EXPLORING THE IMPACTS OF LANDFILLS ON BIRD COMMUNITIES: AN OPPORTUNITY FOR GRASSLAND BIRD CONSERVATION

by

ZACHARY ARNOLD

(Under the Direction of RICHARD HALL)

ABSTRACT

Anthropogenic land use change is dramatically altering the structure and composition of wildlife communities. Landfills represent a unique environment for wildlife, simultaneously providing a massive food subsidy from human waste and often encompassing ecologically-valuable habitat types. In this thesis, I use community science data to quantify characteristics of bird communities at landfills across the United States. Landfills were found to have frequent sightings of human-adapted generalist species, including a widespread invasive species. However, landfills additionally harbored several species of habitat specialists, including declining grassland birds. Based on this finding, I compiled guidelines for landfill managers to establish and maintain bird-friendly grasslands on landfill caps. By planting native species that provide high-quality foraging and nesting habitat, and adopting bird-friendly mowing schedules, landfills can benefit birds and provide opportunities for local community engagement. The findings of this thesis suggest that landfill properties present an opportunity for conservation of grassland species.

INDEX WORDS: Community composition, Ecological restoration, Citizen science, Avian ecology, Multifunctional landscapes, Native plants

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Background and Motivation

Land-use change associated with human activity has dramatically shaped global biodiversity and has been implicated as a driver of large-scale declines in diverse taxa, including birds. In North America alone, bird populations have declined by three billion breeding individuals since 1970 (Rosenberg et al. 2019). These declines are not just observed in rare species; broad-scale losses have also been noted in common bird species, which may play disproportionately large roles in ecosystem functioning and health (Rosenberg et al. 2019). These losses are attributed to a number of anthropogenic drivers including climate change, collisions with buildings, and especially habitat loss and degradation (Loss et al. 2015; La Sorte et al. 2017). Despite these overall losses, some bird species have experienced population increases in recent years, with many bird communities shifting from habitat specialists to widespread generalists that thrive alongside humans (Clavel et al. 2010; Rosenberg et al. 2019). In order to maintain functional and taxonomic diversity of birds, and the ecosystem services they provide, it is crucial to understand how human-altered landscapes shape local and regional patterns of bird diversity, and how these landscapes can be managed to incorporate habitats supporting declining specialist species.

Human-dominated landscapes can provide birds with stable food resources intentionally (e.g. bird feeders) or unintentionally (e.g. agricultural crops; Isaksson 2018). As the commonest method of refuse disposal in the world, landfills represent a large and widespread form of food subsidy that attracts a number of birds, including dietary generalists such as vultures, crows, gulls, and non-native pest species, like (in the US) starlings and house sparrows (Belant et al. 1998; Turrin et al. 2015). Aggregations of these birds at high density has led to concerns for public health including collisions with aircraft, risk of disease spillover, and interference with landfill operations (Plaza et al. 2019; Pfeifer et al. 2020). As a result, many landfills implement population control and culling through a variety of techniques (Baxter and Allan 2006; Cook et al. 2008; Thiériot et al. 2012). At the same time, diverse habitat types contained within landfill properties may attract a wide range of species that do not forage on refuse and thus do not pose threats to health and safety. Landfill properties often contain constructed grasslands (Hauser et al. 2001) and wetlands (Brown 1994) which have the potential to harbor habitat-specialists that are locally rare in urbanized landscapes. To date, the majority of studies on birds at landfills have focused on the 'nuisance' trash-foraging species, and little is known about the overall impacts of these novel habitats on bird communities (Plaza and Lambertucci 2017).

As humans increasingly modify landscapes globally, adaptive management strategies that give landscapes multiple functions are more important in the conservation of biodiversity than ever before (Lovell and Johnston 2009). For example, intensive agriculture is necessary to maintain global human populations, but by incorporating principles of ecology, multifunctional farms can be designed to serve economic, social, and environmental functions (Lovell and Johnston 2009). One study that removed cropland at farm field edges to create wildlife habitat found that despite their reduced size, these fields were equally as productive as farms that had not lost their edges, likely due to greater pollinator diversity and abundance in the edge habitat (Pywell et al. 2015). While landfills are a necessary part of waste disposal, the US Environmental Protection Agency has recently pushed for sites to seek post-closure uses that turn capped landfills into community assets (ORD 2014). Given the technical limitations of building directly on landfills and the need to prevent deep-rooting tree species from colonizing and damaging the integrity of the cap, seeding capped landfills with grasses and periodically mowing is a popular and practical solution used by landfill managers (OSRTI 2006). By choosing native grassland species and adopting mowing practices that minimize impacts on breeding and wintering birds, management of landfill grasslands for bird habitat could support some of the most rapidly declining bird species in the US, thus playing a role in the conservation of biodiversity, while simultaneously meeting the needs of landfill managers (Rahman et al. 2011)

There are several precedents of both active and closed landfills providing benefits to wildlife and the general public. Fresh Kills Landfill in New York was the largest landfill in the world and now houses debris from the Twin Towers (Melosi 2006). In 2006, a 30-year plan was devised to turn the area into the largest urban park in New York, consisting of reclaimed wetlands, constructed grasslands, and recreational facilities (Melosi 2006). While not yet completed, parts of the park are open to the public and at least 202 bird species have been reported there (eBird 2021). Other sites have opportunities to embrace multifunctionality at a smaller scale while still operational. In Georgia, The Athens-Clarke County landfill established a bird watching trail, holds an annual vulture festival to educate the public, and built an outdoor classroom to host school-children (ACC undated). This nature-based recreation could shape long-term plans for the site's future use. In spite of the potential benefits of ecological restoration at landfills for people and wildlife, landfill managers often lack resources to create and maintain wildlife habitats in active and closed landfills.

Project Objectives

There are two overarching goals of this thesis. The first is to quantify characteristics of bird communities at landfills at a continental scale, and the second is to provide guidelines for landfill managers to create and manage bird-friendly grassland habitat in the southeastern United States.

In Chapter 2, I used publicly accessible citizen science (otherwise known as community science and henceforth referred to as CS) data from birdwatchers to characterize bird community composition at landfills spanning the continental US. I hypothesized that if landfills are dominated by human-adapted generalist species, then they would have lower species richness and higher species similarity across space (i.e. exhibit biotic homogenization) than nearby reference sites. Additionally, if most birds are attracted to landfills to forage on human refuse, birds feeding at higher trophic levels and with generalist diets should be more commonly encountered at landfills relative to the background (county-level) species pools. Alternatively, if natural habitats within landfill properties are attracting birds, I predicted that landfills would have similar patterns of species richness and community turnover as reference sites. Further, if landfills are attracting species specialized to habitats that are scarce in human-modified landscapes (e.g. grasslands and wetlands), I expect to see higher representation of these species when compared to surrounding areas.

In Chapter 3, I developed a guide to creating bird-friendly grassland habitat on capped landfill sites, for use by landfill managers and county planners in the southeastern US. This guide includes a decision tree for implementing and maintaining grassland habitats, a list of recommended plantings and the wildlife they support, bird-friendly mowing guidelines, and ideas for engaging local communities in restoration. I consulted with local stakeholders including the director of Athens-Clarke County Solid Waste Department and the conservation coordinator at the State Botanical Garden of Georgia. Combining their expertise with the scientific and technical literature, I suggest ways in which capped landfills can play a role in the conservation of biodiversity while simultaneously meeting management needs and benefiting the public.

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CHAPTER 2

NOT JUST TRASH BIRDS: QUANTIFYING AVIAN DIVERSITY AT LANDFILLS USING COMMUNITY SCIENCE DATA[1]

[1] Arnold, Z.J., Wenger, S.J., & Hall, R.J. Submitted to *PLOS One,* 11/03/2020

Abstract

Landfills provide seasonally reliable food resources to many species of wildlife, including those perceived to be pest or invasive species. However, landfills often contain multiple habitat types that could attract diverse wildlife, including species of conservation concern. To date, little is known about the characteristics and composition of wildlife communities at landfills relative to local and regional pools.

Here we used the community science database eBird to extract avian species occurrence data at landfills across the US. We compared species richness and community similarity across space in comparison to similarly-sampled reference sites, and further quantified taxonomic and dietary traits of bird communities at landfills.

While landfills harbored marginally lower species richness than reference sites (respective medians of 144 vs 160), landfill community composition, and its turnover across space, were similar to reference sites. Consistent with active waste disposal areas attracting wildlife, species feeding at higher trophic levels, especially gulls, were more frequently observed at landfills than reference sites. However, habitat specialists including two declining grassland species and migratory waterfowl, were more frequently encountered at landfills than reference sites.

Together, these results suggest that landfills harbor comparable avian diversity to neighboring sites, and that habitats contained within landfill sites can support species of conservation concern. As covered landfills are rarely developed or forested, management of wetlands and grasslands at these sites represents an opportunity for conservation.

Introduction

Land use change associated with human activity has dramatically shaped global biodiversity, and has been implicated as a driver of large-scale declines in birds (Betts et al. 2019; Rosenberg et al. 2019). Some human-modified habitats, including farmland, urban parks and backyards, attract wildlife by providing food subsidies or mimicking or preserving fragments of natural habitats, potentially mitigating these declines. However, these habitats may also support predominantly human-adapted generalist or invasive species, contributing to biotic homogenization of landscapes (Devictor et al. 2007; Sol et al. 2017). Nevertheless, as human populations continue to grow and natural land cover declines, human-dominated landscapes are emerging as an important element in biodiversity conservation (Shwartz et al. 2014).

Landfills remain the commonest method for disposing of human waste, and attract a variety of wildlife (Plaza and Lambertucci 2017). The availability of large quantities of seasonally reliable food provided by landfills can dramatically alter wildlife ecology, with consequences for their populations and health. These food subsidies can compensate for reductions in natural food availability and are thought to contribute to global increases in gull populations in spite of crashes in natural marine-derived prey (Duhem et al. 2007; Ackerman et al. 2018) and support imperiled species such as the endangered Greater Adjutant Stork, *Leptoptilos dubius*, in India (Singha et al. 2002). Landfills can also influence the distribution and movement of wildlife across landscapes; many European White Storks, *Ciconia ciconia,* have abandoned their seasonal migrations to Africa and instead overwinter at Spanish landfills (Gilbert et al. 2016). Landfill sites have been suggested to negatively influence biodiversity, directly through exposure to contaminants and pathogens (Plaza and Lambertucci 2017), and indirectly by supporting human-adapted and exotic invasive species that outcompete specialist, range-restricted and native species (Belant et al. 1998; Turrin et al. 2015).

Aside from the active areas of trash disposal, landfills can also contain habitats that could support species which do not directly utilize refuse (Fig 2.1). Landfills provide natural or restored habitats, including constructed wetlands (Brown 1994) and grasslands (Hauser et al. 2001) that are scarce in urbanized landscapes and have the potential to harbor declining and specialist species. Moreover, remnants of historical habitat can be found on the periphery of landfill sites. After landfills are completed and covered, restrictions on subsequent land use provide potential opportunities for restoration and conservation, including parks, hiking trails, and nature preserves (Weng et al. 2015; Melosi 2016). Studies that have looked at birds using landfills have primarily focused on cosmopolitan and those perceived as nuisance species (Slate et al. 2000; Singha et al. 2002; Duhem et al. 2007; Gilbert et al. 2016; Ackerman et al. 2018), and thus the overall effects of landfills on wildlife community composition are not well understood.

Birds are an excellent taxon to explore patterns of diversity, because they are widespread, visible, and increasingly, large numbers of birdwatchers use community science (also known as citizen science or volunteer-led science, henceforth referred to as CS) databases such as eBird (Sullivan et al. 2009) to document their observations. In particular, birdwatchers frequently visit landfills in an attempt to locate unusual species attracted to active landfills, such as out-of-range gulls and crows, as well as migratory waterfowl, shorebirds, and grassland birds that use the mosaic of habitat types present (Schaffner 2009). Here we describe patterns of taxonomic and trait diversity of birds reported by birdwatchers at frequently visited landfills across the US, in comparison to nearby reference sites and county-level species pools. We predicted that if landfills were dominated by widespread, generalist, human-adapted species, we would see: (i) lower species richness at landfills than at reference sites; (ii) altered community composition at landfills; (iii) higher species similarity, and lower turnover across space, among pairs of landfills compared with pairs of reference sites; (iv) more records of omnivorous species with generalist diets at landfills, relative to their observed frequency in background species pools. Alternatively, if landfills also support a diverse community of native species, we would expect similar patterns of species richness, community composition and turnover between landfills and reference sites, and representation of habitat-specialized species (i.e. grassland and wetland birds).

Materials and methods

Community science data and study site selection

The eBird database, managed by the Cornell Lab of Ornithology, is the largest CS database of bird observations worldwide, and allows birdwatchers to document the species richness, and species abundance of birds seen at a given location, on a given date (Adams 2020). Summary data from over 100 million annual bird observations, vetted by volunteer reviewers to query unusual observations, are freely available to the public (Adams 2020). eBird data have been used to study species range expansion (Clark 2017), to model population changes of migratory species (Walker and Taylor 2017), and to explore phenological shifts in migration (Mayor et al. 2017).

In this study we collected eBird data on the encounter frequency of species from frequently-visited landfills across the US, nearby similarly sampled reference sites in the same county, and county species pools. Checklist data in eBird is summarized into histograms, which show the percentage of complete checklists (i.e. those for which observers indicated that they recorded all the birds they saw) that each species appears on for a given time-step. Species recorded on incomplete checklists have their encounter frequency downweighted so that they do not overly influence their relative abundance in the dataset. Multiannual data is binned into 48 time-steps (four per month) spanning the calendar year. Although checklist-level data including the original observer's species level-counts are available on request, we chose to work with encounter frequency data to avoid biases related to inaccurate counts and incomplete checklists Gyekis et al. 2019).

We identified landfills by searching for the word "landfill" in eBird's "explore hotspots" feature (a hotspot is defined as a publicly viewable site that is visited by many birders). Assuming that landfills with a larger number of submitted checklists would more accurately reflect the true species richness of a site, we excluded landfills with less than 100 total checklists (Callaghan et al. 2017). While many landfill sites have both active sites and covered portions, we wanted to focus this study on landfills with at least one active site, so we also excluded sites labeled "(covered)" on eBird. To maintain a representative sample of species across the annual cycle and include migratory species, we further excluded sites at which data was missing for more than 15 time-steps across the calendar year, and at which data was missing for more than three consecutive time steps. Additionally, we excluded sites labeled "restricted-access" to avoid sampling bias. Finally, we excluded large hotspots that were amalgamations comprised of many smaller sites. For example, South Padre Island consists of 22 specific hotspots and one broad hotspot (South Padre Island (LTC 034)) that represents the entire island. In this case, South Padre Island (LTC 034) would be excluded. These criteria, resulted in a total of 19 landfills being included in the analysis. In order to do a pairwise comparison, reference sites were chosen within the same counties as each landfill by selecting the county hotspot with the most similar number of total checklists submitted, and meeting the additional criteria for public access and data across seasons. To compare landfill communities to the surrounding species pool, we also downloaded county-level data on the seasonal encounter frequency of species. Analyses included all data up to December 2019. Before analysis the data was cleaned to remove hybrid or non-species level taxa.

We assigned dietary trait data to each species using EltonTraits, a database published in 2014 that contains species-level attributes of 9993 extant bird species (Wilman et al. 2014). Each species was assigned to one of five diet classes: “Omnivore,” “VertFishScav,” “Invertebrate,” “PlantSeed,” and “FruiNect.” Omnivore species were defined as those that consume food from the four other categories, with no category making up 50% or more of their diet (Wilman et al. 2014). Populations that were recently split into separate species were assigned the diet class of their previous species name. For example, the Sage Sparrow, *Amphispiza belli*, was recently separated into two distinct species, the Sagebrush Sparrow, *Artemisiospiza nevadensis*, and the Bell’s Sparrow, *Artemisiospiza belli*, and as a result, both species were assigned the diet class given to the Sage Sparrow in EltonTraits.

We first conducted our analyses using the full list of species recorded at each site, and secondly with a restricted list of the most commonly encountered species, which we defined as species with an encounter frequency greater than 5%. The first analysis ensures that migratory and rare or hard-to-detect species are represented in the dataset, whereas the second ensures exclusion of species recorded by chance (e.g. flyovers) that are not ‘using’ the site. We present results using the first method (i.e. all species included), and only discuss the second (common species only) when patterns differed between the two.

Data analysis

All analyses were performed in the R programming language (R Core Team 2019).

To test our prediction that species richness at landfills differed from reference sites, we calculated the total species richness at each landfill and its paired reference site. Because these are count (discrete) data, the standard regression assumption of normality of residuals cannot be met. Therefore, we performed a paired Wilcoxon rank test for differences in species richness between our site types.

To assess our second prediction that landfills have different avian community composition, we calculated site-specific species-level encounter frequencies (i.e. the number of checklists for a given site in which a species was recorded, divided by the number of complete checklists submitted for that site). We treated landfills and reference sites as separate communities, and performed a non-metric multidimensional scaling (NMDS) analysis, using ANOSIM to test for differences, in the *vegan* package (Oksanen et al. 2019). To assess taxonomic-based differences in community composition, we conducted an indicator species analysis using the *indicspecies* package in R (De Caceres et al. 2010). This identified species that occurred more frequently at landfills than expected, relative to paired reference sites.

To test our third prediction that landfills share more species across space than do reference sites, we calculated pairwise species similarity between pairs of landfills and pairs of reference sites, using Jaccard's Index (JI):

$$JI = \frac{Shared\ Species}{Shared\ Species + Unshared\ Species}$$

We calculated JI for all pairwise combinations of landfills (and reference sites) and plotted the relationship between JI and inter-site distance (McKinney 2006). If landfills are dominated by widespread generalist species, we expected to see higher values of JI for landfill pairs than for reference site pairs, and for the slope of the relationship between JI and inter-site distance to be shallower for landfills than for reference sites (i.e. lower species turnover across increasing geographic distances).

To test our fourth prediction that dietary generalists and species feeding at higher trophic levels are overrepresented at landfills when compared to county-level species pools, we calculated the prevalence of each dietary group by summing the site-level encounter frequencies for all species within the 5 dietary categories defined in EltonTraits. We calculated the same quantities using the county-level data, and assessed differences in the frequencies of each dietary type using a chi-squared test.

Results

Summary data and selected sites

We identified 19 landfills and 19 paired reference sites that met our criteria (Fig 2.2). The dataset included data from 7,277 checklists for landfills and 7,165 from paired reference sites; the number of checklists per site varied from 103 (Fountain Avenue Landfill in Kings County, New York) to 1225 (Cameron Co. landfill, Texas). A complete list of landfills, reference sites, and the number of checklists per site can be found in Appendix A. The mean distance between paired landfill and reference sites was 18.2 km (min = 1.4 km, max = 40.0 km).

Species richness, community composition, and turnover

Landfills had a median species richness of 144 species (min: 84, max: 214), while their paired reference sites had a median of 160 (min: 82, max: 225) (Fig 2.3A). A paired Wilcoxon test revealed a small but significant difference between these two medians ($P = 0.023$, $V = 38.0$). An ANOSIM test revealed a significant difference in community structure between landfills and reference sites (P = 0.0016) (Fig 2.3B). However, the magnitude of this difference is small (R = 0.143).

Species similarity, measured by JI, showed a decreasing but saturating relationship with inter-site distance for both paired landfill sites and reference sites (Fig 2.3C) For landfills, the overall median JI was 0.405 (min: 0.1418, max: 0.6991) while the same metric was 0.400 (min: 0.1516, max: 0.8401) for reference sites. Our 19 sites generated 171 pairwise comparisons for each site type; due to lack of independence (pseudoreplication) among these pairwise comparisons, we did not conduct formal statistical analyses. However, we found no evidence that species similarity between landfill pairs was higher or decayed more slowly with inter-site distance than between reference site pairs

Taxonomic and trait diversity

The indicator species analysis revealed that thirteen species were encountered significantly ($P < 0.05$) more frequently at landfills than reference sites (Table 2.1). Of these, six species were gulls, one (European Starling, *Sturnus vulgaris*) is a widespread invasive species, three are migratory waterfowl and three are grassland birds. Notably, Ross's Goose (*Chen rossi*) and Slaty-backed Gull (*Larus schistisagus*) were seen very infrequently at landfills (respective encounter frequencies of 0.44% and 0.50%). However, they were seen even less at reference sites, resulting in significant differences (respective encounter frequencies of 0.13% and 0% respectively).

The relative frequency of dietary types showed no significant difference between landfills and their representative counties when all species were included (P = 0.121, $X^2 = 7.303$) (Appendix B). However, when the analysis was limited to the most common species (i.e. those appearing on at least 5% of checklists), the diet classes at landfills did not represent a random sub-set of the county-level species pool ($P = 0.049$, $X^2 = 9.52$) (Fig 2.4). This difference is driven by the overrepresentation of carnivores (i.e. the "VertFishScav" diet class), accounting for 25.4% of species encountered at landfills, compared to 15.3% of the background species pool, and the underrepresentation of granviores ("PlantSeed" diet class), which represented 20.0% of species at the landfill level compared to 25.8% for the county. Additionally, there were more insectivores ("Invertebrate" diet class) recorded at the county level, 27.9% of species, compared to 23.5% at the landfill level.

Discussion

Active landfills are attractive to many species of wildlife, including those perceived to be pest species, but additional habitat types contained within landfills may attract a wide-range of other species. Our goal was to quantify avian diversity at landfills relative to nearby reference sites and their county-level species pools, predicting that if landfills were primarily attractive due to resource subsidies at active trash disposal sites, landfills would be less speciose, dominated by dietary generalists and widespread human-adapted species. However, we found only partial support for these predictions: median species richness was slightly lower (by 16 species) at landfills than reference sites, and there was no evidence for differences in species turnover across space between site types. Although differences in community composition indicated that carnivores and scavengers, especially gulls, are overrepresented at landfills relative to reference communities, our indicator species analysis also revealed that some habitat specialists (waterfowl and grassland birds) were also more likely to be encountered at landfills. Together, these suggest that landfills have the potential to harbor comparable avian diversity to the surrounding landscape even after refuse disposal sites are covered.

Matching past research, we found evidence that trash disposal sites attract scavenging and human-adapted dietary generalists, including gulls and invasive European starlings (Washburn 2012; Ackerman et al. 2018). Increased abundance of human-adapted species found at landfills has led to a variety of public health and safety concerns, including bird-aircraft collisions (Burger 2001; Sodhi 2002), increased disease risk (Ortiz & Smith 1994; Plaza et al. 2018), and general nuisances. Consequently, much of the bird-landfill literature has focused on population control and culling measures (Baxter and Allan 2006; Cook et al. 2008; Thiériot et al. 2012), leaving questions about diversity and community composition relatively unaddressed.

We also found evidence that habitats contained within landfills, such as constructed wetlands, and grassland habitats, are attracting associated habitat specialists. While we did not perform any direct evaluation of habitat diversity of landfills compared to reference sites, our findings are consistent with past studies that have shown a positive correlation between habitat diversity and bird species richness in human-modified urban parks (Chaiyarat et al. 2019). Of particular note, two declining grassland species (Eastern Meadowlark and Savannah Sparrow) were more likely to be encountered at landfills than nearby reference (Pardieck et al. 2018). This is likely due to the creation and maintenance of grassland habitat on covered portions of landfills. When landfills are covered, grasses are often grown on top of an earthen cap to minimize erosion and infiltration of water (Hauser et al. 2001). These areas are regularly mowed to prevent the growth of deep-rooting species, which are believed to be able to pierce the containment system (OSRTI 2006). Additionally, migratory waterfowl, including Ruddy Duck and Northern Shoveler, were encountered more frequently at landfills than at reference sites. These birds are likely attracted to the constructed wetlands at landfills which are designed to limit widespread environmental impact of leachate (Brown et al. 2000).

These analyses highlight the potential for landfill sites to provide conservation value. With over 2,600 landfills in the US, each averaging 94 acres, there is a significant area of land tied up in waste management (Landfill-level data… 2020). After landfills are completed and covered, end uses are limited. However, completed landfills have been converted into a host of different assets including parks, hiking trails, and wildlife habitats (Simmons 1999; Klenosky et al. 2017). Rahman and colleagues specifically suggest capped landfills could provide conservation value to grassland bird species (2011). Recent land-use change has led to significant declines in suitable grassland habitats across the US (Hoekstra et al. 2004). Restored grasslands at landfill sites potentially offer opportunity for conservationists to work collaboratively with landfill managers. By planting native grasses, mowing outside of nesting season, and alternating mowing years, landfill managers can help provide habitat to species that have suffered drastic habitat losses and population declines. While concerns exist surrounding the bioaccumulation of toxic materials from constructed wetlands (Boucher at al. 2010), there is also opportunity for properly designed wetlands to benefit migratory waterfowl populations (Davis et al. 2008).

This study provides one of the first multi-species analyses of landfill use by birds at a continental level. However, we note several limitations and biases related to site selection and CS data collection that should be considered in the interpretation of our results. First, mirroring past CS studies (Kelling et al. 2015), the location of landfill sites meeting our minimum checklist number criterion was highly spatially biased towards areas of high human population density. Fifteen of our nineteen landfills were east of the Mississippi River, and the majority of those sites were located in the northeastern US. Second, due to a lack of information on the exact geographic size and habitat composition of eBird hotspots, landfill and reference sites were matched only by proximity and sampling efforts. Since geographic area is a known predictor of species richness (Chamberlain et al. 2007), it is possible that our results could be biased if reference sites were systematically different in area to landfills. Similarly, reference sites were assumed to represent more "typical" wildlife habitats at the county level than landfills, although we were unable to test this explicitly. Finally, the potential for inconsistent counting associated with untrained community scientists led us to work with encounter frequencies, but it is still possible that highly-visible, large-bodied birds such as gulls and vultures may be inherently more detectable than secretive grassland or woodland species. As the amount of data submitted to eBird increases, future studies could expand this analysis to include additional landfills in underrepresented regions, along with more standardized surveys of paired landfills and reference sites accounting for size and habitat types.

Our findings suggest the need for further investigation of bird communities at landfills in habitats other than active trash disposal sites. In particular, extensive grassland areas at covered landfills may have potential to support declining grassland birds if planted with appropriate seed mixes and subject mowing schedules that avoid the breeding season. Considering that many landfills have restricted areas not available to community scientists, targeted surveys carried out by researchers would provide insight on these under-studied habitats. Additionally, surveys of other taxa, including plants, amphibians, and reptiles are needed to quantify the biodiversity value of landfills more generally, and to inform conservation-based management practices at active and covered landfills.

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Table 2.1: The results of an indicator species analysis which reveals species that are encountered significantly more frequently at landfills than at reference sites. Species are described as either generalists (red), grassland specialists (green), or waterfowl (blue). The R statistic measures the magnitude of the difference between encounter frequency at landfills and reference sites. * widespread invasive species

Species	Group	Encounter Frequency	
		Landfill	Reference Site
Herring Gull	Generalist	44.44	14.33
Ring-billed Gull	Generalist	46.47	22.32
Iceland Gull	Generalist	12.49	2.24
Lesser Black-backed Gull	Generalist	10.30	0.95
European Starling*	Generalist	53.50	34.51
Glaucous Gull	Generalist	10.05	0.46
Savannah Sparrow	Grassland Specialist	12.46	5.85
Ross's Goose	Waterfowl	0.44	0.13
Eastern Meadowlark	Grassland Specialist	13.53	3.25
Northern Shoveler	Waterfowl	8.60	4.41
American Pipit	Grassland Specialist	4.13	2.14
Ruddy Duck	Waterfowl	8.37	3.22
Slaty-backed Gull	Generalist	0.50	0.00

Figure 2.1: The variety of habitats at landfills and the birds that use them. Satellite image of Athens-Clarke Co. Landfill in Georgia, USA, depicting the various habitat types available at many landfills, including species that use each habitat. (A) Red-bellied woodpecker, *Melanerpes carolinus*; (B) Eastern meadowlark, *Sturnella magna*; (C) Wood duck, *Aix sponsa*; (D) Turkey vulture, *Cathartes aura*.

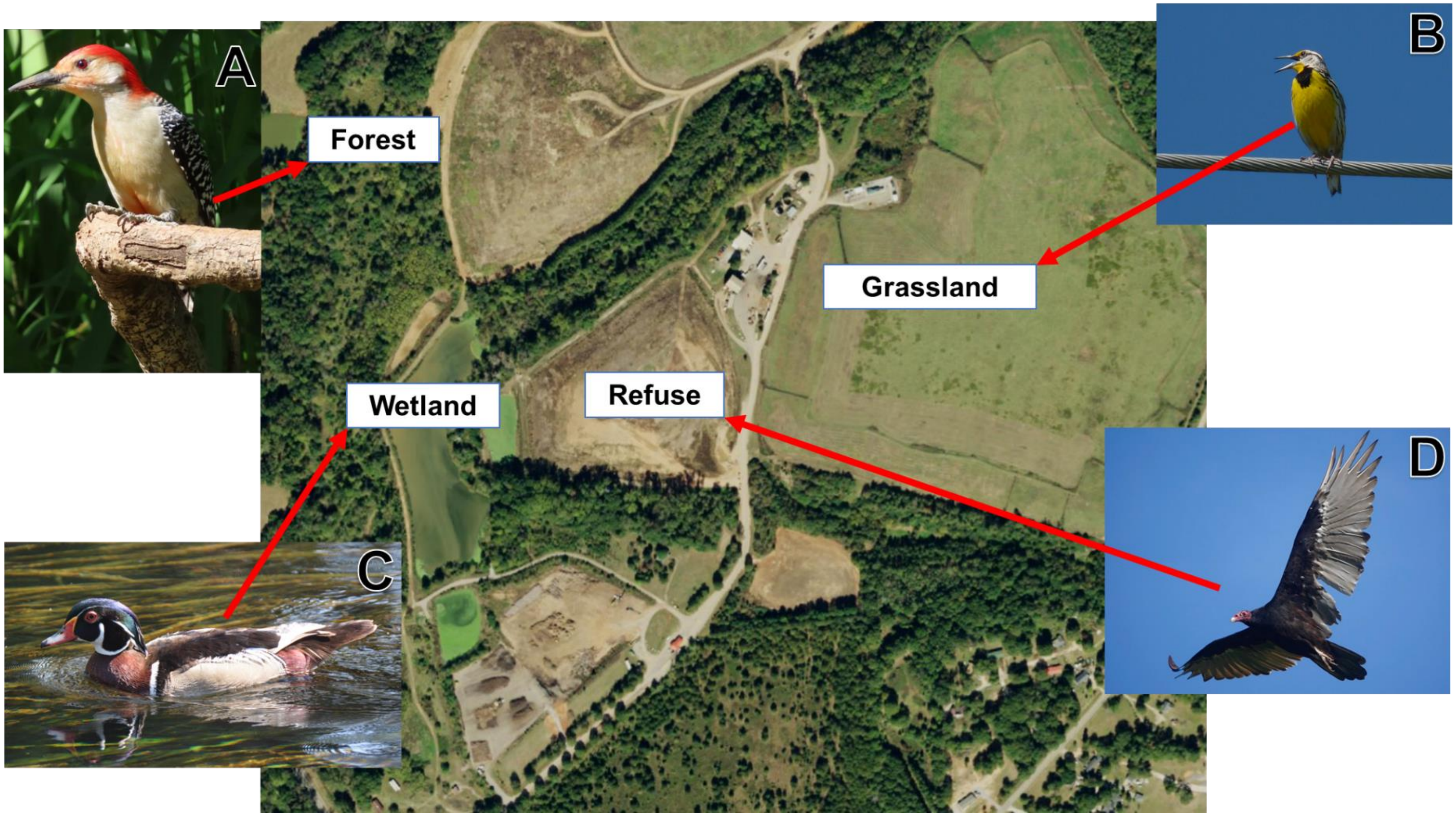


Figure 2.2: Map of sites selected for analysis. The geographic distribution of landfills included in the analysis. Dot color represents the total number of bird species recorded by birdwatchers in the eBird database for each landfill.

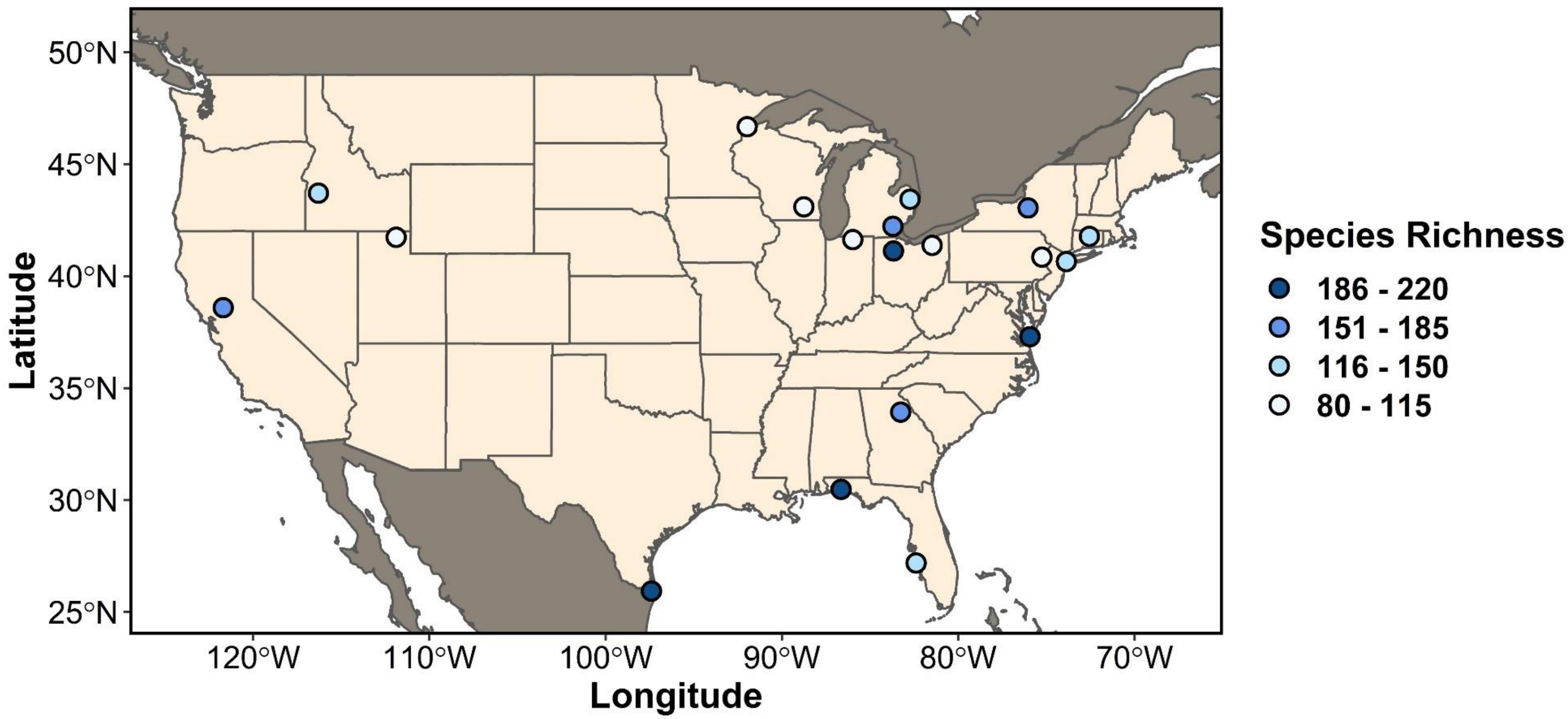


Figure 2.3: Comparison of species richness, community composition, and species turnover. Species richness and community comparison for landfills (green circles) and reference sites (orange triangles). Paired sites are connected by lines. (A) Box plot showing the distributions of species richness at selected landfills and reference sites. Horizontal lines and shaded box limits represent the median and interquartile range of species richness. (B) NMDS plot comparing communities, using species encounter frequencies. Using Jaccard's distance, 20 runs, and three dimensions, an acceptable stress value of 0.0773 was achieved. (C) Changes in community similarity (measured by Jaccard's Index) between pairs of landfills and pairs reference sites, plotted as a function of inter-site distances. Lines represent a spline fit using the geom_smooth function and 'loess' method in ggplot.

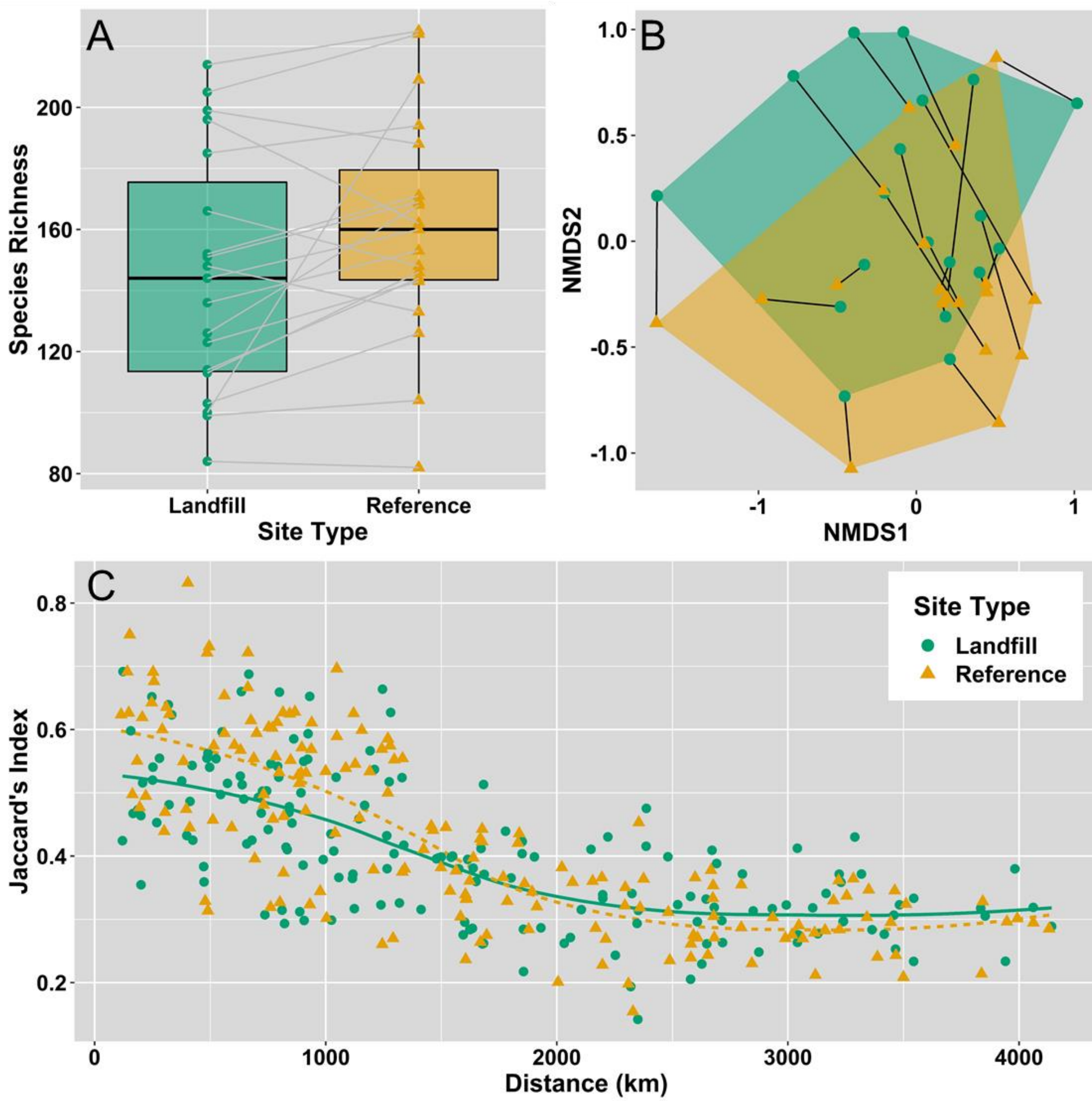
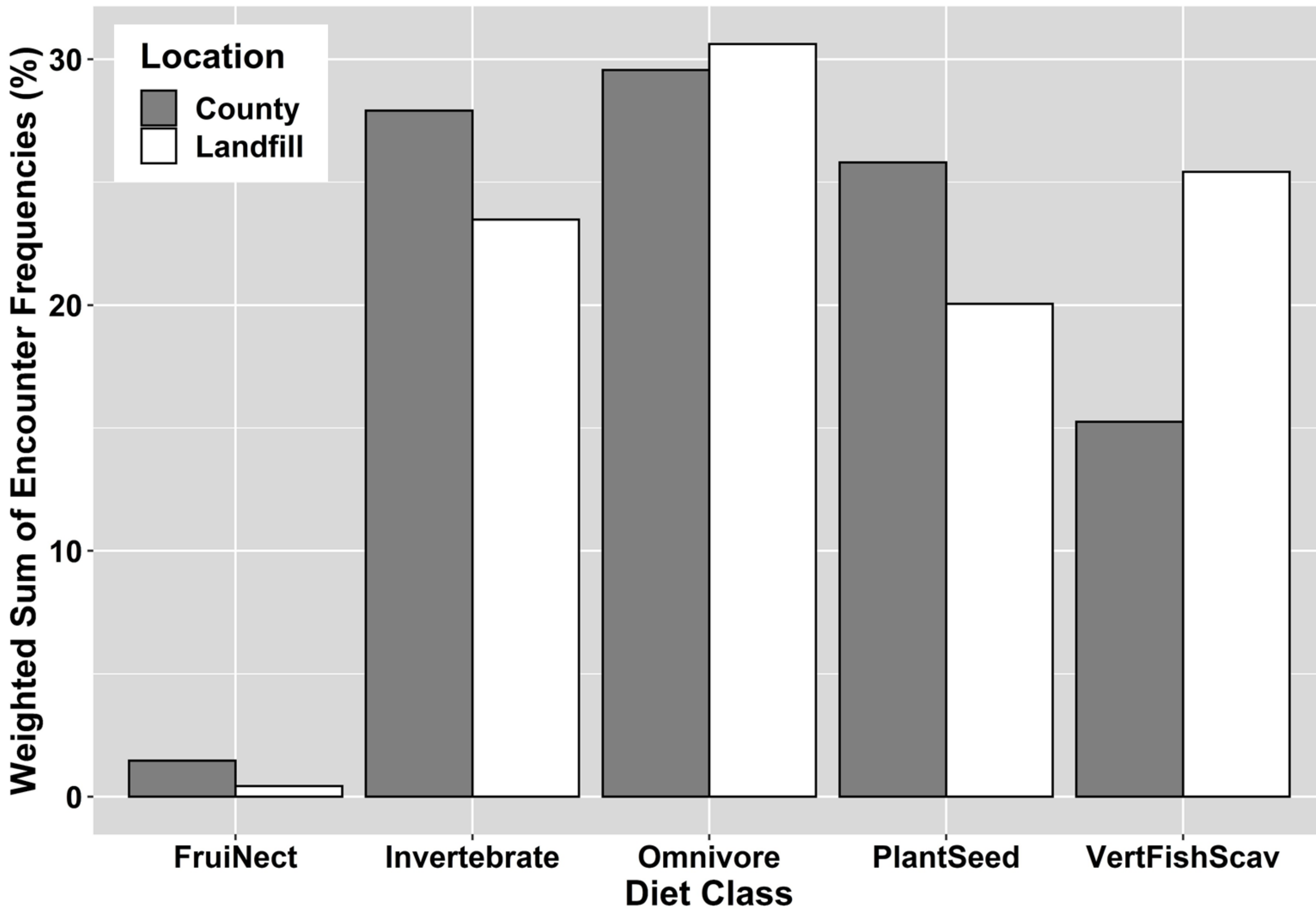


Fig 2.4. Comparison of the common species' encounter frequencies for EltonTraits diet classes. Frequency of the most common species' diet classes at landfills (white) compared to background county-level species pools (grey). All species with an average encounter frequency greater than 5% were included.



CHAPTER 3

ESTABLISHING BIRD-FRIENDLY GRASSLAND HABITATS AT LANDFILLS IN THE SOUTHEASTERN UNITED STATES[2]

[2] Arnold, Z.J., Ceska, J.F., & Hall, R.J. To be submitted to *Waste Management*

Executive Summary

- Natural habitats found at landfills host a surprising diversity of birds, presenting opportunities for conservation. As landfills are completed and closed, grasses are often planted on the cap and regularly mowed to prevent the establishment of deep rooting species. These grasses protect the landfill cap from erosion, but also have the potential to support declining grassland bird species.
- This report provides practical guidelines for the establishment and maintenance of grassland habitat at landfills in the southeastern United States, including landfills yet to be built, those that are currently operational, and landfills that have already been capped and covered.
- Native grasses and flowering plants require less maintenance after establishment, enhance the aesthetic appeal of capped landfills, and provide high quality habitat for birds, pollinators and other beneficial wildlife. Thus, they are ideal candidates for landfill covering systems.
- We provide a list of plant choices suitable for a variety of locations with in a landfill site, and additional resources for where to acquire these plants. To address concerns about plant root depth on landfill caps, we focus on species that will not damage the covering system, but still provide benefits to local wildlife. We also suggest additional wildlife-friendly plant species that may not be suited for planting on a landfill cap, but can be planted on the periphery of landfill properties.
- After establishment, a rotational mowing schedule reduces time demands of mowing on landfill staff and ensures habitat is available to provide nesting sites in the summer and as a food source for migrating and wintering bird species.

- Involving local communities in managing and monitoring restored grassland areas at landfills has the potential to benefit both landfill managers and community members. Community volunteers can reduce maintenance demands on landfill staff, and enjoy health and well-being benefits from access to greenspace.
- Historically, grasslands were an important component of southeastern US landscapes, supporting a diversity of wildlife and benefiting people by supporting pollinators necessary for sustained crop yields, storing carbon, and minimizing soil erosion. Despite these benefits, grasslands have been lost to land conversion for agriculture, forestry and urban development. Restoring grasslands at landfills can therefore play an important role in bringing back imperiled grassland birds and providing benefits to surrounding human communities through ecosystem services and nature-based recreation.

Background

Bird diversity at landfills

Landfills are the most common method for waste disposal and have the potential to alter local wildlife communities (Plaza and Lambertucci 2017). Refuse at landfills attracts a variety of wildlife species that feed on discarded human food, including birds such as vultures, gulls and crows. Because aggregation of birds at refuse can lead to aviation risks (Burger 2001; Sodhi 2002), interference with daily operations, and increased exposure to contaminants and infectious diseases (Ortiz and Smith 1994; Plaza et al. 2019), most management related to birds at landfills has focused on techniques to deter bird visitation (Baxter and Allan 2006; Cook et al. 2008; Thiériot et al. 2012). However, landfill sites often contain a variety of natural habitats, including grasslands (Hauser et al. 2001) and wetlands (Brown 1994), which support diverse bird species. For example, birdwatchers have recorded 168 bird species at the Athens-Clarke Co. landfill in north Georgia (eBird 2021), including woodland, grassland and wetland specialists in addition to species attracted to refuse. A recent study of bird communities at United States landfills found that several species of conservation concern are more frequently encountered at landfills than nearby reference sites (Arnold et al. in revision). By preserving parcels of natural habitats in urbanized landscapes, landfills have the potential to contribute to bird conservation.

One group of birds that particularly stand to benefit from conservation-oriented management at landfills is grassland birds (Rahman 2011). Grassland birds are one of the most imperiled groups of animals on the continent (Knopf 1994); 74% of grassland species have declined since 1970, representing a loss of over 700 million individuals (Rosenberg et al. 2019). These declines are linked to pesticide use, the timing of mowing/harvesting, and direct conversion of natural grasslands into agricultural fields, woodland or residential and commercial development (Stanton et al. 2018; Askins et al. 2007; Vickery et al. 1999). At landfills, many of these threats are absent, or subject to fewer constraints (e.g. the timing and frequency of mowing), and given the limitations on land-use post-closure, there remains potential for landfill grasslands to provide habitat for birds far into the future, Moreover, grassland birds are typically smaller-bodied and less likely to form dense aggregations than the species attracted to active refuse disposal sites, and thus pose no threats to regular landfill operations or public health.

The importance of grassland habitats for birds and people

When people think of grasslands, their minds typically are drawn to the rolling prairies of the Great Plains or the open savannas on the African continent, not the southeastern US. However, grasslands were historically a common habitat in disturbance-dependent southeastern ecosystems. Many of these grasslands were likely small in size (less than 40 km across) and were scattered throughout the landscape contributing to a diverse mosaic of forest, prairies, and wetlands (Barden 1997).

Southeastern grasslands are highly diverse ecosystems containing hundreds of species of grasses, wildflowers, sedges, and shrubs, many of which are found nowhere else in the world (Davis Jr. et al. 2002). These grasslands provide nesting habitat for breeding birds, food and cover for seed-eating resident and overwintering species, and are crucial refueling sites for migratory species as they move from their wintering grounds in South America to their breeding ranges in more northern sites (Fig. 3.1). Southeastern prairies are home to a variety of insects and small mammals which support predators such as barn owls.

Grasslands provide humans with a number of benefits, otherwise known as ecosystem services. Grasslands support flowering plants that provide nectar and larval food resources for pollinating insects, on which 35% of global crop yields depend (Klein et al. 2007). Additionally, grasslands are effective at sequestering carbon, helping to reduce the impacts of climate change (Zhao et al. 2020). Of particular interest to landfill managers, grasses stabilize topsoil and reduce the risk of erosion by wind and water (Zhao et al. 2020). Furthermore, grassland vegetation reduces surface runoff, thus minimizing the potential for leachate penetrating landfill caps (EPA 2021).

Despite their many benefits, grasslands are imperiled globally. The southeastern United States has lost an estimated 99% of its historical prairies (SGI Undated a). Grassland vegetation is highly dependent on disturbance, historically relying on fire and grazing to prevent the establishment of woody vegetation (Brawn et al. 2001). Since European settlement, grasslands have been threatened by fire suppression and loss of native megafauna, as well as land conversion and encroachment of invasive species (Wilsey et al. 2019). The single biggest threat to grasslands is conversion to agricultural fields; while superficially similar, agricultural fields may be unsuitable for birds due to mowing coinciding with bird breeding, and use of insecticides that reduce food availability (Vickery et al. 1999).

After suffering years of decline, the importance of southeastern grasslands is being recognized. Groups like the Southeastern Grasslands Initiative (SGI) are helping to protect, establish, and restore southern prairies (SGI Undated a). A list of organizations working to conserve grasslands in the southeast is provided in Appendix C.1. In Athens, GA, Georgia Power, the Wildlife Conservation Society, and SGI partnered to restore a grassland under an electrical line right-of-way (Fig 3.2B). While the restoration is still underway, an increase in insect and bird diversity has been noted in just a few years since the initial intervention (Ceska 2019). The Athens example is just one of many grassland restorations underway in human-modified habitats like roadsides and powerline cuts (SGI Undated b). Despite their size, these small plots of native grassland vegetation, often called pocket prairies, have increased local biodiversity, suggesting that even small capped landfills can have conservation value (Turo and Gardiner 2019). Restored landfill grasslands are particularly valuable in areas with little remaining grassland habitat (Rahman et al. 2011).

The benefits to revegetating landfills for landfill managers and the public

In addition to benefits for wildlife, revegetating landfills can help achieve closure and capping goals of landfill managers. Because plant roots stabilize and prevent water-logging of the soil, the US Environmental Protection Agency (EPA) recommends revegetation as a means of reducing water infiltration (EPA 2021). While native plants are ideal candidates for vegetative cover (Morrow et al. 2017), many sites opt for planting exotic grasses, often in monoculture, as that is the most readily available nursery material (OSRTI 2006; Fig. 3.2A). Closed sites require periodic mowing, gas ventilation, and ground water monitoring for 30 years post-closure, often maintaining the area as grassland (EPA 2021).

Establishing native vegetation on capped landfills, as opposed to exotic grasses, will enhance the value of grassland habitat, without creating unrealistic goals for managers. When compared to turf grasses, grasses maintained as wildlife habitat require less frequent mowing, and thus may provide long-term savings that potentially offset initial costs. (Simmons 1999). Additionally, conversion of capped landfills into greenspace can promote sustainable development in urban settings and receives great support from the public (Zhang and Klenosky 2016). Similarly, wildlife habitat programs have positive benefits on employee morale and improve relationships with regulators (Cardskadden and Lober 1998). Presently, many capped landfills provide little ecological value, despite the required maintenance and upkeep, so in recent years, the EPA has pushed for sites to seek alternative post-closure uses including parks, hiking trails, and wildlife habitats (Klenosky et al. 2017; Simmons 1999).

Creating greenspace on landfills can also benefit the public. Firstly, landfill conversion to greenspace has potential economic benefits by increasing property values, attracting business investments, and promoting further residential development (Zhang and Klenosky 2016). Particularly in urban areas, greening projects such as creating wildlife habitat on capped landfills can serve as “flagship” demonstrations, showing the public what is possible on previously degraded landscapes (Zhang and Klenosky 2016). Additionally, urban residents who have access to greenspace are typically healthier both mentally and physically than those without access (Lee and Maheswaran 2011). Given the rise in popularity of many nature-based recreation activities such as birdwatching, capped landfills present an opportunity to create spaces for wildlife and people.

A guide to creating and managing native grasslands on landfill caps

Here we outline the best practices for managers to maximize the value of capped landfills as grassland habitat for birds. While the general principles are applicable nationwide, these recommendations specifically focus on landfills in the southeast. An overview of this process is summarized as a decision tree (Fig. 3.3).

Prior to restoration

The EPA recommends deciding on end-uses prior to landfill construction (ORD 2014). If wildlife habitat is selected as an end-use, an ecological survey should be conducted prior to development to describe the on-site conditions (Simmons 1999). The results of such a survey will be valuable in determining exactly which plant species to establish on the capped site (Table 3.1). See Appendix C.2 for further information on plants for birds. Local experts, including environmental consultancy agencies, universities, botanical gardens, and nurseries, can assist managers by conducting surveys and creating location-appropriate restoration plans; a list of environmental consultants operating in the southeast is provided in Appendix C.3. Plans that incorporate restoration for wildlife habitat may also gain more support from the public (Simmons 1999).

Establishing grasslands on recently capped landfills

The EPA requires landfill caps to be composed of a low-permeability infiltration layer and an erosion layer to protect it. The erosion layer must be comprised of a minimum 6 inches of earthen material that is capable of sustaining native plant growth (EPA 2020) While not required, the addition of compost can provide quality soil for prairie species. Once the soil is in place, the first and most crucial step is establishing a cover crop using a native seed-mix that will quickly stabilize the soil, giving other seeds the chance to take hold. Seed can be applied directly to the prepared topsoil of the cap. Red clover, splitbeard bluestem, and little bluestem are three examples of quickly establishing, versatile grasses that would be suitable for many landfill sites (Table 3.1). Many nurseries have native grass seed mixes that contain suitable grasses; see Appendix C.4 for a list of nurseries and seed banks that sell seeds suitable for the southeast, in sufficient quantity for most landfill sites.

After a crop cover has been established, a greater diversity of species can be added by seeding following a mowing of the cover crop. Although each species has its own ideal seeding time, in general seeding should be done between the beginning of October and the end of December. Species should be chosen such that they provide high quality forage for birds and insects throughout the year. For example, a mixture of golden alexanders, lance-leaf coreopsis, narrowleaf mountainmint, and New England aster would lead to a field with plants in bloom from April through October.

For newly established sites, mowing can be done anywhere from once per year to once every three years. Mowing less frequently than every three years may allow the establishment of woody vegetation to establish that will be too large for mowing equipment to handle and must be cut down by hand (KDF 2010). Because so many bird species rely on southeastern grasslands for food and cover to survive the winter, managers should mow in late winter or early spring to a height of 8-10 inches (KDF 2010). If mowed below six inches, the grasses and wildflowers may die, risking erosion and potentially compromising cap integrity (KDF 2010). Mowing in February and March will mean there is sufficient seed for wintering birds and that the vegetation will have time to grow back before breeding birds begin to nest. Furthermore, managers can choose to practice rotational mowing, in which they rotate mowing different patches in different years; this both saves time and ensures that high-quality habitat is always available (KDF 2010).

Sites should not be mowed if the soil is wet, as heavy equipment has the potential to create ruts in the soil, both damaging plant growth and risking the integrity of the cap.

Ameliorating previously capped landfills

Sites with pre-existing grasslands may require more management, which could be prohibitive for some sites. If a site is dominated by exotic grasses, such as bermudagrass (*Cynodon dactylon*) and tall fescue (*Lolium arundinaceum*) extra care must be taken to remove these species and allow native grasses to establish. This is best done by mowing prior to the growing season for that species, followed by application of herbicide while the plants are growing (Harper 2017). Other methods for removing unwanted grasses include prescribed fire, repeated tilling, and smothering with dark plastic, but these methods are not advised for landfill caps (Harper 2017). Prior to seeding with the chosen mix, sites should be mowed to the lowest setting possible, to expose the soil. Sites will then need to be mowed three times between March and October to a length of approximately 10-16 inches, enabling light to reach the newly added seeds. After a couple years, the native plants should begin to outcompete the original grasses. Certain patches may not respond to this treatment and unwanted species may still dominate the area. In these cases, selective mowing and application of herbicides can help the native species take over (Harper 2017).

Peripheral Plantings

Peripheral sites on landfill properties can host other plant species that are not suitable for planting directly on the cap. As there are no concerns about deep rooting species off of the cap, larger plant species that do not require regular mowing can be grown in the periphery. Large flowering and fruiting species, including elderberry and American beautyberry, and woody vines such as trumpet creeper, have the potential to attract insect- and fruit-eating migratory songbirds such warblers and thrushes. Additionally, these plants attract nectar feeding hummingbirds and provide nest sites for species such as American goldfinch.

Rather than planting from seed, it may be effective to plant small-sized seedlings known as plugs. Planting from plugs is cheaper than using larger plants and will enable faster establishment than planting seeds. Furthermore, not all plants grow effectively from seed, so by planting plugs the managers can increase the diversity of plants available.

Engaging local communities in habitat stewardship

Landfill properties present an opportunity to involve local communities in environmental stewardship. Some landfills, such as the Southern Services Landfill in Nashville, Tennessee have outreach programs that partner with high school students to aid in the planting of native shrubs (WM Undated).

How the landfill can benefit from local communities

Landfill management can benefit from community involvement in a variety of ways. Firstly, volunteer activities can provide labor for conservation projects. Volunteers can plant and maintain pollinator gardens on the property, perform trail maintenance, and enhance wildlife habitat by installing bird, bee, and bat houses. Managers may also seek volunteers to aid in the spot-spraying of exotic plants on landfill caps. Due to safety concerns, some volunteer involvement may not be suitable for active landfills, but there remain opportunities at operational landfills. For example, at the active El Sobrante landfill in Corona, California that contains 700 acres of intentionally managed wildlife habitat, Boy and Girl Scout troops have participated in a number of restoration activities, including planting native milkweed plants, restoring nesting habitat for federally-listed endangered bird species, and building bird boxes for barn owls. These activities have not only helped management achieve conservation goals, but also helped fulfill badge requirements for 11 Eagle Scout projects (WHC Undated).

Landfill managers can also benefit from local experts in the consultation and design phases of conservation activities. Gardening groups, local Audubon Society chapters, and university classes can provide expertise for projects not directly related to landfill operations. The Atascocita Recycling and Disposal Facility in Humble, Texas sought the expertise of the Houston Zoo and Texas Master Naturalists to select tractable restoration projects. They created a centralized location for habitat enhancement and community involvement by refurbishing a barn that serves as a center for volunteer and learning activities (WM Undated). Additionally, local experts (e.g. university researchers, volunteer ecologists, expert bird-watchers, etc.) can monitor the success of restoration, evaluating nesting success, adult survival, and overall bird health.

How local communities benefit from landfills managed for wildlife habitat

There are numerous opportunities for community involvement at landfills, without interfering with daily landfill operations. For example, creating nature trails can provide access to hikers and birdwatchers, while keeping them away from active sites and preventing trampling of wildlife habitat (Fig 3.4). Landfills also provide opportunities for public education and outreach in the form of guided walks and outdoor classrooms (Fig 3.4). A trail leading to a lookout over a revegetated cap provides the public with an opportunity to understand the restoration that has taken place. Likewise, a small and more intensively managed wildflower meadow on the property can serve as an educational tool to teach kids about the benefits of pollinators, and to highlight the larger-scale restoration taking place on the landfill cap.

Conclusion

Capped landfills planted with monocultures of non-native grasses provide little value for wildlife, but through the use of native plants and timely mowing, landfill managers have the opportunity to restore these landscapes to enhance conservation outcomes for imperiled grassland birds and other beneficial wildlife. This document provides general advice for landfill managers in the Southeastern US in planning, implementing and maintaining grassland restoration, but local experts should always be consulted before restoration action takes place. Where applicable, including the local community into the decision-making process ensures lasting benefits of landfills to people and wildlife following closure.

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Table 3.1: List of plants that are suited for habitats at landfills, along with birds and insects that are attracted to those plants. Information retrieved from: USDA Natural Resources Conservation Service – Plants Database.

List of Plantings		
Planting Type	**Plant Options**	**Wildlife of Interest**
Erosion control	**Red clover** (*Trifolium pratense*), **splitbeard bluestem** (*Andropogon ternarius*), **little bluestem** (*Schizachyrium scoparium*), **broomsedge bluestem** (*Andropogon virginicus*), **indiangrass** (*Sorghastrum nutans*)	**Birds:** Northern bobwhite, wintering sparrows and wrens, eastern meadowlark, migratory dickcissel and bobolink **Insects:** Bumblebees, dusky skipper butterfly
Adding diversity to the cap	**Golden alexander** (*Zizia aurea*), **lance-leaf coreopsis** (*Coreopsis lanceolata*), **narrowleaf mountainmint** (*Pycnanthemum tenuifolium*), **New England aster** (*Symphyotrichum novae-angliae*), **hairawn muhly grass** (*Muhlenbergia capillaris*), **smooth oxeye** (*Heliopsis helianthoides*)	**Birds:** American goldfinch, indigo bunting, blue grosbeak **Insects:** Short-tongued insects, black swallowtail and Ozark swallowtails caterpillars, sweat bees, ground nesting bee
Peripheral plantings	**American beautyberry** (*Callicarpa americana*), **butterfly milkweed** (*Asclepias tuberosa*), **dotted horsemint** (*Monarda punctata*), **trumpetweed** (*Eutrochium fistulosum)*	**Birds:** Migratory thrushes, vireos, wood warblers, Ruby-throated hummingbirds **Insects:** Monarch butterfly, long-tongued bees, three-lined flower moth, eupatorium borer moth

Figure 3.1: Examples of bird species that utilize grassland habitats in the southeast at different times of the year. (A) Indigo buntings (*Passerina cyanea*) nest in grasslands during the summer months. (B) American goldfinches (*Spinus tristis*) are year-round residents that feed on abundant seed from native grasses and forbs. (C) Savannah sparrows (*Passerculus sandwichensis*) spend the winter months in the southeast, before migrating back to northern parts of North America. (D) Bobolinks (*Dolichonyx oryzivorus*) are long-distance migrants that benefit from southeastern grasslands as stop-over sites.

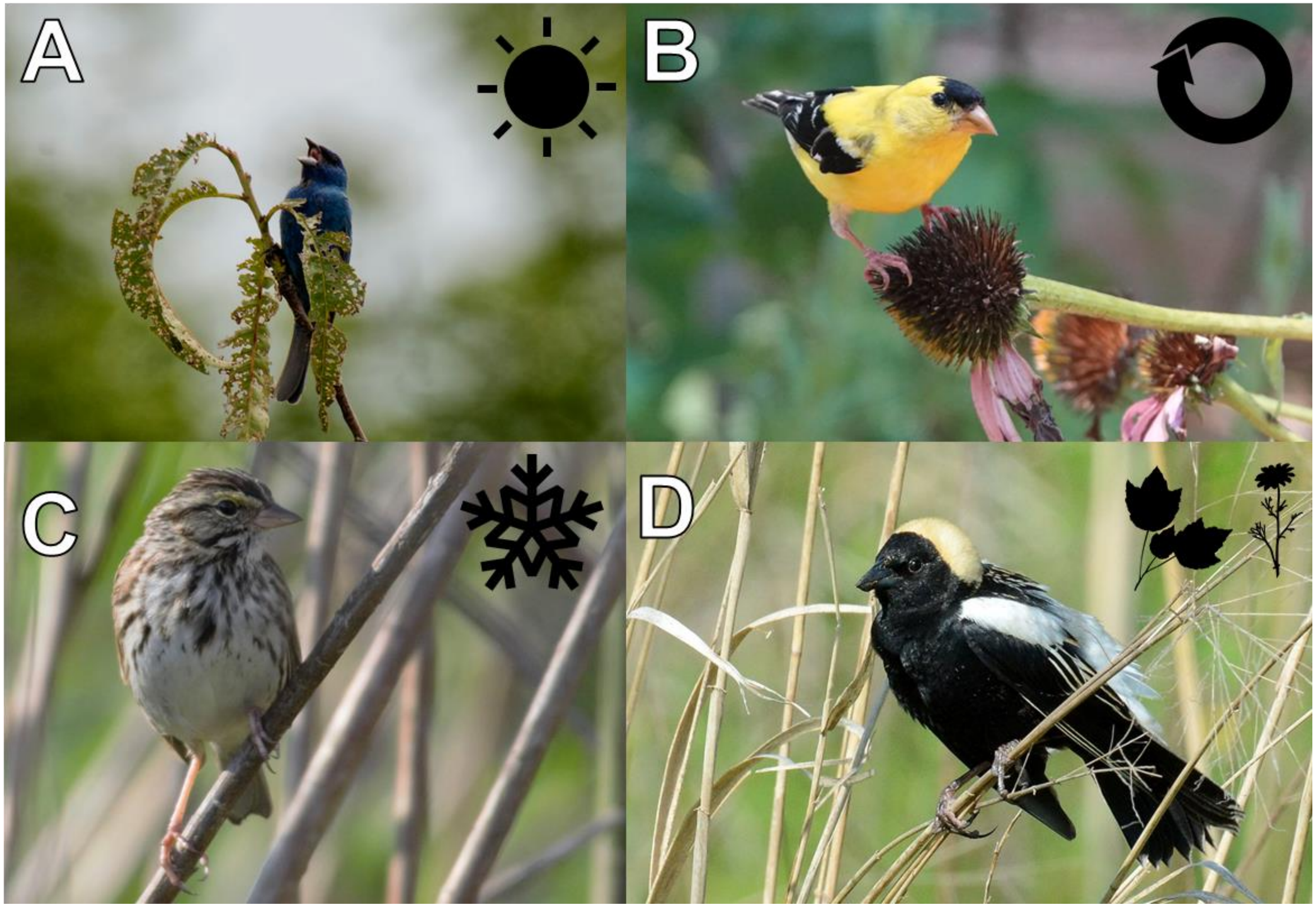

Figure 3.2: Examples of natural and man-made grasslands. (A) A capped landfill planted with exotic grasses. Lower plant diversity and lack of cover limit its utility for wildlife. (B) Example of a grassland restoration project in a powerline right of way at the State Botanical Garden in Athens, GA. (C) a mature southeastern prairie.

Figure 3.3: Decision tree summarizing how to establish grassland habitat on a capped landfill including steps required prior to planting (yellow), the removal of exotic species (red), the establishment of grassland plants (green), and recommended maintenance (blue).

Figure 3.4: Athens-Clarke County landfill as a case study exemplifying how managers can seek to engage local communities (Landfill [date unknown]).

Case Study: Athens-Clarke County Landfill

The ACC landfill partnered with the local Audubon society to establish a birdwatching trail (panel A) that has enabled community members to see locally and regionally rare bird species found at the landfill, such as barn owl, painted bunting (*Passerina ciris*), and white crowned sparrow (*Zonotrichia leucophrys*).

Each year ACC holds a festival at the landfill, highlighting "nature's clean-up crew" – vultures. The vulture festival has presentations from experts (panel B), children's activities, a bird walk, and guided tours of landfill operations. Festivals such as this one can not only raise awareness about bird populations, but also landfill management.

ACC partnered with College of Environment and Design at the University of Georgia to construct an outdoor classroom. The project provided service-learning opportunities for college students, diverted around 90,000 pounds of waste and created a beautiful space that saw over 2,500 visitors in 2013. Pictured here (panel C) is "the path of less waste" constructed out of used bathtubs and scrap metal.

CHAPTER 4

CONCLUSION

By providing a massive food subsidy in the form of human refuse, as well as harboring natural habitats that are scarce in human-dominated landscapes, landfills epitomize how human land use can influence ecological communities in diverse ways. Further, constraints on how landfill sites can be developed post closure provide an opportunity for wildlife conservation and nature-based recreational benefits to the public. In this thesis, I quantified bird community structure at landfills, and based on the finding that landfills can provide habitat for declining grassland birds, I developed a guide for landfill managers to implement bird-friendly grassland habitat management pre- and post-closure.

My research adds to the understanding of how landfills influence bird communities at local and regional scales. First, I found that landfills have similar species richness and patterns of community turnover as nearby reference sites. Second, while human-adapted and dietary generalist species attracted by refuse are overrepresented at landfills, so are several grassland specialist and waterfowl species. These findings point to the potential biodiversity value of existing habitats at active landfills and the potential conservation value of restoration efforts to enhance their suitability for wildlife post closure. Many other human-modified habitats have been managed for biodiversity, conservation including quarries, roadsides, and powerline rights of way (Beneš et al. 2003, Schulz & Wiegleb 2000). While conservation in anthropogenic landscapes shows promise, some mitigation strategies may be needed to avoid negative impacts. In the case of landfills, ensuring that wildlife is discouraged from feeding at refuse disposal sites avoids negative consequences for landfill operations, human and wildlife health, and may indirectly support beneficial wildlife in surrounding habitats by reducing the density of mid-sized predators such as raccoons and feral cats.

My study used publicly available community science (CS) data to address questions at scales I would not have been able to explore using only my own observations. CS engages members of the public to take ownership of the environment around them and can help to educate community members, and is increasingly used in scientific publications to track responses of species and ecological communities to anthropogenic and climate change over large spatial scales (Kobori et al. 2016; Clark 2017). In spite of these advantages, care must be taken to avoid biases and data quality issues inherent in using data collected by the public who may lack training in best practices for data collection. For example, known issues with interpreting raw data submitted by birdwatchers to eBird include species misidentifications, inaccurate counts and spatial biases in data collection that lead to overrepresentation of highly diverse sites, or sites close to large urban centers (Lloyd et al. 2020). While some of these quality issues are addressed by expert screening of submissions prior to being made publicly available, additional care must be taken by end users in analysis and interpretation. In Chapter 2, I addressed concerns of miscounting and biases in sampling effort by working with encounter frequency rather than raw abundance, and by comparing landfills to nearby sites that had been sampled a similar number of times. Overall, if properly screened and interpreted, CS furthers science by creating opportunities to study ecological phenomena at otherwise impossibly large scales and benefits society by engaging the public in environmental stewardship.

Expanding on the findings of Chapter 2, Chapter 3 applied current knowledge of grassland ecosystems to develop practical guidelines for implementing bird-friendly habitat management practices at landfills. The goal of this report was to serve as a resource for landfill managers and decision makers who may want to take part in ecological restoration. This report will be distributed to grassland researchers, landfill managers, and interested stakeholders. Given the extent of the literature on bird control at landfills, many managers may have negative perceptions of attracting birds to landfills, representing a hurdle in convincing sites to adopt these recommendations. I aimed to address these concerns by highlighting that unlike refuse-scavenging species, grassland birds do not pose a threat to landfill operations or public health, and instead enhance the conservation and aesthetic value of landfills. Similarly, planting native grasses and wildflowers may represent increased up-front costs and effort for landfill managers and staff. However, these initial costs may be offset by involving local community volunteers in restoration, and the benefits of reduced future maintenance costs through rotational and less frequent mowing. Furthermore, creating attractive, wildlife-friendly habitat at landfills could improve public perceptions of waste management, by providing educational and recreational opportunities for local communities, especially by providing greenspace to communities in urban locations that have reduced access to natural areas.

Given that protected areas are insufficient to sustain global biodiversity, privately-owned and public lands are becoming increasingly important in conservation measures (Kamal et al. 2013). As 24% of global land area is classified as degraded, restoration of degraded lands, including landfills, could provide important habitat, increasing connectivity among fragmented wildlife populations and facilitating range shifts of populations in response to climate change (Plieninger & Gaertner 2011). Previous research has highlighted the value of landfill caps as wildlife habitat, including their potential to harbor grassland bird species of conservation concern in the UK (Rahman et al. 2011).

This thesis sets the groundwork for several promising directions for future research in biodiversity patterns and restoration of landfills and other human-modified sites. I hypothesized that a diversity of habitat types at landfills could explain the observed community characteristics, but did not explicitly test this theory. Using satellite imagery to analyze landcover types at landfill sites would help elucidate this potential relationship. Additionally, my analysis did not explore the productivity of landfill habitats and further research is needed to quantify nesting success, survival, and overall health of birds using landfills. Furthermore, future studies could focus on the diversity and abundance of pollinating insects at landfills, exploring the value of landfills to other beneficial wildlife populations. While this thesis provided management recommendations focused exclusively on grassland restoration at landfills, future studies could investigate the opportunity of ameliorating other habitats at landfill properties. For example, researchers could explore best practices for creating high-quality wetland habitat in retention ponds. Similarly, recommendations could be made to aid in the conservation of biodiversity during landfill operations by protecting remnant habitats, repelling wildlife from potentially harmful contaminants, or setting up bird boxes for cavity-nesting species.

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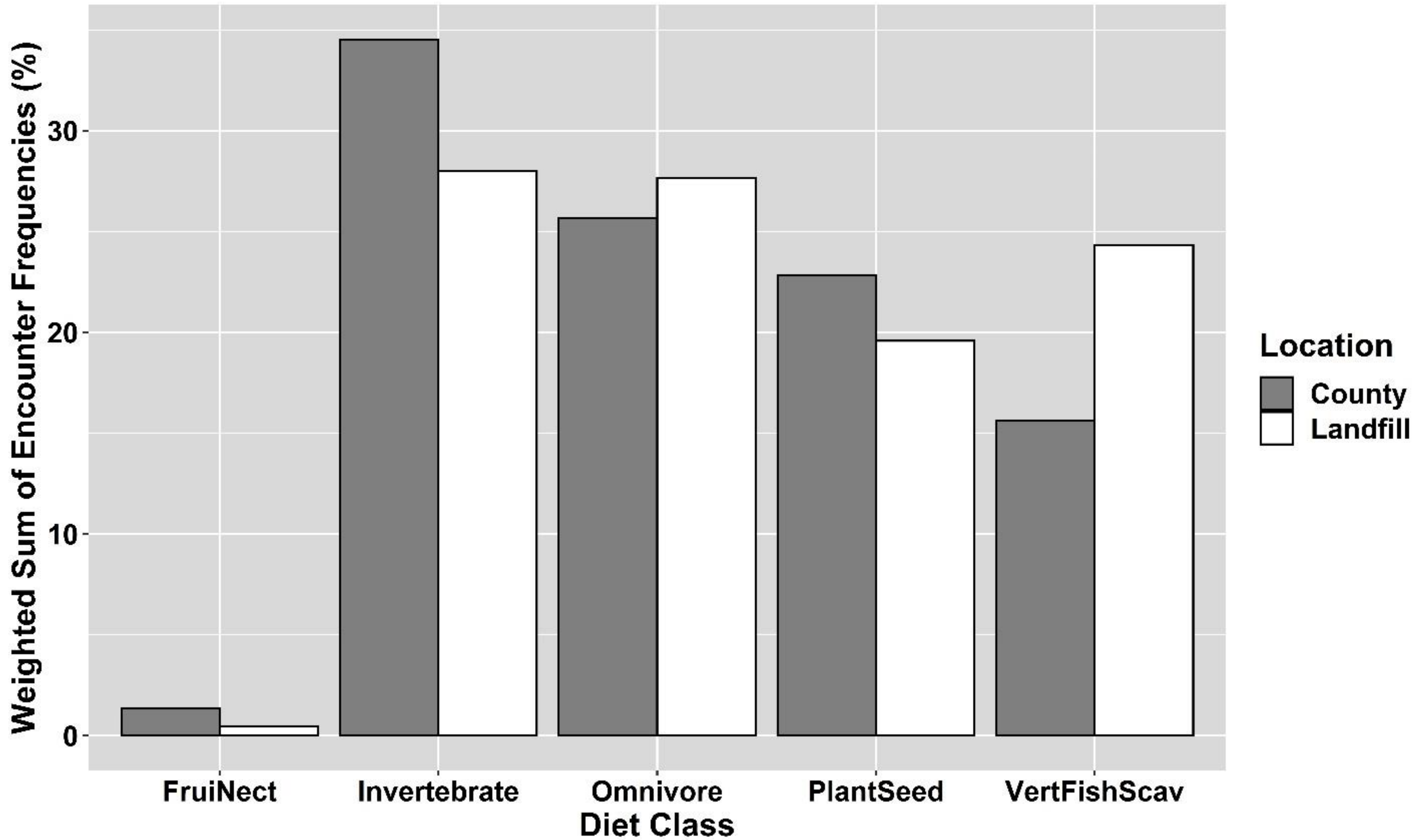
APPENDICES

Appendix A. Chapter 2: Complete list of sites included in the analysis. American states are identified using two letter postal abbreviations. Checklist No. represents the total number of checklists submitted at each hotspot. Hotspot names appear exactly how they do in the eBird database.

State	County	Checklist No.	Landfill Hotspot	Checklist No.	Reference Site Hotspot	Checklist. No.
ID	Ada	51706	Ada County Landfill	454	Boise State Intermountain Bird Observatory Riverside Study Site	462
UT	Cache	26699	Logan Landfill	153	Newton Reservoir --South End Access	150
TX	Cameron	91106	Brownsville Landfill (LTC 041)	1225	South Padre Is.--Bay Access mudflats N. of Conv Ctr.	1224
GA	Clarke	28377	Athens-Clarke Co. Landfill	359	Whitehall Forest	386
OH	Cuyahoga	85044	Solon Landfill	107	Bradley Woods Reservation	106
WI	Douglas	28514	Superior Landfill	773	Connors Point	747
IN	Elkhart	19710	Elkhart County Landfill and Pond	105	Pumpkinvine Nature Trail--South of IN4	104
OH	Hancock	11522	Hancock County Sanitary Landfill Wetland	148	Clay Pits--Strawbridge Pond	148
CT	Hartford	93206	Manchester Landfill & Laurel Marsh	221	Suffield WMA	218
WI	Jefferson	16602	Johnson Creek Landfill	378	Glacial Drumlin State Trail--Lake Mills west to Zeloski Marsh	359

NY	Kings	65959	Fountain Avenue Landfill	103	Prospect Park--Upper Pool	104
VA	Northampton	23994	Cheriton Landfill	715	Oyster	711
PA	Northampton	21275	Grand Central Landfill	267	Ballas Park	272
FL	Okaloosa	9668	Okaloosa Landfill	386	Destin--west jetty	319
NY	Onondaga	43342	DeWitt Marsh and Landfill	224	Jamesville Beach County Park	239
MI	Sanilac	3274	Tri-City Landfill (Sanilac Co.)	180	Flynn Twp. Nature Center	146
FL	Sarasota	61693	CCSWDC Landfill	288	Quick Point Nature Preserve	296
MI	Washtenaw	96435	Ann Arbor Landfill/Wheeler Service Center	787	Crooked Lake	769
CA	Yolo	54412	Yolo County Central Landfill pond--from levee road by CR28H	404	West Davis pond	405

Appendix B. Chapter 2: Comparison of the all species' encounter frequencies for EltonTraits diet classes. Frequency of all species' diet classes at landfills (white) compared to background county-level species pools (grey).



Appendix C. Chapter 3: Online resources for native plant revegetation at landfills

C.1 Organizations specializing in southeastern grassland conservation:

Southeastern Grassland Initiative

- https://www.segrasslands.org/

Georgia Plant Conservation Alliance

- https://botgarden.uga.edu/conservation-science/georgia-plant-conservation-alliance/

Piedmont Prairie Partnership:

- https://www.segrasslands.org/piedmont

C.2 Information on native plants for wildlife:

- Searchable database of native plants and the bird species they attract:
  - https://www.audubon.org/native-plants
- USDA database with information and fact sheets for thousands of plant species found in North America:
  - https://plants.sc.egov.usda.gov/java/
- The learning center from Prairie Moon Nursery has information on establishing prairies, attracting birds and pollinators, and so much more:
  - https://www.prairiemoon.com/blog/learning-center

C.3 Environmental consultancy agencies of the southeast:

- Wiregrass Ecological Associates:
  - https://soforest.com/wiregrass-ecological-associates/
- CCR Environmental, Inc:
  - http://ccrenvironmental.com/ccrenvironmental.html
- EnviroScience
  - https://www.envirosciencein c.com/

C.4 Nurseries and seedbanks servicing the southeast:

- Roundstone Native Seed LLC:
  - https://roundstoneseed.com/
- Mellow Marsh Farm Inc:
  - https://www.mellowmarshfarm.com/
- Prairie Moon Nursery offering custom seed mix design services:
  - https://www.prairiemoon.com/custom-seed-mixes

C.5 Relevant Government Fact Sheets:

- EPA information on landfill revegetation:
  - https://www.epa.gov/sites/production/files/2015-08/documents/revegetating_fact_sheet.pdf
- Guide for utilizing closed landfills as community assets including specific recommendations for environmental restoration:
  - https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100LHOS.txt
- Information on mowing for wildlife management
  - https://fw.ky.gov/Wildlife/Documents/mowing.pdf