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 0.5 | 0.5 | . | 1 | 2 | . | 1 | 20 |
| Hypericum perforatum | | **p** | . | . | . | . | 1 | . | . | . | 1 | 1 | 3 | 1 | 2 | . | . | . | . | 2 | 1 | 2 | 1 | 2 | . | 1 | 2 | . | 4 | 14 |
| **Acer negundo K** | | **p** | . | . | . | . | 0.5 | . | . | . | . | . | . | . | . | . | . | . | . | 0.5 | 0.5 | 1 | 0.5 | . | . | 0.5 | 0.5 | . | . | 7 |
| Poa trivialis | | **p** | . | . | . | . | . | 1 | 1 | 0.5 | 1 | 1 | 2 | 1 | 1 | . | . | . | 1 | 0.5 | 0.5 | . | 0.5 | . | . | . | . | . | . | 12 |
| Poa palustris | | **p** | . | . | . | . | . | . | . | 1 | . | . | 1 | 1 | 0.5 | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | 5 |
| **Crataegus monogyna k** | | **p** | . | . | . | . | . | . | . | 0.5 | . | . | . | . | 0.5 | . | . | . | . | . | . | 0.1 | 0.1 | . | . | . | . | 1 | 1 | 6 |
| Vicia sepium | | **p** | . | . | . | . | . | . | . | 0.5 | 2 | . | . | . | . | . | . | . | 0.5 | 0.1 | . | . | . | . | . | 1 | 1 | 1 | 1 | 8 |
| Festuca glauca | | **p** | . | . | . | . | . | . | . | 0.5 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 |
| **Robinia pseudacacia k** | | **p** | . | . | . | . | . | . | . | . | . | . | 1 | . | . | . | . | . | . | 0.1 | . | . | 0.5 | . | . | . | . | . | . | 3 |
| **Euonymus europaeus k** | | **p** | . | . | . | . | . | . | . | . | . | . | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . | | . | . | 1 |
| Acer campestre | | **p** | | | | | | | | | | | | | | 1 | 0.5 | . | . | . | . | 0.1 | 0.1 | . | . | | . | . | 1 | 5 |
| **Medicago lupulina** | **x** | | 2 | 3 | 6 | 8 | 3 | 5 | 4 | 4 | 5 | 4 | 3 | . | . | 1 | 1 | 0.5 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 4 | 4 | 2 | 2 | 25 |
| **Trifolium aureum** | **x** | | 5 | . | . | 1 | 0.5 | . | . | 1 | . | . | . | 1 | . | 0.5 | . | . | . | 0.5 | 0.5 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 16 |
| Bromus tectorum | | | 5 | 3 | 3 | 4 | 3 | 3 | 3 | 5 | 4 | 6 | 5 | 4 | 4 | 4 | 2 | 3 | 2 | 0.5 | 1 | 2 | 4 | 3 | 2 | 4 | 5 | 4 | 4 | 27 |
| Bromus hordeaceus | | | 5 | 3 | 1 | 1 | 2 | 1 | 1 | 4 | 1 | 0.5 | . | 5 | 2 | 1 | 1 | 1 | . | 1 | . | 1 | 2 | 1 | 2 | . | 1 | . | 1 | 22 |
| Geranium molle | | | 1 | 1 | 1 | 2 | 1 | 4 | 2 | 2 | 1 | 2 | 0.5 | 1 | 1 | 2 | 2 | 1 | 1 | 0.5 | 0.5 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 27 |
| Cerastium semidecandrum | | | 5 | 5 | 1 | 3 | . | 5 | 0.5 | 2 | 2 | 2 | . | 1 | 0.5 | 2 | . | 1 | . | 1 | 0.5 | 1 | 0.5 | 1 | 1 | 1 | 1 | 2 | 1 | 23 |
| Arenaria serpyllifolia | | | 1 | 1 | . | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | 2 | 2 | 1 | . | 1 | 1 | 1 | . | 0.5 | . | 1 | 0.5 | 0.5 | 1 | 1 | 1 | 1 | 1 | 23 |
| Tripleurospermum inodorum | | | 1 | 1 | . | . | . | . | . | 1 | 1 | 0.5 | . | . | . | . | . | . | . | 0.5 | . | 2 | 0.5 | 0.5 | . | . | . | . | . | 9 |
| Senecio vulgaris | | | 1 | . | 0.5 | . | 0.5 | 1 | . | . | 2 | . | 0.5 | . | . | . | 1 | . | . | . | . | 1 | 0.5 | . | . | . | 1 | . | 1 | 11 |
| Conyza canadensis | | | . | . | 1 | 1 | 3 | . | 0.5 | 1 | 1 | 1 | 0.5 | 1 | . | 1 | 3 | . | 1 | . | 0.5 | 1 | 1 | 2 | . | 2 | 2 | 1 | 1 | 20 |
| Trifolium arvense | | | . | . | 1 | . | 4 | 3 | 2 | 1 | 2 | 3 | 3 | 1 | 1 | 2 | . | 1 | 1 | 3 | 3 | 3 | 3 | 1 | . | 5 | 10 | 3 | 3 | 22 |
| Chrysanthemum segetum | | | . | . | 1 | . | . | . | 0.5 | 0.5 | 0.5 | 1 | 1 | 1 | 0.5 | 1 | . | . | 1 | 1 | 1 | 2 | 2 | 2 | . | 2 | 1 | 1 | 2 | 19 |
| Chenopodium album | | | . | . | 1 | . | 0.5 | . | . | . | . | 1 | 1 | . | 3 | 1 | . | 3 | 1 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | . | 0.5 | 0.5 | . | 1 | 16 |
| Erigeron annuus | | | . | . | 1 | 0.5 | 2 | . | . | 0.5 | 2 | 2 | 2 | 1 | 0.5 | 1 | 1 | . | 1 | 2 | 2 | 4 | 2 | 2 | . | 2 | 1 | 4 | 2 | 21 |
| Erodium cicutarium | | | . | . | 3 | . | . | . | . | 1 | 1 | 1 | . | . | 2 | 1 | . | . | 1 | 0.5 | 0.5 | 1 | 1 | . | . | 1 | 1 | 1 | 1 | 15 |
| Galinsoga ciliata | | | . | . | 5 | . | . | . | . | . | 1 | . | . | 1 | 2 | . | . | . | 2 | . | . | 1 | . | 1 | 1 | . | 1 | 1 | 1 | 11 |
| Echinochola crus-galli | | | . | . | 0.5 | . | . | . | . | . | . | . | . | . | . | . | . | 1 | 2 | . | . | 1 | . | . | . | . | 1 | . | 1 | 6 |
| Vicia angustifolia | | | . | . | . | 0.5 | . | 0.5 | 0.5 | 0.5 | . | . | . | 1 | . | . | . | . | 1 | . | . | 0.5 | 1 | . | . | 2 | 1 | 1 | 1 | 12 |
| Crepis tectorum | | | . | . | . | 1 | . | . | . | 3 | . | . | . | 1 | . | . | . | . | 1 | . | . | 1 | . | . | . | . | . | . | 1 | 6 |
| Diplotaxis tenuifolia | | | . | . | . | 0.5 | . | . | . | . | . | . | . | 1 | . | . | . | . | 0.5 | . | 0.5 | . | . | . | . | . | . | . | 1 | 5 |
| Lapsana communis | | | . | . | . | 3 | . | . | . | . | . | . | . | . | . | . | . | . | 0.5 | . | . | 2 | 0.5 | 0.5 | . | . | . | . | 1 | 6 |
| Viola tricolor arvensis | | | . | . | . | 0.5 | . | . | . | . | . | . | . | . | . | . | . | . | 1 | . | . | . | . | . | . | . | . | . | 1 | 3 |
| Capsella bursa-pastoris | | | 1 | . | . | . | 0.5 | 0.5 | . | 0.5 | . | . | . | . | . | . | . | . | 0.5 | 0.5 | . | . | . | . | . | . | . | | | 6 |
| Galinsoga parviflora | | | . | . | . | . | 1 | . | 3 | . | 1 | . | 2 | 3 | 3 | . | . | 0.5 | 0.5 | 1 | 1 | 0.5 | 0.5 | 0.5 | . | 1 | 1 | . | 1 | 16 |
| Setaria viridis | | | . | . | . | . | 5 | . | 5 | . | . | . | . | . | 2 | . | 1 | 1 | 1 | 2 | 3 | 0.5 | 0.5 | 2 | 3 | 1 | 2 | . | 2 | 15 |
| Euphorbia peplus | | | . | . | . | . | 0.5 | . | . | . | . | . | . | 1 | . | . | . | . | . | 0.5 | 0.1 | . | . | 1 | 1 | . | . | . | . | 6 |
| Apera spica-venti | | | 1 | . | . | . | . | 0.5 | 0.5 | . | . | . | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 4 |
| Myositis arvensis | | | 1 | . | . | . | . | . | . | 1 | . | 1 | . | . | . | . | . | 1 | 1 | . | . | . | . | . | . | . | . | . | . | 5 |
| Viola arvensis | | | 1 | . | . | . | . | . | . | 0.5 | . | . | . | . | . | . | . | 0.5 | 0.5 | . | . | . | . | . | . | . | 1 | . | . | 5 |
| Bromus sterilis | | | . | . | . | . | . | . | . | 1 | . | . | . | . | . | . | . | 0.5 | 0.5 | . | . | . | 0.5 | . | . | 1 | . | 1 | 1 | 7 |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Poa annua | | | . | . | . | . | . | . | . | . | 0.5 | 0.5 | . | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . | 1 | 1 | 5 |
| Senecio viscosus | | | . | . | . | . | . | . | . | . | . | 0.5 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 |
| Helianthus annuus | | | . | . | . | . | . | . | . | . | . | 0.5 | . | . | . | . | . | . | . | . | . | . | 0.5 | . | . | . | . | . | . | 2 |
| Linaria vulgaris | | | . | . | . | . | . | . | . | . | . | . | 1 | . | . | . | . | . | . | . | . | 1 | . | . | . | . | . | . | 2 | 3 |
| Berteroa incana | | | . | . | . | . | . | . | . | . | . | . | . | 1 | . | . | . | . | 0.5 | . | . | 2 | 5 | 2 | 3 | 1 | 1 | . | 2 | 9 |
| Lactuca serriola | | | . | . | . | . | . | . | . | . | . | . | . | . | 0.5 | . | . | . | . | 1 | . | 1 | . | . | . | . | 1 | . | 1 | 5 |
| Zea mays | | | . | . | . | . | . | . | . | . | . | . | . | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 |
| Lamium pupureum | | | . | . | . | . | . | . | . | . | . | . | . | . | 0.5 | . | . | 0.5 | . | . | . | . | . | . | . | . | . | . | . | 2 |
| Polygonum aviculare | | | . | . | . | . | . | . | . | . | . | . | . | . | 0.5 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 |
| Amaranthus retroflexus | | | . | . | . | . | . | . | . | . | . | . | . | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 |
| Solanum nigrum | | | . | . | . | . | . | . | . | . | . | . | . | . | 2 | . | . | . | 0.5 | . | . | . | . | 0.5 | 0.5 | . | . | . | . | 4 |
| Lamium amplexicaule | | | . | . | . | . | . | . | . | . | . | . | . | . | 0.5 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 |
| Papaver agremone | | | | | | | | | | | | | | | | | 1 | . | . | . | . | . | . | . | . | . | . | . | . | 1 |
| Tricitum aestivale | | | | | | | | | | | | | | | | | | 1 | . | . | . | . | . | . | . | . | . | . | . | 1 |
| Quercus robur k | | **p** | | | | | | | | | | | | | | | | | | . | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | . | . | . | . | 5 |
| Bromus thominii | | | | | | | | | | | | | | | | | | | | | . | | | 1 | . | 1 | 1 | 1 | . | 4 |
| Ambrosia artemisifolia | | | | | | | | | | | | | | | | | | | | | | | | | | . | 2 | . | 1 | 2 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Bryophytes** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Ceratodon purpureus | | | 90 | 95 | 95 | 95 | 95 | 95 | 95 | 95 | 95 | 95 | 40 | 60 | 40 | 13 | 20 | 40 | 40 | 40 | 45 | 40 | 40 | 40 | 40 | 40 | 40 | 80 | 60 | 27 |
| Mnium stellare | | | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 20 | 20 | 10 | 13 | 7 | 40 | 20 | 20 | 20 | 10 | 10 | 10 | 10 | 10 | 5 | 5 | 5 | 27 |
| Scleropodium purum | | | . | . | . | . | 3 | 3 | 3 | 3 | 3 | 3 | 10 | 10 | 10 | 9 | 3 | 10 | 20 | 20 | 10 | 5 | 5 | 10 | 10 | 10 | 8 | 5 | 5 | 23 |
| Amblystegium juratzkanum | | | . | . | . | . | 3 | 3 | 3 | 3 | 5 | 5 | 5 | 5 | 5 | 9 | 3 | 5 | 20 | 20 | 10 | 5 | 5 | 10 | 10 | 10 | 10 | 5 | 4 | 23 |
| Polytrichum formosum | | | . | . | 2 | 2 | 2 | 2 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 10 | 2 | 5 | 10 | 10 | 5 | 5 | 5 | 5 | 10 | 10 | 10 | 5 | 2 | 25 |
| Cladonia coniocrea | | | . | . | 1 | 1 | 1 | . | . | . | 5 | . | 4 | . | 2 | 6 | 3 | 2 | 2 | 1 | 2 | 1 | 3 | 3 | 10 | . | 2 | 3 | 3 | 19 |
| Marchantia spec | | | | | | | | | | | | | | | | | | | | | | | | | | | 2 | 2 | 2 | 3 |

# Space for Urban Wildlife: Designing Green Roofs as Habitats in Switzerland

**by Stephan Brenneisen**

University of Applied Sciences Wädenswil, Grüental, Postfach 335, CH 8820
Wädenswil, Switzerland

## Abstract

Research focusing on the biodiversity potential of green roofs has led to an amendment in building and construction law in Basel, Switzerland. As part of the city's biodiversity strategy, green roofs are now mandatory on new buildings with flat roofs, and guidance is provided for the creation of different plant and animal habitats on the green roofs. Design criteria for the creation of these habitats include varying the substrate thickness and using natural soils from nearby areas. (Studies of green roofs in Zurich, Switzerland, have shown that natural soils can benefit biodiversity through their suitability for locally and regionally endangered species.) The design and construction of green roofs to re-create habitats require close cooperation among all specialists involved. Research and comprehensive planning are also important for creating space on roofs for urban wildlife.

**Key words:** Basel; biodiversity; extensive green roofs; urban ecology; land-use regulations

## Introduction

Extensive green roofs have generally been considered relatively species-poor alternative habitats for plants and animals, populated only by highly mobile pioneer species and unsuitable as permanent habitats for ground-dwelling organisms (Buttschardt, 2001). However, initial investigations in Basel, Switzerland, on a green roof set up as a dry pond and on an additional sample area have indicated that the low biotic diversity of many green roof surfaces is primarily due to their thin substrate layer (Brenneisen, 2003). A shallow substrate layer is the hallmark of current cost-conscious roof construction, but it exacerbates the already challenging conditions for plants and animals on green roofs. Methods have recently been developed to improve the design of building-integrated habitats for urban wildlife (Brenneisen, 2003).

Well-designed green roofs can provide habitat compensation for rare and endangered species affected by land-use changes. This has been established by research programs focusing on the ecological-compensation potential of extensive green roofs in Basel (Brenneisen, 2003) and London, England (Kadas, 2002; Jones, 2002). The results of these studies contrast with those of earlier studies from Germany, which found that only common, highly mobile species can establish on green roofs (Klausnitzer, 1988; Riedmiller, 1994; Mann, 1998). One reason for the differences in the results could be the varying numbers of individuals caught and identified. The survey in Basel collected 12,500 individual spiders, and this increased the statistical chance of finding rare species. Another reason could be that the research in Basel and London was carried out on green roofs with varying substrate thicknesses, which create different microhabitat conditions and greater potential for diverse suites of organisms to establish. On the Basel roofs, the vegetation ranged from geophytes and succulents (e.g., *Sedum* species) sparsely colonizing open areas to dense dry-herb and grass communities. On the most biodiverse roofs investigated, at the Rhypark building, a dense combination of microhabitats was found to support an assemblage of 79 beetle and 40 spider species. Thirteen of the beetle species and seven of the spider species were classified in Red Data Books (Platen, Blick, Sacher & Malten, 1996; Geiser, 1998; Pozzi, Gonseth & Hänggi, 1998) as endangered. A comparison of colonization rates on new roofs showed that the number of species of beetles and spiders increased over a period of three years on green roofs specifically designed for biodiversity, whereas approximately the same number of species were found on a conventional extensive green roof both three and five years after construction (Figure 1) (Brenneisen, 2003).

In addition to examining the influence of design on green roof biodiversity, the study also showed the importance of using natural substrates (Brenneisen, 2003). The adaptation of spider and beetle fauna to natural soil and other substrates such as sand and gravel from riverbanks seemed to be a factor for successful colonization. The results showed that near-natural habitats can be established on roofs. Compensatory microhabitats were constructed in Basel for invertebrates associated with riverbanks (Rossetti roof), with rocks and rock debris (Nordtangente roof), and with high mountain habitats and dry grasslands (Rheinfelden roof). Wet/dry meadows and heath/moor habitats can also be re-created on rooftops where there is restricted drainage combined with an appropriate amount and distribution of annual rainfall, or if the substrate provides sufficient water retention. An example of this habitat is the green roof system at the water-filtration plant in Wollishofen, on the outskirts of Zurich (Landolt, 2001).

## Basel's Biodiversity Strategy for Green Roofs

Findings from this research have led to an amendment in the building and construction laws in Basel. Swiss land-use regulations stipulate that interference with the natural environment be kept to a minimum, and that soil be used in a sustainable way. Federal legislation on the conservation of nature and cultural heritage requires that endangered species be appropriately protected. In accordance with these regulations, the canton of Basel mandates the design and use of substrates for extensive green roofs as part of its current biodiversity strategy. In general, green roofs must be constructed on all new buildings with flat roofs (Nature and Landscape Conservation Act § 9; Building and Planning Act § 72). On roofs of over 500 square meters, the substrates must be composed of appropriate natural soils from the surrounding region and must be of varying depths.

## Warm-Dry Regions

The Basel area is part of the central European mosaic of warm-dry regions and contains their typical flora and fauna. Figure 2 shows some of the habitat types associated with the area, which have been newly re-created on the green roof of the Cantonal Hospital of Basel. The substrate regimes on this roof ranged from gravel and sand (simulating river terrace conditions) to topsoil coverage (for near-natural dry meadows). The substrate depths were 6, 12, and 20 centimeters (Figure 3). The roof was seeded with a mixture of native annual and perennial herbs.

### Moderate and humid climates

Appropriate green roof regimes have also been developed for landscapes in more humid climates. The four 90-year-old green roofs at the Wollishofen water plant in Zurich provide a good example (Landolt, 2001). The biological diversity of the surrounding area's species-rich wet meadows was conserved on these roofs after much of the habitat disappeared due to agricultural intensification. The original reason for installing the green roofs in 1914 was not for conservation but to cool the building and the water inside. Nonetheless, the roofs are now refuges for 175 recorded plant species, including 9 orchid species. Some of them, such as *Orchis morio*, *O. latifolia*, and *O. militaris*, are listed in Red Data Books and classified as endangered. The geobotanist Elias Landolt has recommended that the green roofs in Wollishofen be granted cantonal protection (Landolt, 2001). There are other green roofs where orchids or other rare and even endangered species could establish; however, the Wollishofen roofs are especially valuable because they sustain more or less entire plant communities known from the more natural habitats at ground level.

## Natural Soil and Technical Substrates

The substrate on the roofs in Wollishofen is composed of 15 centimeters of topsoil from the surrounding area placed over a 5-centimeter layer of gravel (Figure 4). Water drainage is thus often limited on the Wollishofen roofs, and what is often perceived as a problem for an engineer becomes an opportunity for nature: Periods of high water retention alternating with dry periods reproduce conditions similar to those found in seminatural habitats such as moors and wet meadows. Such conditions were important factors in conserving typical local and regional biodiversity on the green roofs in Wollishofen.

In conclusion, although technical substrates (that is, substrates developed specifically for green roofs) have many practical advantages in terms of weight, consistent drainage, and efficient installation, they are generally suboptimal where biodiversity is concerned.

## Implementation and Construction of Biodiverse Green Roofs

To implement the guidelines for green roofs under Basel's building and construction law, close cooperation is required between the local authorities and conservation scientists, as well as between structural and landscape architects, green roof companies, and contractors. To be successful, an urban biodiversity strategy for green roofs should be based on a regional research program that has investigated the opportunities for using green roofs as habitats and the specific conditions required by the species that would populate them. In addition, habitat and design concepts, as well as techniques for installing specific substrates on roofs, should be established.

Planning the creation of near-natural green roofs is highly challenging. Selection and storage of suitable substrates is crucial, as is determining the most suitable construction method. When redeveloping typical secondary urban habitats, such as those associated with brownfield sites and other valuable vegetated areas, the topsoil and/or substrate should be saved (if it is suitable) for subsequent use on a green roof. The top 15 centimeters of the substrate must be carefully removed and appropriately stored so that some of the existing vegetation, seed bank, and soil organisms can be conserved. Microhabitats can also be varied on green roofs by using substrates such as gravel and sand taken from layers under the soil of the construction site or from a nearby area. Landscape and construction planners should work together with the green roof company to decide on the best way of getting the substrate onto the roof and ensuring its efficient distribution over the total roof area. Careful planning and installation is time well spent, because a well-constructed roof can persist more or less carefree for over half a century, disturbed only by annual inspections of rooftop equipment and drains.

Replacement habitats have also been created on roofs in London (Frith & Gedge, 2000; Gedge, 2002). These include green roofs designed to mitigate habitat loss for the rare black redstart (*Phoenicurus ochruros*) and invertebrates associated with redeveloped brownfield sites.

## Limitations of Green Roofs for Conserving Biodiversity

So far, I have emphasized the general ability of green roofs to protect species and nature. However, a supplementary study in the DB (German railroad) shunting yards in Basel (Brenneisen & Hänggi, 2006), which directly compared green roofs to areas of conservation importance on the ground, clearly showed the limitations of the roofs for supporting certain species. Some animals could not reach the green roof areas due to their restricted mobility—for example, *Atypus* species in the order of the web spiders (Araneae). Others simply did not visit (let alone colonize) the substitute habitats on the roofs. And still others could not adapt to or use the harsh environments of the roofs. Earthworms, or example, are unable to survive on green roofs due to the limited depth of the substrate; they perish during high temperatures in summer because they cannot migrate to deeper, cooler regions of the soil.

The size of the replacement habitat provided by green roofs is also a limiting factor. In the recent study (Brenneisen & Hänggi, 2006), the shunting yards cover several hectares and are thus in a different order of magnitude to a typical green roof, which may cover between a hundred and a few thousand square meters. The area of habitat needed by individual species for colonization then becomes the central issue.

## Ground-Nesting Birds on Roofs

A further possible habitat function of green roofs is the provision of nesting locations for ground-nesting birds. Examples of this can already be found in the literature, particularly with regard to the little ringed plover (*Charadrius dubius*), northern lapwing (*Vanellus vanellus*), and skylark (*Alauda arvensis*) (Brenneisen, 2003). No long-term study of how a brood develops on flat roofs or whether flat roofs can actually sustain these species has been completed. However, because of the huge potential area for roof greening on industrial and commercial land on the outskirts of residential areas, it can be expected that consistent, extensive greening would lead to significant improvements for birds.

As part of the Ground-Nesting Birds on Flat Roofs project at the University of Applied Sciences Wädenswil, a number of green roof locations in Switzerland with possible breeding pairs of northern lapwing and little ringed plover are being observed and investigated. The investigations are focusing on how breeding takes its course on the roofs, whether young birds can survive, and, if necessary, how changes in the design of flat roofs can improve breeding success rates. (See Baumann, 2006).

## Conclusion

Extensive green roofs can provide suitable habitat for animal and plant species that are able to adapt to and develop survival strategies for extreme local conditions and are also mobile enough to reach habitats on roofs. Unlike habitats on the ground, current green roof systems do not have deep soil layers; as a result, in extremely dry periods plants cannot draw up groundwater, and ground-dwelling animals have no opportunity to retreat to lower-lying, damper areas. Designing green roofs so that they have varying substrate depths and drainage regimes creates a mosaic of microhabitats on and below the soil surface and can facilitate colonization by a more diverse flora and fauna.

As a potential tool for preserving and restoring biodiversity in urban areas, green roofs need to be seen less from the perspective of ornamental gardening and energy conservation and more from a regional perspective of landscape and ecological planning. The functional and technical approach taken by most green roof developers and creators today can be enhanced by the spatial approach taken by conservation science practitioners.

## Acknowledgments

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# Glossary

**Extensive green roofs:** A low-management type of green roof that has soil depths ranging from three to seven inches. Due to the shallow soils and the extreme environment on many roofs, plants are typically low-growing groundcover species that are extremely sun and drought tolerant.

**Brownfield:** Formerly developed land.

**Figure 1: Number of species of spiders and beetles on green roofs in Basel with structured and unstructured design, surveyed over a three-year period. Structured roofs were designed to increase faunal diversity. Red shading indicates species of conservation interest listed in the Red Data Book.**

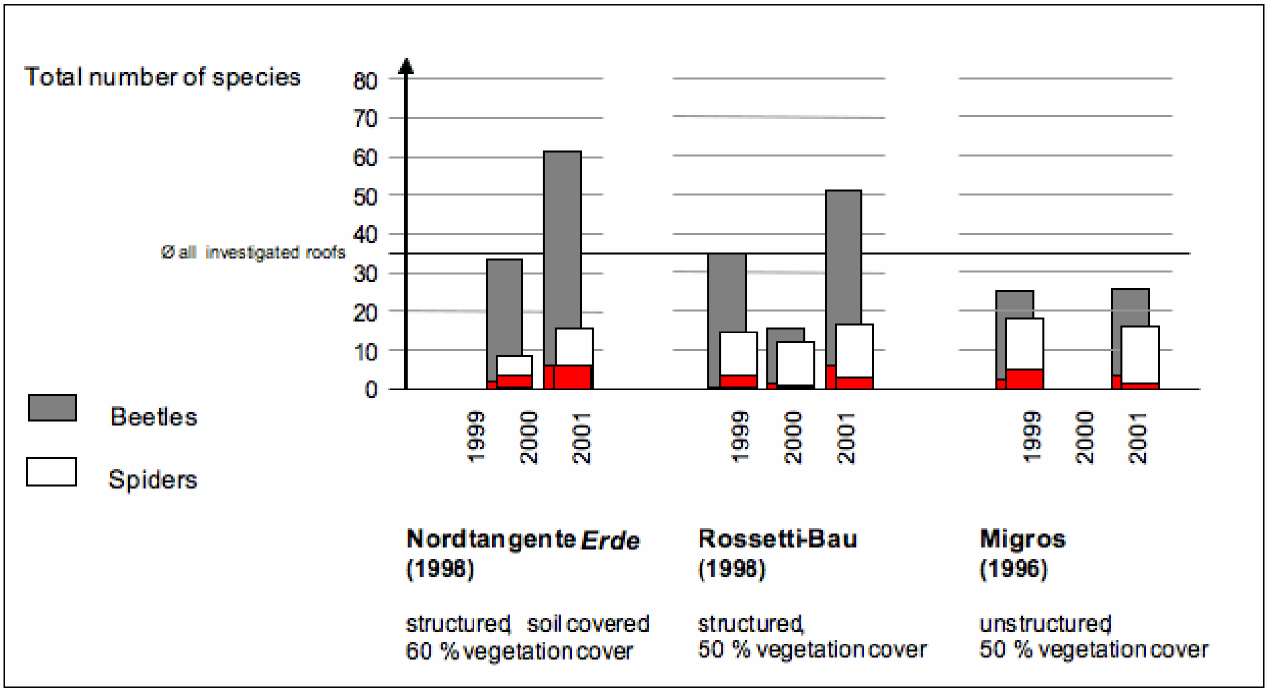


**Figure 2: Newly constructed green roof on the Klinikum 2 of the Cantonal Hospital of Basel, built in accordance with the city's new guidelines on green roofs and urban biodiversity. (Photo: Stephan Brenneisen)**

**Figure 3: Different substrate depths (6, 12, and 20 cm) used to create various vegetation forms as a basis for the colonization of diverse fauna on the Cantonal Hospital roof.**

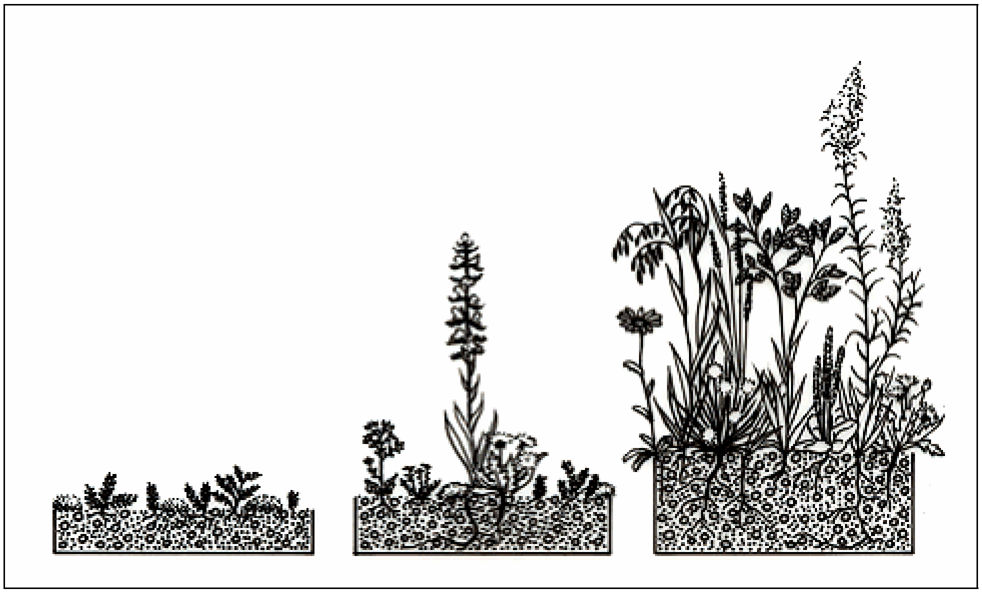
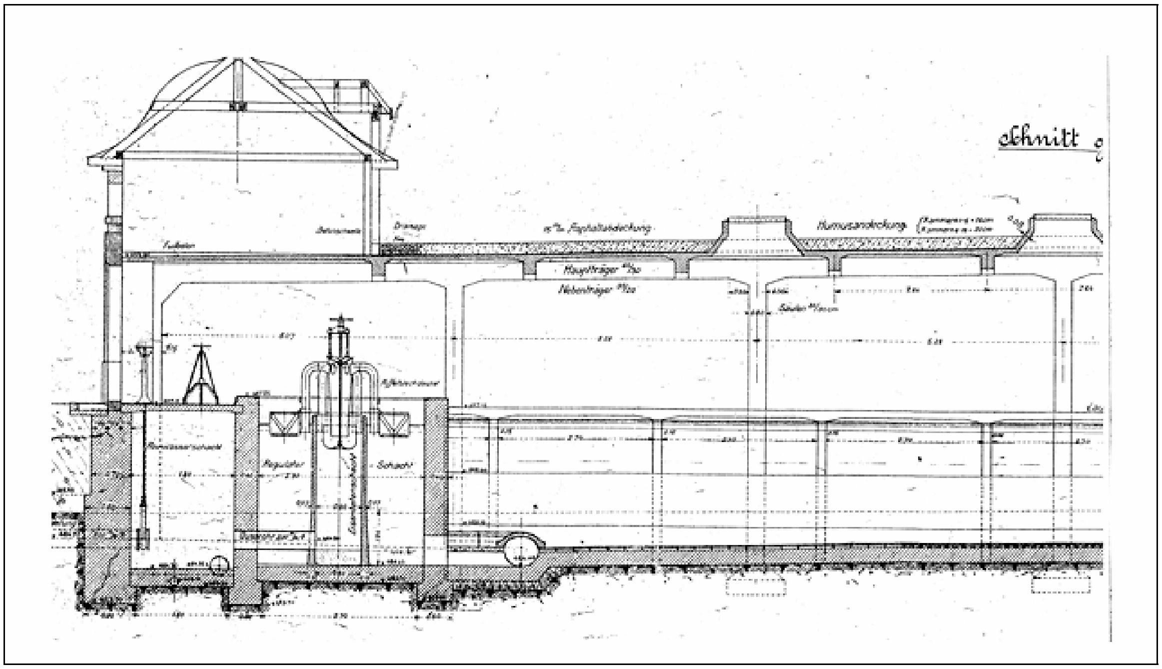


**Figure 4: Construction plan of the lake water filtration plant (with green roof) in Wollishofen, Zurich. The building was erected in 1914.**



# Ground-Nesting Birds on Green Roofs in Switzerland: Preliminary Observations

**by Nathalie Baumann**

University of Applied Sciences Wädenswil, Dept. of Natural Resources Sciences
Green Roof Competence Centre, Grüental, Postfach 335, CH 8820 Wädenswil,
Switzerland

## Abstract

Bird species in Switzerland are threatened by habitat loss and fragmentation due to increasing urbanization. New research is showing that green roofs can provide food habitat for some bird species. But little research has been done on the potential of green roofs for providing nesting locations for birds, particularly ground-nesting species. This preliminary two-year study (part of a larger, multiyear project) examined the breeding success of the little ringed plover (*Charadrius dubius*) and northern lapwing (*Vanellus vanellus*) on flat green roofs in five sites in Switzerland surrounded by varied levels of development. Results show that northern lapwings have begun to breed consistently, though as of yet unsuccessfully, on some green roofs. Because the observation time was short, the available data are incomplete. Nonetheless, they show certain tendencies with regard to the habitat selection and behavior of young and adult birds—important information that can be applied to future research and green roof design.

**Key words:** Biodiversity; breeding success; green roofs; ground-nesting birds; little ringed plover (*Charadrius dubius*); northern lapwing (*Vanellus vanellus*); urban ecology

## Introduction

Investigations of the habitat potential of flat green roofs have indicated that this technology may lead to significant gains in biodiversity. Already, numerous IUCN Red List species of spiders and beetles have been found on green flat-roof habitats in Europe (Brenneisen, 2003a). There is also evidence for the habitat potential of green roofs for endangered bird species (Brenneisen, 2003a). Until now, little consideration has been given to the ecological functions that green roofs may perform for organisms within the larger landscape. Because of their mobility, many bird species can reach green roofs in urban areas, and at least some can utilize these roofs for feeding and breeding. In a recent study, Brenneisen (2003a) found that species such as the black redstart (*Phoenicurus ochruros*), house sparrow (*Passer domesticus*), and white wagtail (*Motacilla alba*) use green roofs as food habitats for insects and seeds. The same researcher also conducted a literature search on the breeding success of birds on green roofs and found some references to single observations but none to successful roof broods. In the studies surveyed, observation times were too short, and the data collection was not designed for systematic observation of ground-nesting birds.

Not enough attention has been given to the behavior of adult and young birds on green roofs to generate specific design guidelines. More exact investigations are required. The following preliminary report summarizes data from a long-term study of birds on green roofs, conducted at the University of Applied Sciences, in Wädenswil, Switzerland. The results focus mainly on ground-nesting bird species and their breeding success on flat roofs. The long-term study is intended to address the question: How can green-roof design (with suitable vegetated and nonvegetated sections) favor breeding success?

## Methods

We examined green roofs at five sites with previously recorded single observations of the northern lapwing (*Vanellus vanellus*) and little ringed plover (*Charadrius dubius*). The sites were located in different Swiss cantons (Aargau, Berne, Zurich, and Zoug), and their surroundings varied from urban to rural. In 2005 and 2006, use of the roof areas as breeding habitat by these two species was recorded from the end of March until the middle of July. From the time of the birds' arrival, in March, through to July, observations were made once weekly for three hours at the same time of day; during breeding, the frequency of observation was increased. Observations were made with field glasses (10 × 36 mm), and notes were taken in standardized field books (recording habitat, behavioral, and landscape descriptions). They were primarily made from neighboring buildings with good vantage points so that the birds were not significantly disturbed.

## Study Species

The northern lapwing is a wading bird in the plover family. It is native to temperate Europe and Asia and is occasionally seen in North America. Highly migratory over most of its range, it sometimes winters further south in northern regions of Africa and India. Lowland breeders in the westernmost areas of Europe are resident (Kooiker, 1997). The northern lapwing breeds on cultivated land and in other short-vegetation habitats. It lays three to four eggs in a ground scrape, and the chicks hatch out after 27 days of brooding. The chicks leave the nest early and after 42 days are able to fly away. From the time they leave the nest (day one), they have to find their food and water by themselves. The numbers of this species have been adversely affected by intensive agricultural techniques (Kooiker, 1997). The northern lapwing settled in the extensive wetlands of Switzerland's central country decades ago. However, when these wet areas were drained for agricultural use, populations of the species rapidly decreased (Schweizerische Vogelwarte Sempach, 2006). Some populations were able to adapt to the cultural landscape by breeding in damp meadows and fields. Unfortunately, intensive management of agricultural soil and increasing urban sprawl have led to further declines. However, now it appears that the species is shifting to the use of green flat roofs as new brood habitat.

The little ringed plover likewise belongs to the wading bird group. Native to Europe and western Asia, its natural habitat is gravel and sand banks along the edges of rivers. It nests on the ground on stones with little or no plant growth and lays three to four eggs. The chicks hatch after 25 to 27 days of brooding and leave the nest early. As with the northern lapwing chicks, little winged plover chicks are precocial and must find food and water for themselves from the day they hatch. After 24 to 27 days they are able to fly away (Schweizerische Vogelwarte Sempach, 2006). In Switzerland, the little ringed plover was driven out of its natural riverine habitats at the beginning of the last century because of watercourse corrections. The species now uses gravel pits, industrial sites, and green roofs.

Both the little ringed plover and northern lapwing are listed as endangered and have high protection priority in European biodiversity programs (see, for example, Natura 2000, and its non-EU counterpart, the Emerald Network). The little ringed plover, according to Natura 2000, needs particularly special protection measures. The northern lapwing is a priority species within the bird-protection organizations of Switzerland (e.g., SVSBirdLife Schweiz, Schweizerische Vogelwarte Sempach) (Bollmann, 2002).

## Sites

Five observation sites were chosen for the preliminary study. The choice of the sites was based on references of breeding on green roofs made by ornithologists at Schweizerische Vogelwarte Sempach and SVS/BirdLife Schweiz.

## Shoppyland Schönbühl (Canton of Berne)

For seven years, ornithologists have observed northern lapwings on the green roof (about 8,346 square meters) of the Frischezentrum ("Freshness Centre") of the Shoppyland shopping complex. However, only within the last year or so have clear observations been made of nesting (approximately three nests) and breeding (Schneider, 2004). The substrate on this roof is purely mineral and consists of blown clay and volcanic material 6 to 8 centimeters thick. The vegetation consists mainly of *Sedum*, moss, and certain grasses. In spring and autumn 2004, 15 cubic meters and 47 cubic meters, respectively, of composted substrate (Ricoter) were added to the existing substrate, and a thin layer of plant seed (Basler roof herb mixture) was sown (Figure 1). The goal of adding this supplementary material was to enhance the nesting-habitat potential of the roof for northern lapwings. Shoppyland is near Lake Moos, where several northern lapwing individuals have been observed since 1990. This population, which is under pressure from development, could be a reference or source population for the settlement of the Shoppyland flat roof.

## Steinhausen (Canton of Zoug)

The flat roof in Steinhausen is on an office building in an industrial zone (Figure 2). The building was constructed in 1993; its roof was sealed with bitumen and covered with a layer of rolled gravel. Meager vegetation was planted on a thin humus layer; it is dominated by *Sedum* species but also includes carnation plants (*Dianthus carthusianorum* L.) and moss. The gross surface of the roof is approximately 3,200 square meters. As with the Shoppyland site, natural habitat areas are in proximity to the building. They include Zuger Lake and its banks, as well as nearby agricultural fields, which for decades have been settled by a population of northern lapwings. These sites have decreased drastically in area over the decades, and the northern lapwing has had to look for other habitat—for example, green roofs (see Figure 3).

## Kaiseraugst (Canton of Aargau)

For many years, the little ringed plover has been nesting and breeding in the Ernst Frey AG gravel pit, in Kaiseraugst, which has a surface area of 95,447 square meters (Dasen, 2005). However, within the last year, most of the pit was filled in (Figure 4); only the very northeastern section of it is still open, and this area is characterized by plentiful vegetation. Flat green roofs were constructed on three modular research buildings adjacent to the pit to explore their potential as effective habitat replacements. The behavior of the little ringed plover in its secondary habitat is being observed to find out which landscape features are particularly important to them and to measure its food-search activity radius. The green roofs were designed with reference to the habitat conditions of the bird species. They consist of a mixture of open area (with gravel and sand) and closed area with vegetation (growing on composted soil).

## Zurich–Kloten (Canton of Zurich)

Several northern lapwing individuals have been observed on two large neighboring flat green roofs in Zurich–Kloten. These surfaces measure approximately 2,000 square meters in area and are covered with eight centimeters of mineral substrate (blown clay and volcanic material) and a mix of moss and *Sedum* species. Directly adjacent to the roofs is a 74-hectare protected natural area. This area is managed as extensive long-grass meadow, an ecologically valuable grass landscape. On these urban grasslands, several northern lapwings have been nesting and breeding for many years.

## Hochdorf (Canton of Lucerne)

The company 4B, in Hochdorf, owns factory buildings with approximately 2,000 square meters of roof surface area. The substrate on the roof is gravel and crushed stone, upon which is a meager covering of moss. In 2002, a pair of little ringed plovers was observed breeding on the roof. Since then, they have returned each year.

## Results 2005

The 2005 investigations supplied us with interesting preliminary data, in particular about the northern lapwing (see Table 1 for a summary of the data). In the Shoppyland, Steinhausen, and Zurich–Kloten sites, older breeding hollows of the northern lapwing were found on all the flat green roofs. These provide evidence that the northern lapwing has returned consistently to the flat roofs over multiple seasons (ranging from 2 to 13 years) and made primary broods. In 2005, however, none of the six primary broods were successful (i.e., chicks hatched, but none survived to fledge; most died after a few days). Three secondary broods were attempted but none were successful.

During March 2005, the population of adult northern lapwings on the Shoppyland flat green roof went from three to two when one individual died. And at the beginning of April, one of the two remaining individuals was found dead on the ground, most likely attacked (from the nature of its injuries) by a bird of prey. Consequently, there were no breeding attempts in 2005.

At the Zurich–Kloten site, northern lapwings have already bred for several years in the nearby grassland. In 2005, however, six pairs of adults used the two flat green roofs to breed. The reasons why they chose this breeding habitat are still uncertain and yet to be examined. Some may have resettled on the roof after the loss of their first brood in the grassland a few hundred meters away. Although the clutches of eggs in the second brood exhibited good hatching success, no chicks survived.

Little plovers were not observed on the roofs of the three modular buildings in Kaiseraugst. Four successful broods were observed in the adjacent gravel pit. The investigation showed that the little ringed plover needs damp places and prefers uneven surfaces (Dasen, 2005). Recommendations for creating habitat for this species on flat green roofs might include designing the roofs with uneven surfaces and water-retaining substrates.

At the Hochdorf site, no breeding success was observed this year for the little ringed plover.

At the Steinhausen site, two pairs of northern lapwings were observed brooding (Figure 5). A total of six chicks hatched but did not survive very long. Unfortunately, the carcasses of the dead chicks could not be found and examined (they may have been carried off by a bird of prey). After the chicks disappeared, the adult birds disappeared too. We presume that the chicks died because of inadequate food and water.

## Results 2006

Observations were made at the same sites in 2006. A new site was also added in Rotkreuz (Canton of Zoug). At that site five pairs of northern lapwings had chicks that hatched, but the chicks died after about five days. The results of the other sites are shown in Table 2.

This year observation cameras were installed and tested for the first time at the Steinhausen and Rotkreuz sites. The goal is to use the cameras to observe the nest sites around the clock and gather more information about the development of the young birds. As the cameras' technology and methodology need to be refined, no further information and data is provided here.

## Discussion

Ground-nesting bird species such as the little ringed plover and northern lapwing are under strong anthropogenic pressure in Switzerland, and to a lesser degree in other European countries. Rising urbanization has led to increased loss and fragmentation of their habitat (swamps, wetlands, and grassland). But these species have shown time and again that they can adapt to the changes and to the urban landscape. The little ringed plover, for example, selects gravel pits as a secondary habitat, and the northern lapwing chooses extensively managed areas of agricultural land. In recent years, both species have begun to utilize green flat roofs.

The vegetation on the green roofs in this study consists mainly of *Sedum* species and a few herbs that cover 10% to 30% of the roofs and thus constitutes very little biomass. Plant selection is limited by the kind of substrate used (blown clay and volcanic materials) and the shallow depths at which this substrate is applied. The vegetation offers almost no faunal food source (insects, spiders, and other small animals), which is particularly important for young precocial birds (such as the ground-nesting species), which are not fed by adults and must find food and water by themselves. It also offers little cover from birds of prey such as crows. Since the main aim of this project is to develop green roof technologies and systems as habitat replacement, we will be focusing on the proper vegetation structure needed to facilitate reproductive success. As with any habitat restoration or compensation project, this structure—and the resources it provides—must be understood or the replacement habitat runs the risk of becoming an ecological sink.

Organic materials such as compost, roof garden soil, and humus, and nonorganic substrates such as blown clay, volcanic material, and lava stone can increase the water-holding capacity of green roofs and, in the case of the organic materials, contribute valuable nutrients. Besides finding their own food, young precocial birds must find their own water. However, there is little data on this topic, and experts disagree about the necessity of water sources on green roofs. There are examples of northern lapwing colonies that have had good breeding success despite the absence of water sources such as small ponds, pools, ditches, and damp mud surfaces (Kooiker, 2000). Kooiker (2000) reported breeding success by northern lapwings in extensively used meadows with short vegetation or soils without any vegetation, and a yellow-brown surface. The northern lapwing sites examined in this study corresponded partially to these requirements.

Although the data described here consist of a very small sample size, they do provide evidence that the northern lapwing and little ringed plover use green roofs as breeding habitat. The data also show that adult northern lapwings can, in some cases, permanently change their breeding sites depending upon the needs of their young. These observations provide incentive to gather more data in connection with flat roofs and ground-nesting bird species so we can begin to design green roofs as ecologically valuable habitat for these species.

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**Figure 1: Project workers add compost substrate (about 4 cm) to the topsoil of the roof at Shoppyland, Berne. (Photo by N. Baumann)**

**Figure 2: The green roof in Steinhausen, Canton Zoug. (Photo by L. Jensen and A. Kaufmann)**

**Figure 3: Arial photo of the surroundings at the Steinhausen site, Canton Zoug, with habitat use of northern lapwings (*Vanellus vanellus*) mapped on. (Photo by L. Jensen and A. Kaufmann—© search.ch/Endoxon AG, TeleAtlas)**

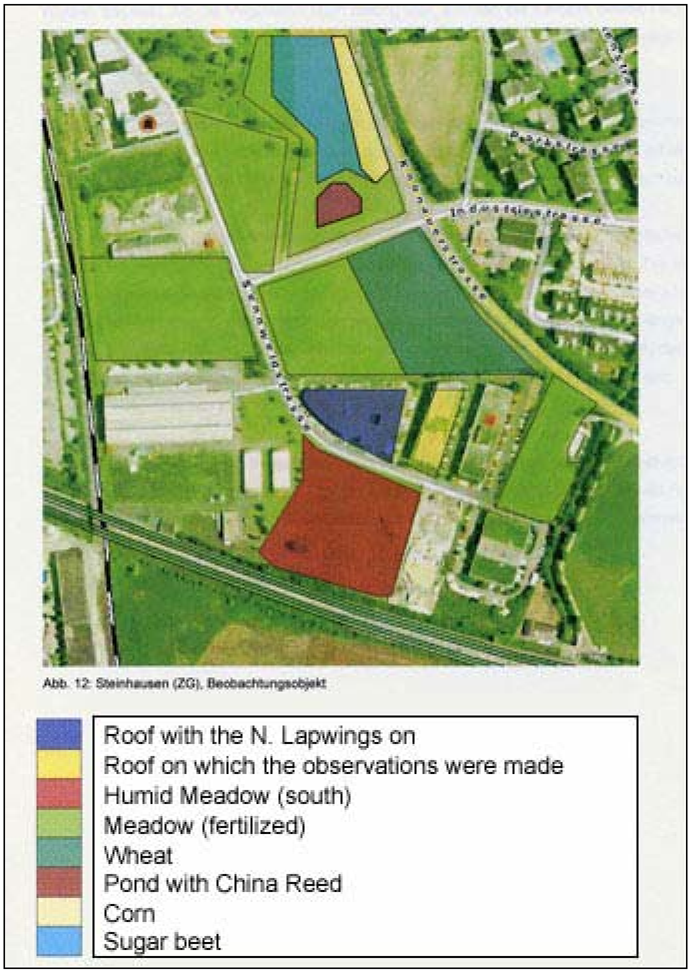

**Figure 4: The gravel pit Frey AG, in Kaiseraugst, Canton Aargau. (Photo by N. Baumann)**

**Figure 5: A northern lapwing (*Vanellus vanellus*) brooding on the green roof in Steinhausen, Canton Zoug. (Photo by A. Kaufmann)**

**Table 1. Summary of results for 2005 at the five observation sites.**

| Sites | Number of breeding pairs | Hatchings, brooding success |
|---|---|---|
| Steinhausen | 2 | 4 young birds (none survived) |
| Shoppyland | 1 | 0 |
| Kaiseraugst (gravel pit only) | 1 | 4 young birds (successful) |
| Hochdorf | 0 | 0 |
| Zurich-Kloten | 3 | 9 young birds (none survived) |

**Table 2. Summary of results for 2006 at the five observation sites.**

| Sites | Number of breeding pairs | Hatchings, brooding success |
|---|---|---|
| Steinhausen | 1 | 4 young birds (none survived) |
| Shoppyland | 1 | 3 eggs (none hatched) |
| Rotkreuz | 5 | 12 young birds (none survived) |
| Kaiseraugst (gravel pit only) | 1 | 4 young birds (successful) |
| Hochdorf | 0 | 0 |
| Zurich-Kloten | no data | no data |

# Extensive Green Roofs in London

### by Gary Grant

EcoSchemes Ltd, Unit 1, Coombe Lane, Axminster, EX13 5AS, U.K.

## Abstract

This paper gives an overview of extensive green roofs in London and considers their potential to benefit the conservation of biodiversity. Categories of green roofs described include grass roofs of the early 1990s; mass-produced *Sedum* roofs, first installed in the late 1990s; and recently installed roofs made from crushed concrete and brick designed to provide habitat for the rare black redstart (*Phoenicurus ochruros*). The role that green roofs potentially play in conserving rare invertebrates associated with derelict sites is discussed, as are possible future directions for biodiverse green roofs. Green roofs are acknowledged as a premier example of multifunctional urban design.

**Key words**: Green roofs; living roofs; urban nature conservation; urban biodiversity; building-integrated vegetation; black redstart; green facades; multifunctional urban design

## Introduction

The purpose of this paper is to summarize the various categories of extensive green roof (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau, 1995; 2002) that have been constructed in London during the past 15 years, describe their ecology (as far as it is known), and provide some insight into the objectives of the designers. I also review a number of recent ecological surveys of green roofs that have been conducted in London. In addition, I discuss how the green roof concept may continue to develop in the future.

First, some background: London is the capital of the United Kingdom and has a population of 7.5 million. It was founded by the Romans about 2,000 years ago on the Thames, a tidal river, which once flowed through salt marshes, alder swamps, and oak forests. Since that time, London has grown to include the original urban center, inner-city areas that flourished during the 19th century, and sprawling suburbs that continued to grow into the 20th century. The Greater London area now covers 1,579 square kilometers. (For further general information about the city of London, see www.london.gov.uk). London has a temperate climate, with warm summers and mild winters. The highest recorded summer temperature was 38.1°C (100.58°F) at the Royal Botanic Gardens, Kew, in 2003. Moderate rainfall occurs year-round (average annual precipitation is 700 millimeters). Because it is unusual for temperatures to fall below freezing, snow is uncommon and rarely settles. (For more information on London's climate, see www.metoffice.gov.uk.) London has many parks and green spaces, including some with extensive tracts of seminatural habitat; however, the distribution of these areas is uneven, with deficiencies often seen in the poorest inner-city communities. Many buildings destroyed by bombing raids during World War II were not immediately rebuilt, and these vacant sites were colonized by wildlife. As London's industry and docks declined, other sites were cleared and subsequently colonized by diverse vegetation. However, from the 1980s to the present day, with government policy encouraging the reuse of abandoned sites, these sanctuaries for nature have been increasingly redeveloped. Although new parks have occasionally been created within the redeveloped sites, these are nearly always ecologically impoverished, lacking the diversity and cover provided by the original vacant sites. This squeeze on urban biodiversity has led urban nature conservationists to look more closely at buildings as potential locations for habitat to compensate for that lost through urban-renewal schemes. The potential for roof greening is considerable: Roofs cover 24,000 hectares, or 16% of Greater London (Greater London Authority, 2001).

## Grass Roofs

In the late 1980s and early 1990s, various charities, institutions, housing cooperatives, and individuals in and around London commissioned the architecture firm Architype and others associated with the Walter Segal Trust (see www.segalselfbuild.co.uk) to design a number of new buildings. The architects had adopted the philosophy of "footprint replacement," whereby green space lost through development is reestablished on the roof (an approach very eloquently expounded by Malcolm Wells, the American advocate of earth-sheltered building—see www.malcolmwells.com). I was one of the client's representatives for one of these buildings (the Center for Wildlife Gardening, built for the London Wildlife Trust) and was subsequently asked to advise on the specification for the green roofs on this and a number of other buildings, including the Center for Understanding the Environment (CUE) Building at the Horniman Museum Extension and 11 Shaw's Cottages (Figure 1), both in south London.

The latter was constructed in 1993 as a private residence for the architect Jon Broome, formerly of Architype. The building consisted of one main curved roof and four subsidiary flat roofs covering a total of 200 square meters. The roof membrane for each section was made of butyl rubber and protected by a nonwoven polypropylene geotextile fleece supported by a plywood deck. In order to promote biological diversity, a variety of substrates were used, including a chalk and subsoil mixture, loamy topsoil, and gravel. Substrate depth varied between 50 millimeters for the gravel and up to 100 millimeters for other areas. On the steepest sections, lawn turf, which had been rescued from the building footprint, was placed upside down (to promote plant colonization) on a framework of wooden battens. The various areas were seeded at the recommended rates with commercially available native wildflower seed mixes designed for alkaline, neutral, and acid soils (Emorsgate EM6, EM5, and EM7, respectively; see www.wildseed.co.uk for species lists). In addition, a mix of annual cornfield weeds (Emorsgate EC1) was used to provide a show of color in the first growing season. The gravel was seeded with *Sedum acre*. The owner added more *S. acre* and *S. reflexum* later. Coir matting with a 25-millimeter mesh size was used to prevent soil erosion on the sloped roof sections. No management is undertaken apart from removal of *Buddleja davidii* and tree seedlings.

In 2001, botanist Barry Nicholson and I returned to describe the vegetation in the two larger sections of the roof (Grant, Engleback & Nicholson, 2003). It was remarkable how much the areas had converged, despite their differing soil chemistry and aspect. Vegetation cover on both substrates was completely closed. Bryophytes and sedums were prominent in both, and a very similar range of other species was present, including several ruderals. The main difference between the two sections was the domination of *Geranium molle* in the chalk-rubble area. The turfed areas supported a dense tussocky grassland sward that consisted of the grasses *Agrostis stolonifera*, *Dactylis glomerata*, and *Phleum bertolonii*, and included the herb *Cerastium fontanum*, *Trifolium repens*, *Plantago lanceolata*, *Rumex obtusifolius*, *Malva sylvestris*, *Medicago lupulina*, and *Euphorbia peplus*. A shady drip zone on a flat part of the roof below an overhanging section of turfed pitched roof had developed a spontaneous cover of *Geranium robertianum* and *Plantago lanceolata*.

Jones (2002) sampled invertebrates at 11 Shaw's Cottages as part of a study of eight extensive green roofs in London. Although none of the species were endangered, a total of 54 species were found, the most for any of the roofs studied. Species singled out for special mention were *Metabletus foveatus*, a ground beetle of dry sandy places, *Scolopostethus decoratus*, a ground bug of open sandy heaths, and *Pseudeuophrys erratica*, a spider found under stones and on walls normally in the north of England and Scotland. Jones noted that invertebrate species diversity is related to roof age, substrate depth, and substrate structure—a pattern that had previously been established by Brenneisen (2001) in a detailed study of green roofs in Basel, Switzerland.

The CUE Building at the Horniman Museum, in Forest Hill, south London, with a 250-square-meter pitched roof, was also designed by Architype and opened in 1994. In specifying the green roof, I worked closely with Peter Costa, a building-services engineer who wanted to cool the structure in summer through increased evapo-transpiration by irrigating the roof. Five years after construction, the roof's reservoir pond was filled and its automatic irrigation system abandoned (having been clogged with algae), although some occasional watering continues. One section of the roof is south facing and has an 8-degree pitch; the other is north facing and has a 27-degree pitch (Figure 2). The roof is mowed annually, usually in late summer.

The green roof was established using 100 millimeters of low-fertility subsoil mixed with alginate (to improve water retention) on a wooden batten grid. A commercially available *Festuca-Agrostis* turf was then laid on the soil layer, and wildflower plugs were inserted. *Campanula rotundifolia*, *Galium verum*, *Prunella vulgaris*, *Scabiosa columbaria*, *Leucanthemum vulgare*, *Lotus corniculatus*, *Viola tricolor*, and *Vicia cracca* plugs were specified, although the current presence of other species uncharacteristic for the locality suggests that a different combination was actually used.

Nicholson (2004) surveyed the vegetation ten years after establishment and found that the roof had developed into a species-rich neutral grassland supporting a number of plants notable to London. The south-facing section was sandy and dry. The dominant grasses found in this area were *Festuca rubra*, *Agrostis capillaris*, and *A. stolonifera*, while *Dactylis glomerata* and *Poa pratensis* occasionally occurred. Meadow wildflowers included *Anthyllis vulneraria*, *Salvia verbenaca*, *Leucanthemum vulgare*, *Trifolium repens*, *Lathyrus pratensis*, and *Lotus corniculatus*. Gaps in the turf supported annuals including *Aira caryophyllea*, *Vulpia myuros*, *Cerastium glomeratum*, *Arenaria serpyllifolia*, *Geranium rotundifolium*, and *Viola arvensis*. Mosses were also frequent in the more open areas, including *Bryum capillare*, *Ceratodon purpureus*, *Hypnum cupressiforme*, *Pseudoscleropodium purum*, and *Brachythecium rutabulum*. The north-facing section was wetter and also dominated by *Festuca rubra* and *Agrostis* species, but it also contained taller meadow grasses such as *Arrhenatherum elatius* and *Phleum bertolonii*. There was a luxuriant growth of mosses made up of *Rhytidiadelphus sqaurrosus*, *Brachythecium rutabulum*, *B. albicans*, *Kindbergia praelonga*, and *Calliergonella cuspidata*. Meadow wildflowers were more abundant on the north-facing section, and annual species, although present, were less prevalent than on the south-facing section.

## Sedum Roofs

Canary Wharf is a major high-rise office complex (Figure 3) being built in a former dock area in east London (construction was started during the 1980s and has yet to be fully completed). In 1987, I was at a meeting with the developer, Olympia & York, when that company expressed an interest in using green roofs to improve the appearance of buildings overlooked by the main office tower. However, it wasn't until 1999, long after the development had passed into new ownership, that the first of several buildings in the area (now totalling over 5,000 square meters) was fitted with commercially available pregrown *Sedum* matting supplied by major green roof manufacturers (for example, companies such as Bauder, Alumasc, and Sarnafil). Some of the material was imported from continental Europe, and the rest was grown in the U.K. Between 2000 and 2004, other *Sedum* roofs were installed at scattered locations across London, covering a total area of more than 10,000 square meters. A further 11,000 square meters of *Sedum* roofs were installed in 2005 by Bauder alone, and more roofs are planned (data from www.livingroofs.org, and

Bauder). *Sedum* roofs are the predominant type of extensive green roof in London. A typical *Sedum* mat is 20 millimeters thick and is delivered as a roll and laid onto 50 to 70 millimeters of growing medium—typically crushed brick or light, expanded clay aggregate. Sometimes *Sedum* mats are laid onto another water-retention layer. Another method is to hydroseed or plug plant *Sedum* into a 70-millimeter-thick layer of growing medium. Sedum is popular with green roof manufacturers because of its drought and frost resistance. Species used in the matting at Canary Wharf include *Sedum album*, *S.acre*, *S.reflexum*, *S.spurium*, *S.pulchellum*, *S.sexangulare*, *S.hispanicum*, *S.kamtshaticum*, and *Saxifraga granulata* (Jones, 2002). It forms a closed sward but is also colonized by mosses (such as *Tortula muralis* and *Ceratodon purpurea*) and ruderal species such as *Stellaria media*. *Sedum* mats are not irrigated (except sometimes during establishment), but weeds and tree seedlings are normally removed as part of routine maintenance.

Jones (2002) surveyed the invertebrates of three of the Canary Wharf *Sedum* roofs and found a total of 48 species. Notable species included *Helophorus nubilis*, a scarce "crawling water beetle," *Chlamydatus evanescens*, a nationally rare leaf bug, *Erigone aletris*, a North American spider recently naturalized in the U.K., and *Pardosa agrestis*, a nationally scarce wolf spider. It is suspected that *Chlamydatus evanescens*, perhaps along with other invertebrates, was imported into the U.K. with pregrown *Sedum* mats from central or eastern Europe.

## Black Redstart Roofs

The black redstart, *Phoenicurus ochruros*, spread northward from continental Europe in the 19th century and started breeding in Britain in the 1920s. It colonized London's bomb sites after World War II and its derelict industrial sites from the 1960s onward. The species is rare in the U.K.: There are between 50 and 100 breeding pairs, and the bird's nests, eggs, and fledglings are fully protected under U.K. law (although its habitat is not). A Species Action Plan has been devised for the black redstart under the U.K. Biodiversity Action Plan (BAP) system (see www.ukbap.org.uk and www.blackredstarts.org.uk). In 1997, proposed redevelopment of derelict sites in Deptford, southeast London, which included some of the breeding localities of this bird, alerted local conservationists to the need to provide replacement habitat (Frith & Gedge, 2000). Green roofs were identified as the potential solution to this problem and were designed to mimic the conditions found on the derelict sites favored by the black redstart. Initially termed "brown roofs," these roofs were constructed from recycled crushed concrete and brick aggregate and were allowed to be colonized naturally (Gedge, 2003; Figure 4).

The first such roof (constructed in 2002) was on the Laban Centre; another was built at the nearby Creekside Centre. An estimated 15,000 square meters of roof designed to benefit black redstarts are already planned (Gedge, 2003), most of them mandated by local authorities (following advocacy by external activists) as part of the building-permit process. Further plans for roofs of this type are expected because the regeneration of London's postindustrial areas is far from complete. Based on present trends, Gedge (personal communication, 2005) estimates that a further 400,000 to 500,000 square meters of biodiverse green roofs will be constructed in London as these areas are redeveloped.

Natural colonization by plants on the roofs in Deptford has been disappointingly slow. In hopes of speeding up plant growth, a locally appropriate wildflower seed mix has been applied, adapted from a seed mix I have developed for similar habitats on the main campus of the London 2012 Olympics. This strategy follows the example of similar aggregate-covered roofs in Basel, Switzerland (Brenneisen, 2001).

As well as the black redstart, there is concern for other species—most notably rare invertebrates—associated with derelict sites in London (Harvey, 2001). The London Wildlife Trust has estimated that of the 1,400 wildlife sites identified by the Greater London Authority, about 25% are previously developed sites likely to be redeveloped (Chipchase et al., 2002). Brown or biodiverse roofs have also been suggested as part of the solution to this problem (Wells, 2001), but recent surveys of the invertebrates of green roofs (Jones, 2002; Kadas, 2003) suggest that they do not support the species of conservation concern on derelict sites. This should not come as a surprise, however, since the green roofs already in existence were not designed to re-create the habitats found on derelict sites. In a new Ph.D. research project, Gyongyver Kadas, of the Royal Holloway College of the University of London, is experimenting with various treatments in test plots on roofs at Canary Wharf and London Zoo (see http://www.livingroofs.org/livingpages/casekomodo.html) to see how to maximize habitat for wildlife (including invertebrates of conservation concern). In Switzerland, increases in invertebrate diversity on green roofs have resulted from creating areas that retain moisture, varying substrate content and depth, and leaving dead stems and wood (Brenneissen, 2001). It is hoped that by comparing new local research with results from overseas, there will be a continuous improvement in London green roofs designed to mitigate habitat loss.

## Future Directions

As the results of current research become available, there will be a higher level of sophistication in the design of green roofs. For example, where the primary focus is on conservation of particular species, such as some of the rare aculeate hymenopterans (stinging insects such as bees and wasps), rooftop microhabitats can be customized to include unvegetated friable (e.g., sandy) substrates with a varied microtopography (hollows, clifflets, etc.), plenty of scattered rocks, rubble, and dead wood and logs, and a more diverse vegetation cover.

However, not all buildings are suited to an approach in which relatively large volumes of substrate are used. In the industrial fringes of cities, modern commercial buildings tend to be steel clad. It is possible to cover steel with *Sedum* mats, which bring some ecological benefits; however, ecologists are looking for alternative treatments that more closely mimic natural habitats. A centuries-old Japanese tradition of cultivating moss has recently been promoted for green roofs in the West by Dobson (1996), Schenk (1997), and others. Mosses, lichens, and other lightweight vegetation requiring little or no soil may be valuable and more affordable alternatives to conventional green-roof plantings. Moss blankets have an interesting associated fauna (e.g., tardigrades) that is still relatively poorly understood. A recent innovation from Fentiman Consulting is a cement-based coating designed to encourage the growth of moss. A French company, MCK Environnement, is using a process called Bryotec to supply pregrown moss panels (see www.greenroofs.com/archives/gf_feb04.htm). On former industrial sites in east London, lichen heaths grow on layers of 20-millimeter-deep pulverised fuel ash (Figure 5), suggesting that such vegetation could be established on lightweight roofs using the same or similar material. In the future, a range of lightweight panels or large tiles could be made available to cover commercial buildings and provide different types of low-growing vegetation matched to particular locations or mixed to create diversity on a particular structure.

Another technique that will become more commonplace is the green facade, which utilizes pregrown mats or tiles or more complex hydroponic systems, such as those created by the French botanist Patrick Blanc (Figure 6).

The city of London (the district constituting the historical financial center of London) is also promoting green roofs in conjunction with the British Council for Offices. Inevitably, in the urban core, most new green roofs will be roof gardens, which are accessible and intensively managed (Osmundson, 1999). The principles and techniques applied to wildlife gardening (Baines, 1985; Gibbons, 1992; see also www.wildlife-gardening.co.uk) can also be applied to intensive roof gardens, where dense native small tree and shrub plantings can provide food and cover for nesting songbirds, and ponds can support dragonflies and other aquatic insects. See the Mayor's Living Roofs campaign, launched in 2004, at http://www.london.gov.uk/mayor/auu/livingroofs.jsp.

## Multifunctional Urban Design

Green roofs are arguably the best example of multifunctional urban design, whereby elements on, in, and around the built environment serve several purposes. A roof (or external wall) can and should be more than just a weather-proof surface or structural element—it can be part of a living, cooling, cleansing skin that not only helps reduce flooding, urban heat-island effects, and air and noise pollution but also provides wildlife habitat and tranquillity.

## Conclusion

There is a small but growing body of evidence from London and elsewhere that green roofs can provide valuable wildlife habitat. These roofs may be constructed to mitigate loss of habitat due to redevelopment of abandoned sites or to provide new habitat in areas of the city where there is a deficiency. Much of the wildlife that has often arrived accidentally on neglected sites can surely be deliberately encouraged to colonize new buildings and make our future cities more attractive and biodiverse.

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## Glossary

**Expanded clay aggregate:** A lightweight building material made by kiln-heating clay. The process is also used to make expanded shale and slate, which, along with clay, were patented in 1918 as Haydite.

**Extensive Green Roof:** A low-management type of green roof that has soil depths ranging from three to seven inches. Due to the shallow soils and the extreme environment on many roofs, plants are typically low-growing groundcover species that are extremely sun and drought tolerant.

**Intensive Green Roof:** A mid- to high-management type of green roof that requires a reasonable depth of soil to grow trees, large plants, or conventional lawns and is labor-intensive, requiring irrigation, feeding, and other maintenance.

**Figure 1: Part of the main roof at 11 Shaw's Cottages, south London (photo by the author).**

**Figure 2: The north-facing section of the roof on the CUE Building, Horniman Museum (photo by B. Nicholson).**

**Figure 3. Sedum roof on Retail Building, Canary Wharf, east London (photo by the author).**

**Figure 4. Black redstart roof three years after construction (photo by D. Gedge).**

**Figure 5. Lichen heath growing on 20 millimeters of pulverized fuel ash on a derelict site in east London (photo by D. Gedge).**

**Figure 6. Living wall by Patrick Blanc at Quai Branly, Paris. (Photo P. Blanc)**

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# Rare Invertebrates Colonizing Green Roofs in London

**by Gyongyver Kadas**

Royal Holloway University of London, Biological Sciences
4 West Heath Drive, London NW11 7QH U.K.

## Abstract

The biodiversity potential of green roofs in London and their potential role in invertebrate conservation and habitat mitigation were studied. In summer and autumn 2004, I investigated three different habitat types: green (*Sedum*) roofs, brown/biodiverse roofs, and brownfields. The study focused on three diverse invertebrate groups: Araneae (spiders), Coleoptera (beetles), and aculeate Hymenoptera (wasps, ants, bees). A high abundance of invertebrates were found on the roofs. At least 10% of species collected at the study sites were designated nationally rare or scarce, in accordance with criteria established by the intergovernmental agency Natural England. The data indicates that green and brown/biodiverse roofs can be important tools for invertebrate conservation.

**Key words:** biodiversity; brown/biodiverse roofs; brownfield sites; green roofs; invertebrates; nationally rare and scarce species; spiders

## Introduction

Even our most industrial, built-up cities need not be completely devoid of green space and wildlife. While parks and gardens come to mind as obvious refuges for nature, plants and animals are often more adventurous with regard to the places they colonize and use. Not many people associate rooftops with wildlife habitats, but if suitable niches are available or provided, plants and animals will rapidly move in and establish communities. In some cases, green roofs offer the only valuable wildlife sanctuaries in our cities and towns. Of particular importance is the fact that these rooftops already exist, so no additional space has to be sacrificed. The potential to provide habitat for wildlife on green roofs is tremendous. In London, for instance, 26,000 hectares of available roof space could be greened with little effort, and this would create 28 times the green space of Great Richmond Park (Grant, Engleback & Nicholson, 2003).

The term "green roof" describes both intensive, ornamental roof gardens and extensive roofs with more naturalistic plantings or self-established vegetation. Intensive green roofs are like parks and gardens at roof level and require deep soil and regular maintenance. Extensive roofs have more naturalistic plantings and shallower natural substrates and are either sown with (local) wildflower mixes or *Sedum* matting or left to colonize naturally. Extensive green roofs require little or no maintenance and are relatively inexpensive to establish.

The environmental benefits provided by green roofs are well documented (Grant, Engleback & Nicholson, 2003; Getter & Rowe, 2006). What green roofs can achieve in terms of biodiversity, however, is less well known. They may provide new habitats in areas that currently lack suitable wildlife space, act as green corridors linking existing habitats, facilitate wildlife movement and dispersal, and serve as refuges for declining and rare species. One of the most pressing issues in the U.K. is the role that green roofs might play in terms of habitat mitigation for the lost biodiversity of redeveloped brownfield sites. (In the U.K., "brownfield" land is land that has had a previous industrial use but can be built on; it is not necessarily contaminated.)

Brownfield sites include some of the most species-diverse habitats left in the U.K. They are sometimes referred to as "English rainforests" ("A Bleak Corner of Essex," 2003), because some of them harbor the same number of rare invertebrates that can be found in ancient woodlands (Gibson, 1998). The best sites may contain up to half of an entire county's invertebrate fauna (Gibson, 1998; www.buglife.org.uk). With the intensification of modern farming methods in rural areas, these sites, which have largely escaped improvement, have become wildlife refugia—habitat "islands" in a "sea" of industrial agriculture (Angold et al., 2006; www.buglife.org.uk).

So what is the problem? There is increasing pressure to redevelop the brownfield sites. In London, for example, according to the latest estimates, 24,000 new homes are expected to be built each year (DETR, 2000). The general government strategy is to build 60% of these homes on brownfield sites (DEFRA, 2003). Huge swathes of industrial brownfield along the Thames estuary are slated for redevelopment, and this will have an immense impact on wildlife.

To offer suitable habitat replacement for the community of invertebrates associated with brownfield sites, we need to understand the ecology behind these habitats, along with the ecology of green roofs. This will help us design green roofs to maximize their biodiversity potential. The aim of this paper is to document some of the invertebrate diversity associated with green roofs in London, as a first step to understanding their ecology.

## Methods

### Study Sites

In summer and autumn 2004, I sampled and quantified the fauna and flora of nine sites, including three *Sedum* green roofs ("FC4," "Retail," and "Waitrose," located in Canary Wharf; Figure 1), two recently constructed brown/biodiverse roofs ("Laban Dance Centre" and "Creekside Education Centre"; Figure 2), and four brownfield habitats ("Wood Wharf" in Canary Wharf; "Sentinal" and "BR," near the Laban Dance Centre; and "Creek Ground," adjacent to the Creekside Education Centre; Figure 3) in the London area. Our study sites were chosen to encompass a good representation of green roof, brown roof, and brownfield habitat. The roofs were covered with different substrate types such as aggregate, *Sedum* matting, and other vegetation, so that the influence of substrate on community development could be investigated. Table 1 lists the ages and areas of the roof and brownfield sites. As previously mentioned, green roofs are not common in the U.K., so it is difficult to find suitable study sites. Moreover, as the general construction practice to date has incorporated green roofing based on *Sedum* matting, the availability of green or brown roofs based on aggregate is limited.

### Sampling Techniques

The research focused on sampling the invertebrate population of the study sites. It targeted certain groups of importance to the U.K. Biodiversity Action Plan and English Nature's Species Recovery Programme (www.english-nature.org.uk) notably, Araneae (spiders), Coleoptera (beetles), and aculeate Hymenoptera (wasps, ants, and bees, excluding sawflies and parasitic wasps). These groups were identified to species level: Spiders were identified by the author and checked by Peter Harvey; hymenopterans were identified by Peter Harvey; and beetles were identified by Richard Jones. The presence and abundance of other incidental invertebrates were also recorded.

Pitfall trapping was the primary sampling technique. At each sampling site, 10 pitfall traps (125 ml, 85 × 60 mm polystyrene cups) were buried in the substrate, with their rims flush with the surface. The traps were filled with a solution of 33% antifreeze and 67% water. Every three weeks from May through October, the traps were emptied and refilled. The contents of each pitfall trap were collected in a single separated container.

## Results

Results indicated a high abundance of invertebrates on the roofs. In some cases, the total number of individuals was higher on roofs than at our brownfield sites (Figure 4). This was surprising, considering that the brownfield sites are very species rich. It should be noted that the brown roofs surveyed in this research were created just one year prior to sampling. Consequently, these sites were in the early stages of succession but are expected to increase in invertebrate abundance over time. On the *Sedum* green roofs, the total number of invertebrates collected was in fact higher than on the brownfield sites. However, the data was somewhat distorted by the high numbers of snails: At least half the invertebrates collected on the *Sedum* roofs were snails. The presence of snails in such high numbers was somewhat puzzling but may be best explained by the lack of mammalian predation. Moreover, snails are commonplace at green roof farms, so they were most likely brought in on the original *Sedum* matting and persisted over the years. I decided to include snails in the analysis since they do provide a valuable food source for birds.

Figure 5 shows the mean number of invertebrates collected in each trap at one collection. This table mimics the results of

Figure 4; however, it presents a more accurate picture because individual traps can be lost or taken by birds.

The species diversity index was calculated for all sites (see Figure 6). The data indicated that the brownfield sites were more species rich than the *Sedum* green roofs and the sampled brown roofs. As mentioned earlier, however, the brown roofs were only a year old, and this probably explains the somewhat low species diversity. (Indeed, my results for 2005 and 2006 do indicate that biodiverse roofs become more species rich over time [Kadas, 2002]).

The high abundance of invertebrates is, in and of itself, of great interest. Furthermore, at least 10% of our collected species from the target groups are in fact considered nationally rare and scarce, as defined by the intergovernmental agency Natural England (Figure 7; Table 2). The data shows that all of the sampled *Sedum* green roofs and even the newly created brown roofs house spider species listed as nationally rare and scarce (Figure 8). Most of our green roofs—but most importantly, both of the new brown roofs—accommodate beetle species of national importance (Figure 9). This data implies that if suitable habitat is created on green or brown roofs, it could provide an essential tool for species conservation.

## Discussion

### (i) Biodiversity Potential of Green Roofs

The main aim behind this project was to determine the biodiversity potential of green roofs. What can they offer? How can they be used for habitat creation in the "urban jungle"? The results are most surprising. Even the relatively few *Sedum* green roofs present in London provide effective habitat for a large number and diversity of invertebrates. Furthermore, the newly created substrate-based brown/biodiverse roofs at Laban and Creekside are highly species rich. It will take some time before these roofs are fully colonized by flora and fauna, but the early results indicate that their potential is enormous.

This research compares green roofs with well-established urban brownfield sites. It would be interesting to compare green roofs with greenfield sites (semirural agricultural land). Research shows that most brownfield sites are more species diverse than greenfield sites (Gibson, 1998; www.buglife.org.uk). The planting of monocultures and the use of intensive management systems in greenfields tend to lower their species diversity. It is possible, therefore, that green roofs could support more species on the whole and have higher species diversity than these semirural sites.

### (ii) Species of Interest

In addition to providing valuable habitat for wildlife in general, green roofs can host a number of species of interest that are rare or scarce in other habitats. Many of the species collected in this study are in fact highly localized and have a low or limited range of distribution. Consequently, the establishment of green roofs may provide additional resources for these species—and in some cases, the only habitat in which they can survive.

My project focuses on spiders, beetles, and aculeate Hymenoptera. The results show that at least 10% of all species recorded are in fact faunistically interesting. All are either RDB (Red Data Book) species, nationally rare or scarce, or have limited range of distribution (Figure 7). Consequently any additional habitat provided for these species—such as green roofs—is vital for their long-term survival. My results suggest that meaningful habitats can be created and managed in urban areas.

### (iii) Araneae

Spiders were chosen as one of the main focus groups in this project not only because several spider species are threatened in the East Thames Gateway but also because spiders occupy the mid-trophic level of the food chain, and thus they give a good indicator of the abundance of species in the lower and higher trophic levels. Spiders display a wide variety of foraging strategies, which dictate requirements for vegetation and soil structure (Gibson, Hambler & Brown, 1992). This invertebrate group is so diverse in terms of foraging and habitat requirements that spider abundance and species richness may be considered a good measure of the overall biodiversity potential of the sampled habitats.

Seventy-two different species were collected from the study sites in 2004. This represents almost 12% of the total U.K. (Harvey, Nellist & Telfer, 2002) and 30% of the Greater London spider fauna (Milner, 1999). It is remarkable that such a high percentage of London's spider fauna has been found on these roofs—which represent a relatively small space—in a single year. Furthermore, five new species were recorded for Greater London: *Pardosa agresits* and *P. arctosa* (Lycosidea); *Steatoda phalerata* (Salticidae); and *Silometopus reussi* and *Erigone aletris* (Lyniphidae). The last of these species (*E. aletris*) has never been collected in southern England before.

As noted already, the roof habitats are not only being colonized by ubiquitous invertebrate species but also by local, rare, and highly specialized species (Figure 8). In fact, we collected wetland spiders of national importance such as *Arctosa leopardus* and *Pirata latitans* (both from the Lycosidae). These species take advantage of the diverse surfaces of the roofs, such as the shadier sections—even those created by architectural features such as solar panels—and areas where rainwater is allowed to accumulate. This is further evidence of the tremendous potential these roofs have for biodiversity conservation.

### (iv) Coleoptera

The majority of beetle species feed on vegetation or decaying organic matter, hence the number and identity of different beetle species gives an indication of the amount of resources that the habitat can provide. The results for beetles in my survey were very similar to those for spiders. Over 10% of the collected species found on the green and brown/biodiverse roofs had national or local conservation status (Figure 9). Some of the species found were very rare, such as *Microlestes minutus*, which has only been recorded six times in the U.K. Two of these records came from the newly created biodiverse roof in Canary Wharf. This finding suggests that if a suitable habitat is created, wildlife will soon colonize.

The *Sedum* green roofs had extremely high populations of the ladybird *Coccinella* 7-*punctata*. Indeed, it might be said that roofs were almost infested with ladybirds and their larvae. The precise reason for this is not yet known. I can only speculate that aphids are very numerous on these roofs, which are insecticide free, and that the ladybirds are taking advantage of the profusion of aphids. Another ladybird, *Hippodamia variegata*, was also found in relatively high numbers on the brown/biodiverse roofs, and this is noteworthy because of the species' status as nationally scarce.

### (v) Aculeate Hymenoptera

While this study attempted to focus on aculeate Hymenoptera, the sampling technique used was not the most ideal to target this group. Pan trapping was used, but in many cases, the traps went missing. To sufficiently analyze the presence of this group, it would have been necessary to include visual surveys of the roofs. My results, however, do indicate that aculeate Hymenoptera species are present, and furthermore, that green and brown/biodiverse roofs give vital resources to many of our nationally rare and scarce species. Most of these species are highly localized and can only be found on brownfield sites. Therefore the presence of these species on the roofs is especially important. Since many brownfield sites are earmarked for redevelopment, green and brown roofs could provide the essential habitat needed for the survival of these species. It has to be added, however, that for successful conservation of target species, the roofs must be designed for their specific habitat requirements. While *Sedum* plants can provide vital pollen and nectar resources for hymenopterans, roofs composed entirely of *Sedum* matting only offer these resources for a limited time, namely the relatively short flowering period of the plants. It is essential to provide a wide range of native wildflowers in our roof habitats to prolong the resource availability for these species.

It is also essential to provide nesting material for these species. I have recorded significantly higher numbers of Hymenoptera on biodiverse roofs when material such as old wood and sandbanks are provided.

## Conclusion

Green, biodiverse roofs could play an important role not only in creating additional wildlife spaces in urban areas but also in the conservation of rare or endangered species. This research shows that green roofs house a large swathe of invertebrates, at least 10% of which are nationally rare or scarce. Consequently, the potential for these artificial habitats is vast.

## Acknowledgments

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## Glossary

**Brown/biodiverse roofs:** These are substrate-based (rather than sedum-based) extensive roofs created specifically for biodiversity. The substrate in many cases is recycled aggregate, and it is generally left to colonize naturally or is seeded with an annual wildflower mix or local seed source.

**Pan trapping:** A sampling technique similar to pitfall trapping that uses a yellow pan trap (dimensions: 250 × 350 × 40mm).

**Succession:** The sequential change in vegetation and the animals associated with it, either in response to an environmental change or induced by the intrinsic properties of the organisms themselves.

**Figure 1: Retail *Sedum* roof, Canary Wharf, London.**

**Figure 2: Laban Dance Centre (brown/biodiverse) roof.**

**Figure 3: Sentinal, flood defence wall (brownfield site), Deptford, London.**

**Figure 4: Total number of invertebrates collected at each study site in 2004.**

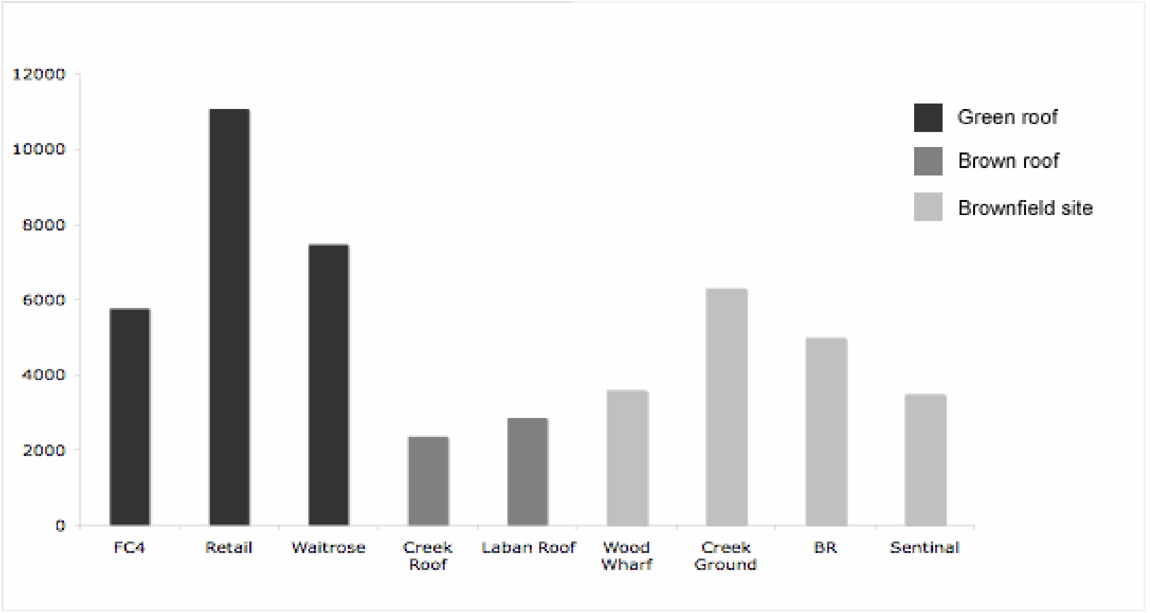

**Figure 5: The mean number of invertebrates collected in each trap (2004).**

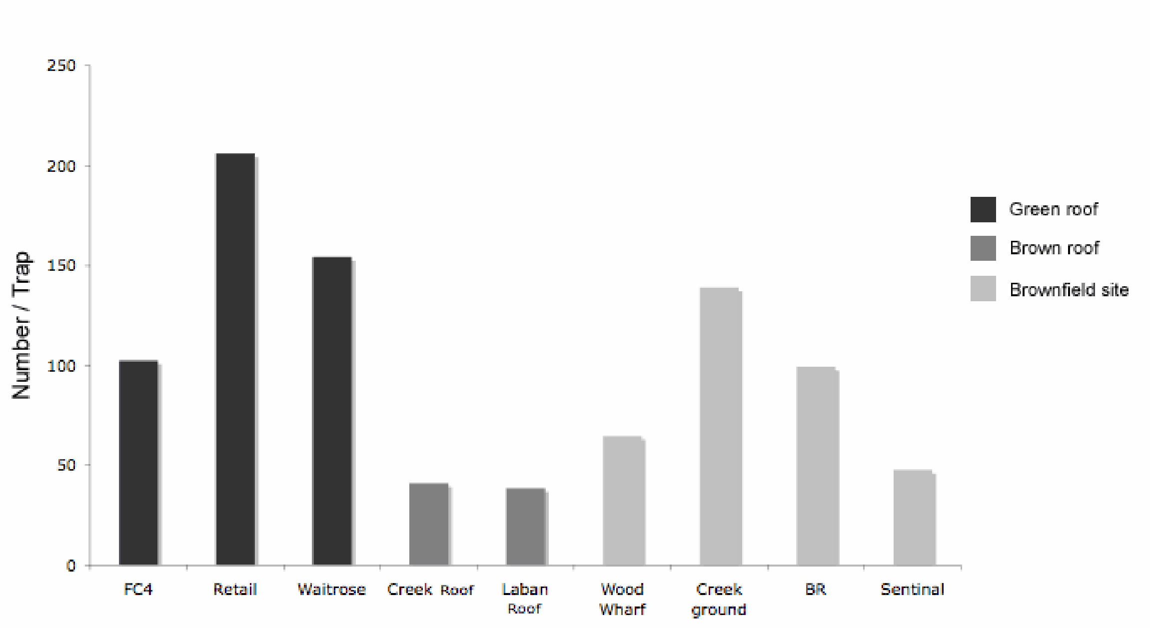

**Figure 6: Shannon-Weiner species diversity index of invertebrates in 2004.**

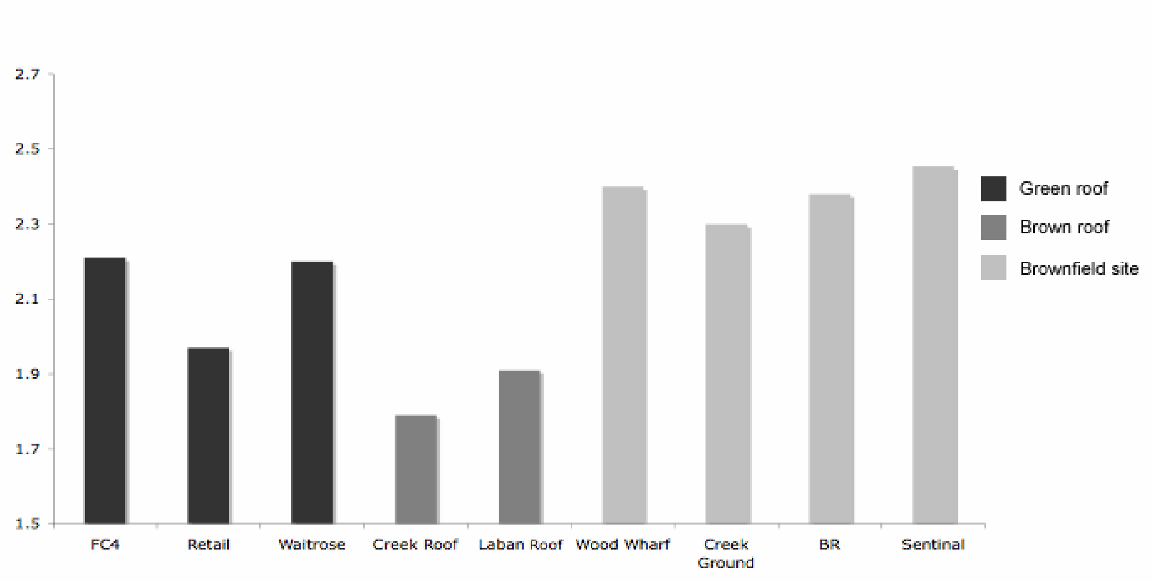

**Figure 7: Total number of taxonomic arachnid (Araneae), aculeate Hymenoptera, Coleoptera, and notable species in the sample (2004).**

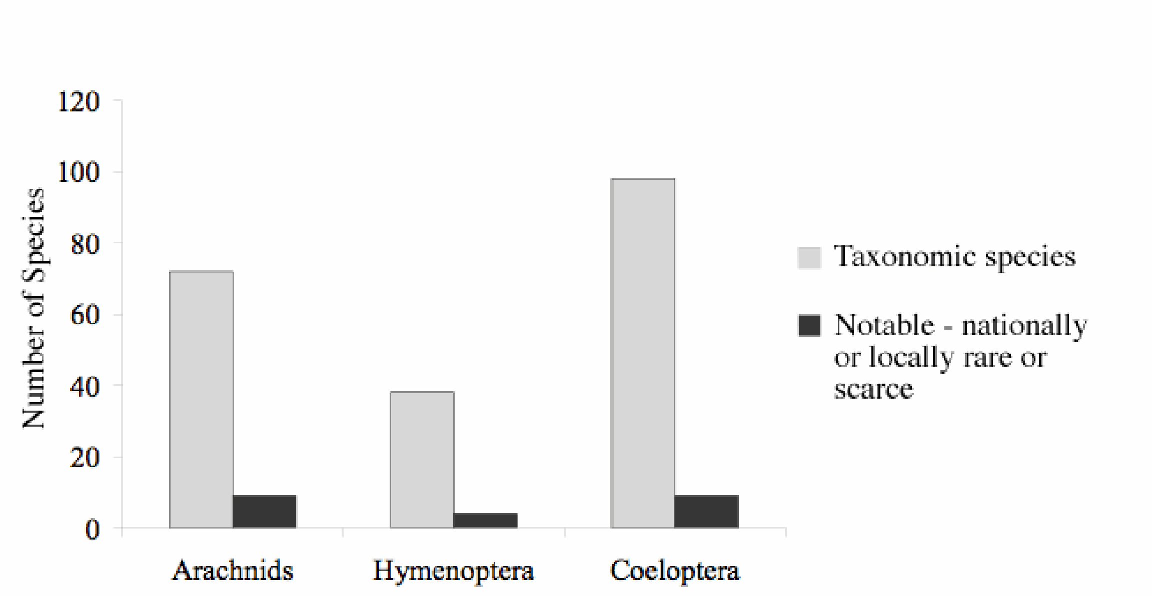

**Figure 8: The proportion of species of importance in the 2004 sample for spiders.**

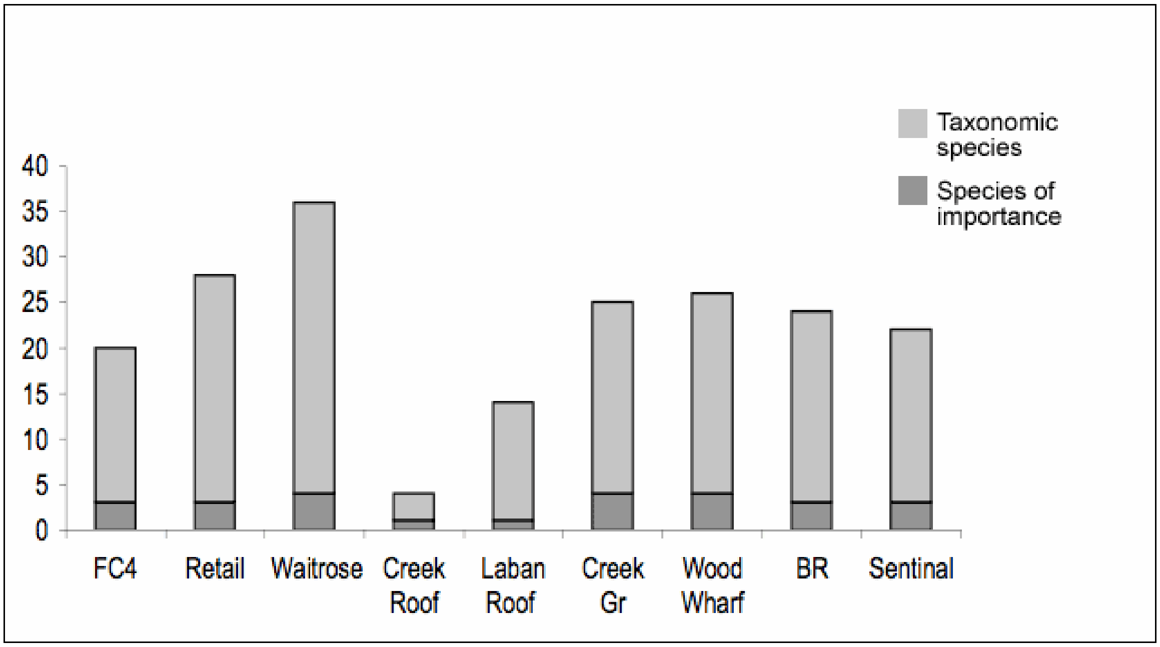

**Figure 9: The proportion of species of importance in the 2004 sample for beetles.**

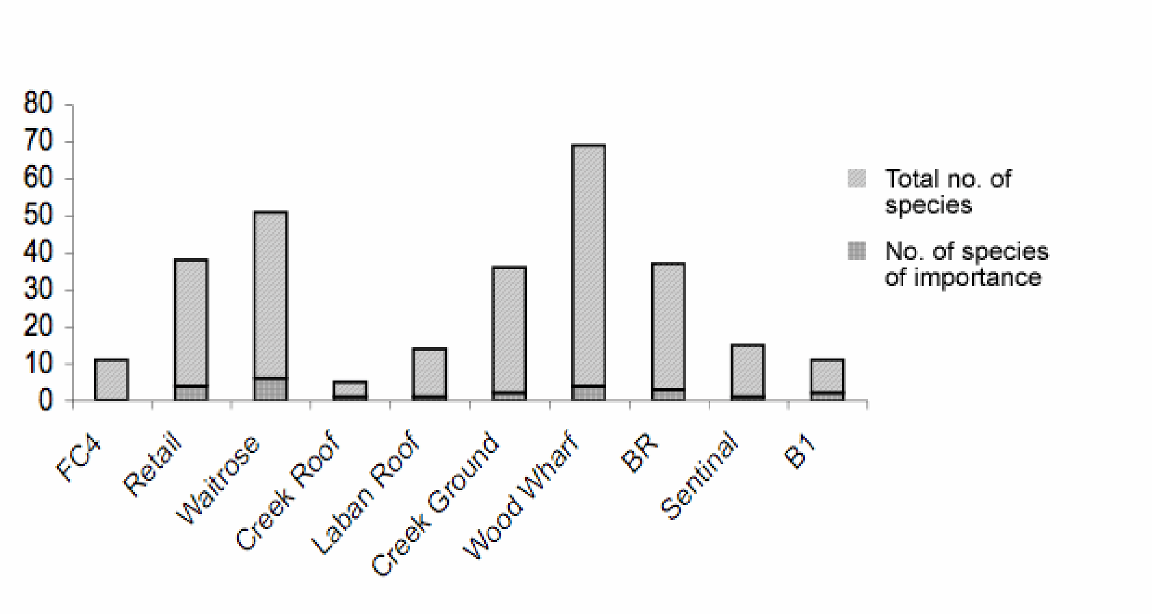

**Table 1. Age, elevation, and area of the green and brown/biodiverse roofs in the study, and the age and area of the sample brownfield sites.**

| Green/Brown Roofs | Age (yrs) | Height (m) | Area of Roof (m2) |
|---|---|---|---|
| Fc4, Canary Wharf: TQ375803 | 9 | 66.7 | 800 |
| Retail, Canary Wharf: TQ376804 | 6 | 18 | 300 |
| Waitrose, Canary Wharf: TQ377803 | 5 | 20 | 600 |
| Creek Roof, TQ376773 | 3 | 5 | 80 |
| Laban Roof, TQ376775 | 3 | 25 | 200 |
| **Brownfield Sites** | | | **Area of Sampled Site (m2)** |
| Creek Ground: TQ375773 | 3 | | Approx: 2000 |
| Wood Wharf: TQ381803 | Not known | | Approx: 5000 |
| Sentinal: TQ377773 | 4 | | 150 |
| BR (Black Redstart): TQ377777 | 5 | | 100 |

**Table 2. Invertebrate species list for all samples (2004).**

| **ARACHNIDS—Spiders** | | |
|---|---|---|
| **Family** | **Species** | **Status (Where status is not indicated, the species is known to be common.)** |
| Agelenidae | Agelenidae immature | |
| Lycosidae | Alopecosa puverulenta | |
| Amaurobiidae | Amaurobious similis | |
| Araneidae | Araneid immature | |
| Araneidae | Araneus qudratus | |
| Linyphiidae | Bathyphantes gracilis | |
| Salticidae | Bianor aurocintus | **Nationally scarce, notable A** |
| Clubionidae | Clubiona reclusa | |
| Dictynidae | Dictyna unicata | |
| Linyphiidae | DipLocephalus cristatus | |
| Linyphiidae | Diplostyla concolor | |
| Gnaphosidae | Drassodes cupreus | Local (only found in a specific [local] region) |
| Gnaphosidae | Drassodes immature | |
| Gnaphosidae | Drassodes lapidosus | |
| Theridiidae | Enoplognatha immature | |
| Theridiidae | Enoplognatha ovata | |
| Theridiidae | Enoplognatha thoracica | Local |
| Linyphiidae | Erigone aletris | **1st record for south England in Canary Wharf** |
| Linyphiidae | Erigone arctica | **Local 1st record since 1957** |
| Linyphiidae | Erigone atra | |
| Linyphiidae | Erigone dentipalpis | |
| Linyphiidae | Erigone immature | |
| Salticidae | Euophrys immature | |
| Salticidae | Euophrys lanigera | Local |
| Salticidae | Heliophantus flavipes | |

| | | |
|---|---|---|
| Linyphiidae | Lephyphantes imm. | |
| Linyphiidae | Lepthyphantes leprosus | |
| Linyphiidae | Lepthyphantes minutus | |
| Linyphiidae | Lepthyphantes tenuis | |
| Linyphiidae | Linyphiid immature | |
| Lycosidae | Lycosidae immature | |
| Linyphiidae | Meioneta rurestris | |
| Tetragnathiedae | Meta mengei | |
| Gnaphosidae | Micaria pulicaria | |
| Linyphiidae | Micrargus herbigradus | |
| Linyphiidae | Microlinyphia pusilla | |
| Linyphiidae | Milleriana inerrans | Local |
| Theridiidae | Neottiura bimaculata | **Local 1st record for London** |
| Linyphiidae | Oedothorax apicatus | Local |
| Linyphiidae | Oedothorax fuscus | |
| Linyphiidae | Oedothorax immature | |
| Linyphiidae | Oedothorax retusus | |
| Linyphiidae | Ostearius melanopygius | **Nationally scarce, notable A** |
| Tetragnathiedae | Pachygnatha clercki | |
| Tetragnathiedae | Pachygnatha degeeri | |
| Lycosidae | Pardosa agrestis | **Nationally scarce, notable B, 1st London record** |
| Lycosidae | Pardosa agricola | **Local 1st record for London** |
| Lycosidae | Pardosa amenta | |
| Lycosidae | Pardosa immature | |
| Lycosidae | Pardosa monticola | **1st record since 1957** |
| Lycosidae | Pardosa nigriceps | |
| Lycosidae | Pardosa palustris | |
| Lycosidae | Pardosa prativaga | |
| Lycosidae | Pardosa pullata | |
| Liocranidae | Phrurolithus festicus | |
| Linyphiidae | Prinerigone vagans | Unknown |
| Salticidae | Salticidae | |
| Salticidae | Salticidea immature | |
| Salticidae | Salticus scenicus | |
| Linyphiidae | Silometopus reussi | Local |
| Agelenidae | Tegenaria domestica | |
| Agelenidae | Tegenaria duellica | |
| Agelenidae | Tegenaria gigantea | |
| Agelenidae | Tegenaria immature | |
| Agelenidae | Tegenaria sp | |
| Theridiidae | Theridion melanurum | Synanthropic |
| Lycosidae | Trochosa ruricola | |
| Linyphiidae | Troxochrus scabriculus | Local |
| Thomisidae | Xysticus cristicus | |
| Thomisidae | Xysticus immature | |
| Thomisidae | Xysticus kochi | Local |
| Araneidae | Zilla diodia | **Nationally scarce, notable B** |

| | | |
|---|---|---|
| Zodariidae | Zodarion italicum | **Nationally scarce** |
| Araneidae | Zygiella x-notata | **1st record for London** |
| | Harvestman | |
| | | |
| **COLEOPTERA—Beetles** | | |
| **Family** | **Species** | **Status** |
| Anobiidae, woodworm beetles | Stegobium paniceum (Lin.) | Local |
| Anthicidae, "ant" beetles | Anthicus antherinus L. | Local |
| | Anthicus floralis | Local |
| Apionidae, Minute weevils | Pseudapion rufirostre (Fab.) | |
| Byrrhidae, pill beetles | Simplocaria semistriata (Fab.) | |
| Cantharidae, Soldier beetles | Cantharis lateralis (Lin.) | Local |
| Carabidae, Ground beetles | Amara aenea DeGeer | |
| | Amara aulica (Panz.) | |
| | Amara curta Dej. | **Nationally scarce, notable B** |
| | Amara eurynota Panz. | **Very local** |
| | Amara familiaris | Local |
| | Unidentified Amara species | |
| | Bembidion guttula Fab. | |
| | Bembidion quadrimaculatum L. | |
| | Bembidion tetracolum Say | |
| | Bradycellus verbasci Duft. | |
| | Calathus fuscipes Goeze | |
| | Harpalus affinis Schr. | |
| | Harpalus rubripes | |
| | Harpalus tardus Panz. | **Very local** |
| | Microlestes minutulus | **Very rare** |
| | Notiophilus biguttatus Fab. | |
| | Notiophilus rufipes Curt. | |
| | Notiophilus substriatus Wat. | |
| | Pterostichus strenuus Panz. | |
| | Trechus obtusus Erich. | |
| Cerambycidae, longhorn beetles | Grammoptera ruficornis | |
| Chrysomelidae, Leaf and flea beetles | Chaetocnema concinna Marsh. | |
| | Chaetocnema hortensis (Fourc.) | |
| | Haltica lythri | |
| | Longitarsus unidentified species 1 | |
| | Longitarsus unidentified species 2 | |
| | Phyllotreta cruciferae | |
| | Phyllotreta undulata Kuts. | |
| | Psylliodes chrysocephaha (Lin.) | |
| | Sphaeroderma testaceum Fab. | |
| Coccinellidae, Ladybirds | Adalia bipunctata (Lin.) | |
| | Coccinella 7-punctata Lin. | |
| | Exochomus 4-pustulatus (Lin.) | |

| | | |
|---|---|---|
| | Hippodamia variegata (Goeze) | **Nationally scarce, notable B** |
| | Micraspis 16-punctata (Lin.) | |
| | Propylea 14-punctata (Lin.) | |
| | Psyllobora 22-punctata (Lin.) | |
| | Rhyzobius litura (Fab.) | |
| | Scymnus species | |
| | Unidentified ladybird larvae | |
| Curculionidae, Weevils | Anthonomus rubi (Herbst) | |
| | Barypeithes pellucidus (Boh.) | |
| | Ceutorhynchus floralis (Payk.) | |
| | Ceutorhynchus quadridens (Pz.) | |
| | Gymnetron pascuorum Gyll. | |
| | Hypera postica (Gyll.) | |
| | Phyllobius maculicornis | |
| | Phytobius quadrituberculatus | Local |
| | Sitona hispidulus (Fab.) | |
| | Sitona lineatus | |
| | Sitona puncticollis (Steph.) | |
| | Trichosirocalus troglodytes (Fab.) | |
| Dermestidae, Hide & larder beetles | Anthrenus verbasci (Lin.) | |
| Elateridae, Click beetles | Athous campyloides Newm. | **Nationally scarce, notable B** |
| | Agriotes sputator (Lin.) | |
| Hydrophilidae, water beetles | Cercyon species | |
| | Megasternum obscurum Marsh. | |
| | Lagriidae Lagria hirta (Lin.) | |
| Lathridiidae Corticaria species | Enicmus transversus (Ol.) | |
| Leiodidae, fungus beetles | Lyocyrtusa vittata | **Very local** |
| Mordellidae, Flower beetles | Mordellistena pumila (Gyll.) | |
| Nitidulidae, Pollen beetles | Epuraea species | |
| | Meligethes species | |
| | Meligethes aeneus (Fab.) | |
| Oedemeridae, Flower beetles | Nacerdes melanura (Lin.) | **Very local** |
| | Oedemera lurida (Marsh.) | |
| | Oedemera nobilis | Local |
| Phalacridae, smut beetles | Olibrus species | |
| | Olibrus flavicornis (Sturm) | **RDB-K** |
| Scrabaeidae, dung beetles | Aphodius equestris (Panz.) | **Very local** |
| Staphylinidae, Rove beetles | Aleochara species | |
| | Aleocharinae unidentified species | |
| | Unidentified rove beetle | |
| | Ocypus olens | |
| | Othius laeviusculus Steph. | Local |
| | Oxytelus innustus | Local |
| | Oxytelus rugosus | |
| | Quedius boops Grav. | |

| | | |
|---|---|---|
| | Quedius molochinus (Grav.) | |
| | Stenus aceris Steph. | Local |
| | Stenus pallipes | Local |
| | Stilicus orbiculatus | Local |
| | Tachinus marginellus | Local |
| | Tachyporus chrysomelinus (Lin.) | |
| | Tachyporus hypnorum (Fab.) | |
| | Tachyporus nitidulus (Fab.) | |
| | Xantholinus linearis Ol. | |
| Throscidae, small click beetles | Trixagus carinifrons (de Bonv.) | Local |
| | Trixagus dermestoides (Lin.) | |
| Forficulidae, Earwigs | Forficula auricularia L. | |
| Anthocoridae, flower bugs | Orius minutus (L.) | |
| | Unidentified species | |
| Cercopidae, froghoppers | Philaenus spumarius | |
| Cicadellidae, leafhoppers | Aphrodes bicinctus (Schr.) | |
| Coreidae, Leaf bugs | Bathysolen nubilis | **Nationally scarce, notable B** |
| | Coreus marginatus (Lin.) | |
| | Coriomeris denticulatus (Scop.) | Local |
| Cydnidae, shieldbugs | Legnotus limbatus (Geoff.) | Local |
| Lygaeidae, ground bugs | Kleidocerys resedae (Panz.) | |
| | Scolopostethus species | |
| | Unidentified lygaeid | |
| | Unidentified lygaeid species 2 | |
| | Unidentified lygaeid species 3 | |
| | Unidentified lygaeid species 4 | |
| Miridae, leaf bugs | Chlamydatus evanescens Boh. | **RDB3** |
| | Chlamydatus pullus (Reut.) | |
| | Chlamydatus saltitans (Fall.) | Local |
| | Nysius species | |
| | Unidentified mirid | |
| Nabidae, damsel bugs | Nabis nymph | |
| Pentatomidae, Shield bugs | Dolycoris baccarum (Lin.) | Local |
| | Eurydema oleracaea (Lin.) | |
| | Podops inuncta (Fab.) | Local |
| Armadillidiidae, pill woodlice | Armadillidium vulgare (Latr.) | |
| Unidentified | Unidentified species | |
| Unidentified | Unidentified lacewing larva | |
| Unidentified | Unidentified microlepidopteron | |
| Unidentified | Unidentified species | |
| | | |
| **ACULEATE HYMENOPTERA—Bees, wasps, and ants: insects with marked "waist" (defined region between the thorax (chest-plate) and the abdomen (belly)).** | | |
| **Family** | **Species** | **Status** |
| Apoidea | Andrea bicolour | **Locally scarce** |
| Apoidea | Andrea flavipes | |
| Apoidea | Andrea fulva | |

| | | |
|---|---|---|
| Apoidea | Andrea minutula | |
| Apoidea | Andrena nigroaena | |
| Apoidea | Andrea scotica | **Introduced species** |
| Apoidea | Andrea trimmerana | |
| Apoidea | Apis mellifera | **Nationally scarce, notable B** |
| Pompilidae | Auplopus carbonarius | |
| Apoidea | Bombus lapidarius | **Nationally scarce, notable B** |
| Apoidea | Bombus lucorum | |
| Apoidea | Bombus (Psithyrus) sylvestris | |
| Apoidea | Bombus terrestris | |
| Pompilidae | Caliadurgus fasciatellus | |
| Sphecidae | Ectemnius secinctus | |
| Formicoidea | Lasius flavus | **Nationally scarce, notable B** |
| Formicoidea | Lasius mixtus | |
| Formicoidea | Lasius niger | |
| Formicoidea | Lasius umbratus | |
| Apoidea | Lasioglossum calceatum | |
| Apoidea | Lasioglossum lativentre | |
| Apoidea | Lasioglossum leucopus | **Locally rare** |
| Apoidea | Lasioglossum leucozonium | |
| Apoidea | Lasioglossum minutissimum | |
| Apoidea | Lasioglossum morio | |
| Apoidea | Lasioglossum smeathmanellum | |
| Apoidea | Lasioglossum villosulum | |
| Apoidea | Megachile centuncularis | |
| Formicoidea | Myrmica scabrinodis | |
| Formicoidea | Myrmica rubra | |
| Apoidea | Nomada fabriciana | |
| | Parasitica indet | |
| Cimbicidae | Sawfly indet | |
| Sphecoidea | Psen dahlboni | |
| Vespoidea | Trypoxylon attenuatum | |
| Vespoidea | Vespula gernanica | |
| Vespoidea | Vespula vulgaris | |
| | | |
| **HEMIPTERA—Land bugs: These insects have a beak or rostrum for sucking plant or animal juices. Their forewings, when present, are horny with a membranous tip.** | | |
| **HETEROPTERA (Sub-order)** | | |
| **Family** | **Species** | **Status** |
| Miridae | Chlamydatus evanescens | **Nationally rare** |
| Miridae | Chalamydatus saltitan | |
| Miridae | Chalamydatus pullus | |
| Lygaeidae | Cymus glandicolor | |
| Pentatomidae | Eysarcoris fabricii | |
| Lygaeidae | Nysius senecionis | **Very local** |
| Lygaeidae | Nysius sp | |
| Lygaeidae | Scolopostethus sp | |
| Pentatomidae | Syromastus rhombeus | **Very local** |

| | | |
|---|---|---|
| Lygaeidae | Lygaeid nymphs | |
| Miridae | Unidentified | |
| **HOMOPTERA (Sub-order)** | | |
| Homoptera | Unident leafhopper | |
| | unident springtail | |
| | | |
| **DIPTERA—True flies: insects with only one pair of wings, the hind pair of wings reduced to pin-shaped halters.** | | |
| **Family** | **Species** | **Status** |
| Diptera | Sphaerophoria rueppleIlii | |
| Diptera | Syritta pipiens | |
| Syrphidae | Hoverfly larva | |
| | | |
| **ORTHOPTERA—Crickets and grasshoppers: stout-bodied insects with an enlarged saddle-shaped pronotum (first chest-segment). Their hind leg is usually long, modified for jumping.** | | |
| **Family** | **Species** | **Status** |
| Tettigoniidae | Pholidoptera griesoaptera | |
| Acrididae | Chorthippus parallelus | |

# Green Roofs and Facades: A Habitat Template Approach

**by Jeremy T. Lundholm**

Saint Mary's University, Department of Biology/Environmental Studies Program,
Halifax, Nova Scotia, B3H 3C3 Canada

## Abstract

Extensive green roof habitats are characterized by shallow substrates and extreme soil-moisture conditions. This set of characteristics, or "habitat template," has natural analogs in rock barren ecosystems such as cliffs, scree slopes, and limestone pavements. Typical plants used in green roof initiatives often have their origins in rocky habitats, as do a host of other common urban species. This paper examines the implications of using natural ecosystems as templates for green roof design. While green roof plant selection has targeted drought-tolerant species, the incorporation of other features of rocky habitats may improve green roof functions.

**Key words**: biodiversity; biomimicry; community ecology; drought tolerance; ecosystem functions; green buildings; rock outcrops; stormwater; urban ecology

## Green Roofs and Facades as Habitats

The use of plants on building surfaces has a long history, stretching back at least to the legendary Hanging Gardens of Babylon (Larson, Matthes, Kelly, Lundholm & Gerrath, 2004). Incorporation of vegetation on the surfaces of "green buildings" has a more recent pedigree, revolving around the functional benefits of plants to building performance. The impact of urban development on natural ecosystems is severe due to habitat replacement and the amount of energy and materials required to sustain the built environment. Recent approaches to mitigating this damage include the development of technologies to increase the efficiency of building energy use and decrease the export of waste products out of the built environment. Green roofs provide a variety of services to the urban environment, including visual relief, accessible green space, stormwater retention, reduced building energy consumption, and habitat provision for other organisms (Dunnett & Kingsbury, 2004). The vegetation of typical modern cities tends to be composed of remnant patches of pre-urban habitats and spontaneously colonized sections such as vacant lots and pavement cracks.

Modern cities are dominated by the built environment, which contrasts with the original habitats it replaced through its high density of hard surfaces. This salient feature of the built environment can have a number of ecological impacts. Urban habitats are often too dry for substantial vegetation because of shallow or nonexistent soil; or they may be too wet as a result of inadequate drainage caused by the impermeability of hard surfaces (Aey, 1990; Spirn, 1984). The downstream effects of hard surfaces are evident after rainfalls: Most of the water runs off the built environment, and this leads to rates and volumes of water flow that are much greater than in most other ecosystems, where soil intercepts and retains much of the precipitation (Jennings & Jarnagin, 2002). Dark hard surfaces have lower albedo (reflectivity) than vegetated surfaces; buildings with these hard surfaces have high rates of heat absorption and require a high expenditure of energy for summer cooling in temperate regions. The addition of vegetation and soil to hard surfaces mitigates many of these effects.

Plants used to provide ecological functions—such as temperature modification and precipitation interception—on flat building surfaces or walls are typically those adapted to drought-susceptible, shallow-soil environments (Dunnett & Kingsbury, 2004). This is a function of the practical limits of increasing the load on rooftops. While intensive green roofs or "roof gardens" are built to contain small areas with up to a meter of growing medium and luxuriant vegetation, the more economic and widely applied extensive green roofs minimize substrate depth. This latter approach places strong constraints on the vegetation of living roofs (shallow substrates over hard surfaces can mean both drought and flooding during the growing season). To design for the complexities of functioning plant communities in relatively harsh environments on buildings, we need to deal explicitly with the habitats where green-building species originated. We need to match plant communities with environmental conditions in the built environment that mimic conditions in their original habitats. Which habitats are these? What are the ecological characteristics of these areas, and how can knowledge of these characteristics help us improve the performance of green roofs? Viewing building surfaces as potential habitats provides a guiding concept for understanding urban environments. In this paper, I outline the habitat template concept as it is understood by community ecologists. I then show how the concept can be applied to urban environments, with specific reference to green roof habitats, in particular the potential benefits of mimicking habitat and vegetation features of natural habitats in green roof design.

## Habitat Templates

Most species have existed for hundreds if not thousands of times longer than the first human-built structures at the edges of caves. Species also display associations with particular habitats that contain their optimal conditions for growth, survival, and reproduction. Ecologists classify these habitats by dominant vegetation, the presence of water, or other factors. For instance, marshes, grasslands, alpine meadows, coniferous forest, and dunes represent distinct "habitat types." Some species are highly plastic and tolerant of a range of conditions; however, the fact that no single species occurs everywhere demonstrates the fit between species and their preferred habitats. The term "habitat template" refers to a quantitative description of the physical and chemical parameters that define a particular habitat and separate it from other habitats (Southwood, 1977; Suren & Ormerod, 1998). These conditions shape the evolution of organisms and act as a filter that screens out many potential colonizing species not suited to particular habitats.

Conventional buildings function as habitats for many species that spontaneously colonize their surfaces. From the perspective of green building design, we need to ask what kind of habitat templates we have created with conventional building design and how we can alter these templates to suit the species we want as part of green buildings. What do we already have and how can we improve it? With reference to urban ecosystems and green roofs in particular, the question then becomes: What kinds of habitat templates were exploited by current-day urban species before we constructed buildings?

## Urban Habitat Template

Ecologists have been slow to acknowledge urban environments as worthwhile subjects. Urban habitats are often perceived as being too disturbed to generate knowledge about nature (McDonnell et al., 1997), and cities have consequently not been incorporated into mainstream ecological theory (Collins et al., 2000). Studies of urban biodiversity have emphasized the differences between city habitats and surrounding areas (Kunick, 1982), with a particular focus on classifying plant species by their relative ability to colonize human-altered habitats (Hill, 2002; Kowarik, 1990). The dominance of urban areas by nonnative species (Kowarik, 1990) has also fueled the denial of ecological value to these areas. Species diversity typically decreases toward the city center (Alberti et al., 2003), where hard surfaces dominate. Urban-ecology literature also emphasizes the creation of novel environments, especially closer to urban centers, where the built environment dominates the landscape (Aey, 1990; Collins et al., 2000). Most of this work emphasizes disturbance intensity as the primary environmental factor that differentiates biotic communities in natural versus anthropogenic urban habitats (Kowarik, 1990): Areas dominated by the built environment inflict novel selection pressures and harsh conditions on any species that attempts to colonize.

This work tends to ignore the possibility that many urban habitats, while lacking historical continuity with the habitats they replaced, may be (as far as some species are concerned) functionally equivalent to other kinds of natural habitats. Botanists working in urban areas have long recognized that a peculiar set of species tends to colonize hard-surfaced environments in cities (Rishbeth, 1948; Woodell, 1979). These species have varied origins but are often found naturally in rocky habitats, dunes, or other open areas where harsh conditions prevent the formation of forest cover. The habitats offered by buildings and other parts of the built environment tend to lack soil, and thus tree cover seldom develops spontaneously in them. Rooting space available to plants is restricted or compacted, and moisture regimes range from extremely dry to waterlogged due to the poor drainage associated with hard surfaces. These physical factors constrain the pool of available colonists to those that already possess adaptations to similar conditions in nature. Plant species from rocky habitats and other urban-analog environments have adaptations such as drought avoidance (dormancy) and drought tolerance (e.g., succulent leaves) that allow them to survive in such harsh conditions. There is also the case of plants like *Cymbalaria muralis* (note the overt reference to a built-environment template in the species epithet), a cliff-dweller whose flowers orient themselves away from the cliff face—presumably to attract pollinators—but whose fruit pedicels exhibit negative phototropism and promote growth toward cracks in the rock surface, and thus toward suitable microsites for germination. This species actually plants its own seeds!

The first more comprehensive attempts to find natural analogs for urban habitats were led by anthropologists and environmental psychologists who examined the typical suburban landscapes of North America and Europe. They concluded that the suburban landscape copied features of ancestral human habitats on the African savannas—relatively open grassy areas with sparse trees, providing both prospect (the ability to scan the surroundings for food sources or enemies) and refuge (sparse trees) from predators (Orians, 1986; Orians & Heerwagen, 1992) (Figure 1). Such research invokes human evolutionary history in savanna habitats and suggests that our preference for similar landscapes, when we are able to consciously design them for ourselves, is genetically "hard-wired." As the thinking goes, proto-human populations who sought out areas that afforded prospect views and protection would have had better probabilities of survival, and their behavior would have been subject to natural selection. This research articulates the linkages between designed and natural habitats, and argues, in part, for a biological basis to our preference for broad classes of landscapes. While this hypothesis is impossible to test, there is a surprising amount of empirical data suggesting that many modern humans do show innate preferences even for mere pictures of landscapes that contain key features of savanna habitats (Orians, 1986).

This "suburban savanna" hypothesis, however, omits salient features of both current urban habitats and ancestral human landscapes: the built structures themselves. Urban settlements are characterized by hard surfaces of stone, brick, and wood, with little substrate for plant growth (at least on the outside of the structure). Additionally, there is considerable evidence that East African savanna environments would have been inhospitable to early hominids without the scattered presence of rock outcrops to provide shelter (Larson et al., 2004). Thus the suburban savanna hypothesis omits the actual hard-surfaced buildings or shelters from the habitat template.

## The Urban Cliff Hypothesis

The widespread creation of hard-surfaced environments and their colonization by species adapted to rocky habitats suggests that urban development is not simply a process of habitat destruction but one of replacement of original habitats by ones that may be functionally and structurally analogous to rock outcrop habitats (Larson et al., 2004). This idea is supported by recent work showing how plant species that have spontaneously colonized urban habitats—including pavements, walls, roofs, and lawns—are disproportionately drawn from rocky habitats (Lundholm & Marlin, 2006). Other original habitats that contribute urban species include riparian zones and lakeshores (Wittig, 2004), as well as dunes, rocky beaches, and grasslands (Rodwell, 1992, 2000). In a recent study in Atlantic Canada (Lundholm and Marlin, 2006), many of the grasslands that contributed urban species were found to be anthropogenic in nature and composed of European species that originally came from permanently open habitats such as cliffs, dunes, and shorelines (Grubb, 1976).

The urban cliff hypothesis predicts that a large proportion of spontaneously colonizing organisms in cities originate in rare and geographically marginal rock outcrop habitats (Larson et al., 2004). "The reason for this is likely based on the replication in built forms of many key microsite features that make up the habitat template of natural rock-based ecosystems. Why? Likely because the first buildings were simply extensions of rock walls around the mouths of caves in rocky areas. It would have been easy for species originally restricted to rocky environments to opportunistically exploit the expanding rock-wall habitats created by growing human populations that built more of their own optimal habitats (rock shelters) as they moved out of the caves" (Larson et al., 2004).

The habitat templates represented by rocky areas differ greatly from those of surrounding ecosystems (Larson, Matthes & Kelly, 2000). Areas with an abundance of natural hard surfaces have more extreme hydrological conditions than areas with deeper soil. On natural limestone pavements, for example, where poor drainage causes flooding in the spring and fall, drought can be a severe stressor in the summer due to shallow soils (Stephenson & Herendeen, 1986). Plants in these areas are forced to deal with the combined stresses of flooding and drought within the same growing season. The analogy with urban areas is striking: Urbanization creates similar hydrological challenges due to the increase in hard surfaces from less than 5% prior to urbanization to over 40% in some urbanized regions (Jennings & Jarnagin, 2002). Decreased infiltration in urban areas causes greater amplitudes of flow rates and soil-moisture availability over time—flooding occurs during and immediately after storms, but shallow substrates and water loss due to overland transport result in drier conditions between storms. Green roofs have the capacity to mitigate these effects by replacing hard surfaces with vegetated surfaces, thereby decreasing runoff (Köhler et al., 2002; vanWoert et al., 2005).

## Habitat Templates and Green Building Surfaces

It is clear that hard surfaces are responsible for several key environmental impacts of cities, and that these anthropogenic surfaces have analogs in the natural world. Why then should we not look to the vegetation of natural hard-surfaced areas for guidelines in mitigating the impacts of urban areas? (See Table 1 for references to studies describing the natural vegetation of many of the world's shallow-substrate environments). The ability of green roofs to reduce stormwater runoff and insulate buildings depends in part on the depth of the substrate and corresponding vegetation biomass. But there is a trade-off between the maximization of environmental benefits and the minimization of costs: Increasing substrate depth adds to the cost of implementation, especially if reinforcement is required, and so roofers attempt to minimize load on the roof surface. The need to select plants that can survive in shallow substrates forces us to target specific habitat templates. Many green roof species are already drawn from European limestone pavements and dry meadows because they can tolerate harsh rooftop conditions (Dunnett & Kingsbury, 2004). Plants in the genus *Sedum*, long the favorites of green roofers, are frequent components of the vegetation of vertical cliffs in Europe and North America (Bunce, 1968; Holmen, 1965; Hotchkiss, Woodward, Muller & Medley, 1986).

Some natural rock outcrops are largely devoid of vegetation; however, they may still support plant life where cracks, ledges, and other microtopographic features permit the accumulation of organic matter. Other types of natural rock outcrops can have almost full cover of vegetation in shallow soils over bedrock (Catling & Brownell, 1995). The adoption of rock outcrop plants on green roofs would thus mimic a particular kind of outcrop—one where vegetation cover is maximized but total biomass production is limited by shallow substrate. An additional constraint is that while some rock outcrop habitats undergo succession and gradually change into other habitats, such as forest (Burbanck & Phillips, 1983), green roofs are kept permanently at an early stage of succession, either by the extreme stress of shallow substrates or, in deeper media, by the selective removal of woody vegetation. A typical shallow-substrate extensive green roof thus is a manifestation of a very particular habitat template (Figures 2a–2c). Other aspects of the habitat template of natural rock outcrop ecosystems have also been incorporated into green roof designs. Spatial heterogeneity in substrate characteristics is a hallmark of natural rock outcrops (Larson et al., 1989, 2000; Catling & Brownell, 1995; Lundholm & Larson, 2003). While most green roofs feature a uniform substrate, recent initiatives have incorporated spatial heterogeneity in the form of varied soil depths in order to increase species diversity in the vegetation and provide a greater range of habitats for invertebrates (Brenneisen, 2004).

Green facades can also be examined through the habitat-template lens. The vegetation that spontaneously colonizes stone walls can be drawn from a variety of habitats but is dominated by cliff and rock outcrop species (Rishbeth, 1948; Woodell, 1979). The design of walls and other vertical surfaces determines the degree to which plants can grow on them: Building material, degree of shading, aspect, and the presence of microtopography determine the available niche space, much as they do on natural cliffs (Rishbeth, 1948; Larson et al., 2000). The development of green walls or facades is thus a deliberate manipulation of the habitat template to maximize vegetation cover for the purpose of visual relief, building energy savings, or other benefits (von Stülpnagel, Horbert & Sukopp, 1990).

Current attempts to find effective green roof plants revolve around testing species for their tolerance of drought and their ability to survive and spread on green roof substrates (Monterusso, Rowe & Rugh, 2005). Examination of the original habitats of these species shows that they share their living space with a variety of other organisms that together constitute the "vegetation": bryophytes, lichens, and algae. Of particular interest to the green roof industry may be the cryptogamic crusts that form in a variety of horizontal and vertical barrens (Catling & Brownell, 1995; Quarterman, 1950; Schaefer & Larson, 1997). These tend to be dominated by cyanobacteria, which form mats when water is plentiful. Some of the species that occur in these systems have the ability to fix nitrogen and may also play a role in soil stability (West, 1990; Belnap & Gillette, 1998). In shallow-substrate green roof systems, it is possible that these cryptogamic mats can contribute directly to the desired functions of green roofs by cooling the roof surface and retaining water.

The key driving force in plant selection for extensive green roofs has been to find plants that can survive and proliferate in very shallow soil environments. While current plantings often feature polycultures of individually selected species, there has been no work on the role of plant species diversity per se on the functioning of green roofs. Research in other plant communities has identified the potential for larger amounts of species diversity to positively affect ecosystem functions such as biomass production, stability, and nutrient retention or absorption (Tilman et al., 1997, 2001). In general, a community with more species might more completely utilize existing resources due to niche complementarity, which allows the coexistence of species that can use different forms of resources or exhibit resource consumption at different times of the year. In a green roof context, the consumption of water by plants is likely not to be fast enough to make a difference during heavy storms, but for lighter rain events, greater plant uptake of water might decrease runoff. On the other hand, there may be a danger of drought if water consumption occurs more rapidly in more diverse communities. The only study to test this in a simulated green roof environment found no relationship between species diversity and water uptake (Dunnett, Nagase, Booth & Grime, 2005), so it remains to be demonstrated that green roofs with more species function differently than species-poor roofs.

The emerging green roof industry relies on a set of tried-and-true plants that can tolerate the harsh conditions of rooftops. These tend to be succulents from the Crassulaceae, or stonecrop family. A current international trend in green roof horticulture is to begin incorporating regionally appropriate native plants on green roofs (e.g., Monterusso et al., 2005). Certain green roof functions, such as wildlife habitat provision, might also be enhanced by the use of native species. Native insects may be more attracted to native green roof vegetation due to the provision of appropriate food sources or pollen resources. The use of native species that can tolerate harsh conditions is welcome in any urban greening project, providing aesthetically pleasing and educationally valuable biodiversity in hard-surfaced environments that are typically low in biodiversity (McKinney, 2002).

The design of vegetated surfaces on buildings has largely proceeded from engineering considerations, with a more recent focus on the horticultural requirements of desired species. The growing interest in—and potential environmental and economic benefits of—using entire communities of plants on green buildings necessitates a more nuanced understanding of the habitat templates we design and the relationships between community structure, environmental conditions, and ecosystem functions. These concerns must move research on building-surface vegetation into the forefront of current progress in fundamental ecological research.

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## Glossary

**Anthropogenic**: Caused by humans.

**Cryptogamic crust**: Mat formed by plants that reproduce by gametes or spores rather than seeds (e.g., algae).

**Negative phototropism:** Growth away from the direction of a light stimulus.

**Riparian**: Pertaining to the banks of a stream or river.

**Figure 1: A typical suburban front yard. The "suburban savanna" hypothesis ignores the built structure and other hard surfaces as ecological elements in this landscape (photo by J. Lundholm).**

**Figure 2a–2c: Natural (a), spontaneous urban (b), and designed (c) rock pavement habitats. The natural pavement is a limestone barren on the Bruce Peninsula, in southern Ontario. The designed site is a green roof in Portland, Oregon. (Photos by J. Lundholm)**

**Table 1. Descriptions of natural vegetation in shallow-substrate environments.**

| | | |
|---|---|---|
| East & Central US | Cedar glades (limestone barrens) | Quarterman 1950, Baskin et al. 1995 |
| Great Lakes | Alvars (limestone barrens) | Catling & Brownell 1995, Schaefer & Larson 1997 |
| South +E US | Granite barrens + cliffs | Oosting & Anderson 1937, 1939, Burbanck & Platt 1964, Collins et al. 1989, Wiser 1994 |
| Southern Ontario, Canada | Limestone cliffs, talus slopes | Larson et al. 1989, Bartlett et al. 1990, Cox & Larson 1993 |
| Illinois US | Limestone cliffs | Nuzzo 1996 |
| SW US | Desert cliffs | Camp & Knight 1997 |
| Ireland | Burren, limestone barrens | Ivimey-Cook 1965, Ivimey-Cook & Proctor 1966 |
| UK | Limestone pavement | Gauld & Robertson 1985 |
| UK | Sea cliffs | Rodwell 2000, Malloch et al. 1985 |
| UK | Inland cliffs | Bunce 1968, Jackson & Sheldon 1949 |
| Sweden, Estonia | Alvars (Limestone grassland, barrens) | Krahulec & van der Maarel 1986 |
| N Sweden | Steep slopes | Lundqvist 1968 |
| S Finland | Acid silicate rocks | Makirinta 1985 |
| Estonia | Alvars (Limestone grassland) | Pärtel et al. 1999 |
| Poland | Rocky ridge | Michalik 1991 |
| E Mediterranean | Cliffs | Davis 1951 |
| W Mediterranean | Calcareous cliffs | Escudero 1996 |
| Colombia | Sandstone outcrops | Arbeláez & Duivenvoorden 2004 |
| Brazil | Shaded cliffs | Alves & Kolbek 1993 |
| Iran | Cliffs, steep slopes, outcrops | Akhani & Ziegler 2002 |
| Egypt, Libya | Limestone plateau | Gimingham & Walton 1954; Kassas & Girgis 1964 |
| Guinea | Rock outcrops, Inselbergs | Porembski et al. 1994 |
| Nigeria | Granitic outcrops | Hambler 1964 |
| S Africa | Rock outcrops | Rutherford 1972, Fuls et al. 1992 |
| Malay Peninsula | Limestone outcrops | Chin 1977 |
| New South Wales, Australia | Sea cliffs | Adam et al. 1990 |
| Western Australia | granite outcrops | Hopper et al. 1997 |
| Victoria, Australia | Granite outcrops | Ashton & Webb 1977 |
| New Zealand | Scree slopes | Fisher 1952 |

# The Floristic Composition and Community Structure of the Forest Park Woodland, Queens County, New York

**by Carsten W. Glaeser**

City University of New York, Herbert H. Lehman College, Department of Biological Sciences, 250 Bedford Park Blvd., Bronx, NY 10468

## Abstract

In 2000, a census was conducted within a 167-hectare wooded section of Forest Park, in Queens County, New York, to document the current floristic composition and structure of the woodland community. All woody stems ≥ 2.0 centimeters (cm) diameter at breast height (DBH) within a permanent and contiguous 0.5-hectare (50 × 100 meters) plot were identified, recorded, and measured for diameter, height, and x, y coordinates. The plot contained 771 stems from 22 woody species (15 genera and 13 families) reflecting a Shannon-Wiener index of 2.17 and a Simpson's index of 0.162. Five species were singletons, and three species were nonnative invasives. Stem DBH ranged from 2.0 to 116.7 cm, with a mean of 8.55 cm, and stem density was 1,542 stems per hectare. The largest-diameter trees were the oaks: red oak (*Quercus rubra* L.), black oak (*Q. velutina* Lam.), and white oak (*Q. alba* L.) (Fagaceae). The census revealed a young tree population largely dominated by characteristic pioneer species such as sweet birch (*Betula lenta* L., Betulaceae), black cherry (*Prunus serotina* Ehrh., Rosaceae), and the nonnative invasive Amur corktree (*Phellodendron amurense* Rupr., Rutaceae). The top dominant taxa based on Forest Inventory and Analysis importance values (IV) were *Betula lenta*, *Quercus rubra*, *Phellodendron amurense*, *Cornus florida* L. (flowering dogwood, Cornaceae), and *Prunus serotina*, and the dominant arborescent family was Fagaceae, represented by *Quercus rubra*, *Q. velutina*, *Castanea dentata* (Marshall) Borkh. (American chestnut), and *Fagus grandifolia* Ehrh. (American beech). The top dominant taxa based on importance values within the small-diameter class were *Betula lenta*, *Phellodendron amurense*, *Cornus florida*, and *Prunus serotina*. The top dominant taxa within the large-diameter size class were *Quercus rubra*, *Betula lenta*, *Q. velutina*, and *Cornus florida*. Ecological dominance in this urban woodland is shifting away from its historical legacy as an oak-hickory forest. The observed disturbance patterns, the decline in traditional dominant tree species, the abundance of pioneer tree species across the diameter-size classes, and the continued colonization by *Phellodendron amurense* may be weighted factors imposing structural change throughout the woodland.

**Key words:** ecological dominance hierarchy; fragmented forests; forest census; frequency distribution; nonnative invasive species; pioneer species; randomization tests; species importance values; stem-size class; urban forest ecology

## Introduction

From the late 19th century through the 20th century, development along the urban-suburban interface altered much of the original landscape on western Long Island, New York. The New York metropolitan region, including outer boroughs such as Queens County, is now devoid of much natural landscape; nevertheless, it may contain more than 3,000 species of vascular plants (Brooklyn Botanic Garden, 1999). These plants survive in forested islands or fragments of wooded parkland—the patchy remnants of a once large and contiguous temperate forest ecosystem. Forest Park, in Queens County, is the largest of the urban woodlands on western Long Island, and it contains a sizeable portion of the local flora (Greller et al., 1979; New York City Department of Parks & Recreation [DPR], 1990, 1991). Early floristic inventories of Queens County and its environs have been critical to documenting not only local plant diversity but also changes in plant communities brought about by increased land development and human-induced disturbances (Greller, 1979; Greller, 1985; Greller, Panuccio & Durando, 1991; Harper, 1917a, 1917b). Despite Forest Park's size and status, it has not been closely studied, and thus little information is available to parkland personnel and administrators wishing to develop ecology-based management tools.

Knowledge of the floristic composition and structure of woodland communities is critical to understanding the greater dynamics of woodland ecosystems, and it is only with hard ecological data that sound management practices can eventually be applied. Currently, most of the fragmented woodland ecosystems within the city of New York have not been fully investigated beyond their floristic composition. The objective of this study—the first comprehensive one of the woodland since Greller, Calhoun, and Iglich (1979)—was to investigate the current health of the arborescent community in Forest Park.

## History of Forest Park

In 1892, the New York legislature authorized the Brooklyn Parks Department to purchase the first parcel of parkland in Queens County (Figure 1). Additional acquisitions occurred into 1898, resulting in the expansion of the parkland to 218 hectares. Originally called Brooklyn Forest Park, it was transferred to the city of New York with the consolidation of Greater New York in 1898. The park, along with other parks in Brooklyn and Queens, was managed by the Brooklyn Parks Department until the Queens Department of Parks was established in 1911. Brooklyn Forest Park was renamed Forest Park and served as a multiuse park intended to provide a variety of recreational amenities to the public, including natural areas. Land use within the park area from the colonial period to the end of the 19th century had consisted mainly of timber harvesting, farming, and cattle grazing. These activities were halted when the park was established (New York City DPR, 1990). The designation of a 218-hectare park in Queens County amid a burgeoning human population (now exceeding 2.3 million inhabitants) was a crucial step in the conservation of local biodiversity.

In 1990, the New York City DPR's Urban Forest Education Program (UFEP) prepared a management plan for all urban forests within New York City. The major goals were to mitigate the impact of human disturbance on the ecology of park woodlands and to maintain and preserve native forest plant communities that were no longer subject to forces of natural disturbance. Forest Park became the first wooded parkland in Queens County evaluated for a natural-areas management plan by the New York City DPR's Natural Resources Group (NRG) (New York City DPR, 1996). This management plan has served as a model for all DPR wooded parks, such as neighboring Cunningham Park and Alley Pond Park (Tim Wenskus, NRG, personal communication, 2001). The plan identified vital plant communities and set priorities for woodland conservation. It also highlighted the park as containing the most extensive undisturbed forests in all of Queens County. Of the 218 hectares of parkland included in the management plan, an estimated 76% (167 hectares) was listed as closed forest canopy. The management plan, however, lacked an important ingredient for the management of the wooded landscape—a quantitative woodland census.

## Location, Structure, and Condition

Forest Park (42° 30' north latitude and 73° 51' west longitude) is located in southwest Queens County and situated along the Harbor Hill terminal moraine of the southern point of the Glaciated Appalachian Plateau, formed by the Wisconsin glaciation (Cunningham & Ciolkosz, 1984; Greller et al., 1979; Sanders, 1974). The topographic elevations from the 1935 New York City Department of Parks maps series range from 18 to 42 meters (m) above sea level (Figure 2).

The woodland is mature throughout, as evidenced by the presence of large oaks, hickory, and flowering dogwood (Figure 3). Tree falls are common. Referencing the documented woody plant diversity in Forest Park and elsewhere in Queens County, Greller, Calhoun, and Iglich (1979) described the woodland as an oak, mixed dicot–dogwood type. However, visual observation suggests that the woodland is an oak-hickory-dogwood forest.

The overall knob-and-kettle topography is well vegetated with both herbaceous and woody flora. (In 2000, to account for the diversity of the understory flora within the study location, I conducted a survey of spring ephemerals and vines not included in the larger woodland census [Glaeser, unpublished data]. The survey revealed 15 families of herbs and ferns, represented by 26 genera; woody vines consisted of one family represented by two genera). Forest gaps atop the knobs are often covered by a mix of understory shrubs, saplings, grasses, and other herbaceous plants. In contrast to other neighboring wooded parks, most kettles in Forest Park lack seasonal water and are variably vegetated.

From informal observations made throughout Forest Park, it is evident that unregulated high-impact activities such as mountain biking, horseback riding, and off-trail pedestrian use of the park have negatively impacted the plant community. Vandalism is equally evident in the form of cut trees, brush fires, graffiti, and litter. Though unquantified, the loss of plant cover and severe compaction and erosion of soil due to human activities has resulted in a degraded landscape in great need of restoration.

## Methods

During the winter of 1999–2000, I delineated and surveyed a 50 × 100 m (0.5-hectare) permanent plot, divided into fifty 10 × 10 m quadrats, located within the 29-hectare Northern Forest Management Zone in Forest Park (Figure 2). A major criterion for plot selection was that no landscape-management activity—for example, thinning, tree planting, or weed control—was to have occurred within the study area. (All prior landscaping activity in the park was recorded in DPR woodland-management records.) This was to ensure that human-induced disturbance would not skew the data. The study plot, by general appearance, was representative of the greater Forest Park woodland.

All woody stems ≥ 2.0 centimeters (cm) diameter at breast height (DBH) were counted, regardless of tree or shrub characteristic. This was an unconventional DBH measurement, contrasting with those of forest censuses performed elsewhere within the New York City park system, in which only stems at least ≥ 7.6 cm DBH were counted (Greller et al., 1979; Rudnicky & McDonnell, 1989; Stalter, 1981; Stalter, Munir, Lamont & Kincaid, 2001). Each taxon within the plot was identified to species, and the botanical nomenclature followed Gleason and Cronquist (1991). Species importance values and family importance values were used to determine the dominance hierarchy or ranking of the woody taxa within the plant community (Ferreira & Prance, 1998; Mori, Boom, de Cavalino & dos Santos, 1983). Both measures of importance value (IV) were calculated as follows: IV = (relative density + relative frequency + relative dominance) × 100.

A species-area curve (the accumulation of tree species as a function of the sample area) was prepared by approximate randomization analysis (Figure 4) (Manly, 1997; Mori, Becker & Kincaid, 2001; Rice & Kelting, 1955). Randomization shuffled the plot combinations 500 times without replacement.

Bootstrapping for confidence intervals of importance values at 95% was applied to the top ecologically dominant taxa. Confidence intervals were needed to measure the uncertainty of a sample statistic, such as importance values across the larger Forest Park plant communities (Dixon, 1993; Manly, 1997; Sokal & Rohlf, 1995). Frequency distribution for stem diameter, regression tests, descriptive statistics, and quartiles for diameter size classes were performed with StatView software (version 5.0, SAS, 1992). Upper and lower quartiles (25%) of the dataset were used to divide stems into the three stem-size classes. This approach was in contrast to other studies that utilized nonstatistical methods for determining size classes (Auclair & Cottam, 1971; Brewer, 2001; Parker, Leopold & Eichenberger, 1985).

## Results

A total of 771 stems were identified, consisting of 22 tree and shrub species in 15 genera and 13 families. The mean number of species per quadrat was 5.60, and the mean number of stems per quadrat was 15.48. The stem density for all woody taxa measured at ≥ 2.0 cm DBH was 1,542 stems per hectare. In contrast, when calculated using a 10-cm DBH cut point, the mean stem density was 270 stems per hectare. This was a similar result to that found for neighboring Cunningham Park woodland (Queens County), which at the 10.0 cm DBH cut point had a stem density of 244 stems per hectare (Glaeser, unpublished data), and for the Alley Park woodland (Queens County), which had a density of 245.5 stem per hectare (Loeb, 1992). Quantitative measurements of diversity were as follows: Shannon-Wiener index (H') = 2.176; Simpson's index = 0.162.

The middle curve of the species-area curve shows the mean number of species per plot. The mean markedly increases and does not level off at quadrat 50, suggesting that censusing a larger area would reveal more taxa (Figure 4). The lower and upper curves are the minimum and maximum number of species found in the randomization of the quadrats, respectively. The maximum values on the curve level off at quadrat 15; it can be inferred from this that a maximum number of species (22 taxa) would be found in 15 quadrats.

## Species Importance Values

*Betula lenta*, sweet birch (IV = 51.99), was the ecologically dominant species in the 0.5 hectare plot (Table 1). It had the highest relative density of all taxa, at 28.15%, a relative frequency of 14.18%, and relative dominance—an extrapolation of basal area—of 9.66%. The second-ranked species was *Quercus rubra*, northern red oak (IV = 49.55), which had a relative density of 4.28%, relative frequency of 8.16%, and relative dominance of 37.11%. The third-ranked species was the nonnative invasive *Phellodendron amurense*, Amur corktree (IV= 33.35) (see Glaeser & Kincaid, 2005), which had a relative frequency of 9.93% and relative dominance of 2.92%. Note that at 20.49%, this species' relative density was second to that of *Betula lenta*. The fourth species in the dominance ranking was *Cornus florida*, flowering dogwood (IV = 32.45). This understory tree ranked third in terms of relative density (14.92%). The dominance ranking and abundance of *C. florida* is of interest because of its susceptibility to numerous foliage pathogens such as anthracnose (*Discula* species). *Quercus velutina*, black oak (IV= 28.07), ranked fifth in overall ecological dominance; however it ranked tenth in relative density (1.30%). *Prunus serotina*, black cherry (IV = 27.14), ranked sixth in ecological dominance; it had a relative density of 11.0% and was the third most frequently encountered tree species, with a relative frequency of 12.77%. *Quercus alba*, white oak (IV=17.44), ranked seventh in ecological dominance but third behind *Q. rubra* and *Q. velutina* in relative dominance at 12.21%. *Acer rubrum* L. (red maple), *A. platanoides* L. (Norway maple), *Liriodendron tulipifera* L. (tulip tree), *Ilex verticillata* L., A. Gray (common winterberry), and *Nyssa sylvatica* Marshall (black gum) appeared as singletons and ranked low in ecological dominance due to low counts and small diameter size.

The bootstrap 95% confidence intervals were used to determine the certainty of a parametric mean, such as the species importance values (Manly, 1997). Confidence intervals were determined for seven of the ecologically dominant taxa (Figure 5).

## Family Importance Values

Family importance values were applied to the 13 tree and shrub families (Table 2). The Fagaceae was the dominant and richest of the tree families. It was represented by five species and collectively contained 74 individual stems comprised of *Quercus rubra*, *Q. velutina*, *Q. alba*, *Castanea dentata*, and *Fagus grandifolia*. The collective IV for species within the Fagaceae was 102.57 out of a possible 300. The relative density was a low 9.60%, while the relative frequency was 16.05%, or equivalent to that of the top three ranking families. The Fagaceae had a relative dominance of 77.5% and a combined basal area of 11.71 square meters, which was eight times the basal area of the next-dominant-ranking family (Betulaceae). Members of the Fagaceae were found in 39 of the 50 sampled quadrats (78.0%). The second-ranked family in the dominance hierarchy was Betulaceae (IV= 54.27), represented by a single species, *Betula lenta*. Owing to this species's abundance, Betulaceae had a relative density of 28.03% and relative frequency of 16.46%. The third-ranked family was the Cornaceae (IV=36.02), represented by two species: *Cornus florida* and *C. alternifolia* L.f. Both the relative frequency and relative density of this family were 16% (placing it very close in relative frequency to Fagaceae and Betulaceae); however, its relative dominance, at 3.40%, was markedly low. Fourth in family ranking was the Rutaceae (IV=34.94), represented by *Phellodendron amurense*. The Amur corktree had a relative density of 20.49%, second highest overall next to the Betulaceae (Figure 6).

## Stem Diameters

The use of lower and upper quartiles (or the 25 percentile) of the sampled population statistically partitioned all arborescent stems into small- and large-size diameter classes and a central 50-percentile for the midsize-diameter class. The diameter-size classes were as follows: small-size diameters (2.0 to < 2.8 cm DBH, n = 202); midsize diameters (2.8 to < 7.48 cm DBH, n=372); and large-size diameters (7.48 to 116.7 cm DBH, n=197).

Species richness within the small-size-diameter class was 19 tree species, representing 13 families. Stem density was 402 stems per hectare, and the combined basal area (BA) was 0.893 square meters. The top four ecologically dominant taxa, in decreasing order of importance, were *Betula lenta* (IV=73.54), *Phellodendron amurense* (IV= 65.45), *Cornus florida* (IV= 44.99), and *Prunus serotina* (IV= 36.44) (Table 3). *Betula lenta* displayed the greatest relative density with 26.8%, followed by *Phellodendron amurense* (24.38%), *Cornus florida* (14.43%), and *Prunus serotina* (11.94%). The most frequent taxon encountered was *Betula lenta* (relative frequency 20.18%), and it was followed by *Phellodendron amurense* (16.67%), *Cornus florida* (15.79%), and *Prunus serotina* (12.28%).

The midsize-diameter class contained the most abundant stems of the three size classes: n=372 (Table 4). Species richness within this group was 17 tree species, distributed among 10 families. Stem density was 744 stems per hectare, and basal area (BA) was 6.66 square meters. Within this size class, the largest tree was *Cornus florida* (7.48 cm DBH). The top four ecologically dominant taxa were, in decreasing order of importance, *Betula lenta* (IV=81.68), *Phellodendron amurense* (IV=61.47), *Cornus florida* (IV=48.92), and *Prunus serotina* (IV=30.62). The most frequently encountered taxon was *Betula lenta* (relative frequency 18.59%), and it was followed by *Phellodendron amurense* (14.74%), *Cornus florida* (17.95%), and *Prunus serotina* (11.54%). *Betula lenta* also displayed the greatest relative density (31.45%), and it was followed by *Phellodendron amurense* (24.19%), *Cornus florida* (14.79%), and *Prunus serotina* (9.68%). *Betula lenta* ranked highest in relative dominance (31.64%) and was followed by *Phellodendron amurense* (22.53%), *Cornus florida* (16.19%), and *Prunus serotina* (9.40%).

The species richness within the large-size class was 13 tree species, distributed among 7 families. Stem density was 394 stems per hectare, and basal area (BA) was 145.48 square meters. The ecologically dominant taxa within this group were, in decreasing order of importance, *Quercus rubra* (IV= 70.25), *Betula lenta* (IV= 51.11), *Quercus velutina* (IV= 34.84), and *Cornus florida* (IV= 33.34) (Table 5). Unique among the dominant taxa in this size class is *Betula lenta*; though second in ecological dominance, it had a high relative density (23.35%) compared with *Cornus florida* (15.74%), *Quercus rubra* (14.72%), and *Prunus serotina* (12.69%). The most frequently encountered taxon was *Betula lenta*, with a relative frequency of 19.15%, and it was followed by *Quercus rubra* (16.31%), *Cornus florida* (14.89%), and *Prunus serotina* (12.77%). The oaks—*Quercus rubra*, *Q. alba*, and *Q. velutina*—displayed the greatest relative dominance in the large-size class. The largest oak specimen was a *Quercus rubra* measuring 116.7 cm DBH. Though the *Quercus* species were low in abundance, their larger basal areas accounted for the increased relative dominance.

The basic structural characteristics of the top three ecologically dominant taxa within all the diameter-size classes were compared (Table 6).

*Betula lenta* was within the top three taxa in all size classes. It was the dominant taxon within the small- and midsize-diameter classes and ranked second to *Quercus rubra* within the large-size class. *Cornus florida* was among the top three taxa in the small- and midsize classes. The nonnative invasive *Phellodendron amurense* ranked second in dominance within the small-size and midsize classes. Throughout the study plot, the largest trees were the oaks, yet they only made up 9% of the entire sampled population.

The frequency distribution for all tree diameters placed 66% of all stems (n=771) within the first 2.0–4.0 cm histogram interval (Figure 7). *Betula lenta*, *Phellodendron amurense*, *Cornus florida*, and *Prunus serotina* composed 80% of the stems within the first histogram interval and 70% in the second histogram interval.

## Discussion

The 0.5-hectare study plot contained a rich array of trees and shrubs with ≥ 2.0 cm DBH. This low DBH cut point allowed for the inclusion of many more species and stem counts than would a cut point of ≥ 7.6 cm DBH, a measurement used in previous wooded parkland inventories (Greller et al., 1979; Stalter, 1981). Twenty-two species were tallied from sampling 771 stems at ≥ 2.0 cm DBH. A notable fact is that the 22 species were identified within the 2.0–7.6 cm DBH range (n=580), which is 9 more species than would have been identified had the DBH cut point been ≥ 7.6 cm. Of the 22 species identified in the Forest Park woodland, 19 were native to the temperate Northeast, and three were nonnative invasive species (*Phellodendron amurense*, *Acer platanoides*, and *Rhamnus frangula* [glossy buckthorn]).

The 95% confidence intervals applied to species importance values for the top seven dominant taxa provided an indication of confidence in these values. The taxa with the larger sample sizes (n)—for example, *Betula lenta* (n=217), *Phellodendron amurense* (n=158), *Cornus florida* (n=115), and *Prunus serotina* (n=85) had a smaller confidence interval, and thus I am more confident that the true values lies within the range of the limits (Figure 5). Based on the overlapping confidence limits of the seven ranked taxa and on inferential ecological dominance for the New York City urban woodland at large, the dominance ranking of *Quercus velutina*, for example, may be from rank number two to rank number seven. For *Phellodendron amurense*, it may be from rank number two to rank number five.

It is theorized that forest disturbances (of any type and scale) result in gaps that are heterogeneous due to gap-phase regeneration. Recovery from disturbances often results in a mosaic of forest patches at different stages of succession. Trees found within gaps may consist of either pioneer species or climax species or both, and thus gap-phase regeneration adds to stand diversity. Numerous studies have related forest composition to the size and frequency of these disturbances (Brokaw & Scheiner, 1989; Veblen, 1989; Whitmore, 1989). In general, plant communities respond to disturbances differently, and their responses vary with the type of disturbance, be it logging (Ramirez, 2001; Yoshida, Yoko, Ozawa, Mahoko & Shibata, 2005), anthropogenic pressure, fires (Loeb, 2001), or natural tree falls, such as those observed in Forest Park. I believe that a combination of tree falls, herbivory, and other unquantified disturbances has promoted a tree species distribution and composition more typical of pioneer species than of climax species in this mature oak-hickory hardwood forest.

Of the top 12 ecologically dominant trees and shrubs in Forest Park, 3 share characteristics associated with pioneers of disturbed sites. Pioneer trees generally produce copious amounts of small, readily dispersed seeds; have seeds that can only germinate in full sun; and are relatively short-lived (Whitmore, 1989). *Betula lenta*, *Phellodendron amurense*, and *Prunus serotina* possess some or all of these traits and are of special interest because of their high representation within the study plot (density and frequency) (Figure 8). The pioneer status of these species is supported by their high representation within the small and mid-size diameter classes. The environmental variables influencing the demographic responses of these pioneer taxa are undetermined for Forest Park. Yet previous reporting on two other *Betula* species in Japan has indicated that increased light intensity—affecting such variables as soil properties, litter accumulation, canopy cover, and snow depth—is the most important factor for *Betula* species dominance (Yoshida et al., 2005). Yoshida suggested that the presence of any canopy plays an important role in the distribution success of *Phellodendron amurense* due to the fact that the species' seeds are bird-dispersed. Seedling photosynthetic performance under shade conditions is also a factor.

Both *Betula* species and *Phellodendron amurense* are regarded as shade intolerant in the forests of Hokkaido, Japan (Koike & Sakagami, 1985; Yoshida & Kamitani, 1999). The environmental variables that influence the success of these pioneer taxa in the forests of northern Japan may be considered with regard to the situation in Forest Park, at least until further empirical investigation occurs.

The distribution of woody stems in the Forest Park study site was typical for a mature woodland stand in that it contained an abundance of small- to mid-size-diameter stems and relatively few large stems (Figure 7). This skewing of the stem-diameter distribution toward the early stages of gap-phase regeneration is widely accepted as a general trend for mature and aging forest (Hara, 1988). That pioneer taxa were highly represented in this study is also typical, as Hara suggested. However, though the Fagaceae was the ecologically dominant family within the large-diameter size class, it had very little representation within the small- and mid-size-diameter classes (Table 3 and Table 4). The current cause of the depauparate regenerative capacity among this family is speculative, yet the consequences are a concern for the greater ecology of Forest Park.

Predation upon seed resources by overabundant populations of *Sciurus carolinensis* Gmelin (eastern gray squirrel), *Tamias striatus* L. (eastern chipmunk), and *Mus* species (common field mouse) may be occurring. It is possible that representatives of the Fagaceae may be found in a size-class measurement of ≤ 2.0 cm DBH or as newly emerged seedlings. A recensusing of the Forest Park woodland scheduled for 2010 may register additional Fagaceae saplings that have grown into the ≥ 2.0 cm DBH size class.

It has long been established that nonnative invasive species are a threat to native ecosystems. Invasive species impact upon all levels of biotic organization by modifying the fundamental properties of ecosystems (Henderson, Dawson & Whittacker, 2006). Invasive species in eastern U.S. forests may out-compete natives, occupy unfilled niches, or have negative allelopathic impacts on the growth of their arborescent neighbors. Threats to the diversity of native plant populations by the establishment of nonnative plants have been noted elsewhere in Queens County (Stalter, Munir, Lamont & Kincaid, 2001). It has recently been proposed that the nonnative invasive *Phellodendron amurense* (with a relative density of 20.49% in this study) may be interfering with the growth of the Fagaceae. North of Philadelphia (Montgomery County, Pennsylvania) as well as in the New York City area (Queens and Bronx County), *P. amurense* has aggressively invaded disturbed forests. Due to lack of regeneration of native species, oak-hickory hardwood forests are being transformed into *Phellodendron* forests (The Nature Conservancy, 2005). It has been suggested that root exudates from *Phellodendron amurense* may be inhibiting the growth of its neighbors in oak-hickory forests.

This census revealed an extremely low regenerative potential for all the oak and other traditional canopy trees amid highly abundant pioneers and a successfully colonizing nonnative invasive tree, *Phellodendron amurense*. Considering that the 0.5-hectare study plot is representative of the greater Forest Park, the lack of regeneration of the canopy trees—and the potential loss or disruption of their contribution to the ecology, habitat, and microclimate dynamics of the forest—is a cause for serious alarm.

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## Glossary

**Allelopathic:** Of or relating to allelopathy, the suppression of growth in one plant species due to chemicals produced by another.

**Approximate Randomization Analysis:** A randomization test involves the comparison of an observed test statistic with a distribution that is generated by randomly reordering the data values in some sense.

**Bootstrapping:** The essence of bootstrapping is that in the absence of any other information about a population, the values in a random sample are the best guide to the distribution, and that resampling the sample is the best guide to what can be expected from re-sampling the population. Much of the research on bootstrapping has been aimed at developing reliable methods for constructing confidence limits for population parameters (see Manly, 1997).

**Climax species:** The plant species that inhabit an area that has undergone the final stage of vegetational succession.

**Confidence interval:** The interval within which a parameter of a parent population is calculated (on the basis of the sampled data) in order to determine a stated probability of lying. The larger the sample size (n), the smaller the confidence interval and the more accurate the estimate of the parent mean.

**Confidence limits:** The upper and lower boundaries of the confidence interval.

**Descriptive statistics:** The general statistics of individual organisms or population (e.g., mean tree diameter or height).

**Diameter at breast height (DBH):** The outside-bark diameter of a tree measured at 4.5 feet (1.37 meters) above the forest floor on the uphill side of the tree.

**Frequency distribution:** A set of frequencies or probabilities assigned to a set of events.

**Gap-phase regeneration:** The pioneer phase during which trees begin to colonize a site.

**Importance value (IV):** An abundance estimate consisting of the sum of three relative values: relative density (the number of a given species/family expressed as a percentage of all species present), relative frequency (the frequency of a given species/family expressed as a percentage of the sum of frequency values for all species present), and relative dominance (the basal area of a given species expressed as a percentage of the total basal area of all species present (Oxford Dictionary of Ecology).

**Knob-and-kettle topography:** Also known as "sag and swell" topography, this is a landscape type sometimes associated with recent terminal moraine (debris and deposits laid down at the edge of a glacier). It consists of hummocky mounds (knobs) alternating with depressions (kettles).

**Pioneer species:** A species that is adapted to the early stages of vegetational succession.

**Point estimate:** The estimation of a parameter of a parent population as a single value. An arithmetic mean, such as mean density, is a single number called point estimate in statistics and must always be accompanied by some information upon which its usefulness as an estimate can be judged.

**Quartiles:** The value of a variable below which three quarters (1st or upper quartile) or one quarter (the 3rd or lower quartile) of a distribution lie. The median is the 2nd quartile.

**Regression analysis (simple and multiple linear regression):** Simple linear regression and multiple linear regression are related statistical methods for modeling the relationship between two or more random variables using a linear equation. Simple linear regression refers to a regression on two variables while multiple regression refers to a regression on more than two variables. Linear regression assumes the best estimate of the response is a linear function of some parameters (though not necessarily linear on the predictors). See http://en.wikipedia.org/wiki/Regression_analysis.

**Shannon-Wiener index (H'):** One of several indices used to measure biodiversity. It takes into account the species evenness (relative abundance) of a population or community as well as the special richness (total number). For more information, visit http://en.wikipedia.org/wiki/Shannon-Wiener_Index.

**Simpson's index:** A simple mathematical measure of diversity in a community, devised by E.H. Simpson in 1949. See http://www.tiem.utk.edu/~gross/bioed/bealsmodules/simpsonDI.html.

**Species richness:** The total number of different species present.

**Singleton:** Occurring singly.

**X, Y coordinates:** The most common tools for identifying points in space are the Cartesian coordinates. The x-axis is the abscissa and y-axis is the ordinate. During vegetation surveys, Cartesian coordinates display the spatiality of individuals across a study plot and reveal the basic patterns of distribution—random, regular, and clumped.

**Figure 1: Forest Park lies at the western end of Long Island and along the edge of the Harbor Hill terminal moraine. The park is unique in that it contains the largest remaining tract of contiguous wooded ecosystems in Queens County, New York (167 hectares).**

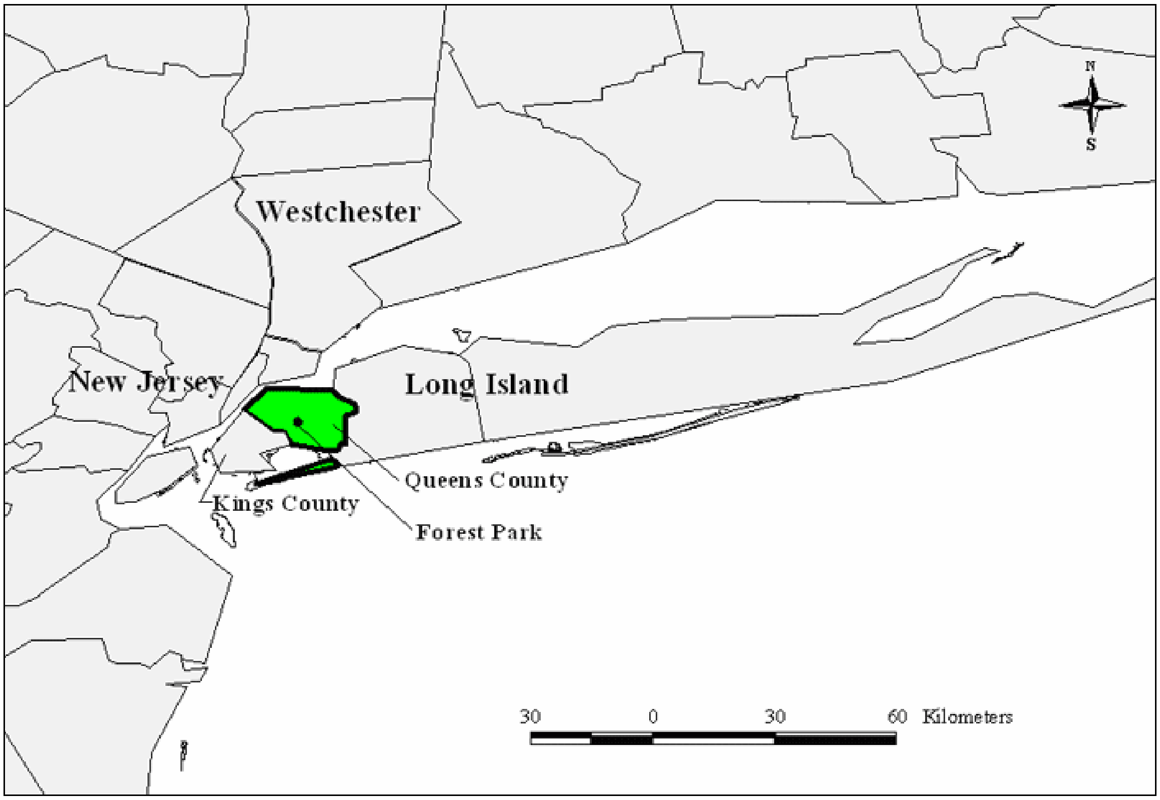


**Figure 2: A topographical view of the 50 × 100-meter study plot positioned within the 29-hectare Northern Forest Management Zone of Forest Park amidst the surrounding urban communities.**

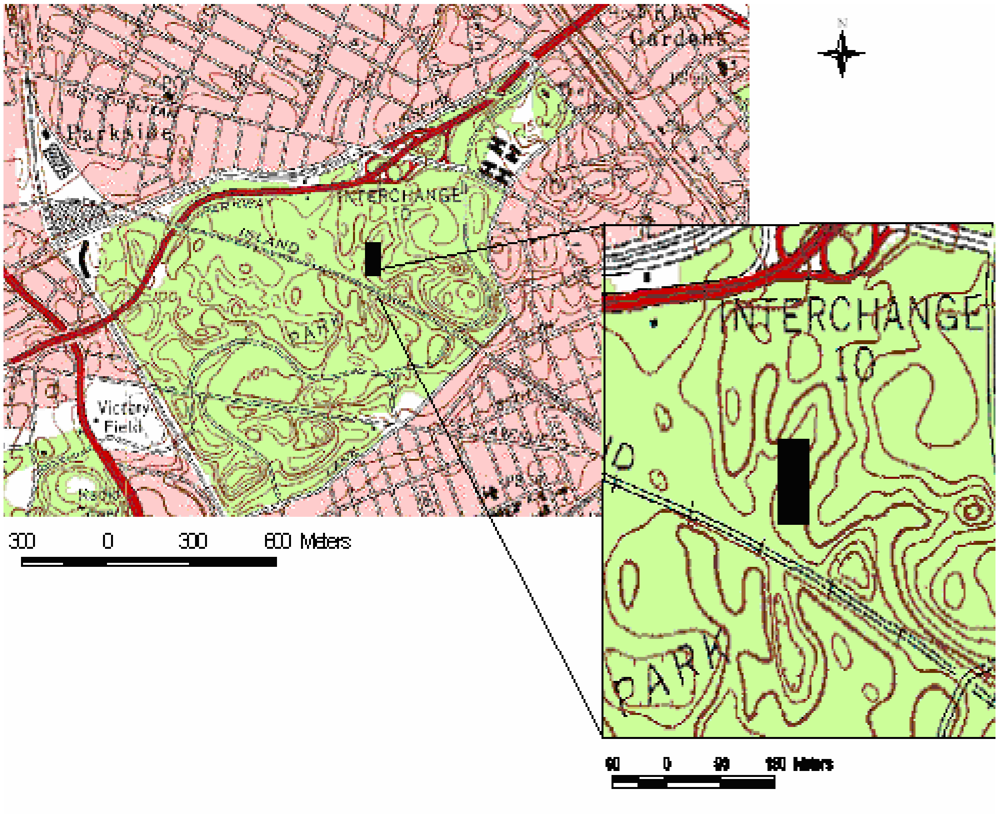


**Figure 3: A mature and aging *Quercus velutina* in the Northern Forest Management Zone of Forest Park, surrounded by a high density and frequency of pioneer species such as the nonnative invasive *Phellodendron amurense* (saplings in the foreground) and *Betula lenta* (poles in the background).**

**Figure 4: Randomization species-area curve generated from sampling quadrat combinations (NS=500) without replacement in Forest Park. The lower curve represents the minimum number of species and the upper curve the maximum number of species attained for each combination of quadrats.**

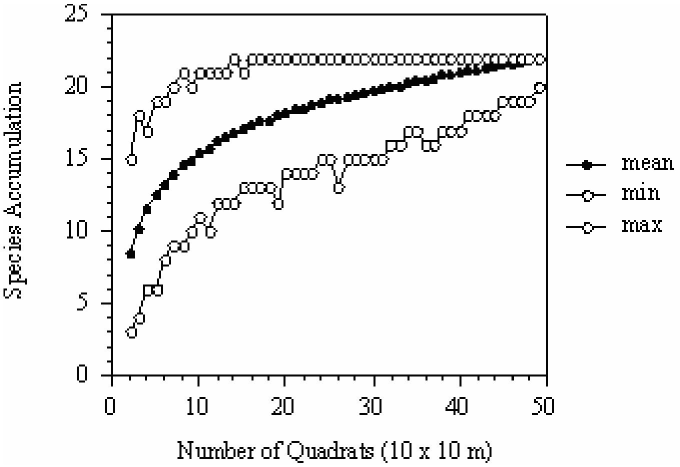
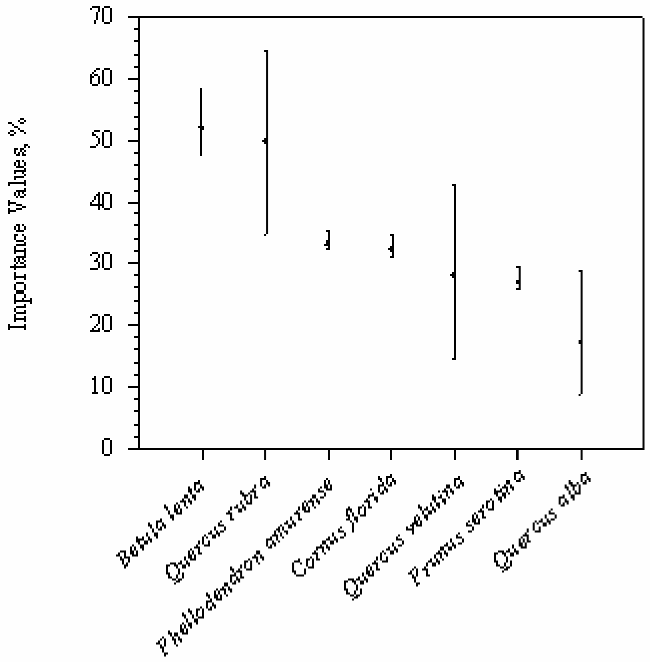
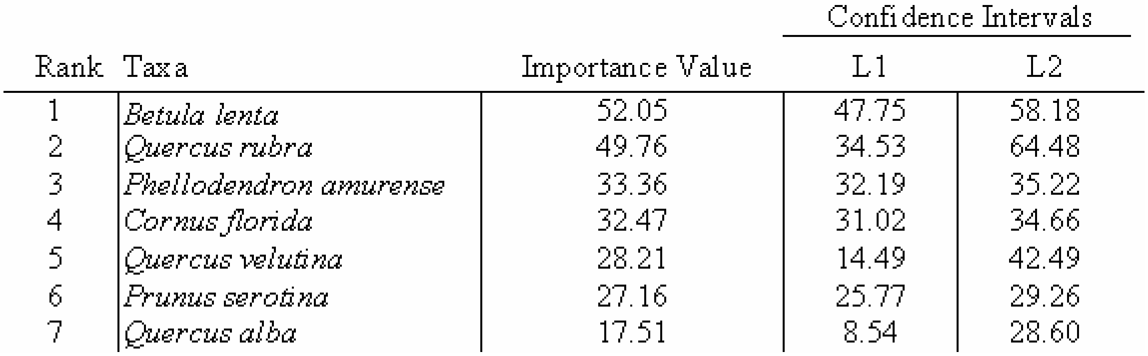


**Figure 5: Importance values of seven ecologically dominant taxa in decreasing order of importance with 95% bootstrap confidence intervals. Bootstrap samples with replacement occurred for the 771 stems (NS=10,000). L1 and L2 represent the lower and upper limits of the confidence intervals.**





| | | | Confidence Intervals | |
|---|---|---|---|---|
| Rank | Taxa | Importance Value | L1 | L2 |
| 1 | *Betula lenta* | 52.05 | 47.75 | 58.18 |
| 2 | *Quercus rubra* | 49.76 | 34.53 | 64.48 |
| 3 | *Phellodendron amurense* | 33.36 | 32.19 | 35.22 |
| 4 | *Cornus florida* | 32.47 | 31.02 | 34.66 |
| 5 | *Quercus velutina* | 28.21 | 14.49 | 42.49 |
| 6 | *Prunus serotina* | 27.16 | 25.77 | 29.26 |
| 7 | *Quercus alba* | 17.51 | 8.54 | 28.60 |

**Figure 6: The top six ecologically dominant tree families of the 0.5-hectare plot in Forest Park ranked in decreasing order by importance values and tree abundance for each family.**

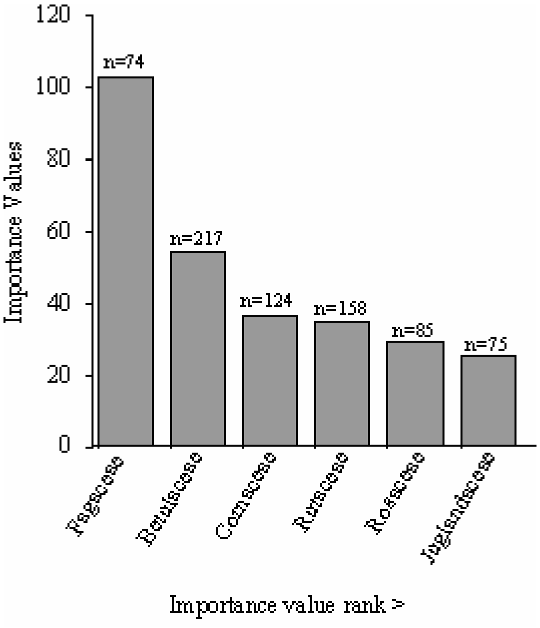


**Figure 7: Frequency distribution of all tree diameters within the 0.5-hectare plot in Forest Park (n=771). Tree diameters ranged from 2.0 to 116.7 cm, DBH (Weibull fit, w2=9.376; p<0.01).**

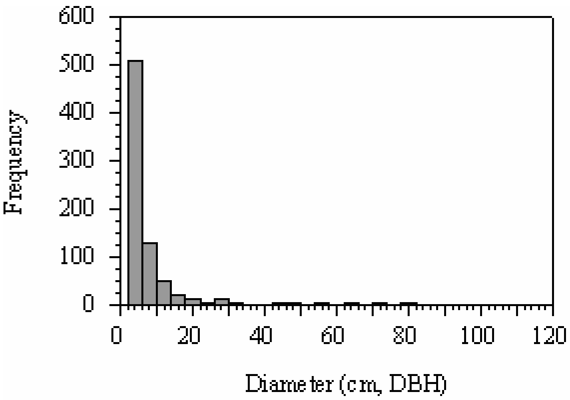


**Figure 8: Frequency distributions of tree diameters (DBH) of the three most abundant gap-phase species in the 0.5-hectare plot in Forest Park: (a) *Betula lenta* (n=217); (b) *Phellodendron amurense* (n=158); and (c) *Prunus serotina* (n=85).**

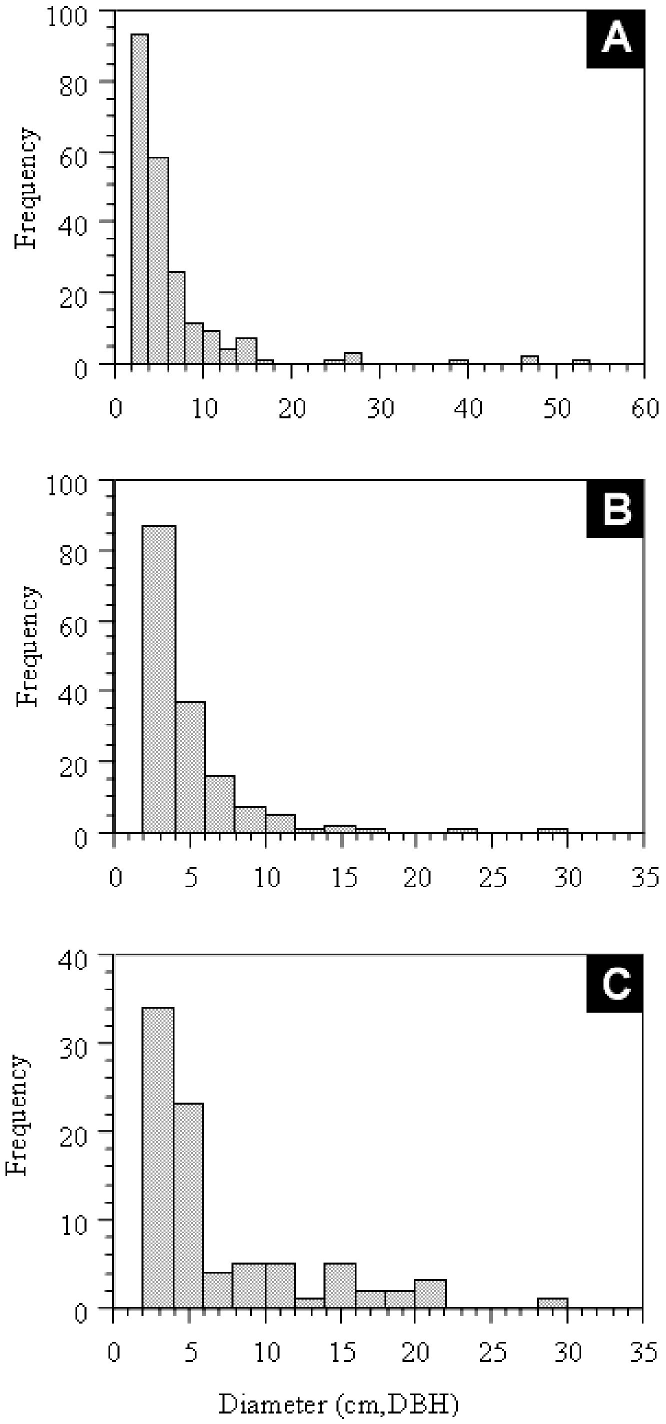


**Table 1. Ecological-dominance ranking of the 22 woody species (n=771) within the 0.5-hectare Forest Park plot in decreasing order of importance value (IV), the sum of each species' relative density, relative frequency, and relative dominance.**

| Rank | Species | No. of Stems | Rel. Dens. | Rel. Freq. | Rel. Dom. | IV |
|---|---|---|---|---|---|---|
| 1 | *Betula lenta* L. | 217 | 0.2815 | 0.1418 | 0.0966 | 51.99 |
| 2 | *Quercus rubra* L. | 33 | 0.0428 | 0.0816 | 0.3711 | 49.55 |
| 3 | *Phellodendron amurense* Rupr. | 158 | 0.2049 | 0.0993 | 0.0292 | 33.35 |
| 4 | *Cornus florida* L. | 115 | 0.1492 | 0.1418 | 0.0335 | 32.45 |
| 5 | *Quercus velutina* Lam. | 10 | 0.0130 | 0.0284 | 0.2394 | 28.07 |
| 6 | *Prunus serotina* Ehrh. | 85 | 0.1103 | 0.1277 | 0.0335 | 27.14 |
| 7 | *Quercus alba* L. | 13 | 0.0169 | 0.0355 | 0.1221 | 17.44 |
| 8 | *Carya tomentosa* (Poiret) Nutt. | 33 | 0.0428 | 0.0816 | 0.0124 | 13.67 |
| 9 | *Carya ovata* (Miller) K. Koch | 22 | 0.0285 | 0.0532 | 0.0071 | 8.88 |
| 10 | *Carya glabra* (Miller) Sweet | 20 | 0.0259 | 0.0497 | 0.0098 | 8.54 |
| 11 | *Fagus grandifolia* Ehrh. | 13 | 0.0169 | 0.0248 | 0.0397 | 8.14 |
| 12 | *Sassafras albidum* (Nutt.) Nees | 20 | 0.0259 | 0.0461 | 0.0034 | 7.54 |
| 13 | *Vaccinium corymbosum* L. | 7 | 0.0091 | 0.0213 | 0.0003 | 3.06 |
| 14 | *Cornus alternifoliai* L.f. | 9 | 0.0117 | 0.0142 | 0.0013 | 2.71 |
| 15 | *Castanea dentata* (Marshall) Borkh. | 5 | 0.0065 | 0.0177 | 0.0002 | 2.44 |
| 16 | *Lindera benzoin* (L.) Blume | 3 | 0.0039 | 0.0106 | 0.0001 | 1.46 |
| 17 | *Rhamnus frangula* L. | 3 | 0.0039 | 0.0071 | 0.0003 | 1.13 |
| 18 | *Acer rubrum* L. | 1 | 0.0013 | 0.0036 | 0.0000 | 0.49 |
| 19 | *Acer platanoides* L. | 1 | 0.0013 | 0.0036 | 0.0000 | 0.49 |
| 20 | *Liriodendron tulipifera* L. | 1 | 0.0013 | 0.0036 | 0.0000 | 0.49 |
| 21 | *Ilex verticillata* (L.) A. Gray | 1 | 0.0013 | 0.0036 | 0.0000 | 0.49 |
| 22 | *Nyssa sylvatica* Marshall. | 1 | 0.0013 | 0.0036 | 0.0000 | 0.49 |
|  | SUM | 771 |  |  |  | 300.00 |

**Table 2. Ecological-dominance ranking of woody families in decreasing order by importance values.**

| Rank | Family | No. of Stems | Rel. Dens. | Rel. Freq. | Rel. Dom. | IV |
|---|---|---|---|---|---|---|
| 1 | Fagaceae | 74 | 0.0960 | 0.1605 | 0.7725 | 102.89 |
| 2 | Betulaceae | 217 | 0.2815 | 0.1646 | 0.0966 | 54.27 |
| 3 | Cornaceae | 124 | 0.1608 | 0.1646 | 0.0348 | 36.02 |
| 4 | Rutaceae | 158 | 0.2049 | 0.1152 | 0.0292 | 34.94 |
| 5 | Rosaceae | 85 | 0.1103 | 0.1482 | 0.0335 | 29.19 |
| 6 | Juglandaceae | 75 | 0.0973 | 0.1317 | 0.0292 | 25.82 |
| 7 | Lauraceae | 23 | 0.0298 | 0.0617 | 0.0034 | 9.50 |
| 8 | Ericaceae | 7 | 0.0091 | 0.0247 | 0.0003 | 3.40 |
| 9 | Rhamnaceae | 3 | 0.0039 | 0.0082 | 0.0003 | 1.24 |
| 10 | Aceraceae | 2 | 0.0026 | 0.0082 | 0.0001 | 1.09 |
| 11 | Magnoliaceae | 1 | 0.0013 | 0.0041 | 0.0000 | 0.54 |
| 12 | Aquifoliaceae | 1 | 0.0013 | 0.0041 | 0.0000 | 0.54 |
| 13 | Nyssaceae | 1 | 0.0013 | 0.0041 | 0.0000 | 0.54 |
|  | SUM | 771 |  |  |  | 300.00 |

**Table 3. Ecological-dominance ranking of woody taxa in the small-size-diameter class (2.0 to < 2.8 cm, DBH) in decreasing order by importance values (n= 202).**

| Rank | Taxa | No. of Trees | Rel. Dens. | Rel. Freq. | Rel. Dom. | IV |
|---|---|---|---|---|---|---|
| 1 | *Betula lenta* L. | 54 | 0.2687 | 0.2018 | 0.2650 | 73.54 |
| 2 | *Phellodendron amurense* Rupr. | 49 | 0.2438 | 0.1667 | 0.2441 | 65.45 |
| 3 | *Cornus florida* L. | 29 | 0.1443 | 0.1579 | 0.1477 | 44.99 |
| 4 | *Prunus serotina* Ehrh. | 24 | 0.1194 | 0.1228 | 0.1222 | 36.44 |
| 5 | *Vaccinium corymbosum* L. | 5 | 0.0249 | 0.0439 | 0.0227 | 9.15 |
| 6 | *Sassafras albidum* (Nutt.) Nees | 5 | 0.0249 | 0.0351 | 0.0269 | 8.69 |
| 7 | *Cornus alternifoliai* L.f. | 6 | 0.0299 | 0.0263 | 0.0304 | 8.65 |
| 8 | *Carya glabra* (Miller) Sweet | 5 | 0.0249 | 0.0351 | 0.0240 | 8.39 |
| 9 | *Carya tomentosa* (Poiret) Nutt. | 4 | 0.0199 | 0.0351 | 0.0181 | 7.31 |
| 10 | *Castanea dentata* (Marshall) Borkh. | 4 | 0.0199 | 0.0351 | 0.0148 | 6.98 |
| 11 | *Carya ovata* (Miller) K. Koch | 4 | 0.0149 | 0.0263 | 0.0159 | 5.71 |
| 12 | *Quercus alba* L. | 3 | 0.0149 | 0.0263 | 0.0150 | 5.62 |
| 13 | *Lindera benzoin* (L.) Blume | 3 | 0.0149 | 0.0263 | 0.0106 | 5.18 |
| 14 | *Fagus grandifolia* Ehrh. | 2 | 0.0100 | 0.0175 | 0.0138 | 4.13 |
| 15 | *Acer platanoides* L. | 1 | 0.0050 | 0.0088 | 0.0069 | 2.07 |
| 16 | *Liriodendron tulipifera* L. | 1 | 0.0050 | 0.0088 | 0.0060 | 1.97 |
| 17 | *Ilex verticillata* (L.) A. Gray | 1 | 0.0050 | 0.0088 | 0.0055 | 1.93 |
| 18 | *Nyssa sylvatica* Marshall. | 1 | 0.0050 | 0.0088 | 0.0055 | 1.93 |
| 19 | *Rhamnus frangula* L. | 1 | 0.0050 | 0.0088 | 0.0051 | 1.88 |
|  | SUM | 202 |  |  |  | 300.00 |

**Table 4. Ecological-dominance ranking of woody taxa in the midsize-diameter class (2.8 to < 7.48 cm, DBH) in decreasing order by importance values (n=372).**

| Rank | Taxa | No. of Trees | Rel. Dens. | Rel. Freq. | Rel. Dom. | IV |
|---|---|---|---|---|---|---|
| 1 | *Betula lenta* L. | 117 | 0.3145 | 0.1859 | 0.3164 | 81.68 |
| 2 | *Phellodendron amurense* Rupr. | 90 | 0.2419 | 0.1474 | 0.2253 | 61.47 |
| 3 | *Cornus florida* L. | 55 | 0.1479 | 0.1795 | 0.1619 | 48.92 |
| 4 | *Prunus serotina* Ehrh. | 36 | 0.0968 | 0.1154 | 0.0941 | 30.62 |
| 5 | *Carya tomentosa* (Poiret) Nutt. | 18 | 0.0484 | 0.0897 | 0.0531 | 19.12 |
| 6 | *Carya ovata* (Miller) K. Koch | 14 | 0.0376 | 0.0705 | 0.0382 | 14.64 |
| 7 | *Sassafras albidum* (Nutt.) Nees | 11 | 0.0296 | 0.0513 | 0.0256 | 10.65 |
| 8 | *Carya glabra* (Miller) Sweet | 9 | 0.0242 | 0.0449 | 0.0236 | 9.27 |
| 9 | *Fagus grandifolia* Ehrh. | 8 | 0.0215 | 0.0321 | 0.0240 | 7.75 |
| 10 | *Quercus rubra* L. | 4 | 0.0108 | 0.0192 | 0.0115 | 4.15 |
| 11 | *Rhamnus frangula* L. | 2 | 0.0054 | 0.0128 | 0.0060 | 2.42 |
| 12 | *Cornus alternifoliai* L.f. | 2 | 0.0054 | 0.0128 | 0.0047 | 2.29 |
| 13 | *Vaccinium corymbosum* L. | 2 | 0.0054 | 0.0128 | 0.0029 | 2.11 |
| 14 | *Quercus alba* L. | 1 | 0.0027 | 0.0064 | 0.0055 | 1.45 |
| 15 | *Quercus velutina* Lam. | 1 | 0.0027 | 0.0064 | 0.0048 | 1.39 |
| 16 | *Castanea dentata* (Marshall) Borkh. | 1 | 0.0027 | 0.0064 | 0.0014 | 1.05 |
| 17 | *Acer rubrum* L. | 1 | 0.0027 | 0.0064 | 0.0010 | 1.01 |
|  | SUM | 372 |  |  |  | 300.00 |

**Table 5. Ecological-dominance ranking of woody taxa in the large-size-diameter class (7.48 to 116.7 cm, DBH) in decreasing order by importance values (n=197).**

| Rank | Species | No. of Trees | Rel. Dens. | Rel. Freq. | Rel. Dom. | IV |
|---|---|---|---|---|---|---|
| 1 | *Quercus rubra* L. | 29 | 0.1472 | 0.1631 | 0.3921 | 70.25 |
| 2 | *Betula lenta* L. | 46 | 0.2335 | 0.1915 | 0.0861 | 51.11 |
| 3 | *Quercus velutina* Lam. | 9 | 0.0457 | 0.0497 | 0.2530 | 34.84 |
| 4 | *Cornus florida* L. | 31 | 0.1574 | 0.1489 | 0.0271 | 33.34 |
| 5 | *Prunus serotina* Ehrh. | 25 | 0.1269 | 0.1277 | 0.0304 | 28.50 |
| 6 | *Quercus alba* L. | 9 | 0.0457 | 0.0567 | 0.1288 | 23.12 |
| 7 | *Phellodendron amurense* Rupr. | 19 | 0.0965 | 0.0851 | 0.0191 | 20.07 |
| 8 | *Carya tomentosa* (Poiret) Nutt. | 11 | 0.0558 | 0.0638 | 0.0105 | 13.02 |
| 9 | *Carya glabra* (Miller) Sweet | 6 | 0.0305 | 0.0355 | 0.0091 | 7.51 |
| 10 | *Fagus grandifolia* Ehrh. | 3 | 0.0152 | 0.0213 | 0.0374 | 7.39 |
| 11 | *Carya ovata* (Miller) K. Koch | 4 | 0.0203 | 0.0284 | 0.0030 | 5.17 |
| 12 | *Sassafras albidum* (Nutt.) Nees | 4 | 0.0203 | 0.0213 | 0.0022 | 4.38 |
| 13 | *Cornus alternifoliai* L.f. | 1 | 0.0051 | 0.0071 | 0.0009 | 1.31 |
|  | SUM | 197 |  |  |  | 300.00 |

**Table 6. Basic structural characteristics of three ecologically dominant taxa within each of the size classes of the 0.5-hectare Forest Park plot.**

| | **Small-Size Trees** | | | **Mid-Size Trees** | | |
|---|---|---|---|---|---|---|
| | **BELE** | **PHAM** | **COFL** | **BELE** | **PHAM** | **COFL** |
| **Density (stem ha-1)** | 108 | 98 | 58 | 234 | 180 | 110 |
| **Diameter (cm, DBH)** | | | | | | |
| **total trees** | 54 | 49 | 29 | 117 | 90 | 55 |
| **mean** | 2.35 | 2.36 | 2.39 | 4.64 | 4.43 | 4.85 |
| **standard deviation** | 0.26 | 0.27 | 0.27 | 1.20 | 1.27 | 1.22 |
| **minimum** | 2.00 | 2.00 | 2.00 | 2.90 | 2.90 | 2.90 |
| **maximum** | 2.80 | 2.80 | 2.80 | 7.20 | 7.10 | 7.48 |
| **skewness** | 0.19 | -1.38 | 0.16 | 0.58 | -0.69 | 0.30 |
| **Basal area (m2 ha -1)** | 0.24 | 0.22 | 0.13 | 2.10 | 2.78 | 1.07 |
| **Composition (BA %)** | 0.15 | 0.14 | 0.08 | 1.37 | 1.82 | 0.69 |

Species Acronyms: BELE - *Betula lenta*; PHAM - *Phellodendron amurense*; COFL - *Cornus florida*;

| **Table 6. Continued** | **Large-Size Trees** | | | | |
|---|---|---|---|---|---|
| | **QURU** | **BELE** | **QUVE** | **Others** | **Total** |
| **Density (stem ha-1)** | 58 | 92 | 18 | 586 | 1542 |
| **Diameter (cm, DBH)** | | | | | |
| **total trees** | 29 | 46 | 9 | 293 | 771 |
| **mean** | 42.20 | 15.10 | 70.89 | 8.46 | 8.50 |
| **standard deviation** | 27.38 | 11.02 | 14.35 | 10.43 | 13.44 |
| **minimum** | 8.00 | 7.50 | 49.50 | 2.00 | 2.00 |
| **maximum** | 116.70 | 52.00 | 95.00 | 81.50 | 116.7 |
| **skewness** | 0.58 | 2.13 | 0.19 | 4.21 | 4.08 |
| **Basal area (m2 ha -1)** | 57.05 | 12.53 | 36.81 | 40.11 | 153.04 |
| **Composition (BA %)** | 37.27 | 8.18 | 24.05 | 26.22 | 100.00 |

Species Acronyms: BELE - *Betula lenta*; QURU - *Quercus rubra*; QUVE - *Quercus velutina*

# Short-Tailed Shrews (*Blarina brevicauda*) Exhibit Unusual Behavior in an Urban Environment

**by Virgil Brack Jr.**

Indiana State University, Department of Ecology and Organismal Biology
Terre Haute, IN 47089

## Abstract

Ecological studies typically stress the use of habitats by wildlife in natural environments. However, in urban environments, habitat use may be altered, or it may be easier to discern use or behaviors overlooked in more natural settings. This note details unique observations of the northern short-tailed shrew (*Blarina brevicauda*) congregating around a bird feeder, living in a flower bed isolated within a parking lot, entering buildings, eating hamburger, and using an arboreal nest in suburban Cincinnati, Ohio.

**Key words**: arboreal nest; barriers to movement; *Blarina brevicauda*; Cincinnati; foods; habitats; scavenging; short-tailed shrew

## Introduction

As our world becomes increasingly developed, many species of wildlife adapt in unpredictable ways. For example, the white-tailed deer (*Odocoileus virginianus*), once extirpated from vast areas of the eastern U.S. but now overpopulated there, plagues many cities and suburban areas, and the peregrine falcon (*Falco peregrinus*), once considered endangered by the U.S. Fish and Wildlife Service, has been delisted in part because of the success of campaigns to reintroduce the species in urban environments.

*Blarina brevicauda*, the northern short-tailed shrew, has a broad distribution that covers the northeastern United States, including all of Ohio, and it uses a variety of habitats (Whitaker & Hamilton, 1998). Most shrews are not readily found in heavily developed areas, but *B. brevicauda* may be an exception. The following are observations regarding unique foods, unique habitats, and unique behaviors of shrews in two suburban areas of a major metropolitan region.

## Study Area

Observations were made at two locations on the west side of Cincinnati, in Hamilton County, Ohio. The first was a residence on a busy street (2348 Neeb Road), and observations were made during the period 1989–2003. The house had been built in 1971 and was similar to many other residences in the area. It was sited on a 0.13-hectare plot with houses on both sides, and the grounds were maintained in a manner typical of a residential development. During winters, three relatively intensively used bird feeders were maintained at the back of the residence.

The second location was an office building about 2.9 kilometers south of the residence, at 781 Neeb Road. It was in an area of mixed use that included residences, apartments, a diverse array of businesses (such as office buildings and filling stations), and a combination church and school. Initial development of this area had likely occurred roughly 200 years earlier (a roadhouse and tavern once stood on the site), but the most intensive urbanization likely occurred in the mid-1900s. Nearby, redevelopment and in-filling has occurred on a regular basis, so the area is a mix of old and newer developments. At the office-building location, observations were made during the period 2000–2005.

## Eating Unique Foods

Most shrews, including *Blarina brevicauda*, feed primarily on invertebrates found in the soil where they burrow (Whitaker & Hamilton, 1998). At the residence, I found the area below the winter bird feeders riddled with burrows of *B. brevicauda*. The shrews may have been drawn to invertebrates attracted by waste bird food and droppings, or directly to waste bird food. The bird feeders were filled mainly with sunflower and thistle seed, but they also contained small quantities of corn and millet. Although *B. brevicauda* is considered carnivorous (George, Choate & Genoways, 1986), Eadie (1944) indicated that seeds were regularly included in the diet; caches of corn have been found in burrows of wild individuals (Whitaker & Hamilton, 1998); and Martinsen (1969) documented a captive individual surviving on cracked corn. *Blarina brevicauda* also consumes subterranean fungi (Whitaker, 1962), which may be abundant below bird feeders. Carter (1936) provided observations of a shrew active at a suet bird feeder. There is also evidence that *B. brevicauda* eats vertebrates such as small mammals, salamanders, snakes, small birds—and even small hares (George et al., 1986).

On two occasions during different winters when hamburger was temporarily stored in a garage near an outside door at 2348 Neeb Road, *Blarina brevicauda* entered the garage via a crack under the door, burrowed through the cellophane wrapper, and ate portions of the meat. On both occasions and on several others, I saw the shrew in the garage. Shull (1907) indicated that captive short-tailed shrews ate beef, even in preference to some types of natural food, such as snails, that require time and effort to process. Eadie (1944) found feathers in scat, which he attributed to scavenging of carrion, and he suggested *B. brevicauda* fed on dead vole (*Microtus*) species. In addition, researchers bait traps and maintain individuals in traps or in the lab with dog or cat food. Consumption of many types of meat suggests short-tailed shrews may scavenge more than is generally believed. Although recent studies have not identified shrews as scavengers (DeVault & Rhodes, 2002; DeVault, Rhodes & Shivik, 2003; DeVault, Brisbin & Rhodes, 2004), the methods used to detect use of carrion organisms have depended upon carrion removal, which would not occur when a small shrew was feeding on a large carrion item. Moreover, scavenging by shrews on larger animals would leave little evidence in scats, because indigestible items such as fur need not be consumed. Even when shrews feed on small mammals, hide, appendages, and bones frequently are not consumed (Eadie, 1944; Shull, 1907).

## Living in an Office Parking Lot

Areas of unsuitable habitat are not often traversed by many species of small mammals. Schreiber and Graves (1977) indicated that power-line corridors may be barriers to dispersal by *Blarina brevicauda*; but Yahner (1983) found that *B. brevicauda* moved between shelterbelts in southern Minnesota more often than four other species of small mammals studied (one other shrew and three rodents). At the office building on the west side of Cincinnati, *B. brevicauda* resided in a flower bed used for growing vegetables. The flower bed was surrounded on three sides by an asphalt parking lot and abutted the building on the fourth side (Figure 1). A busy street ran in front of the parking lot, and a less-used street ran beside the lot and building. There were residential and commercial lawns behind the office building and across the two adjacent streets. On one occasion, a shrew was caught in and removed from the office building. The shrew had to have climbed at least three steps to enter the building.

Miller and Getz (1977) indicated that *Blarina brevicauda* has broad habitat requirements but is most common in areas with greater than 50% herbaceous cover, and Getz (1961) indicated that the shrew avoids areas with little cover. The flower bed had far less than 50% vegetative cover throughout much of the growing season, and during late autumn through early spring it generally had no cover. However, the flower bed did have a layer of mulch, which may have been used in a manner similar to the way shrews use leaf litter to make shallow runways.

## Nesting in a Tree

*Blarina brevicauda* is semifossorial, burrowing through forest litter and loose damp soil (George et al., 1986). In early October 2003, I found a *B. brevicauda* in a tree in the front yard of the urban residence. The tree was an ornamental crabapple (*Malus* species) in the lawn next to a driveway, 15 meters from a busy paved road (Figure 2). The tree forked 1 meter above ground and at that point was 20 centimeters in diameter. Typical of pruned ornamental lawn trees, it had numerous crotches and prolific branching. While trimming branches about 4 meters above ground level, I noted a nest (a ball of fine grass about 10 centimeters in diameter) in a three-way crotch at the site of previous pruning. When the branch was cut and thrown to the pavement, a shrew was crushed and killed. I did not see the shrew while cutting the limb and suspect it was in the nest.

A variety of small mammals, mostly rodents, make nests in trees, but I found only one reference of *Blarina brevicauda* in a tree, raiding suet at a bird feeder (Carter, 1936), and no references regarding use of arboreal nests. Underground nests of *B. brevicauda* are described as hollow balls 12 to 15 centimeters in diameter and made of grass, sedges, leaves, and even the fur of meadow voles, *Microtus pennsylvanicus* (Eadie, 1944; Hamilton, 1929; Rapp & Rapp, 1945; Shull, 1907). The nest I found in the tree closely resembled those descriptions.

Studies of wildlife most often emphasize natural aspects of the habitat, even when anthropogenic effects dominate the landscape. It is apparent from observations provided here that the short-tailed shrew readily uses an urban/suburban environment—a phenomenon we have had indirect evidence for since the 1980s from diet reports of American kestrels (*Falco sparverius*) feeding in an urban environment (Brack, Cable & Driscol, 1984). Careful observations of wildlife in anthropogenic landscapes may lead to the documentation of behaviors that are infrequent or overlooked in more natural settings. In addition, as suburbia becomes an increasingly dominant landscape form, the need to understand why some species can tolerate these conditions while others cannot becomes increasingly important to wildlife managers and conservation planners.

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# Glossary

**Anthropogenic:** Caused or produced by humans.

**In-filling:** Building between existing development.

**Semi-fossorial:** Semi-burrowing.

**Figure 1: Office building site in Cincinnati. *Blarina brevicauda* was observed residing in the front flower beds (photo by author).**

**Figure 2: Crabapple tree used by *Blarina brevicauda* for nesting at the urban residence site (photo by author).**

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# Habitat observations of *Geum vernum* in Kings Point Park, Long Island, and a Discussion of the Species' Potential Invasiveness in New York State

**by Andrew M. Greller[1], Virginia Dankel,[2] and David C. Locke[3]**

[1] Queens College, Biology Department, Queens College, CUNY, Flushing, New York 11367
[2] c/o BOCES of Nassau County, 2850 North Jerusalem Road, Wantagh, NY 11554
[3] Queens College, Chemistry Department, Queens College, CUNY, Flushing, New York 11367

## Abstract

In this note, we report the occurrence of *Geum vernum* (spring avens) in Kings Point Park, Long Island, New York, and record the habitat conditions of the plant in different park locations. We also discuss the species' potential invasiveness in New York State and one possible reason for its shifting range.

**Key words:** climate change; disturbance; *Geum vernum*; invasive species; swamp forest; urban park

## Introduction

On May 11, 2006, while preparing a site list of noncultivated plants in Kings Point Park, Long Island, New York, for a Long Island Botanical Society field trip, one of us (Greller) found two colonies of *Geum vernum* (Raf.) Torr. & Gray (spring avens). Subsequent visits to the park on May 13 and June 8 revealed four more locations for the species (Figure 1). In one of these locations, nearest to Steppingstone Park, *Geum vernum* was scattered along some 50 meters of trail.

Until recently, *Geum vernum* was considered an endangered species in New York State (NYS). Its legal status, as defined by NYS Environmental Conservation Law section 11-0535, is E—endangered species. The New York Natural Heritage Program's global and state ranking for the species, as determined by the NYS Department of Environmental Conservation and The Nature Conservancy, is G5, S1. However, Mitchell and Tucker (1997) listed *Geum vernum* as possibly exotic to NYS and designated it with an asterisk in parenthesis (*). And just this past year, the Natural Heritage Program moved the species from its rare-plant-status "active list" to its "watch list," and now considers *G. vernum* a "weedy species predicted to expand range" (Young & Weldy, 2006).

## Background of the Park

Kings Point Park is a 175-acre tract of mainly wetland vegetation owned by the Village of

Kings Point, in the Town of North Hempstead, Long Island, Nassau County, New York. The park dates to the 1930s, when several parcels of land were acquired and combined by the village. It was the site of a large Works Progress Administration construction project, during which "hundreds of men were brought to clear trees and install drainage pipes" (Larry Ninesling and Charles Angelo, Great Neck Parks District Office, undated mimeograph). Deep man-made ditches scar the landscape. In the 1940s, a softball field was installed at the southern end of the park on clean fill of morainal origin; baseball fields for Little League play were developed in the 1950s in the north-central section of the park. Since 1938, the park has been administered by the Great Neck Park District, by agreement with the village of Kings Point. Most of the natural vegetation of Kings Point Park is a mosaic of swamp forests. *Acer rubrum* (red maple) is the dominant tree species throughout nearly the entire extent of the swamp forests. Also common, and sometimes locally dominant, are *Liquidambar styraciflua* (sweetgum), *Nyssa sylvatica* (sour gum), *Sassafras albidum* (sassafras), and *Betula lenta* (black birch). Some upland oak forests are present on the best-drained sites. Elevation in the swamps varies from 7 feet above sea level to about 15 feet above sea level. The substrate of the swamps is muck. The upland forest types are located along Red Brook Road and Kings Point Road (Figure 1) on elevations ranging from 20 feet above sea level to 47 feet above sea level. Soils of the uplands are morainal in origin but moist. The park still contains natural springs. It was designated a class I wetland on a NYS Article 24 Freshwater Wetland map, on February 20, 1987.

## Description of *Geum vernum* Locations

All but one of the *Geum vernum* sites are located in swamp forests on muck soils at the edges of paths covered with wood chips. The swamp forest sites show signs of recent disturbance. Compaction of soil may be a factor in the success of *G. vernum* since the largest colony of the species occurs on a site that appears to be a former picnic ground (Figure 2). (An old slab of concrete—barely visible in the photograph—with the sawn-off stump of a barbecue grill pole indicates the site's past use). Soil pH may also be a factor: A pH reading taken from soil on the picnic-ground site was 5.9 (slightly acidic). This is higher than pH levels in bogs and kettle ponds in western Long Island, which can vary from 3.5 to 4.5 (Greller, unpublished data); and it is higher than moist upland sites in nearby Mill Neck (Greller, Locke, Kilanowski & Lotowycz, 1990). It is possible that the decaying concrete is contributing to the relatively high pH reading.

Near the Steamboat Lane parking lot at the southern edge of the park (see Figure 1), there is a small colony of *Geum vernum* adjacent to a disturbed area consisting of a pile of plant debris on top of sand and pebbles. The soil is sandier here, although mosses provide a dense groundcover.

The two types of site (swamp forest and parking lot) have the following features in common (1) an opening (since the plants occur along paths or cleared areas), (2) some recent disturbance, such as the application of wood chips or dumping of plant debris, and (3) a mixture of exotic weeds (e.g., *Alliaria petiolata* [garlic mustard], *Duchesnea indica* [Indian strawberry], *Veronica hederifolia* [ivyleaf speedwell], *Rosa multiflora* [multiflora rose], and *Microstegium vimineum* [Japanese stilt grass]) in the vicinity, in addition to native herbs and woody seedlings. (See Appendix 1 for a list of the plants associated with *Geum vernum* at its principal site.) Weeds are codominants at all *G. vernum* sites in the park. The populations of *G. vernum* here vary from between 50 to 100 plants at the picnic-ground site to as few as 5 at the Steamboat Lane site. The plants appear to be vigorous: all *G. vernum* sites had specimens that flowered and later set fruit (See Figure 3 and Figure 4).

## Discussion

Clemants and Gracie (2006) present a northeastern range map that shows *Geum vernum* occurring in only three areas of NYS. One area is in New York City, another is at the southeastern end of Lake Ontario, and one is at the eastern end of Lake Erie (extending into Ontario, Canada, to range all around the lake). Otherwise, its range is to the south and west of NYS, in southeastern and southwestern Pennsylvania and then beyond that state to the southwest. In New York City, *G. vernum* has been found in Van Cortlandt Park, Bronx County, New York (Gerry Moore, personal communication, 2006).

Open, disturbed habitats, where competition from native species is lacking, provide niches for exotic species. Occurrences of exotic species such as *Alliaria petiolata* (garlic mustard) and *Cardamine impatiens* (narrowleaf bittercress) are becoming commonplace in the eastern U.S., even in mature forest. Southern (mountain) plants have found niches in Long Island habitats: for example, *Magnolia tripetala* (umbrella-tree) in mixed hardwood forest; *Magnolia acuminata* (cucumber-tree) in oak–red maple forest (Greller, Lindberg & Lindberg, 2000); *Magnolia macrophylla* (bigleaf magnolia) in a mixed oak forest in Oyster Bay (Greller and Allan Lindberg, personal observation); and *Aesculus octandra* (yellow buckeye) in two locations (Greller, personal observation)—one at the eastern edge of Kings Point Park, the other on a wooded shoulder of a paved road in Greenvale, Town of North Hempstead.

The arrival of many new exotics and invasives in the New York City area may be linked to record increases in temperature over the past decade. In the United States, the five most recent pentads, or 5-year periods (2000–2004, 1999–2003, 1998–2002, 1997–2001, 1996–2000), were the warmest in the last 110 years for which national records are available (Levinson, 2005). In our area, this trend is illustrated by the fact that the January 2006 average temperature recorded at New York City's Central Park meteorological station was 40.8° F, whereas the normal January average temperature there is 32.0° F (Greller, calculated from data provided by the Weather Underground website).

## Conclusion

Our observations of *Geum vernum* in Kings Point Park suggest that the species is fairly widespread along trails and in other disturbed sites and that it occurs in relatively high pH soils with exotic plants and many native ones. As illustrated in Figure 2, the *G. vernum* sites we located have sparse groundcover. At the principal picnic-ground site, the soil is covered to a large extent by a thin mat of *Veronica hederifolia*. Above the *V. hederifolia* is a vegetation community of low herbs and woody seedlings, in which *G. vernum*, *Aster divaricatus* (white wood aster), and *Alliaria petiolata* codominate (Figure 3).

It is possible that *Geum vernum* is invading our area from the south, extending its natural range in eastern North America as a response to warming winters. Thus, we concur with Young and Weldy (2006) that the plant no longer should be considered endangered by NYS conservation agencies but rather that it should be watched for evidence of an explosive growth in range.

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**Figure 1: Map (aerial photo) of Kings Point Park. Stars show locations where at least one specimen of *Geum vernum* was found. (Photo source: Google Earth)**

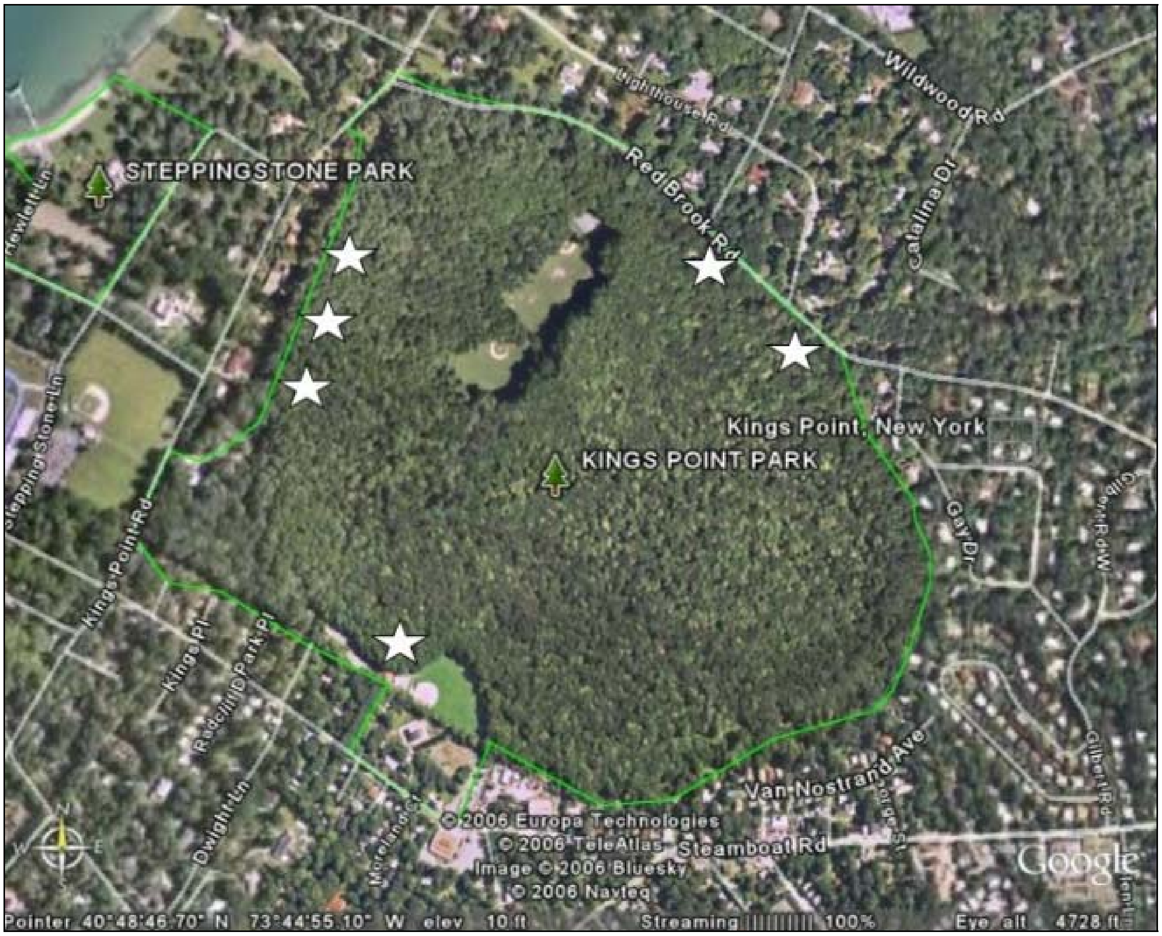


**Figure 2: Former picnic grounds vegetated with *Geum vernum*. One author (Dankel) stands on a concrete slab that once supported a barbecue grill. A mixed hardwood forest is in the background. (Photo by A. Greller; taken June 8, 2006).**

**Figure 3: *Geum vernum* coming into flower (center). Note the pinnately dissected leaves at base of the sterile plant (lower left) and on the lower stalk of the fertile plant. Also note the leaves of *Aster divaricatus* (top right and left) and the fallen stem of a flowering *Alliaria petiolata* (diagonal at upper center of picture). (Photo by A.M. Greller; taken May 11, 2006)**

**Figure 4: Close-up of *Geum vernum* flowers posed on a tree trunk. Note each flower's stalked gynoecium (female reproductive part). (Photo by A.M. Greller; taken May 11, 2006.).**

# Appendix 1. Plants associated with *Geum vernum* at the picnic-ground site (approximately 7.2 × 7.8 meters; see Figure 2) in Kings Point Park, Long Island, New York.

- *Acer platanoides* (seedling)
- *Alliaria petiolata*
- *Allium vineale*
- *Ampelopsis brevipedunculata*
- *Aster divaricatus*
- *Duchesnea indica*
- *Euonymus alatus* (seedling)
- *Hedera helix*
- *Juglans* species (seedling)
- *Lindera benzoin* (seedling)
- *Liquidambar styraciflua* (seedling)
- *Malus* species (seedling)
- *Nyssa sylvatica* (seedling)
- *Parthenocissus quinquefolia*
- Poaceae
- *Polygonatum pubescens*
- *Prunus serotina* (seedling)
- *Quercus alba* (seedling)
- *Ranunculus abortivus*
- *Sassafras albidum* (seedling)
- *Solanum dulcamara*
- *Taraxacum officinale*
- *Trientalis borealis* (one, sterile)(?)
- *Veronica hederifolia*

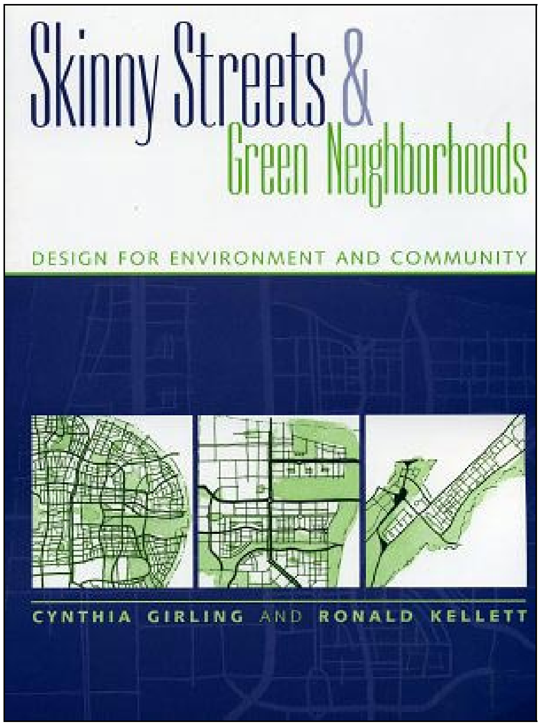
# Book Review: *Skinny Streets and Green Neighborhoods: Design for Environment and Community*

### Cynthia Girling and Ronald Kellett. (2005). Washington, DC: Island Press. Paperback. 354 pp. ISBN: 15559633379.

*Skinny Streets and Green Neighborhoods* is the eye-catching title of an extremely engaging new book about urban planning and ecology. It approaches urban design and "place-making" at the neighborhood scale by focusing on spatial patterns of green (natural) and gray (built) elements. The authors' goals are clear: to achieve both compactness and ecological soundness in North American urban design.

*Skinny Streets* prefaces its design chapters with the now familiar story of post-WWII suburbanization and car-induced sprawl, and the ecological and human harm they have caused. In contrast to the prevailing trends, green neighborhoods are described as those whose density, diversity, and layouts encourage walking and reduced car usage. These neighborhoods, which contrast sharply with those in low-density suburbia, are the basic unit of urban development.

Ten exceptionally well-illustrated case studies of neighborhoods in Canada and the U.S follow: two historic and eight contemporary. Each case is presented as a study in three layers: green network, gray network, and gray fabric. The study of green/gray spatial patterns is accompanied by land-use color transparencies, overlaid on satellite images showing the study area in context. Well-placed, matching bar graphs quantify the details of land use and support the spatial graphics, while pictures and text tie spatial and quantitative data together.



The next three chapters elaborate on the green and gray design layers of the case studies. "Green Networks" discusses urban ecological structure and multiscale planning for incorporating natural processes as part of the urban design, and for the restoration and repair of fragmented ecological elements.

"Gray Networks" focuses on roads and road patterns, discussing the merits of grid and lollipop patterns, as well as the consequences of storm-water runoff from paved surfaces. Design strategies aim for pedestrian functionality but also for streets that are beautiful and environmentally sound—tree-canopied, vegetation-lined, and bioswaled. "Gray Fabric" reviews historical and contemporary theories of neighborhood design, discussing density, transit-oriented development, and placement of commercial areas near enough to high-rise and low-rise residential areas so that "it's too close to drive."

"Green Fabric" and "Urban Water" are the two remaining design chapters. "Green Fabric" focuses on the urban forest, particularly on trees. Trees act as habitat for birds and small animals, definers of urban space, and rainwater diffusers, and they create cooling canopies in summer. "Urban Water" defines water comprehensively as all the water that exists in the city, from rain to runoff to wastewater. The interruption of the hydrologic cycle begins with impervious surfaces that lead storm water and pollution to rivers, streams, lakes, and wetlands. The emphasis here is on restoring a more natural hydrologic cycle at many levels, and making water a visible rather than a hidden element of the urban landscape.

The book ends with an excellent essay on the state of green/gray design today, and what is needed to make dense, green neighborhoods with walkable streets the norm rather than the exception. It may surprise laypeople to learn that planning for green networks alongside gray networks is not standard practice in most communities. These and other reflections are well worth a close reading.

*Skinny Streets* teaches without preaching. Design across multiple scales (from individual city lots to regional plans)—a hard concept to convey in words alone—is illustrated on the first page of each of the six design chapters. The cultural landscape is not discussed explicitly; rather it is woven into gray fabric design through focusing on key civic buildings, and it is related to urban water by the inclusion of fountains and water sculptures. *Skinny Streets* maintains its focus on a design framework of green and gray spatial patterns. By limiting some discussions to key elements such as the urban forest and roads, it achieves its core purpose without getting lost in interesting but distracting side discussions of specific vegetation types, other utility corridors, or political and sociological factors. These pedagogical choices are well matched to the purpose and scope of this book. There is also an excellent bibliography for readers interested in more investigation and detail.

One criticism relates to the endnote section, which could have been more descriptive. For example, it would have appropriate for the authors to clarify over which area—metropolitan or core—the relative population densities of New York, Boston, Vancouver, and Amsterdam were calculated in each case study, so that comparisons were more clear.

*Skinny Streets* is an extremely well-written, well-organized, and coherent book that delivers just enough history, theory, and example at an absorbable pace. Balanced and sensible, it is likely to provoke citizens, developers, planners, and elected officials to reflect more thoughtfully on new designs and projects in their neighborhoods, cities, and regions. Hopefully, it will persuade them to frame their analyses in layers of green and gray.

**Carmela Canzonieri**
**Faculty of Environmental Studies**
**York University, Toronto**