According to standard ecoregion mapping of North America, New York City falls squarely within the eastern broadleaf forest—an ecosystem characterized by an overstory of tall, broadleaf trees, like American beech (Fagus grandifolia) and white oak (Quercus alba). The on-the-ground reality, however, is made obvious in the air: a plane flying low into LaGuardia International Airport offers its passengers a view of the city's expansive network of yards and parks, roads and parking lots. After generations of urbanization, New York City's tree canopy represents a mere 21 percent of its land cover. A comparable percentage is, in fact, represented by mixed grassland vegetation—the turfgrass in public parks, golf courses, and soccer fields. The city's cemeteries also house a significant portion of that vegetation, totaling an area of more than five Central Parks.

At 478 acres, the Green-Wood Cemetery, in Brooklyn, is an active cemetery, a National Historic Landmark, and a curated arboretum, with a diverse and well-established collection of trees. It is also one of the largest urban grasslands in New York City. Founded in 1838, on land that was once forest, Green-Wood includes rolling hills and kettle ponds. This topography, reflective of the landscape's position on a terminal moraine, made it inhospitable for agriculture but an ideal location to site a new kind of cemetery. Green-Wood was among the first cemeteries (after Mount Auburn Cemetery, in Cambridge, Massachusetts, and Laurel Hill Cemetery, in Philadelphia, Pennsylvania) built in the United States during the rural cemetery movement, a period in the mid-nineteenth century in which concerns over disease and rapidly increasing urban populations compelled city planners to site new burial grounds in the nearby countryside, instead of inner-city churchyards. In addition to providing burial space, these romantic, natu-
ralistic landscapes served as counterpoints to the bustle and tumult of cities, providing sites for passive recreation and spiritual reflection in an idyllic environment. Their development predated all public gardens and arboreta in the United States and would help institutionalize what became a quintessential American value: that all people, even city-dwellers, deserved access to green space.

Green-Wood, at the time of its founding, was believed to combine an ideal set of virtues: it was close enough for a daytrip from Manhattan and far enough away that the land around it would never get developed. Since that time, Green-Wood’s surroundings have radically transformed. Now bordered by the densely populated residential neighborhoods of Windsor Terrace, Park Slope, Sunset Park, and Kensington, Green-Wood’s perimeter is directly flanked not by countryside but by the less-than-bucolic Metropolitan Transit Authority’s Jackie Gleason Bus Terminal and a Con Edison substation. Over the past two centuries, the rapid development and urbanization of Green-Wood’s immediate surroundings have increased the cemetery’s relative socio-ecological value. Sunset Park, for instance, has the least amount of green space per capita among New York City neighborhoods. In the face of urbanization and increased disturbances from climate change, Green-Wood has returned to its roots as a community-focused public garden. This is a timely and crucial return for Green-Wood’s resilience as a greenspace and for supporting the ecological health of the New York City region.

In recent years, Green-Wood’s collection of trees and shrubs has gained increased recognition and accolades. Among other things, Green-Wood has collaborated with United States Forest Service on a project that led to the discovery of a new, as yet unpublished, species of wood-boring beetle (Agrilus sp.), and Green-Wood’s oak (Quercus) collection is now a Nationally Accredited Plant Collection. These efforts have highlighted the institution’s importance within New York City’s urban forest and have supported research vital for forest preservation. But what of Green-Wood’s grasslands? Literally overshadowed by the larger, more charismatic trees and shrubs, Green-Wood’s expansive grasslands are by far its most complex, dominant, and resource-dependent vegetation. Alterations to the management practices of these grasslands, therefore, may stand to have the most impact on the sustainability and resilience of Green-Wood in the face of climate change.

**Urban Grassland Ecosystem Services**

Over the last twenty years, with the advent of improved data capture and analytic technologies, researchers and policy makers have become increasingly interested in quantifying the relationship between humans and the natural world. The United Nations codified the conceptual framework of this relationship, known as ecosystem services, in the Millennium Ecosystems Assessment report published at the turn of the twenty-first century. The anthropocentric view of ecosystem services asserts that the natural world serves the needs of humans in measurable ways: by regulating climate and ecosystem health, producing raw materials, supporting natural systems through chemical processes, and providing cultural benefits.

Humans, however, often impact the natural world in ways that demonstrably undermine those services. Urban grasslands showcase this tension. Grasslands provide a permeable surface for stormwater to penetrate, helping mitigate runoff from increasingly frequent extreme precipitation events. They provide habitat for wildlife and space for human recreation on a cushioning vegetated surface. Concurrently, at the soil surface, a seething foundry of microbial activity sequesters greenhouse gases, fixes nitrogen, and processes pollutants. Yet, by definition, urban grasslands, especially cemeteries, are associated with regular surface disruption from mowing and excavation, which destabilizes the soil surface, increasing erosion and releasing stored greenhouse gases. Turf is considered the most widespread irrigated crop in the United States, and its management also requires fossil fuels and a multitude of chemicals, including fertilizers, herbicides, fungicides, and growth regulators. The overall maintenance cost to the American consumer is steep: according to the market research group...
IBISWorld, households spent around $30 billion on landscape maintenance in 2019, with most of those services centered around lawn care. Expectations for high-intensity maintenance are especially pronounced at cemeteries, because they are publicly accessible landscapes of great emotional resonance, segmented by private ownership.

Although ideal for a rural cemetery, Green-Wood’s glacially influenced topography is ill-suited for frequent mechanical mowing: the uneven ground is susceptible to scalping by mower blades and is further scraped by machinery navigating its steep slopes. The high-frequency mowing program causes surface disruption that leaves areas of bare soil and renders Green-Wood’s grassland vulnerable to invasive organisms. Bermudagrass (Cynodon dactylon) is among the most aggressive invaders. Concerns about unsustainable mowing practices and the rapid expansion of Bermudagrass ultimately led to a collaboration between Green-Wood and the College of Agricultural Life Sciences at Cornell University. The three-year partnership officially commenced in 2017 and has focused on developing intelligent and climate-sensitive strategies for grassland preservation and restoration.

**Intelligent Grassland Restoration**

Bermudagrass is a warm-season species found in the humid transition zone in the southern United States. It was likely introduced from eastern Africa through ship ballast and intentional planting as a pasture grass. With the reduced frequency of lethal winter temperatures, grasses and forbs more characteristic of warmer areas are now persisting farther north. The observed northern expansion of Bermudagrass has also been accelerated in urban environments by the heat island effect.

While it is unknown how Bermudagrass arrived at Green-Wood specifically, the population has flourished over the past decade and continues to increase. Bermudagrass spreads with aggressive rhizomes and above-ground stolons, producing an impenetrable monoculture that quickly covers newer, prostrate grave stones. The success of its colonization is in part due to Green-Wood’s function as an active
cemetery with more than one thousand burials each year. Cemetery staff excavate and relocate soil whenever a grave is dug, and Bermudagrass moves with soil and spreads into recently disturbed plots, outcompeting other vegetation. The aggressive nature of Bermudagrass creates two problems: its rapid growth requires more frequent mowing to sustain an aesthetic expected by Green-Wood’s lot owners and other visitors, and the dormant stage of straw-brown vegetation during the cooler months creates a poor visual aesthetic that is highly unfavorable to the majority of cemetery stakeholders.

In order to develop an intelligent grassland management system that is capable of controlling Bermudagrass at Green-Wood, the team knew that it would be essential to assess shifts in plant populations in response to maintenance. The researchers from Cornell are currently investigating the use of new agricultural technologies that can analyze satellite imagery to establish baseline Bermudagrass population levels. This technology will require on-the-ground observations to test its accuracy and will ultimately be integrated into existing mapping systems that are widely used by urban grassland managers. The researchers have also deployed microclimate sensors in three areas of the cemetery that present unique vegetative characteristics due to topography and light intensity. Together, these technologies will allow the team to differentiate plant populations, measure the level of soil disturbance, and define microclimates and soil types across Green-Wood’s landscape.

Intelligent grassland management also relies on tools from a larger toolbox, including refined methods of soil handling, weed seedbank management, and adaptive seed mixtures. The team initiated trials in 2017, which have already yielded positive results. These last two years were the wettest in recorded history, which caused the team to assess fungal disease susceptibility among varieties in the first new seed mixture. But additional mixtures, some containing native species, have established nicely within three months and are now persisting under regular disturbance with little weed competition. These findings suggest that site-specific plant selection can help to address the persistent disturbance associated with the urban environment.

To better understand grassland habitats at Green-Wood, a team of researchers from Cornell and Green-Wood have installed microclimate sensors. They also conducted soil samples with colleagues from the United States Department of Agriculture’s Natural Resource Conservation Service.
The goal is not to eliminate the presence of Bermudagrass but to find ways to realistically manage its presence, a balance which would occur in concert with restoration of the grasslands. Future seed mixtures will be designed to create ephemeral flowering regimes that support specialized pollinator species and will include grass species that thrive on reduced mowing, allowing the turf to store carbon deeper in the soil profile. Colleagues at Oklahoma State University are also conducting genetic fingerprinting of Green-Wood’s existing Bermudagrass population, in order to identify its unique traits. As part of a progressive adaptation strategy, we hope to establish Bermudagrass cultivars that would better meet the needs of urban grasslands in the future.

**Climate-Smart Mowing**

While distinctly rural in design, Green-Wood’s landscape also reflects qualities of the lawn cemeteries that came after the rural cemetery movement: flatter areas of turf bordered by trees. Lawn cemeteries prioritized turf for its assumed ease of maintenance and its neat, uniform appearance. To maintain a manicured aesthetic, however, these lawns demand either vegetation that grows slowly and moves by underground rhizomes, or a consistent, low height-of-cut mowing regimen (often a complete rotation through the landscape every seven days). At Green-Wood, depending on the rate of growth, the maintenance of this aesthetic can equal between thirty-two and thirty-five annual mows, which require over ten thousand gallons of gasoline to complete, emitting roughly two hundred thousand pounds of carbon dioxide into the atmosphere. Operational challenges that come with this level of turf maintenance are compounded by the complexity of Green-Wood’s landscape, leading to worn-out vegetation and rutted soils.

The team of researchers, along with Green-Wood staff and contracted specialists from the landscape management company BrightView, are implementing a data-driven process that is more sensitive to climate change. They initiated a study in the summer of 2019 to reduce mowing frequency by 85 percent on approximately two hundred acres, chosen for their topographical features and known levels of visitation. The team tracked equipment usage to assess actual mowing times and collected detailed observation of grassland response in terms of species richness. After three months, the acreage under the experimental reduced-mowing program was scaled back for several reasons: the disparate areas made it difficult to manage revised specifications; aesthetic concerns were voiced by staff members; and critical feedback came from cemetery stakeholders. While the general public voiced strong enthusiasm for the program, some lot owners saw the longer grass as a symbol of neglect. We learned that it is often best to implement changes like this gradually, allowing for increased community engagement throughout the process.

Nevertheless, much was gained during this first effort. The data gathered have enabled us to align mowing frequency with growth rate, thereby permitting a slight increase in cutting height, while respecting the expectations of stakeholders. These efforts will be strengthened as we continue to sow new seed mixtures in high-visititation areas, incorporating plants that require less mowing, while simultaneously increasing species richness.

**Quietly Planning to Raise Awareness**

The association between humans and grasslands is intimate and well-established: grasslands regenerate the soil for crops, sustain grazing animals, and fulfill an innate human desire to connect with the natural world. While a growing body of research is devoted to ecosystem services provided by urban grasslands, the people who most directly interact with these urban spaces are often unaware that the landscapes are, in fact, grasslands. This is more than semantics. Seeing cemeteries, public gardens, parks, sports fields, and golf courses as urban grasslands forces a paradigm shift. In this light, the grassland is not exclusively a feature of ruralness but rather one that is present in urban environments, within walking distance. This shift can help the public see that green vegetation is everywhere: in parks and gardens, on playing fields, and in cemeteries. The urban
The grassland concept unites all these patches of green and makes them part of a dynamic landscape. It encourages curiosity from a soccer player about the care and health of a ground on which she runs, and it transforms an apartment building’s backyard lawn into an opportunity to combat climate change, simply by doing less.

Raising awareness of the importance of urban grasslands like Green-Wood is a critical step toward sustainable, intelligent management. To this end, Green-Wood and Cornell are forming an Urban Grasslands Institute at Green-Wood, intended to share our findings and communicate the value of these often overlooked grasslands to a diverse urban population. The success of such an initiative is dependent on broader collaborations. The leaders of the project have invited a national group of experts from the field to consult on issues such as species selection and soil type, and will continue to look for opportunities to grow this knowledge base and expand its reach.

As socio-cultural issues evolve, the Urban Grasslands Institute at Green-Wood will share information about a combination of technologies and smarter management practices, helping homeowners and grassland managers prepare for the challenges of a rapidly changing urban climate. While not explicitly articulated, one of the underlying goals of the project is to reform the discordant, one-size-fits-all model of landscape maintenance promoted by the lawn-care industry, which has directly shaped the public’s views of acceptable turf management. We hope to present a more nuanced model that optimizes the relationship between the biological and cultural functions of a landscape.

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