The Environmental Impact of the Lands of the Dead: A Comparative Analysis

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The Environmental Impact of the Lands of the Dead: A Comparative Analysis

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Abstract

In the past 150 years, the American approach to death care has changed drastically. Using practices that I refer to as "modern traditional death care," a new industry has arisen that has normalized burial practices that once were reserved for very wealthy individuals. Today, average decedents undergo elaborate preparation processes meant to preserve them far beyond their final viewing. However, these practices may cause significant environmental damage by pollution of the soil, planting of monocultures, and stripping burial sites of indigenous flora and fauna (Loki et al., 2019).

In response to the alarm raised by these methodologies, a competing practice called “natural death care” has arisen. Operating under a set of standards established by the Green Burial Council, the natural death care industry inters unembalmed corpses encased in biodegradable shrouds or coffins at a depth that facilitates their rapid decomposition (Webster, 2016). The natural death care industry’s claim that its practices promote healthier ecologies seems intuitively plausible, but it is largely untested. My thesis research collected and analyzed data that examined these claims.

During the summer of 2022, I traveled across the eastern United States from mid-Florida to near the Canadian border in New York State to visit paired sets of 20 modern traditional and 20 natural burial sites of similar size, located in the same zip code if possible, and if not in close geographical proximity. I collected six soil samples from each site, which I amalgamated and tested for bulk density and organic matter. I also used a quadrat placed at predetermined intervals to collect 18 floral biodiversity samples from

each site, both photographing and filming the study areas in order to record the sampled flora for quantification. In addition to field work, I used satellite data to assess and to compare the paired burial sites. These methodologies were intended to test my hypotheses that natural burial sites would demonstrate greater verdancy, higher plant diversity, more invasive floral species, a higher percentage of soil organic matter, and lower soil bulk density when compared to their modern traditional counterparts.

The data collected during the course of this study was insufficient to be authoritative, but it does tend to substantiate the claim that the practices of the natural death care industry are generally better for the environment than those of the modern traditional alternative. Conversely, the modern traditional burial sites I studied did not seem to pose the level of unmitigated threat to their proximate environments that their detractors suspect. For example, while biodiversity was very high at natural sites, so was the incursion of invasive species. Modern traditional sites, while less diverse, still showed a reasonable parameter range, and with better control of invasive species. NDVI was generally higher at natural sites, but not at all times of the year. Soil carbon analyses of differences between sites was inconclusive.

This research should be useful to individuals wishing to make ecologically responsible choices regarding their own remains or those of loved ones, to future researchers wishing further to explore these topics, and to policy makers weighing the relative costs and benefits of these burial paradigms as they plan future developments.

Dedication

To my mother, who has been my constant source of love and support. This journey would not have been possible without your unwavering belief in me. Your sacrifices and dedication to our family have taught me the true meaning of hard work and perseverance. This thesis is dedicated to you. Thank you for always being there for me, through the ups and downs. I love you more than words can express.

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In addition to the individual professors mentioned above, I would like to thank the faculty, professors, and TAs in the Sustainability program at Harvard University Extension School for shaping my academic journey and helping me reach the place where I was able to undertake and complete this thesis. I have benefitted immensely both from their erudition and their dedication and consider the time that I have spent in this program to be the richest, most rewarding educational experience of my life.

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Definition of Terms

GBC: Green Burial Council

GIS: Geographic Information Systems

NDVI: Normalized Difference Vegetation Index

SOM: Soil Organic Matter

SOC: Soil Organic Carbon

SWDI: Shannon-Weiner Diversity Index

SE: Standard Error

Chapter I

Introduction

In 1865, Americans across the country turned out to honor Abraham Lincoln while a slow-moving funeral train carried his body in state from Washington, DC, to Springfield, Illinois. The body that these citizens came to see had been carefully treated to maintain its life-like appearance, and filled with chemicals designed to preserve it from decay until it could finally be buried (Spongberg & Becks, 2000). In addition to viewing Lincoln's body, the citizens may not have realized that they were also bearing witness to a profound change that was even then taking place in the American way of death (Fournier, 2018). Instead of quickly burying the bodies of the deceased, it became more and more common among non-indigenous Americans from that time forward to artificially preserve them before interring them in settings that eschewed traditional small burial plots in favor of sites that the World Health Organization (1998) has characterized as "landfills" of the dead.

Unsurprisingly, such "landfills" give rise to obvious concerns among environmentally conscious citizens (Fiedler, 2012). They worry that leaving such high concentrations of heavily-treated remains to decay has the potential to harm surrounding areas in ways that may not yet fully be understood. In addition, they argue that the ecological functions that earlier burial sites often served are not being carried out in these heavily manicured environments Although earlier burial sites obviously represented a significant change to the environment, many of the ones that had previously been found throughout the countryside did in fact offer a range of ecological benefits. Often left essentially undisturbed due both to taboos and to local customs, they could be important as greenspaces (Löki et al., 2019). They were often largely self-contained as well, and could provide small-scale habitats for local flora and fauna (Löki et al., 2019). Some studies indicate that even in heavily transformed landscapes, some protected flora and fauna could be preserved in such burial sites (Spongberg & Becks, 2000). In turn, these might then serve as "stepping stones" for these local species to (re)populate the area. Additionally, they note that these earlier sites performed other important environmental services such as remediating the dead and recycling nutrients as well (Löki et al., 2019

It is reasonable to suppose that the ecological health as well as biodiversity of an area are endangered when high concentrations of chemicals are released into the proximate environment. Such concentrations of chemicals inevitably result when large numbers of heavily embalmed bodies are buried in close proximity in modern traditional burial sites (Löki et al., 2019). The practice of using such sites and filling them with artificially preserved bodies, however, is a relatively recent one in the United States. Although embalming methodology had long been familiar and was sometimes employed, it was not until after Lincoln's train traversed the countryside in the mid-nineteenth century that the practice of embalming almost everyone gradually became standard, giving rise over time to the American death care industry (Fournier, 2018).

The burial methodologies that are now associated with "natural" practices are in fact similar in many ways to what was until recently the ordinary way of treating the remains of the American dead (Fournier, 2018). Bodies destined for natural burial are treated minimally if at all, with the goal of returning them to the earth in a way that promotes its health by allowing the earth’s processes to recycle the body’s nutrients with the least possible disruption (Fournier, 2018). The sites where these bodies are interred are also left as much as possible in their natural condition. They are only minimally maintained, and are designed to blend in with the environment around them (Webster, 2016).

The use of natural burial practices has gained popularity as more and more environmental researchers have raised concerns about the impact of modern traditional sites, especially when these are located in places that are surrounded by dense human development, are proximate to other green spaces, or are subject to being flooded (Żychowski & Bryndal, 2014). Regardless of their genesis, the soils from all kinds of burial sites have distinctive properties relating both to their chemistry and to their morphology (Asare et al., 2020). There have been relatively few studies of the impact of the composition and characteristics of these soils on the proximate environment.

Further, there are very few studies that compare measures of the general ecological health of modern traditional burial sites to that of modern natural burial sites. Most individuals now alive will at some point have to plan for their own deaths, and many will have to decide how to deal with the remains of loved ones. People who are concerned with the health of the planet should find information comparing the environmental impact of the practices employed by the modern traditional and natural death care industries useful as they make their plans.

Research Significance and Objectives

The natural death care industry postulates that its practices, compared to those of the modern traditional death care industry, will result in superior ecological health being experienced in proximate areas. This research is intended holistically to test and evaluate that assumption by collecting comparative data to indicate relative measures of ecological vibrancy in burial sites of each type. I used satellite imagery and generated maps of paired sets of natural and modern traditional sites located in close proximity to one another, and traveled to those sites to collect soil samples and to measure indices of biodiversity, which were then analyzed and compared to one another. This methodology produced an extensive data set that should be useful in increasing understanding of the ecological effects of treating human remains in the manner practiced by each of these industries. Such data will be of interest not only to those choosing death care for themselves and other decedents, but also to policy planners responsible for evaluating the relative costs and benefits of natural and modern traditional burial sites.

Therefore, my research objectives were as follows:

- To evaluate and statistically compare and contrast the ecological impacts of natural and of modern traditional death care
- To collect and analyze data regarding the ecological health of modern traditional and natural gravesites and create a “launching pad” for future research on the relative environmental impact of different burial practices and their associated sites
- To help policy makers and municipal planners weigh the potential benefits and/or detriments of planning natural burial sites versus modern traditional sites in the areas they are reserving for death care

Background

Throughout human history, most civilizations have reserved specific places to bury their dead. Because such places typically are regarded as special and not subject to routine development, many of them became de facto conservation sites (Löki et al., 2019). During the last few centuries, changes in land use have brought about substantial habitat loss all over the planet (Gong et al., 2021). As the availability of habitats has declined, the function of burial places as conservation sites has become even more important, especially because, over time, many such places have undergone benign neglect and tended to experience less human intrusion (Nowińska et al., 2020). This ecological benefit does not, however, accrue to modern traditional burial sites, which are carefully cultivated and manicured to emphasize uniformity. The artificial environment thus created is unlikely to support the kind of biodiversity that previously characterized sites set aside for the interment of the dead (Löki et al., 2019).

In modern American practice, such places where human remains are buried are referred to almost interchangeably by the terms “cemetery,” “graveyard,” and “churchyard,” but the terms are, in fact, historically distinct. “Cemetery,” derived from the Greek term for “sleeping place,” has no particular religious affiliation and traditionally is maintained by a municipality. Cemeteries may serve as repositories for cremains (cremated remains) as well as housing both tombs and mausoleums. By contrast, the term “churchyard” can mean any land that adjoins a communal worship site, and which the faithful may consider sacred ground. The churchyard may include a “graveyard,” which is a section that is set aside for interment of human remains, often of those individuals associated with that religious sect or denomination. Such sites have traditionally been maintained by religious groups associated with a particular faith community (Löki et al., 2019). In order to simplify reference, I use “burial site” in this thesis as an inclusive term to mean all areas that are set aside for communal human interment, without distinguishing their municipal or religious affiliations.

Shortly after the end of the Civil War the modern death care industry began to gain prominence, supplanting older practices that were attuned to the earth’s natural cycles of death, decay, and regeneration. As it grew, it gave rise to artificial landscapes used to bury large numbers of human remains (Fournier, 2018). The modern death care industry appears to be predicated on enabling its patrons to avoid confronting the stark reality of human death and of the body’s inevitable decay (Herring, 2019). It emphasizes artificial rather than natural processes in every aspect from its chemical preservation of cadavers to its demarcation of burial places to the maintenance regimes it imposes on burial sites. To date, however, the environmental costs of these artificial practices is still poorly understood (Löki et al., 2019). Many environmental scientists regard modern traditional burial sites with some suspicion, but the concerns that they raise seem largely to be based on speculation and intuition. These sites require further study and comparative and quantitative analysis geared toward addressing these concerns.

The modern traditional burial site model involves interring large numbers of human corpses in close proximity to one another within a limited space. The potential for environmental contamination when these bodies load the proximate environment with the resulting nitrogen and nitrates associated with their decomposition has up until now been poorly studied (Majgier & Rahmonov, 2012). Additionally, unlike other mammalian corpses, many human remains also contain artificial substances, pharmaceuticals, and medical artifacts (Metcalf et al., 2015). An Australian study found that interred human cadavers are often so heavily loaded with these materials that when their remains come into contact with the microcere as they begin to decompose, they can serve as vectors for the introduction of the resulting nutrients into the ecology of the area (Carter, Yellowlees, & Tibbett, 2007).

Neither modern traditional nor natural burial sites leave the environment undisturbed. As these locations are converted to serve anthropogenic purposes, there are inevitable costs, as well as occasional benefits, to their proximate ecology (Majgier & Rahmonov, 2012). Although academic sources often characterize modern traditional burial sites as environmentally deleterious, these sites can, and sometimes do, offer ecological benefits. For example, they can serve as green spaces in urban landscapes, and some have been found to host taxa that are rare or endangered (Loki et al., 2019).

Burial Conditions and Decomposition

In the middle of the twentieth century, concerns about the environmental impact of burial sites and their potential impact on public health began to emerge (Spongberg & Becks, 2000). To address these concerns, several places installed cemetery boards charged with the responsibility of formulating standards and imposing regulations on burial places, to include their sanitary conditions, their proximity to water resources, and the soil drainage in the areas where they were located (Spongberg & Becks, 2000). Currently, 17 out of the 50 US states have installed cemetery boards designed to mitigate environmental contamination, although to date there are no federal regulations regarding the locations of burial sites (Koepenick, 2018).

One of the best ways to limit the environmental contamination caused by an interred corpse is thought to be promoting its rapid skeletonization, which has the added benefit of allowing for the most efficient use of space (Webster, 2016). Since most research on the subject has of necessity been conducted above ground, however, the rate at which skeletonization occurs can be somewhat difficult to determine (Webster, 2016). On average a human corpse decomposes four times faster in open air than it does underground, and twice as fast as it does underwater (Webster, 2016). Even so, there is considerable variation in the amount of time required for an interred human corpse to decompose completely. On average, complete decomposition requires something between 10-25 years, but, depending on the way the body is treated prior to its interment and the soil conditions in which it is buried, this period can be considerably prolonged (Charzyński et al., 2010).

The decomposition of an interred corpse occurs most readily in relatively dry soil that is loamy and sandy (Webster, 2016). Soil with a permeability coefficient of more than 10 m/s is best suited to promote rapid skeletonization (Janaway, 2008). Decomposition is also promoted by the presence of mesofauna like nematodes and springtails and microorganisms such as bacteria and fungi (Janaway, 2008). Soil characteristics such as its compaction, its aeration, its acidity and its nutrient load all affect the health and activity of the biotic community that it supports. Rates of precipitation and ambient temperatures in the area also have a significant effect on the vibrancy of the biome (Siles et al., 2016). Aside from its effect on the biotic community, an increase in an area’s ambient temperature is also positively correlated with the rate of skeletonization. On average, an increase of 10 degrees centigrade in an area’s above-ground temperature doubles the rate at which an interred corpse decomposes (Webster, 2016).

The depth at which a corpse is interred, however, is negatively correlated with its rate of decomposition (Janaway, 2008). This is attributable to the fact that the soil’s upper portion, commonly called topsoil or the organic layer, is the area most likely to be biologically active (Jacoby et al., 2017). By contrast, the subsoil layer, found at an average depth of 30-50 cm, tends to be much more biologically inert (Parikh, 2012). Organic activity in the topsoil such as the spreading of root systems generally works to transport materials from the subsoil into the topsoil (Jacoby et al., 2017). As precipitation in an area may raise the water table of the soil, this process can work together with organic activity to transport potential contaminants closer to the surface (Jacoby et al., 2017).

The rate of decomposition is negatively correlated with the depth at which a cadaver is interred (Janaway, 2008). Soil is more likely to have biological activity towards its upper portion, which is usually referred to either as the organic layer or the topsoil (Jacoby et al., 2017). The layer beneath the topsoil, usually around 30-50 cm deep, is the subsoil layer which is often much more biologically inert when compared to the organic layer (Parikh, 2012). Generally speaking, the organic activity of the topsoil, such as the spreading of root systems, works to bring up materials from the subsoil into the topsoil (Jacoby et al., 2017). This may work in concert with organic activity, such as precipitation raising the water table of a soil, thus raising its potential contaminants nearer to the surface (Janaway, 2008).

Burial Site Soils and Necrosols Not Related to Burial Paradigm

Burial site soils and necrosols were not extensively studied before the second half of the 20th century, and to date there have been relatively few published academic articles (Charzyński et al., 2010). “Necrosol” is a specific term, referring to those soil horizons located at burial sites that have substantially been transformed by human interference (Majgeir, Rahmonov, & Bednarek, 2014). As such, most academic literature specifies necrosol as being a distinct layer under the topsoil that is no deeper than 2 m. Necrosols display morphological changes that can be attributed to the effect of hummus accumulation and frequent digging, and they often contain detritus such as casket fragments, bone shards, pieces of cloth, and similar non-native elements *(*Charzyński et al., 2010).

Necrosols located in natural and in modern traditional burial sites share a number of common characteristics attributable to the fact that both serve as repositories for human remains. Large mammalian corpses like those of humans are high value nutrient providers in any ecosystem (Carter, Yellowlees, & Tibbett, 2007). When they decompose, even when they have not been treated by modern methods, they release high levels of carbon and nutrients into the soil (Carter, Yellowlees, & Tibbett, 2007). The soils of burial sites where large numbers of human corpses were interred have been shown to contain relatively high concentrations of potassium, iron, magnesium, sodium, nitrates, nitrate ammonia, ammonia, chloride, and orthophosphate (Forbes, Stuart, & Dent, 2005). Interring large numbers of human remains in a contained area produces an inevitable environmental impact regardless of whether the body preparation and burial practices used are those employed by the natural or the modern traditional death care industries.

In fact, the physical act of interment in and of itself causes changes both in the chemical and in the original genetic composition of the soil (Majgier & Rahmonov, 2012). Burial site soils become cramped as they are frequently disturbed when new bodies are buried in proximate areas (Majgier & Rahmonov, 2012). Frequent digging degrades the soil, causing the water table to rise (Fiedler et al., 2004). The decline in soil aeration then limits the available oxygen level, resulting in a decreasing rate of decomposition (Fiedler et al., 2004).

Compared to control samples collected nearby, burial site soils often show signs of poor soil health such as increased density and abnormally high acidity (Fiedler, 2012). Experiments on the environmental effects of the decomposition of porcine cadavers have provided further support for this conclusion (Wilson et al., 2007). The experiments showed that the decomposition process shifted the soil pH balance into a significantly more acidic range. As this occurred, soil oxygen was also reduced when the microbiome shifted in order to digest the porcine remains (Wilson et al., 2007).

Necrosols have been shown to have characteristics that are distinct from those of control soils taken from surrounding areas in that they tend to contain higher concentrations of different chemicals, microbes, and nutrients (Asare et al., 2020). Working in the Czech Republic, Asare et al. (2020) compared arable subsoil layers to sandy necrosols in proximate areas, and found that deposits from human interment can endure for more than 4,500 years. When they compared the necrosols located beneath human remains in prehistoric burial sites to the subsoil strata found in proximate landscapes, the authors found significantly elevated levels of carbon, nitrogen, calcium, sodium, barium, and zinc in the necrosols. Current knowledge is limited, however, regarding how both natural and modern traditional burial practices affect the elemental composition of soil.

Necroleachate and Adipocere

The average human body contains 500 grams of phosphorus, 1.8 kg of nitrogen, 95 g of chlorine, 4.2 g of iron, 140 g of potassium, 1.1 kg of calcium, 19 g of magnesium, 16 kg of carbon, and 100 g of sodium; the remaining 75% is water (Janaway, 2008). These elements are leased from the planet for the duration of an individual’s life, and are due to be returned upon his or her death to be recomposed into the proximate ecosystem (Herring, 2019). This natural process, however, is often disrupted by the manner in which human remains are treated.

The creation and dispersal of a substance called necroleachate is at the center of a great deal of the concern regarding the potential ecological damage caused by modern traditional death practices (Malváo Fernandes, 2020). Necroleachate, a viscous, dark-colored liquid, is produced during the late-stage decomposition of human remains. Its chemical components include water, heavy metals, phosphates, organic materials, salts, ammoniacal nitrogen, and pharmaceutical products (Malváo Fernandes, 2020). Frequently, it also contains other elements that are interred along with the corpse such as various accouterments and components of the decomposing casket (Malváo Fernandes, 2020). Necroleachate may carry an increased load both of biological and of inert agents that concerns some researchers, including nitrogen, bacteria, and various viruses, as well as, to a lesser degree, magnesium, iron, potassium, sulfates, and chlorides (Netto et al., 2021). An unembalmed corpse would be expected to release most of its load of pollutants within the first five years of decomposing (Koepenick, 2018).

Since necroleachate is mostly an organic compound, it is polymerizable with many of the organic materials found within nearby soil structures (Malváo Fernandes, 2020). How pathogenic a particular stream of necroleachate may be largely depends on the composition of the corpse from which it derives, including such bacteria, protozoa, and viruses as that corpse contains (Malváo Fernandes, 2020). If their components are present in the decomposing corpse, the necroleachate it generates can transmit diseases like poliomyelitis, hepatitis A, dysentery, gas gangrene, typhoid, and tuberculosis (Morgan, 2004).

Because it is a substance with a high degree of potential toxicity, necroleachate's interaction with groundwater gives rise to a number of concerns. These concerns have been given additional weight by studies that have been conducted on groundwater near burial sites that found the water to contain several potential toxins. Żychowski and Bryndal, (2014) and Tavares de Cruz et al., (2017) identified heightened loads of pharmaceutical products, viruses, bacteria, zinc, lead, bicarbonates, nitrates, calcium, sodium chloride, iron, and aluminum in groundwaters proximate to burial sites. To address these concerns, most, but not all jurisdictions in the United States establish cemetery boards that conduct routine tests for groundwater contamination by necroleachate in areas close to burial sites (Spongberg & Becks, 2000). Most of these jurisdictions also conduct routine geomorphological inspections of the shale deposits underneath potential burial sites before zoning them for such use (Spongberg & Becks, 2000).

Over the course of approximately five years, the amount of necroleachate generated by a given corpse usually dwindles to the point that it no longer causes serious concern (Koepenick, 2018). Non-biological factors like the height of the water table and local precipitation rates, which have the potential to allow water to pick up the necroleachate, shift it into the local ecology and filter it through the soil, can affect the rate of this decline (Malváo Fernandes, 2020). Hydrological erosion, the spreading of root systems, or simply natural shifts in the ground can breach a grave wall, a term used for the earth or barrier that contains a decedent within a casket or a shroud. When a grave wall is breached, the interment site for that corpse becomes flooded with rainwater that shifts its necroleachate into the proximate environment (Fiedler et al., 2012).

Necroleachate has the potential to spread within a radius of more than 400 meters from the boundaries of the burial site where it is generated (Malváo Fernandes, 2020). A highly viscous substance, it can maintain its integrity and infiltrate soil until it reaches an aquifer (Netto et al., 2021). Soil that is well aerated tends to contain microorganisms that can consume necroleachate and break it down, but the substance is less easily metabolized in compacted, more anaerobic soil that does not support such microorganisms (Malváo Fernandes, 2020). Necroleachate is thus likely to be both more common and more persistent in the kinds of compacted, anaerobic soil usually found in burial sites that have seen heavy, continual use for a number of years.

One suggested method for ameliorating the environmental contamination caused by necroleachate is to plant woody vegetation at interment sites (Malváo Fernandes, 2020). Trees, shrubs, and other types of woody vegetation can take necroleachate up with their root systems and sequester and phytoremediate it without causing damage to themselves (Fiedler et al., 2012). By the time that the tree or shrub itself dies and decomposes, the necroleachate released will be considerably less concentrated because of the benign processes associated with vegetative decomposition (Malváo Fernandes, 2020). Accordingly, sites with more trees, shrubs, and other woody vegetation may be able to reduce the amount of soil contamination caused by necroleachate.

Adipocere. Another factor that affects the rate at which necroleachate is released into the proximate ecosystem is the decomposing body's formation of adipocere. Adipocere is a waxy substance that is grayish-white in color and crumbles easily (Fiedler et al., 2004). It is created when the corpse's fat and soft tissue decompose anaerobically through a process called saponification (Fournier, 2018). The formation of adipocere is promoted in warm, wet, and especially in anaerobic environments (Fielder, 2004).

Adipocere incorporates necroleachate and slows its release, reducing the rate at which its nutrients impact the surrounding ecology to a small trickle over time (Fiedler et al., 2012). If the correct conditions are present, it can extend the period required for the skeletonization of a cadaver almost indefinitely (Fielder, 2004). Due to the fact that adipocere so significantly retards decomposition and thus concentrates toxins, however, large amounts of the substance within a given area carry significant risk for environmental contamination should that adipocere come into contact with the proximate ecology (Fielder, 2004).

If corpses were not interred so close together, the presence of adipocere in a given decomposing corpse might in some instances be helpful to the environment. The main benefit would be realized by its reducing the rate at which necroleachate is released so that it could be processed more effectively. There are, however, a number of dangers associated with the presence of adipocere, not the least of which is that the necroleachate contained in a saponified corpse can suddenly be released when the wax barrier is broken (Fiedler et al., 2004). Another danger is that geological events or extreme weather occurring at a burial site can suddenly release partially decayed remains, adipocere, and necroleachate, making that burial site a vector for acute pollution of the proximate environment (Żychowski & Bryndal, 2014). When such a sudden break does occur, the amount of necroleachate contained within even a single saponified corpse can be environmentally problematic (Fiedler et al., 2004).

Even when there are no unforeseen circumstances, an inhumed body will at some point fully decompose and the seal on the casket will be broken. When this occurs, the unremediated necroleachate inside will immediately release high levels of the body's pollutants (Fiedler et al., 2012). This situation is exacerbated when there are many decomposing bodies interred close to one another, as is the practice in many burial sites. Under such conditions, which might have been a trickle of necroleachate from one body is multiplied into a flood.

Modern Traditional Death Care

The modern traditional death care industry maintains approximately 22,500 burial sites in the United States a year (Fournier, 2018). Along with the human remains interred at these sites, the industry buries an average of 2,500 metric tons of copper and bronze, 82,000 metric tons of steel, 1,350,000 metric tons of reinforced concrete, 30 million board feet of hardwoods, and 16.3 million liters of embalming fluid in American soil every year (Coutts et al., 2018). This amounts to being enough metal to construct the Golden Gate Bridge, enough concrete to construct a highway from New York to Detroit, and enough embalming fluid to fill eight Olympic-sized swimming pools (Fournier, 2018). Most of the bodies buried at these sites are embalmed, although it should be noted that chemicals like formaldehyde have today largely replaced the mercury and arsenic previously used in embalming fluid (Spongberg & Becks, 2000). Even with this modification, however, the decomposition of these bodies still produces a necroleachate that has been found to contain much higher concentrations of heavy metals and alkaline elements than those in the surrounding soil (Jonker & Olivier, 2012). Inevitably, these contaminants will ooze into the proximate ecosystem (Saraiva et al., 2015).

When a body is delivered to a mortuary for modern traditional death care, the embalmer begins by draining it of its fluids, which are then usually deposited in the municipal sewer system without any pretreatment (Barcellos, 2018). The fluids that have been drained are not known to produce any risk to human health or to the environment when they are treated in this manner, since the sewer system is equipped to handle them (Kleywegt et al., 2019). However, the same is not true of excess embalming fluids. When these are dumped into sewer systems they have been shown to possess a significant potential for environmental damage, and are especially dangerous to sensitive aquatic organisms (Kleywegt et al., 2019).

Corpse Preparation in Modern Traditional Death Care

The general aim of replacing a body’s natural fluids with embalming fluid is to preserve it for viewing. To accomplish this, embalming fluids usually contain a mixture of molding agents, germicides, surfactants, dyes, perfumes, and anticoagulants (Spongberg & Becks, 2000).

Embalming fluid is normally composed of varying ratios of formaldehyde, methanol, ethanol glycerin, and a biocide agent such as glutaraldehyde or phenol (Kleywegt et al., 2019). The ratios of the chemicals used are customized for an individual corpse, and are adjusted according to its general state of decomposition or “intactness,” as well as its size, age, and body composition (Brenner, 2014). For every 34 kg of a corpse’s weight, an average of 3.8 liters of embalming fluid is used (Brenner, 2014).

Depending to some extent on their degree of concentration, the chemicals in embalming fluids have a range of environmental effects ranging from relatively benign to highly toxic. The primary reagent for formaldehyde stabilization in embalming fluid is methanol (Balta et al., 2018). Although methanol is not known to bioaccumulate in animals, it has been shown to affect the fertility of the biota, to lower the growth rate of plants, and to kill fish and birds that are exposed directly to it (National Pollutant Inventory, 2021). Under laboratory conditions, methanol does biodegrade (Alberta Environment, 2010); however, since little research has been conducted outside of laboratories, its rate of biodegradation in natural settings is currently unknown (Alberta Environment, 2010).

In contrast to methanol, ethanol glycerine, which is used to restore “living” color to a corpse, is relatively benign. It is a relatively simple component made of natural fats found in both animals and plants (European Commission, 2020). Its environmental uptake has not been shown to present any serious issues unless it is dumped in such quantities that it gluts the environment (European Commission, 2020). Ethanol glycerine has also been shown readily to biodegrade in soil (Federal Register, 2012).

Another major component of embalming fluid is formaldehyde, which is a common pollutant that is formed as a byproduct of various natural reactions. Its purpose in embalming fluid is to “harden” the body so that it does not lose its shape while being viewed (Balta et al., 2018). A known skin and eye irritant, formaldehyde is carcinogenic upon acute exposure to both animals and humans (Balta et al., 2018). It is a volatile organic compound, and if it is ingested formaldehyde can cause a range of effects from internal bleeding to coma to death (Uslu, Bariş, & Erdoğan, 2009). Formaldehyde can build up in the environment, but the actions of sunlight, plants, and microbes in both aerobic and anaerobic soil conditions can break it down into carbon dioxide and formic acid within 7-73 hours (National Research Council, 2011).

The simplest carboxylic acid, formic acid, has been shown to arrest the process of decay in various materials (Santos, 2021). It is a methanol derivative, and its primary industrial use is to expedite fermentation by suppressing the production of butyric acid and lowering the temperature needed for the process to take place (National Library of Medicine, n.d.). Formic acid has extremely high soil mobility because it is poorly absorbed, but its effect on the microbiological activities needed for corpse decomposition in soil are currently unknown (National Library of Medicine, n.d.). It is easily broken down in the environment by normal processes, and it is not known to bioaccumulate (Santos, 2021).

Phenol is a biocide that is another common component of embalming fluid. Its industrial use is primarily in the creation of synthetic fibers (Balta et al., 2018). Phenol is highly toxic to virtually all biota that come into contact with it, affecting everything from vertebrate and invertebrate animals to protozoa and evenalgae (Balta et al., 2018). It has a negative effect on the survival, growth, and fertility of animal offspring that are exposed at any age (Babich & Davis, 1981). Since the evidence is currently inconclusive regarding whether phenol directly causes cancer in animals, it is at this time classified as a tumor promoter rather than as a carcinogen (USDHS, 2008). Normally, phenol does degrade rapidly in the environment, but it has also been shown to bioaccumulate (USDHS, 2008). Its degradation can be retarded by a number of conditions, including a lack of sufficient oxygen or of nutrients in the soil into which it has leached, as well as its simply being present in high enough concentration to preclude sufficient microbial activity (Center for Disease Control, 2009). Since such a wide range of conditions can affect its degradation rate, phenol may persist at burial sites and in necrosols for highly variable and unpredictable periods of time.

Another biocide that is a common component of embalming fluid is glutaraldehyde, which is highly toxic to any biota that are acutely exposed to it (Balta et al., 2018). Glutaraldehyde is, in fact, so highly poisonous that it does not bioaccumulate (Center for Disease Control, 2017). As is the case with a number of chemicals meant to maintain the life-like appearance of a corpse until it can be interred, this biocide is acutely inimical to life processes. In water, glutaraldehyde rapidly degrades under both aerobic and anaerobic conditions, but in soil it degrades only when the conditions are sufficiently aerobic (Balta et al., 2018). It can be volatized by vapor pressure in dry topsoil, but to date there have been no studies dealing with its potential accumulation in burial site soils and necrosols with anaerobic conditions (Balta et al., 2018). How much glutaraldehyde persists in the soils of modern traditional burial sites is not currently known.

Interment and Memorialization in Modern Traditional Burial Sites

After a body has been embalmed, the next step in modern traditional death care is usually to place the corpse in a casket prior to displaying it for viewing. The types of caskets used in most modern traditional burial sites are usually stuffed with artificial fibers designed to look like bedding, and are constructed of wood or other materials heavily treated with sealers and varnishes. Often, they are further adorned with metals such as chromium, copper, nickel, zinc, and bronze alloys (Balta et al., 2018). The purpose of the “bedding” is to create the illusion that the corpse is asleep, rather than dead, during the final viewing (Fournier, 2018). After the viewing and any other ceremonies are completed, the corpse reposing in its casket is transported to the gravesite.

Gravesite preparation and vaults. In a modern traditional burial site, the grave that will be used to house the corpse is normally excavated with a backhoe before a vault is inserted. The vault is typically made of asphalt, steel, plastic, fiberglass, or concrete, and is designed to house the shrouded cadaver or the casket underground (Webster, 2016). The use of vaults is designed to keep the grave from collapsing during the late-stage decomposition of the cadaver (Spongberg & Becks, 2000). Aesthetic considerations have caused most modern traditional burial site owners to require the use of such vaults (Spongberg & Becks, 2000).

The most commonly used substance for vault construction is concrete (Webster, 2016). The environmental impact of concrete vaults has not extensively been studied, but the effect of cement, the primary reagent of concrete, is well established. Every ton of concrete produced and disseminated results in greenhouse gas emissions equaling 30,000 Mt of carbon a year (Andrew, 2018). In addition, wet concrete is highly alkaline, and its cadmium runoff disrupts normal soil function even when it is not buried (Ding et al., 2021). Concrete dust, especially when it is present in sufficient quantities to reach nearby water tables, has been shown to cause significant health problems to humans as well as to other biota (Müller et al., 2020).

The way that modern caskets are constructed and the general use of vaults has largely eliminated the need to specify the minimal depth at which a body should be interred (Spongberg & Becks, 2000). Therefore, contrary to popular belief, there are few local stipulations in the United States requiring that a body be buried at a depth of 1.8 m, or six feet, under the surface (Spongberger & Becks, 2000). It is more common in most modern traditional burial sites for bodies to be interred at a depth of only 1.2 to 1.5 m, or four to five feet (Spongberg & Becks, 2000).

Gravemarkers. Most modern traditional burial sites indicate the places where individuals are interred with gravemarkers. These most common materials from which these markers are manufactured are marble and granite (Fournier, 2018). These markers can in some cases serve as locations where lichen and bryophytes can grow, (Nowińska, Czarna, & Kozłowska, 2020), but ultimately they may do the local ecosystem more harm than good. Over time all gravemarkers will erode, affected not only by natural precipitation but also by the artificial irrigation of the modern traditional burial site. The use of pesticides, chemical fertilizers, and cleaning agents, all of which may be used to varying degrees in such sites, can further accelerate the rate of erosion (Fournier, 2018).

Many of the chemical solutions that modern traditional burial sites employ to maintain their appearance have the potential to deposit their salts into the pores of stone gravemarkers (National Parks Service, 2021). Once deposited, the salts recrystalize in the pores and slowly build up pressure as they accumulate, eventually cracking the stone (National Parks Service, 2021). The open cracks create new surface areas on the gravemarker that are in turn available for erosion, creating runoff that seeps into the proximate environment (UCL, 2018).

When they are located in areas with environmental conditions favoring colonization by microbes that create acidic environments, granite gravemarkers are especially subject to such erosion (National Science Foundation, 2018). The microbes make the granite even more porous by pitting it with acid deposits, further exposing its surface area to erosion (National Science Foundation, 2018). As the resulting acidified granite effluent infiltrates the local topsoil, it is likely to increase its acidity. While a single gravemarker may have only a minimal environmental impact, it is likely that the presence of large numbers of gravemarkers eroding in the presence of frequently applied chemicals may present more of an environmental risk than the paucity of research on the matter would suggest.

Maintenance of Modern Traditional Sites

In addition to the environmental concerns raised by the embalming and interment of bodies in modern traditional burial sites, there are several issues that arise from the way these sites are maintained. Communities that are located in but not indigenous to North America frequently consider burial places with tall grasses and naturally occurring vegetation to be “neglected” (Hamilton, 2008). Modern traditional death care settings meet this consideration with regular maintenance routines that require intensive management of local fauna along with frequent mowing, fertilizing, and pesticide use, all of which have negative impacts on the environment (Fournier, 2018).

The rate in which a burial site is mowed in a modern traditional setting is highly dependent on the maintenance regime, funding, and rate of vegetative growth located at a modern traditional burial site (Anderson, 2004). Mowing is typically done in warmer seasons, as they are more conducive to the onset of vegetative growth (Hamilton, 2008). Due to their size, modern traditional sites are frequently mowed with riding lawn mowers cause significant pollution. Aside from the manufacturing of the lawnmower itself and obvious greenhouse gas emissions related to the operation of the equipment, mowing lawns has been shown to release nitrogen oxides and volatile organic carbons into the environment (Anderson, 2004). This is in addition to potential environmental disruption caused by noise pollution and the trimmings from cut grasses, leaves, and other dead vegetation being frequently sent to landfills instead of being reconstituted into the landscape (Fournier, 2018).

The extent to which fertilizers are used in modern traditional gravesites varies significantly according to individual maintenance regimes. While some gravesites discourage their use in the interest of preserving the integrity of grave markers, others overuse them (Fournier, 2018). When fertilizers are overused, they pose various environmental hazards including the release of greenhouse gasses and the potential to pollute waterways resulting from runoff or saturation (Fournier, 2018). A “best practices” document detailing ideal maintenance regimes for modern traditional cemeteries suggests that operations personnel use non-acidic, slow-release organic fertilizers (Chicora Foundation, 2008). Compared to modern alternatives, such fertilizers have been demonstrated to present less potential for ecological damage (Zhao et al., 2013).

Like fertilizers, the rate and degree of pesticide use in modern traditional burial sites varies according to their management practices. The quantities of applied pesticides are not available to the public, but sites with strict maintenance regimes have been shown to employ chemical herbicides to control weeds (Webster, 2016). It is likely that they also use chemical pesticides to prevent insect damage to vegetation. Chemical pesticides contaminate soil organisms, non-target vegetation, and surface and ground water resources (Aktar, Sengupta, & Chowdhury, 2009). Designed to harm targeted biota, they may also become toxic to biota that are not targeted when they bioaccumulate, which can lead to unanticipated environmental devastation (Aktar et al., 2009).

Natural Burial Practices

In light of the many ecological concerns raised by modern traditional death care practices, some environmentally conscious individuals have sought an alternative methodology for dealing with human remains. A competing industry known as natural death care has arisen to offer just such an alternative. The natural death care industry claims that its practices are much less deleterious to the environment than those used in modern traditional death care, and may in some cases actually be beneficial. To date, however, the general public has not been well informed about the natural death care alternative (Tavares de Cruz et al., 2017).

Working under the governance of a private board called the Green Burial Council, the natural death care industry in the US uses methodology designed to help the environment process human remains under conditions that create the least possible disturbance. Landscape maintenance at natural burial sites is limited, and is intended to promote the health of the ecosystem and to result in greater biodiversity. Green Burial Council regulations state that non-native species and artificial artifacts are not to be left at interment locations (Green Burial Council, 2021). The extent to which these practices promote ecological health, however, has not yet been studied.

Interment at a natural burial site is designed to be undertaken in such a way as to expedite decomposition by encouraging natural processes (Webster, 2016). The corpse is neither embalmed nor adorned with artificial accouterments, and it is embalmed at a depth that promotes rapid decomposition (Fournier, 2018). The Green Burial Council encourages the re-use of grave sites once skeletonization is complete in order to promote judicious land management, but it leaves the decision about whether to reuse individual sites to the owners and managers of the burial sites. The Council does not require the re-use of grave sites for licensure (Webster, 2016).

If a burial site is re-used, the bones it contains may either be collected and stored in an ossuary or left in place beside the new corpse (Webster, 2016). What standard of decomposition the natural death care industry is using in public-facing claims about these processes, however, is not completely clear. In one of its documents, it states that a corpse normally takes something between four to six weeks to decompose (Webster, 2016). If full decomposition is intended to be synonymous with skeletonization, this has not been established to be the case. The rate at which an unembalmed human corpse decomposes without a casket is dependent on a number of factors including its own composition, the depth of its interment, precipitation in the area, and the temperature and condition of the soil. Depending on these variables, full skeletonization is estimated to take an average of 10-12 years (Koepenick, 2018). An unembalmed corpse interred with a casket takes an average of 15-25 years to skeletonize (Charzyński et al., 2010).

Corpse Preparation and Interment in Natural Death Care

Natural death care begins with a cadaver being treated minimally, if at all. The corpse is transported to the burial site shortly after viewing. If any preservation is required, this is accomplished primarily with the use of dry ice, sometimes with the addition of essential oils (Fournier, 2018). Most bodies being prepared for natural burial are then put in simple biodegradable shrouds or caskets (Green Burial Council, 2021). The corpse is transported to the interment location shortly after viewing.

Green Burial Council regulations specify that human possessions are not to be interred with a cadaver at a natural burial site (Fournier, 2018). The purpose of this regulation is to avoid introducing extraneous materials that might contain undesirable chemicals with the potential to leach into the proximate environment as the interred body undergoes decomposition (Webster, 2016).

One potential environmental effect that does not appear to have been studied is that of the essential oils with which a cadaver being prepared for natural burial may be treated. Further, no comprehensive list of specific oils that may be used for the purpose appears to be available to laypersons. It is noteworthy that the essential oils used in food preservation are antimicrobial, and are useful in helping to create a moisture barrier between the food that is being preserved and the air (Pandey et al., 2017). It would be reasonable to assume that they serve a similar function in natural death care, but the effect of their presence is similarly antimicrobial with the interred corpse, but this does not appear to have been either studied or reported.

Preparation of Gravesites and Interment in Natural Burial Sites

Natural burial sites usually prepare the number of graves that they anticipate using during the course of the year during the warmer months. These periods are selected because such sites try to avoid introducing heavy equipment into environmentally sensitive areas. Accordingly, most of the interment locations are prepared by hand using picks and shovels, so the sites prepare the graves in advance to avoid the difficulties involved in digging in frozen ground (Fournier, 2018).

Picks and shovels are arguably less intrusive than backhoes, but even they disturb the soil and the nearby plant life. The simple process of digging, however it is accomplished, may have consequences that are as yet poorly understood on the growth and strength of plant roots as well as on the structure of the microbial community in the underlying soil (Majgier et al., 2014). However, there is some anecdotal evidence that not all of the consequences are negative. Some natural burial sites report increased plant growth and diversity over graves where bodies have been interred (Webster, 2016). There is a paucity of hard data to back this claim, but it is presumed that this may be due to the effects of the decomposition process.

Since natural burial sites do not use above ground storage sites such as the mausoleums, tombs, and columbariums that may be found at modern traditional burial sites, they do not employ the necroleachate catchment devices that many modern traditional sites have begun to use (Malváo Fernandes, 2020). Primarily designed to prevent necroleachate from seeping out of above-ground storage sites, these devices are metal or plastic grave coverings coated in powder that turns into a gel when it comes into contact with liquid (Malváo Fernandes, 2020). The period of time that the gel may last and what its specific environmental impact may be are currently unknown. The Green Burial Council neither mentions nor appears to sanction the use of necroleachate catchment devices, which would appear, in any case, to be used for the kind of above-ground storage of decomposing bodies that does not occur at natural burial sites. Their use would be further precluded by the fact that using these devices in their current form would require that metal or plastic be buried with the corpse, a practice that is specifically prohibited by natural burial protocols.

In accordance with their general practice of avoiding the introduction of potentially hazardous materials, natural burial sites use indigenous shrubs and trees to mitigate the uptake of decomposition products. Especially when they are planted at the edges of a burial site, such plants have the further advantage of discouraging the encroachment of non-native species onto the grounds (Webster, 2016). Their roots protect the water table when they draw water up from the soil and incorporate viruses, bacteria, and heavy metals, storing them in woody plant tissue without damage to themselves or the surrounding soil (Webster, 2016).

The ethos of the natural death care movement is also evident in the methodology employed by natural sites for indicating individual interment locations. The licensure requirements of the Green Burial Council prohibit the use of freestanding stone monuments (Webster, 2016). Individual natural burial sites use a variety of methods, however, to indicate the location of specific human remains. Some entirely disallow the use of physical markers and employ only a cenotaph that is engraved with the names of the interred (Webster, 2016). Others encourage the planting of indigenous vegetation above individual graves, while others do allow individual memorials such as GPS markers, locally sourced flat rocks, and wooden panels with engraved epitaphs (Fournier, 2018).

Maintenance of Natural Burial Sites

Natural burial sites generally encourage the growth of vegetation, and rarely prune the plants that populate the area (Fournier, 2018). Most dead vegetation is left in place to be digested by saproxylic insects (Fournier, 2018). Unless they are needed for highly specific reasons, most pesticides and fertilizers, as well as any non-indigenous organisms introduced anthropogenically, are prohibited by the standards of the Green Burial Council (Webster, 2016). When artificial means of controlling aggressive species like *Operophtera brumata* from destroying beech trees are necessary, for example, pesticides are used as sparingly as possible. When less aggressive pests such as *Adelges tsugae* attack hemlocks, more natural methods of treatment like applying horticultural oil are favored (Webster, 2016).

Since natural burial sites are left to the greatest possible extent in an unaltered state, they almost inevitably invite animal incursions. When these occur, they are treated in as noninvasive a manner as possible (Webster, 2016). Best practices for natural burial sites include dealing with factors like deer overgrazing and rodent damage by fencing the sites and planting attractive alternatives for the animals in areas nearby that are less sensitive (Webster, 2016). Given the relatively shallow depth of interment at most natural burial sites, it is natural for concerns to arise about the potential for animal predation. To date, however, there have been no reports that animals have tried to dig up any of the graves (Fournier, 2018).

For those individuals who wish to be buried with the use of environmental protection protocols that exceed even the paradigm the Green Burial Council dictates for natural burial sites, conservation burial sites are available. These are licensed by a separate agency called the Conservation Burial Alliance, and in addition to the strictures imposed by the Green Burial Council they practice minimal burial density and usually are managed by conservation agencies (Conservation Burial Alliance, n.d.). In order for someone to be buried in a conservation site, the individual or his or her agents pay a fee that is designed to protect the land in perpetuity, and incur legal obligations dealing with conservation easements and deed restrictions (Conservation Burial Alliance, n.d.). Although conservation burial sites allow for the use of very specific and articulated biological and mechanical agents to eliminate invasive pests, the Conservation Burial Alliance prohibits the use of any pesticide for any purpose (Green Burial Council, 2021).

Field Studies of Burial Sites

The ecological impact of different kinds of burial sites and practices has not to date been extensively documented. Such studies as have been conducted have mostly been limited to and therefore reflect the biases of industrialized countries (Löki et al., 2019). The resulting gaps in the literature indicate a need for more extensive study and analysis.

Normalized Difference Vegetation Index

One useful method for assessing the relative ecological health of a given area is to measure its verdancy. In general, verdancy measures are good indicators of the quality of the ecological goods and services that vegetation in a given area is able to provide (Pervaiz et al., 2018). The services provided by the vegetation in an area are various, and include such functions as controlling smog, helping to prevent runoff, absorbing toxic pollutants and carbon dioxide, helping to mitigate air pollution, and lowering ambient air temperatures (Pervaiz et al., 2018).

Assessments of verdancy begin with taking a general measure of the vegetative biomass in an area, which can be obtained through satellite imaging geographic information systems (GIS). GIS can also offer information regarding photosynthetic activity in the area being assessed. This is done by mapping the normalized difference vegetation index (NDVI), a dimensionless ratio used to contrast the reflection of light from healthy vegetation on the infrared band with the reflection of energy from dead or senescent vegetation on the red band of light (Bilgili, Satir, & Müftüoğlu, 2013). NDVI is broadly useful for assessing ecosystem health, and is considered a covariate of vegetation distribution, vegetative biomass, CO2 Fluxes, land degradation, and vegetation quality for herbivores in a given ecosystem (Pettorelli et al., 2006). NDVI calculations yields values ranging from -1 to +1, with the positive value increasing in proportion to the presence of healthy biomass in the measured area.

As a measurement of vegetative health and productivity in a specific area, high NDVI values indicate the presence of a healthy and diverse vegetative cover, while low NDVI values indicate either that little or no vegetation is present or that the plant populations in the area are unhealthy or under stress. While NDVI values alone are insufficient fully to assess an area's ecological health, the presence or absence of a healthy, abundant vegetative biomass can be used to predict a site's leaf area index as well as its likely foliage cover, both of which are useful indicators (Bilgili et al., 2013).

Surprisingly few studies using NDVI analysis to study the ecological health of modern traditional burial sites have been reported, and of these none appear to compare them directly to the ecological condition of comparative natural burial sites. One NDVI analysis of burial sites was used to help archeologists locate buried ruins by indicating the kinds of anomalies in plant life that can often be found either when many small items or when large individual items are interred at a given location (Calleja et al., 2018). Another study conducted on the Gora Cemetery in Lahore, Pakistan used data from 2000, 2008, 2013, and 2018, and found that encroachment from the local urban environment caused significant variations in the vegetative cover of the site over time (Pervaiz et al., 2018). The authors also noted that during periods of lessened verdancy, mitigation both for air pollution and for climate change decreased, causing difficulties in the surrounding areas. To date, there appear to be few other records of NDVI studies conducted at burial sites.

Biodiversity

. Since plants are the primary producers of terrestrial ecosystems and provide the structure of biotic communities across trophic levels, a given area's biodiversity is a useful indicator of its general ecological health. Various methods are used by researchers to calculate floral biodiversity at given sites, but in order to compare biodiversity among sites the Shannon diversity index is a tool that ecologists frequently use (Daly, Baetens, & De Baets, 2018). The usefulness of this index is enhanced by the fact that it not only accounts for random floral dispersal in a given area, but also considers both the richness of species and the equitability of the relative numbers of individual plants across species (Daly et al., 2018).

A meta-analysis of 97 studies conducted by Löki et al (2019) spanned burial sites located in 22 countries across five continents and identified 140 protected taxa. These studies were conducted without reference to the burial paradigms used at those sites. It should be noted that orchids were the focus of 11 of the studies that were reviewed, and the results may be biased toward them. Taking this factor into account, it is worth noting that orchids can be considered an umbrella species, or one that may help to conserve other species because of efforts that are designed to protect it (Molnár et al., 2017, Löki et al. 2019). The authors concluded that some of the species studied were useful in indicating the ecological health of the proximate area, while others were not. Visitors to the burial sites had been responsible for introducing large numbers of invasive species, many of which proved able to outcompete and potentially to overcome indigenous flora (Molnár et al., 2017, Löki et al. 2019). Löki et al. (2019) noted that the permanently established graves helped to preserve the floral composition of a given area by virtue of their protection as sacred sites.

The fact that burial site spaces are largely uninhabited by the living gives them the potential to provide local flora and fauna with a refuge, but that same characteristic can also make them havens for invasive species. As previously noted, it is visitors to gravesites who often introduce such species to an area (Rutkovska et al., 2015). Their presence is a common problem; one study of just 10 burial sites in Daugavpils, Latvia, found a total of 49 invasive floral species (Rutkovska et al., 2015). Often these plants imperil indigenous fauna and occupy new niches in burial sites. Further, modern traditional burial sites that are intensively maintained can promote monocultures of invasive grass species (Nowińska et al., 2020). The authors noted that there are indications this phenomenon may become less pronounced as a burial site ages, but state that the phenomenon has not extensively been studied.

In a rural Chinese region, a study of plant species richness was conducted over 199 family-owned burial sites that averaged 55 m2 (Gong et al.2021). Plant species richness was correlated with the size and age of those sites, regardless of whether the plants were pollinated by wind or by insects. Gong et al. (2021) identified a total of 81 species that spanned more than 30 families and 70 genera. The study appeared to be well-conducted, but lacked some specificity as to its parameters, frequently using verbiage like "high levels" in reference to biodiversity and "small" to refer to family graveyards without fully defining those terms. Gong et al. (2021) concluded that in the largely homogeneous agricultural areas where the burial sites they studied were located, such sites might serve as "semi-natural" habitat islands. Even such small burial sites as those they studied, the researchers argued, could play a key role in conserving ecological functions and floral diversity in agricultural landscapes.

Nowińska et al. (2020) studied more than 78 burial sites in Southeastern Poland, collecting 5,004 floristic samples representing 523 species within 75 families. The researchers etermined that the demography of the local flora was most strongly correlated to the relative isolation of the burial site, and least strongly correlated to its size.

Burial sites in the United States have not, at this time, been extensively studied as to their biodiversity. No studies have to date been conducted that compare the biodiversity of modern traditional and natural burial sites. Further, no comparative analyses of the soil health of these sites, such as percentages of organic soil carbon or other indicators, are reported.

Soil

One of the most useful tools that can be used to assess the general health of an ecosystem is a soil bulk density test. This test measures a given soil's degree of compaction by drying out a sample and dividing its dry weight by its volume. In general, highly compacted soil, with higher bulk density values, is a problem for ecosystems because it reduces the amount of air and water that is able to penetrate the soil (Indoria et al., 2020). This, in turn, makes it more difficult for animals to burrow and for microorganisms to thrive, reducing the general health of the biota in an area. The relative lack of air and water in compacted soil also makes it harder for plants to grow, which can negatively impact biodiversity (Indoria et al., 2020). In general, the presence of highly compacted soil is an indicator that the ecosystem is not functioning at an optimal level (Indoria et al., 2020).

Just as heightened bulk density is generally related to poor soil health, lower bulk density tends to be correlated with the presence of an increased amount of soil organic matter (SOM), a good indicator that the soil is generally healthy (Pribyl, 2010). The presence of heightened SOM helps to improve soil structure by making it more porous and thus less subject to compaction. Since the soil is less dense, it allows not only for improved water infiltration and drainage, but also for better air exchange in the soil, which is beneficial to the root systems of plants. The increased presence of organic matter also makes nutrients more available to plants by improving the soil's cation exchange capacity, which can lead to healthier growth (Pribyl, 2010). Finally, the presence of increased organic matter in soil can help it to sequester carbon (Pribyl, 2010).

Testing soil bulk density at burial sites is useful not only because it can offer a general approximation of how efficiently water and nutrients can penetrate the soil, but also of how aerated and microbially active the soil may be in comparative locations. These comparisons can be useful for understanding how different management paradigms affect both natural and modern traditional sites, as well as the extent to which frequent disruptions caused by digging may affect soil health in both types of locations.

Other tools that measure relative and nitrogen and phosphorus levels in soil are also available, and these ordinarily would be useful measures of soil health as well. In a comparison of modern traditional and natural burial sites, however, the frequent inclusion of these chemicals in the kinds of fertilizers used to maintain modern traditional burial sites makes a comparison of their presence or absence to their prevalence at natural burial sites effectively useless.

A German study compared burial site soils and necrosols that contained large amounts of adipocere to control samples of soil that were collected just outside the burial site (Fiedler, Schneckenberger, & Graw, 2004). The native soil of the area, which was made up of sandy loam, should have been the ideal medium to promote rapid decomposition, but researchers found that the frequent digging in the area had raised the water table and thus had reduced the flow of oxygen into the graves. The adipocere-rich burial site soils thus had become anaerobic at a depth of 50 cm. Compared to the control samples which were similarly waterlogged and thus anaerobic at the same depth, the burial site soils were found not only to be more acidic, but also to have an 8% higher bulk density. One notable difference was that the control soils had a greater organic biomass than the burial site soil contained. The researchers indicated that adipocere formation in the burial sites was related to large quantities of dissolved organic carbon and phosphorus in the water coming from the excavated graves, as well as to cadaverine leaching,

A Maryland study compared the enzymatic microbial activity in agricultural and lawn soils to that found in necrosol samples (Emmert et al., 2021). They found the necrosols generally more active than agricultural soils and lawn soils respectively 63% and 30% of the time, but much less variable in their level of activity. At some times of year, microbial activity in the control soils exceeded that found in the necrosols. The phylotype richness of bacteria was not found to vary significantly, however, between the necrosols and the agricultural and lawn samples. Emmert et al. (2021) concluded that changes in land use helped to create the biological characteristics of all the soils they sampled.

Research Question, Hypotheses and Specific Aims

To address important gaps in knowledge, my primary research question was: Do natural death care sites promote greater ecosystem health compared to modern traditional burial sites in the eastern United States? To address this question, I tested the following hypotheses:

- H1: Natural burial sites have 10% higher average of verdancy when compared to modern traditional sites.
- H2: Areas studied for plant biodiversity at sites that employ a natural method of burial have 5% higher values of Shannon’s Diversity Index when compared to those found in modern traditional burial sites.

- H3: Natural burial sites have 10% higher ratios of invasive species compared to those found in modern traditional burial sites.
- H4: Soil samples collected from sites employing natural burial methods have an 5% average increase in soil organic matter when compared to modern traditional burial sites in the same areas.
- H5: Soil samples collected from sites employing natural burial methods have an 8% average decrease in soil bulk density when compared to modern traditional burial sites in the same areas.

Specific Aims

To complete this research, I:

1. Compiled a sample of exclusively natural burial sites in South Carolina, Florida, Georgia, North Carolina, Pennsylvania, Ohio, New Jersey, New York, and Virginia.
2. Collected measurement data of burial sites using Google Maps.
3. Selected a sample of modern traditional burial sites matched as closely as possible to natural sites in the same zip codes.
4. Divided each site into a grid of six areas using a Google Earth layer, and then place a GIS marker in the approximate center of each.
5. Traveled to each site and located all GIS markers placed in each of the six locations per site.
6. Sampled along randomized transect lines and gridded quadrat to calculate metrics related to the community composition at set distances from the center.
7. Collected biodiversity data at each of the six locations from each burial site.

8. Calculated the percentage of non-native and endangered species present in each sample.
9. Collected soil from the six randomized, stratified locations at each burial site located at the center of the gridded quadrat to measure the relative SOM, SOC, and Bulk Density from each location.
10. Tested for statistical differences in ecological variables between the traditional versus natural burial sites.

Chapter II

Methods

Natural burial sites are generally believed to be better for the environment than modern traditional sites, but the evidence for their superiority is primarily anecdotal. This study was designed to test whether and to what degree the claims to superiority advanced by the natural burial industry can be statistically corroborated. The study methodology employed was intended to be holistic, and it involved multiple tiers of data collection and analysis from several sources to test the veracity of the natural burial industry's claims.

Selection of Burial Sites

To compare floral biodiversity, floral verdancy, invasive species encroachment, soil organic matter, and soil density in natural versus modern traditional burial sites across the eastern United States, I first used the GBC's website to locate all the sites east of the western Indiana border that they had accredited either as Conservation or simply as Natural burial sites. Hybrid sites, which intermingled both modern traditional and natural practices in the same designated plot, were not included because they were unlikely to yield meaningful data.

I did, however, include on-site paired burial sites, which have separate areas where natural burial practices and modern traditional practices are employed. Since the study was designed to compare the soil qualities of natural and modern traditional sites, on-site paired sites were often especially useful because of the virtually identical original qualities of their proximately located native soils. An additional practical consideration was that eliminating on-site paired sites from the study would have meant the number of available samples would have been unacceptably small. Conservation sites, which follow the basic protocols for natural sites in a more rigorous form, also were included.

I identified 27 GBC- accredited natural and conservation burial sites located east of the western Indiana border. In all, there were only 39 such GBC-accredited burial grounds in the US and one in Vancouver near the Washington State border, meaning that only 13 of them are found in other parts of the country. For this study, I selected 20 of the eastern sites located across eight states including New York, Pennsylvania, Ohio, Virginia, North Carolina, South Carolina, Georgia, and Florida. The criteria used to select these sites included proximity to other sites, ease of access, and published policies regarding available visitation times. Once these sites had been chosen, they were paired for comparison with nearby modern traditional burial sites. I therefore collected and compared data from a total of 40 burial sites (Table 1).

To pair natural burial sites with modern traditional counterparts, I noted the addresses of the natural sites and placed them all into a categorization of addresses on Google Maps. Using that data, I then collected further information related to the average temperature, elevation, and rainfall between the months of May and August for each of the zip codes where the natural burial sites were located.

Previously unforeseen scheduling issues meant that my investigation had to be extended into early September, but data regarding that month, since it was unanticipated, was not part of my original consideration. After making my initial selections, I used data from a political layer in Google Maps to calculate a rough estimate of the average size of each burial site that I intended to visit. If a natural burial site did not have a modern

Table 1. Designation and description of 20 pairs of matched sites.

Designation	State	Style	Type	Slope
01A	SC	Municipal Cemetery	Field	Gentle slopes
01B	SC	Conservation	Highly forested	Gentle slopes
02A	SC	Municipal Cemetery	Field	Flat
02B	SC	Conservation	Highly forested w/ fields	Gentle slopes
03A	FL	Municipal Cemetery	Old, many parts overgrown. Many mausoleums	Flat
03B	FL	Conservation	Sandy fields with tree copses	Flat
04A	GA	Municipal Cemetery	Field. Extreme density of graves	Gentle slopes
04B	GA	Natural	Intermittent fields and forests	Flat
05A	SC	Churchyard	Field	Flat
05B	SC	Natural	Intermittent fields and forests	Moderate slopes
06A	NC	Municipal Cemetery	Field. Old.	Flat
06B	NC	Conservation	Highly forested	Gentle slopes
07A	PA	Chuchyard	Field	Highly sloped
07B	PA	Natural	Highly forested	Gentle slopes
08A	OH	Municipal Cemetery	Large field, old	Gentle slopes
08B	OH	On-site paired	Small field w/ waist to chest high vegetation	Flat
09A	OH	Municipal Cemetery	Large field, old	Flat
09B	OH	On-site paired	Small meadow surrounded tree/shrub copses	Flat
10A	OH	Churchyard	Field w/ large oaks	Flat
10B	OH	Conservation	Forested with intermittent meadows	Gentle slopes
11A	OH	Municipal Cemetery	Small field, new part of old cemetery across street	Flat
11B	OH	On site paired	Small field with chest high vegetation	Flat

12A	OH	Municipal Cemetery	Field	Flat
12B	OH	Conservation	Highly forested w/ fields knee high vegatation	Gentle slopes
13A	OH	Churchyard	Field	Moderate slopes
13B	OH	Natural	Field and forest	Gentle slopes
14A	NJ	Municipal Cemetery	Field with numerous trees	Gentle slopes
14B	NJ	Natural	Highly forested	Flat
15A	NY	Municipal Cemetery	Field, old	Gentle slopes
15B	NY	On-site paired	Copses of trees and meadows	Gentle slopes
16A	NY	Municipal Cemetery	Old, many trees	Gentle slopes
16B	NY	On-site paired	Forested with central meadow	Highly sloped
17A	NY	Churchyard	Large field, old, many trees	Flat
17B	NY	On-site paired	Meadow w/ numerous trees at margin	Flat
18A	NY	Churchyard	Field	Flat
18B	NY	On-site paired	Highly forested	Gentle slopes
19A	VA	Municipal Cemetery	Field	Moderate slopes
19B	VA	Natural	Field with waist-high vegetation	Moderate slopes
20A	NC	Municipal Cemetery	Field	Flat
20B	NC	On-site paired	Highly forested	Flat

This table offers the designation and general description of each burial site used in this study. The blue color and the letter "A" after its numerical designation indicates that the site was modern traditional. A green color and the letter "B" after a numerical designation indicates that the site was natural. Numbers were assigned to each site based on the order of my arrival to the locations.

traditional burial site adjoining it that was managed by the same firm, I used the size data to find a modern traditional burial site roughly equivalent to its size in the same zip code.

I selected modern traditional sites to visit by using Google Maps and the website Find A Grave. I also created lists of potential backups of modern traditional burial sites in case access or availability should be restricted at the time of my visit because of management policies, current maintenance, or funerals in progress. In two cases, one of which involved a natural burial site in Virginia and another in New York, there was no modern traditional site of a roughly equivalent size that could be found in the same zip code as the natural site. In these instances, I used Google Maps and Find a Grave to select the closest equivalent modern traditional burial sites within a ten-mile radius of the zip code of the natural burial site. One exception to this general practice involved a relatively small natural burial site in Ohio that adjoined a much larger modern traditional site. In order to use best available practices in data collection, I approximated the center of the modern traditional site and collected data from that location, taking care not to exceed the parameters of the adjoining natural site. The final set of 20 independent paired samples was well matched by site characteristics, slope, and location (Table 1).

I collected data from burial sites between early May and late September of 2022. In order to match ambient temperature and plant maturation as closely as possible across sites, I began data collection in the southern United States and moved north as the summer advanced. Although precise data regarding temperature was not recorded during field data collection, ambient temperatures during the field studies generally ranged in degrees Fahrenheit from the low 80s to the low 100s.

As expected, the weather conditions for collecting data were quite variable, including intense sunlight, high winds, and moderate rains. In one instance, a sudden thunderstorm broke over the site I was studying. When this happened, I retreated to my car and waited out the storm, then resumed data collection after it passed. There was, of course, additional water in my soil samples after the storm.

Collection of NDVI Data

To conduct NDVI analysis, I used eos.com's landviewer application. Eos.com catalogs and archives information from various satellites on different parcels of land many times a year. Using this website allowed me to collect time-sensitive analyses of both natural and modern traditional burial sites from January 1 of 2022 to December 31 of 2022. Data ranges outside of this interval were not included because it would have been beyond my ability to confirm the size of each burial site beyond this timeframe.

I used both published online maps and Google Earth to confirm the boundaries of the natural and modern traditional sites I had previously visited, then used these tools as well as my personal experience with the sites to draw boundaries around them using the polygon area of interest tool provided by EOS’s landviewer. I then conducted a time-series analysis of the sites using the Landsat 8 satellite’s dataset over the period of time reviewed, adding new data to my online .csv file for the site each time Landsat conducted a new NDVI analysis. If data were collected from one paired site but not from the other on a given date, the data was marked and was not included in the primary conglomerated analysis. This distinction was made to prevent a host of environmental variables from adding noise to the data set. I then tested for differences in the conglomerated paired NDVI samples by paired t-tests.

While preparing this portion of the data, I became aware that some of the sites were overrepresented both temporally and in the number of times they were scanned in the data set when compared to the sites that had been paired with them. It is likely that the difference was attributable to the fact that some of the paired sites were located in more ostensibly urban environments than their paired counterparts, and thus received more attention during the same time frame. Additional paired t-test analyses were performed using the sets of first analyses from each paired site in the timespan using the generalized hypothesis, and two more sets of analyses were done using the averages for each paired site, as well as all of the date-paired data separated by month for each site. Paired t-tests were also done on combined data from each given month, regardless of the specific dates on which it was collected.

Collection of Biodiversity Data

After selecting the 40 sites, I used political and satellite layers in Google Maps to place six distinct location markers on each of them. Paired sites were always visited on the same day, but I visited natural and modern traditional sites in alternating timeframes to standardize data collection as much as possible. For example, if I visited a modern traditional site early in the morning and then its paired natural site afterwards, I would alternate the sequence for the next pair of visits, going first to the natural site and then to its paired modern traditional site. After arriving at a given site, I used the Google Maps layer I had created to locate each of the site’s six placemarkers. Once there, I used a random number generator on my smartphone to populate a number between 1 and 360, then used that number to determine a compass bearing from which to collect field data.

To collect biodiversity data, I used a 30 meter transect line coupled with a one square meter gridded quadrat. At each point on the map, the transect line was placed in the approximate location of the map pointer and dragged 30 meters in the direction of the randomized compass bearing.

In numerous instances, the linear path of the transect line was obstructed by a physical object of some sort like a large tree, a grave marker, a mausoleum, a paved road or pathway, a gated section of a burial site not available to the public, or a columbarium. In these scenarios, the transect line was unanchored from its location, and measurement of the 30-meter distance was resumed after the obstacle was cleared from the line where it was possible to do so. If the object could not be cleared within a reasonable distance, the line was resumed at the place of its previous measurement past that obstacle. The transect line was newly anchored just past the point where the obstacle interfering with data collection was cleared.

The gridded quadrat was placed to the directional right of the transect line at the 0, 15, and 30-meter marks. At each quadrat location, I recorded a video, and later in the project I also took pictures of each quadrat placement to review for further assessment. I made numerical estimates of the populations of forbs, grass, legumes, tree saplings, and bryophytes and collected them into a physical gridded paper notebook. Plants were counted as being within the quadrat area if they were rooted within that area. If, for example, a forb was leaning outside of the quadrat but was rooted within the square, it would be counted. However, if a forb were rooted outside of the quadrat while leaning into it in such a way as to have its biomass predominantly in the quadrat, it was not included in this analysis. For the sake of this study, bryophytes were determined to be individuals when perimeters were distinct from one cluster to the next. They were not counted as individuals when clusters were interconnected. Vegetation that appeared to be dead was also excluded.

Plants were identified in the field when possible, and their identity was verified by consulting the videos as well as the photographs taken during the later samplings and comparing them with pictured vegetation in reference materials. While some field identification was possible, time constraints and limited internet access often made such attempts impractical, and photographic and video records were inevitably consulted for verification in every case. All identifications, including field work, videos, and photographs, were triple confirmed using the applications LeafSnap, PictureThis, and PlantNet on an Android smartphone. In three instances when I could not confirm the identity of plants because video artifacts made it impossible clearly to discern their species, I consulted the book *Common Grasses, Legumes, and Forbs of the Eastern United States: Identification and Adaptation* by A. Ozzie Abaye to identify them.

I uploaded the data collected in the grid notebook to an online .csv file that was used to note the richness and species population of each gridded quadrat sample. For each species I observed, a grid of 25 cells representing each of the squares in the quadrat was taken. Then, the population of that species was recorded in that cell. In instances where a square in the quadrat was not populated with the observed species, the cell was left blank so as to record the section as a zero. While the online grid was being calculated, a cell separate from the grid was designed to sum the numbers of each of the 25 cells together to calculate the population of that species in the quadrat. I used this method both to collect granular data and to prevent potential miscounting.

Once data collection was complete, I designed a separate online workbook to take the auto-counted information and record it in order to perform an automatic calculation of the SWDI for each sample taken at a site and for the site as a whole. These numbers, in turn, were used to conduct a Hutcheson's t-test, a modified t-test used for calculating the difference between the SWDI values of two groups, on the collected information. I used a regular paired t-test analysis to compare the ratios of invasive species from both modern traditional and natural burial sites.

Invasive species detection was initially undertaken using the PictureThis Android app, but its classification system proved to be overzealous for my purposes, frequently conflating noxious weeds with invasive species. To avoid this bias, I used published records from state databases to determine which species were identified as invasive.

I searched the name of every species listed in each area using the CTRL+F function to locate the same string of information from its binomial nomenclature. In order to eliminate potential mistakes arising from inadvertent misspellings, the search for each species was conducted twice, once for each portion of its binomial name. When a named species was found on the invasive species list, the text calculating its prevalence in the sample was marked in red so that the richness and relative abundance of invasive species could be calculated for each site.

After the above data was completed, figures related both to the relative abundance and to the richness of each invasive species were combined and tabulated to calculate the relative abundance of invasives as a floral class in each burial site. For example, if a site had invasive species X and invasive species Y present in the sample data, the total of their presence was tabulated broadly under "invasive species" and divided by the number of individuals studied at the entire site to calculate the relative abundance of invasive species. The richness of invasive species was also measured and compared against the richness of all species as a whole for a similar analysis comparing the percentage of invasive richness vs. indigenous flora. If, for example, ten species were present at a location and two of them were invasive, both invasive species would be summed into a total number, which would then return that 20% of observed studied species were invasive.

Finally, the relative frequency of each invasive species was calculated at a site together with the mean relative frequency of all invasive species. For example, if invasive species X had a relative frequency of 10% and invasive species Y had a relative frequency of 5% at a given site, the mean relative frequency was 7.5% for the given site. They would later be tabulated separately in a separate analysis which sought to understand if there was a connection between the style of site and the relative frequency. Secondary analyses for invasive richness and invasive relative abundance as a class were then conducted on nonzero numbers from both sites.

Using a list of 944 plants provided by the Environmental Conservation Online System and published by the US Fish and Wildlife Service, I conducted roughly the same analysis to search for the prevalence of endangered species in the studied burial sites. The database I used for this purpose is a federal one, since endangered species, by definition, have trouble establishing a foothold in a given area. Data collection and analysis returned only two results that involved potentially the same species of plant located in two natural sites in New York state. In both instances, potential juvenile versions of *Euonymus americanus* were identified during the biodiversity studies. Both sites, however, also contained juvenile *Liquidambar styraciflua* in the location, and a positive identification of the threatened species could not be made with sufficient confidence to include it in my data sets. That only two instances of endangered species were collected out of 720 samples would not have yielded a sufficient number of such species to consider them a significant presence at the studied burial sites in any case, so this analysis was set aside.

Collection, Processing, and Testing of Soil Samples

After completing biodiversity data collection along each transect line, I collected a soil sample from the middle square of the gridded quadrat that I placed at the end of each transect. I selected these sites for soil samples because they were located in randomized directions thirty meters away from the beginning point on the map, and thus they were not reflective of any bias I might have had in placing the original markers. The center of the quadrat grid proved to be a useful tool to certify that the soil samples were taken from roughly the same space in relation to the end of the transect lines.

Using the methodology described by Hunnings, Donohue, and Heckendorn (2019), I used two instruments inserted at a 150 mm depth to collect approximately 1.7 deciliters of soil from each of the six locations at the transect line ends. I used a stainless-steel soil probe with a line on it marking the 150 mm depth to extract soil cores. After extracting the soil core sample, I closed the resulting hole by using a gardening knife to collapse the soil around the hole and stepping on it in order to prevent any avoidable aesthetic damage to the area.

The soil cores from each site were then collectivized into a joint waterproof container, resulting in a 1.02-liter soil sample. After this, I cleaned the soil instruments with a 99% isopropyl alcohol solution to avoid any possible biological contamination of the next site. I stored the collected soil containers in a large cooler that was routinely refreshed with ice before delivering them to Clemson University's agricultural science lab for testing.

Clemson's agricultural science lab tested the soil samples for bulk density and for the percentage of organic matter. Loss on ignition testing, which involves weighing a soil sample, subjecting it to 800C to "burn off" its organic matter, and then weighing it again and comparing the results, was the method employed to test for percentages of organic matter. The bulk density test was done by drying a soil sample and then dividing its weight by its volume. The results of this test provide a general estimate of the water penetration, aeration, and compaction of a given soil sample.

After I received all of my data back from the lab, I compiled it in an online .csv file. I then ran t-tests from each data set to determine whether or not there was a significant relationship between the style of a burial site and the amount of organic carbon in the soil sample. Another set of t-tests was run to determine relationships between the bulk density of soils and the style of the burial sites.

When I got the results back, they were returned as SOM (soil organic matter) percentage values instead of SOC (soil organic carbon) values. To address this, I multiplied each SOM number by 0.58 to yield its SOC content. When I got the results back, I was surprised at the results I received. To validate them further, I used the GPS pointers that I previously had placed on each site to collect information from a data set published by Esri using Soilgrid.org's SOC prediction algorithm.

Soilgrid.org is a website that partners with the World Soil Information Service (WoSIS) database to provide soil information from real world locations obtained from geological surveys, remote sensing, and covariate data gathered from multispectral imagery associated with high soil organic carbon. This information provides, in part, an estimation of the soil organic carbon present in a given area. However, the website does not provide a method to query information regarding soil organic carbon concentrations at specific sites on a scale sufficient for my purposes.

I was able to use Esri to address this issue, because it has published an authoritative resource using a map layer and soilgrid.org’s algorithm to provide precise information on a much more granular scale. With Esri I was able to collect estimated concentrations of SOC from each map pointer’s location, which I then recorded into a .csv file with data for depths both of 30 cm and 2 m at each burial site. After collecting the data, I conducted another t-test on averaged soil sites as well as on the individual soil samples.

Chapter III

Results

As this series of analyses progressed, I became aware that there were multiple ways to approach the data I had obtained. In order to account for potential blind spots, I conducted separate analyses on different sections using the same raw data. These multiple perspectives are considered and discussed both in this section and in the following section.

NDVI by Year Analyses

I conducted the initial broad, direct yearly comparison of NDVI analyses of paired modern traditional and natural burial sites using only the dates on which data from both sites was available. If, for example, data was returned for July 4, 2022, at a modern traditional site but not at its natural counterpart, the date-available data from the modern traditional site was not included in the mean. The mean for modern traditional burial sites was 0.46, and the mean for natural sites was 0.53. This analysis showed that there was a mean 12.4% mean difference in verdancy (standard error (SE = 0.08) favoring the natural burial sites in 2022 ($P < 0.0001$, n=254, paired t-test. These data, however, do not account for the frequency with which a series of paired sites appeared in the available data set, the number of months represented in the data set under these conditions, or the temporal under and overrepresentations of different sites in the data sets.

To address the possibility of the data being skewed by under or over-representation of specific months or of individual burial sites in paired sites, I took the first available date-paired NDVI of each pair for every month and compared them on a yearly scale. This “year-firsts” analysis was intended to account for anomalies in the data that might have arisen when comparing the means of a given site on a month-by-month and site-by-site basis.

The choice of limiting the data set to the first date when data from both sites in a paired set was available rather than using means helped to avoid “smoothing” numbers out, and accounted for situations when, for example, a month like July might have had five valid paired dates in the analysis at a given site, while February might have only one, or none at all. This analysis showed that natural burial sites were significantly more verdant by 11.8% (SE=0.08) than their modern traditional counterparts over the course of the calendar year 2022 ($P < 0.01$, $n = 174$, paired t-test).

Although the “year-firsts” analysis helped to account for some of the factors that might skew the data, it did not allow for consideration of enviro-temporal anomalies with the potential to cause significant variance or, in fact, for all the available data on a given site to be included. One issue with this type of analysis is that while multiple sets of data for a given site might be available toward the beginning of a given month, it was sometimes only toward the middle or even the end of that month that valid data could be obtained simultaneously from both sites in a pair.

Comparing the 2022 monthly mean average NDVI values of natural and modern traditional sites returned an 11.5% mean difference (SE=0.09) in verdancy favoring natural burial sites in the eastern United States over their modern traditional counterparts ($P < 0.001$, $n = 240$, paired t-test). The consistency of the greater verdancy of the natural site is indicated by predominance of positive values over the sampling dates (Figure 1).

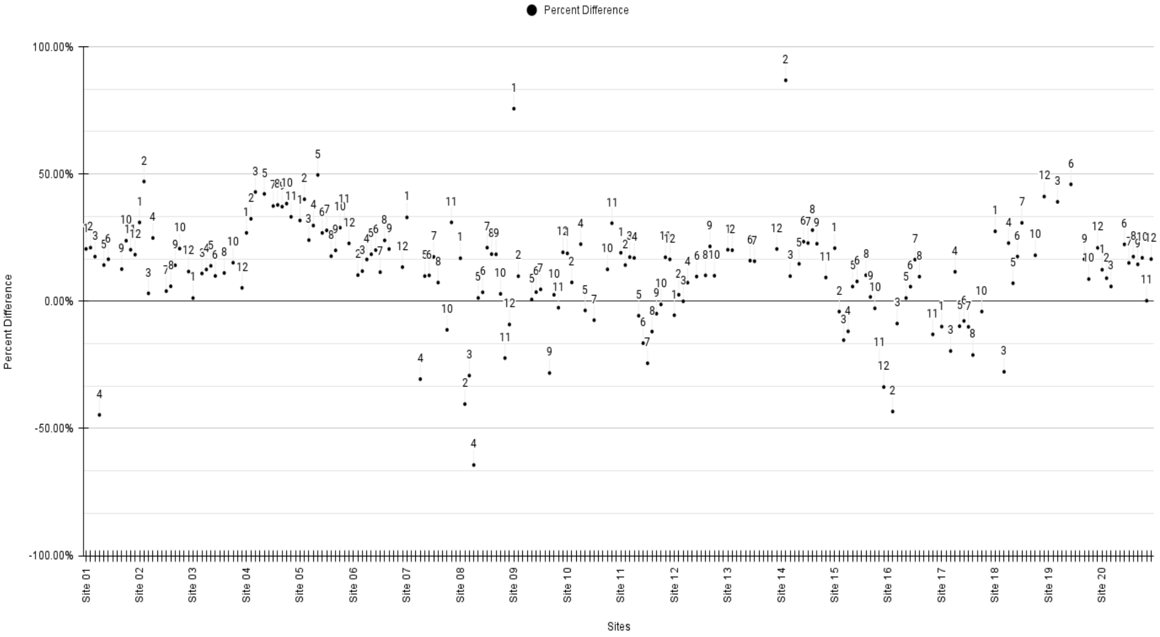

Figure 1. The percentage difference NDVI value per month for every paired site. Tick marks on the X axis indicate different months of the year, and a number above each dot indicate the month of the year the value is taken from. Negative values indicate that the modern traditional site was more verdant than the paired natural site for that month.

The final year-long NDVI analysis for 2022 was also the broadest. For this analysis, I calculated the mean of the NDVI data for all 40 sites and compared them directly against one another. While not ideal for resolution, this process lends perspective regarding how the annual verdancies of burial sites located in the eastern United States compare directly to one another throughout the 2022 calendar year and, by smoothing the data, helps to diminish the variance caused by the wide geographical distribution of the studied sites.

NDVI means were individually calculated per site per month, and these were compared to the data set as a whole. While, for example, other analyses of this data might have overrepresented New York State, the data in this dataset reduced it to its proportional representation in the set as a whole. Directly compared by this methodology, the studied natural burial sites in the eastern United States were 13.9% (SE=0.05) more verdant throughout the year as compared to their modern traditional counterparts ($P < 0.001$, n=20, paired t-test). The results of my four year-long 2022 NDVI analyses comparing the verdancy of both site modalities returned results ranging from 11.5-14%, all in favor of natural burial sites. When the Bonferroni correction is done on these tests, all of the P values were < 0.0125, indicating statistical significance.

NDVI by Month Analyses

While they largely support these results, monthly analyses showed greater variability. The alternative hypothesis sets a threshold of 10% greater verdancy to be expected in natural burial sites than in their modern traditional counterparts, but that such a wide variation would be found in every month seems unlikely. Accordingly, I conducted a series of analyses designed to indicate which months of the year most helped to establish the trend in NDVI over time. In order to conduct analyses on a monthly basis, I performed modified versions of the means and months first test.

The NDVI values had already been shown to be higher in natural than in modern traditional sites in every monthly analysis, and the reported percentage values showing the difference in each set per month echoed this trend (Figure 2).

The first monthly analysis test I performed was a month means paired t-test, which, with only 20 sets of data for each type of burial site (total of 40) to compare to one another, yielded the smallest number of statistically significant results (Figure 2). Of these, the natural burial sites that were studied in 2022 showed significantly larger NDVI values in the months of July ($P = 0.04$), August ($P <.001$), and September ($P = 0.02$). The results were just above 10%, ranging from 10.2% in July and September to 11.5% in August. Including statistically insignificant results, ranges for the year were lowest in April (P = 0.39) with 2.52%, to November (P = 0.14) with a 13.68% mean difference.

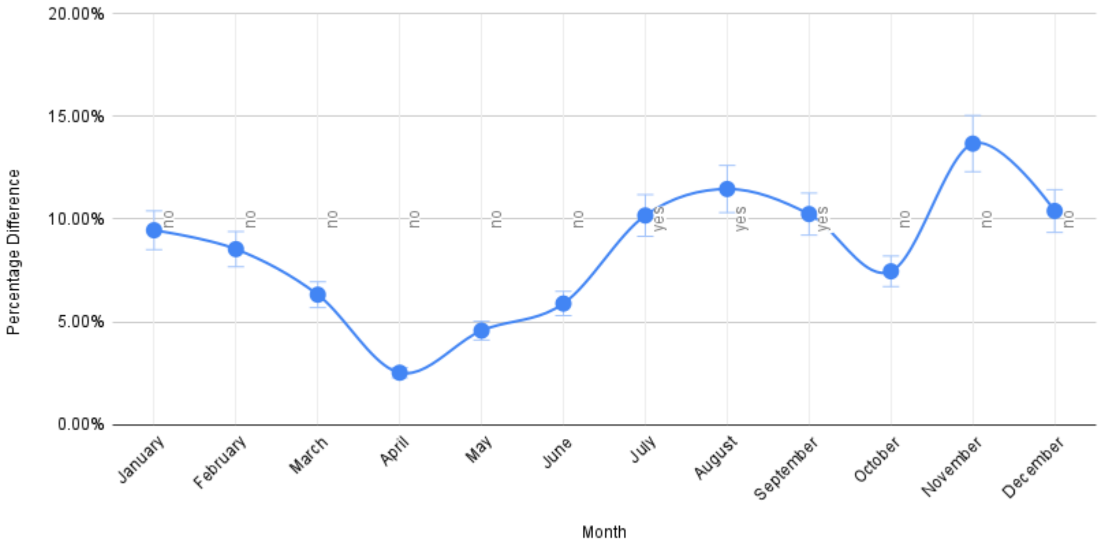

Figure 2. Differences in the mean NDVI values throughout the months of 2022. “Yes” and “no” values indicate whether the performed t-test returned a statistically significant result. The margins around the circular points on the graph are error bars.

The last monthly set of paired t-tests I performed was the months first analysis. This analysis also returned significantly positive results during the months of May (P = 0.034), June (P = 0.001), August (P = 0.002), September (P = 0.007), and October (P = 0.01) of 2022 (Figure 3). The lowest of all statistically significant results was again in May with 7.8%. All other significant results range from 10.5% in October to 14.6% in September, allowing me to reject the null hypothesis for those results.

Of this series of analyses, only the months of August and September returned statistically significant results every time, and each time these were over the ten percent threshold of the hypothesis. With the application of the Bonferroni correction calculation, the September month means analysis falls below the threshold of 0.016, but the other five analyses of these sets of data passed.

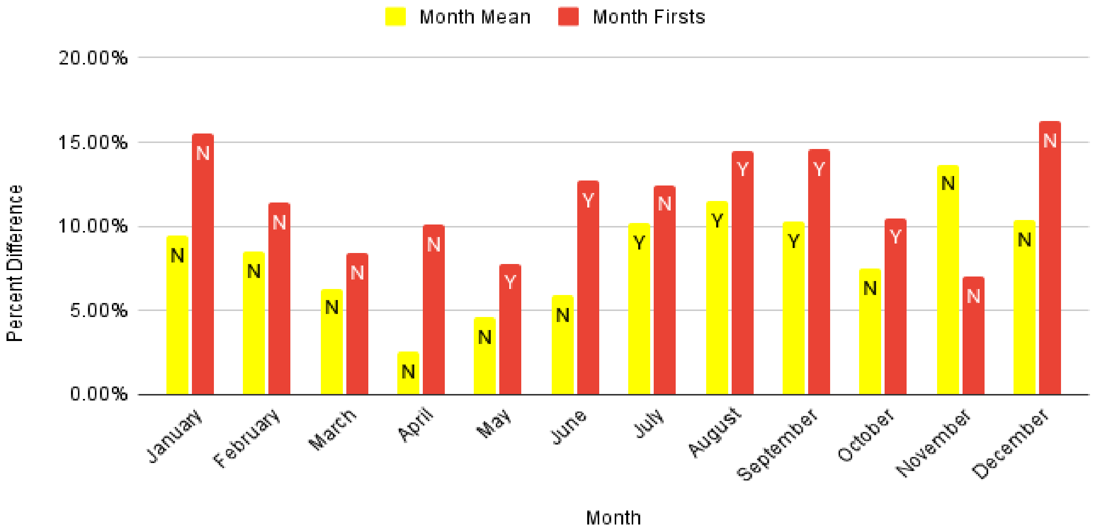

Figure 3. Comparison of month mean and month firsts through 2022. “Y” and “N” values refer to yes or no, and determine whether or not the performed t-test returned a statistically valid result.

Biodiversity

The mean SWDI value for the modern traditional burial sites calculated per site was 1.45, with individual sites ranged from 0.9-2.2. The mean SWDI values for natural burial sites was 2.7 and ranged from 1.7-3.3. The mean percentage difference for the paired sites was 45.6%, with every natural site higher than its paired traditional site (Figure 4). The Hutcheson t-test performed for all compared sites yielded a value of 3.28E-87, indicating that the null hypothesis can be rejected for the site-by-site data.

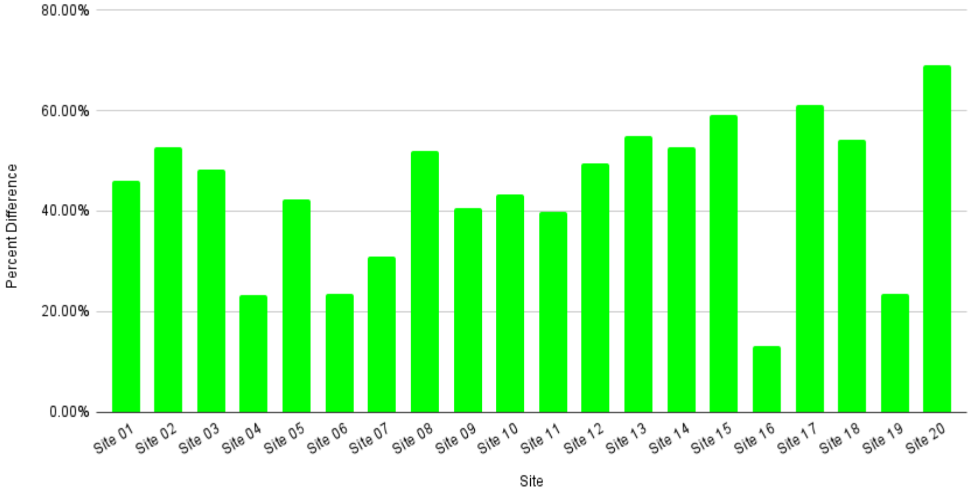

Figure 4. Difference in mean SWDI percentage values per site. Every natural burial site observed had a higher SWDI than its paired modern traditional counterpart.

The consistency of these site-by-site results from the paired sample design is missed if means for all the samples are instead compared (n = 360 for each burial type). Individual samples produced a mean SWDI value of 0.9 modern traditional sites and 1.2 for natural sites (SE=0.3). Non-zero SWDI values for modern traditional ranged from 0.07-1.7. Non-zero SWDI values for natural sites ranged from 0.2-2.1 (SE=0.31). The P-value of the Hutcheson t-test was only significant at 0.045, with the percentage difference between the means of these 720 data points was 31.5%. However, these individual samples are not independent when comparing sites, whereas the paired mean differences are statistically valid.

In every studied instance, natural sites had greater species richness than their modern traditional counterparts (Figure 5). Modern traditional sites had a mean of 12 (SE=5.5) species per site, and natural sites had a mean of 35 (SE=6.5), which constitutes a 191.7% increase in observed species richness at natural sites (P < 0.0001, n=20, paired t-test).

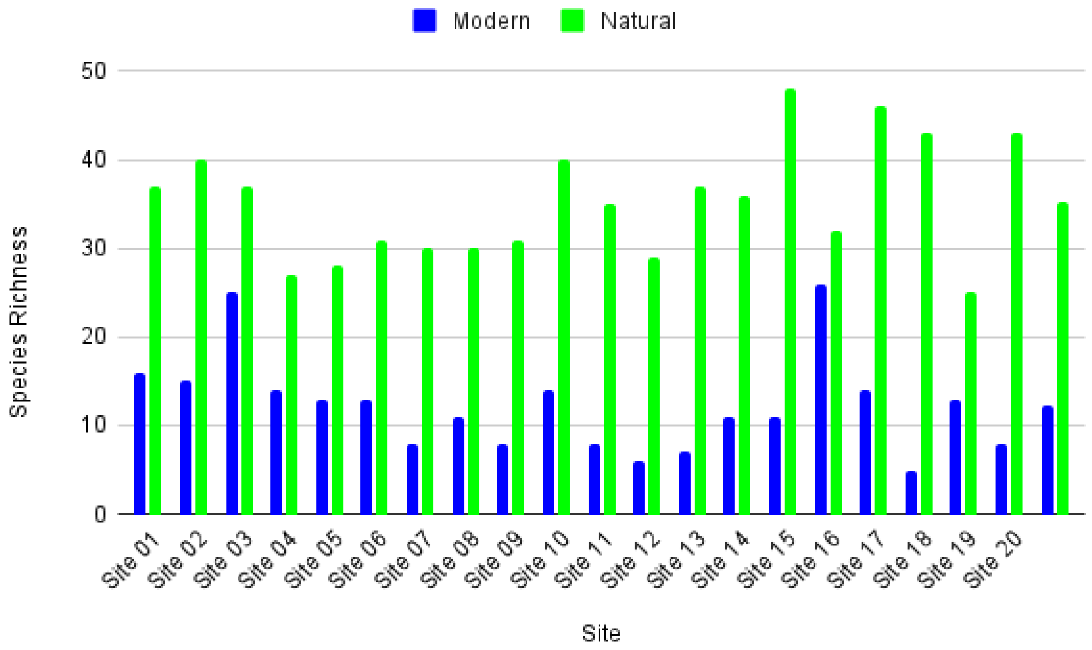

Figure 5. Comparison of the observed species richness at each site.

When calculating evenness for each site using Pielou's evenness index, the mean for modern traditional sites was 0.58, whereas the calculated evenness for natural sites was 0.75. This constituted a 22.4% mean difference (SE=0.09) in species evenness between paired sites, and was highly significant (P < 0.001, n=20, paired t-test). When calculated at a comparative sample level, mean species evenness per a modern traditional sample was 0.7, and the natural counterparts were 0.79; this constitutes a 9.1% mean (SE=0.17) evenness difference between samples in favor of natural sites (P < 0.0001, n =360, paired t-test).

Invasives

Invasive species were positively identified in six of the 20 (30%) of the modern traditional sites I visited with a nonzero mode of 1. Invasive flora were positively identified at 17 of the 20 (85%) of the natural burial sites I visited with a nonzero mode of 1. The nonzero richness of invasive flora at ranged from 1-3 at modern traditional burial sites, and 1-5 at natural burial sites. Of the 45 invasive species identified, 36 (80%) species were identified at natural sites, and 9 (20%) were observed at modern traditional sites. Natural sites had a mean of 1.8 invasive floral species per site, and modern traditional sites had a mean of 0.45 (SE=0.8), which is a statistically insignificant increase of 75% of invasive species in natural sites (P =0.2, n =20, paired t-test). When comparing nonzero means, modern traditional sites had 1.5 invasive species per site (SE=0.8), and natural burial sites had 2.12, a statistically insignificant increase of 29% (P=0.1, n =20, paired t-test).

Excluding sites with no invasive floral species, richness ranged from 6.3-14.3% of observed species at modern traditional burial site, whereas natural sites ranged from 2.3-12.9% observed species. The mean for invasive richness was 2.9% at modern traditional sites and 5.1% at natural sites, which constitutes a just barely statistically insignificant 42% increase (SE<0.05) in the natural burial sites (P=0.06, n=20, paired t-test).

The nonzero relative abundance of invasive species at modern traditional burial sites ranged from 2.4-37.3%. At natural burial sites, numbers ranged from 0.6-27.8%. The mean relative abundance of invasive species in modern traditional sites was 3.6%, and it was 7% at natural sites. This mean difference constitutes a statistically insignificant 49% increase (SE=0.3) in relative abundance of invasive species at natural sites when compared to modern traditional sites (P=0.3, n=6, paired t-test). The nonzero means for relative abundance at modern traditional sites was 12%, while it was 8.2% at natural sites, representing a statistically insignificant 32% (SE=0.09) increase in favor of modern traditional sites (P=0.1, n=6, paired t-test).

When the relative frequencies of invasive species as a class were compared, nonzero numbers from modern traditional burial sites ranged from 5.6-94.4%. Nonzero numbers from natural burial sites ranged from 5.6-44.4%. The mean relative invasive frequency at modern traditional sites was 10.6%, and the mean relative invasive frequency at natural sites was 15% (SE=0.2) which is a statistically insignificant 35.3% increase (P=0.2, n=20, paired t-test). Means of non-zero numbers from modern traditional sites returned a value of 35.3%, while means at natural burial sites were 17.7% (SE=0.2), representing a 50% increase in relative frequency of invasive species to be found at modern traditional burial sites (P=0.1, n=6, paired t-test).

The relative abundance of all invasive species in modern traditional and natural burial sites were compared: the mean at modern traditional sites was 30.3%, and 17.1% at natural site, which is a statistically significant 43% mean increase (SE=0.3) of invasive relative frequency at modern traditional sites (P=0.03, n=35, paired t-test).

Soil

The results of the soil organic matter from Clemson ranged from 2-11.5% with a mean of 5.96% for modern traditional burial sites. The results of the natural sites ranged from 3-7.6% and had a mean of 5.7% (SE=2.1) at natural burial sites. This 5.2% increase in soil organic matter at modern traditional sites was a statistically insignificant (P=0.2, n=20, paired t-test).

When the Clemson SOM data was converted to SOC via a conversion factor of 0.58, the resulting values were found to range from 1.1-6.7% at modern traditional sites, and from 1.7-4.5% at natural sites. The mean SOM value at modern traditional sites was 3.5%; the mean SOC value at natural sites was 3.4%.

When considering the data gathered from Esri using all data points gathered (Figure 6), soil organic carbon concentrations at the 30cm depth ranged from 12.9-43.8 g/kg at modern traditional burial sites, and from 14.9-43.6 g/kg at natural burial sites. The mean for modern traditional sites was 22.4 g/kg (SE=2.8), and the mean for natural sites was 23.9 g/kg, which is a statistically significant 8.3% increase in soil organic carbon at natural sites when compared to their modern traditional counterparts (p=0.03, n=120, paired t-test).

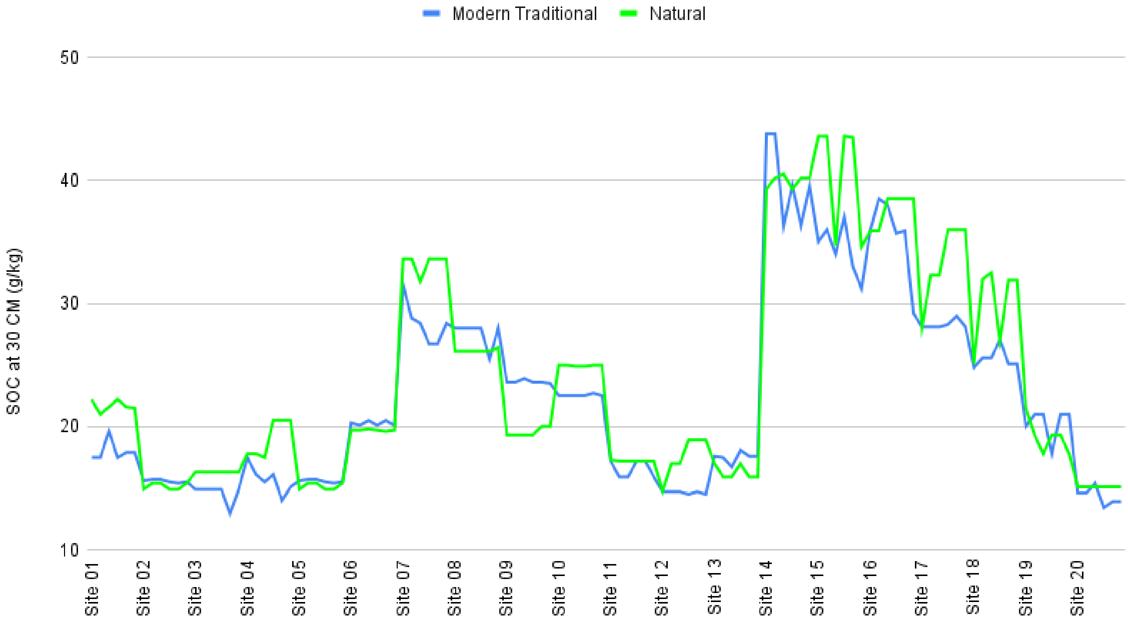

Figure 6. Comparison of the projected SOC values from Esri’s 30cm mark.

Esri-derived data regarding SOC at the two-meter mark at modern traditional burial sites had a range of 3.7-14.4 g/kg, and natural sites had a range of 3.8-15.1 g/kg. The mean for modern traditional sites was 7 g/kg, and the mean for natural sites was 7.3 g/kg (SE=1.2), which constitutes a statistically insignificant 6% increase in soil organic carbon observed from this data set (P=0.1, n=120, paired t-test).

When comparing mean site data from Esri at the 30 cm mark, results ranged from 14.3-39.9 g/kg at modern traditional burial sites, and from 15.1-40.6 g/kg at natural burial sites. The mean of the means from modern traditional sites was 22.06 g/kg, and the mean of the means was 24.22 g/kg (SE=1.2) at natural sites, which is a statistically insignificant 8.9% increase in SOC at natural sites (P=0.1, n=20, paired t-test). When undergoing the same analysis at the two-meter mark, results ranged from 3.9-13.43 g/kg at modern traditional sites, and 3.75-13.7 g/kg at natural sites. This constitutes another statistically insignificant 6.2% mean difference (SE=1.2) in favor of natural sites (P=0.2, n=20, paired t-test).

The results from the soil bulk density test returned from Clemson ranged from 0.74-1.34 g/cm^3 at modern traditional burial sites, and 0.76-1.16 g/cm^3 at natural burial sites. The mean for modern traditional sites was .92 g/cm^3 and the mean for natural sites was 0.93 g/cm^3 (SE=0.17. This constitutes a statistically insignificant .09% increase in soil bulk density at natural sites (P=0.3, n=20, paired t-test).

Chapter IV

Discussion

Given the paucity of available data on this topic from which I could formulate hypotheses, the results supported the predicted differences (Table 2). The natural sites had greater verdancy and biodiversity when compared to their modern traditional counterparts. However, the analyses of the relative presence or absence of invasive species was inconclusive due to a number of issues with the sample size that are discussed in the following sections. The results from the SOC and SOM analyses were confusing given that their percentage values were the inverse of what was predicted, although not significantly different. I discuss and clarify these findings and theorize about the reasons why this may be the case in the associated sections below. The only analysis that did not yield particularly meaningful results, however, was that of soil bulk density. Those findings are also discussed and accounted for below as well.

Table 2. Summary of most important results.

Analysis Portion	Analysis	Modern Traditional Mean	Natural Mean	% Dif	P-Value	Note
NDVI	Matched dates, paired t-test	0.47	0.5	12%	<0.001	All NDVI data derived from Landsat 8
NDVI	NDVI/2022 (First Matched Date of Month by Site), paired t-test	0.46	0.5	11.8%	<0.002	

NDVI	NDVI/2022 (Month Averages by Site), paired t-test	0.46	0.5	11.5%	<0.001	Unpaired dates
NDVI	Simple 2022 average of site, paired t-test	0.46	0.5	14%	<0.001	Unpaired dates
Biodiversity	Hutcheson t-test/site	1.5	2.7	45.6%	<0.001	
Biodiversity	Hutcheson t-test/sample	0.9	1	31.5%	0.046	
Invasive	Invasive richness, paired t-test	3%	5%	42%	0.06	Invasive calculated as class
Invasive	Invasive relative abundance, paired t-test	4%	7%	48%	0.1	Invasive calculated as class
Invasive	Relative invasive frequency averages, paired t-test	11%	15%	29.5%	0.2	Invasives calculated as class
Invasive	Relative frequency of invasives per plant, paired t-test	30%	17%	43%	0.03	Invasives relative frequency compared per species
SOM	Calculated as % of sample, paired t-test	6	5.7	5%	0.3	From Clemson University
SOC	SOC @ 30 cm (g/kg) (6 samples/site), paired t-test	22	24	8%	0.03	Derived from WOSIS/Esri
SOC	SOC @ 2m (g/kg) (6 samples/site), paired t-test	7	7.3	6.%	0.1	Derived from WOSIS/Esri
Bulk density	(g/cm^3), paired t-test	1555	1569	0.09%	0.4	From Clemson University

This table offers a brief summary of the results from my results section. Relevant numbers have been rounded for the sake of clarity.

NDVI

When I proposed the alpha hypothesis, I did not have any comparable data on which to base it, because there were no published studies that compared verdancy in natural and in modern traditional graveyards. The 10% threshold was thus highly speculative and was intended primarily to provide a cutoff point for the comparative analysis. Without data on which to base a judgment of whether it was too high or too low, I did not use it as a hard rule against which to measure my results. I was surprised that the annual NDVI comparisons tracked it so closely.

NDVI values between 0 and 0.2 are generally considered to be bare soil, and values larger than 0.5 are considered to be fully vegetated (Sobrino & Raissouni, 2000). With some rare exceptions, the 20 modern traditional sites I studied were relatively verdant, with a broad annual mean average of 0.46. This is lower than the 0.54 mean average value of their paired natural sites but the difference was statistically significant. . Thus, modern traditional sites likely make valuable contributions to proximate locations by functioning as urban, semi-urban, and peri-urban greenspaces. Despite being altered from natural vegetation, they still can perform functions that include, among other things, providing habitats for wildlife, reducing the heat island effect in cities, absorbing carbon dioxide, and increasing air quality (Kruize et al., 2019). It is common to hear these modern traditional sites described as being “environmentally devastating,” but the established, although relatively rare, research on the subject would not seem to support this stark depiction.

The observed trend of the divergence of NDVI values being relatively high at the beginning of the year, plummeting to its nadir in May, and then rising meteorically during the later months seems likely to be related to the maintenance paradigms for modern traditional sites. Frequently composed largely of grass-dominant co-cultures, modern traditional sites are usually kept artificially green throughout the year. The amount to which their surprisingly high annualized NDVI values can be attributed to this practice is currently unknown. The seasonal cycle of “boom” and “bust” for the species that comprise them, however, varies depending on their geographical location. For example, the January NDVI value of a burial site located in mid-Florida is unlikely to match the January value of a site located near the Canadian border.

I expect this study will be broadly useful in determining the relative verdancy of natural burial sites as compared to that of their modern traditional counterparts, but there are inherent caveats that should be taken into consideration. It is almost certain that the study would have yielded more affirmative results if its month-by-month section had been expanded longitudinally. The datasets used for the analysis can give information going back almost 10 years, but it was not within the scope of this study to set historical boundaries for both modern traditional and natural burial sites over such a period of time. Without the latter information, the former would not have been useful.

It might have been both possible and helpful to use data from two years in the study, but because environmental and temporal factors change from year to year, doing so would have been likely also to have added a great deal of noise to the results. An additional problem would have been that establishing historical boundaries for the burial sites becomes progressively both less certain and more difficult the further back the study extends from the present day. This is especially true in the United States, where the establishment of natural burial sites and their accreditation by the GBC is a fairly recent phenomenon. Future researchers with more access to establishment and accreditation data may want to incorporate broader longitudinal data into their analysis once these factors can more firmly be established.

Other problems with NDVI analysis are related to the nature of the data itself. Bilgili et al. (2013) studied NDVI analyses of parks located in urban settings and asserted since enviro-temporal factors relating to individual plant assets, phenology, and the specific function of a geological area regarding its ecological function are not accounted for in NDVI analyses, they should not be relied on exclusively for evaluating ecological health. While the authors found that NDVI analyses were quite useful for both initial, cursory and longitudinal investigations of urban and peri-urban greenspaces, they argued that these different ecological effects in a studied landmass might confound data or improperly reflect the health and value of greenspaces in urban and peri-urban environments.

Biodiversity

Speaking from gained experience with both natural and modern traditional burial sites, it should be noted that the P-value differences between these figures can best be explained by species distribution. New species commonly were found in most new samples taken from natural burial sites, where they were not in modern traditional burial sites. This factor served greatly to expand biodiversity between sample and site data, as was made rather evident by the calculations of Pielou’s evenness index.

Pielou’s evenness index considers the total number of species within an ecosystem as well as their relative abundance to indicate how evenly they are distributed. By this measure, most modern traditional burial sites, which were composed of two and rarely of three dominant floral species located densely in every sample taken, would be considered much less even than natural burial sites, where plants were far less densely packed. When dominance of a plant species could sometimes be observed at a natural burial site, it was not necessarily established in every sample taken. Flora at natural burial sites was likely to be composed of a greater variety of individual species as compared to that present at modern traditional sites.

The total number of individuals counted from modern traditional sites was 21,789, which came from 28 orders and 41 families (Figures 7 & 8). The total number of individuals counted from natural sites was 12,526, which came from 48 orders and 102 families (Figures 9 & 10). Grasses were easily the most well represented groups in modern traditional sites (Figure 11). Grasses and forbs were almost equally represented in the studied natural burial sites (Figure 12).

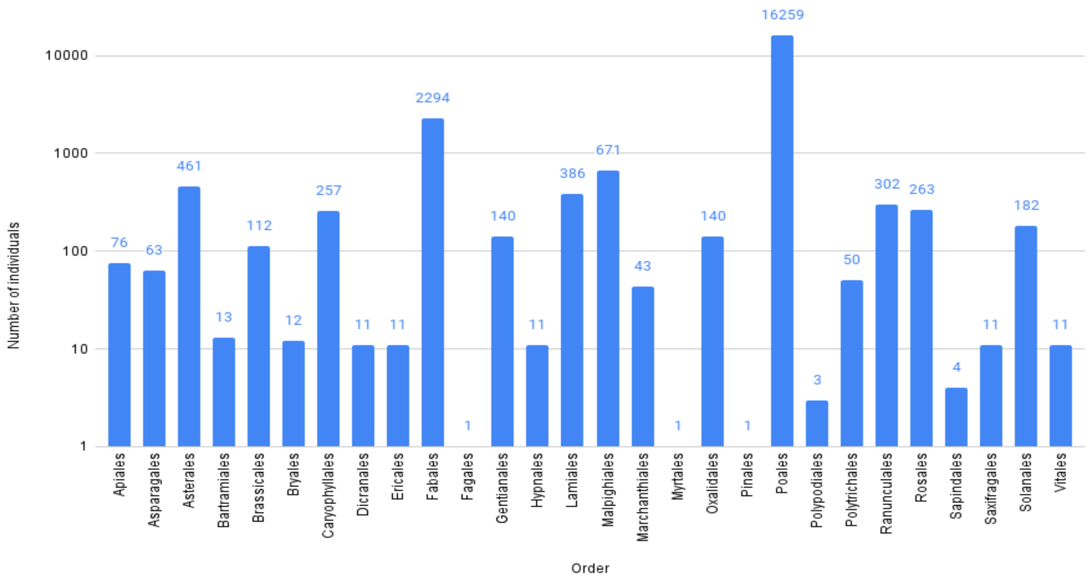

Figure 7. Bar graph of the number of individuals found from each order in all modern traditional burial sites. The y-axis is a log scale; the number of individuals from each order are above the columns.

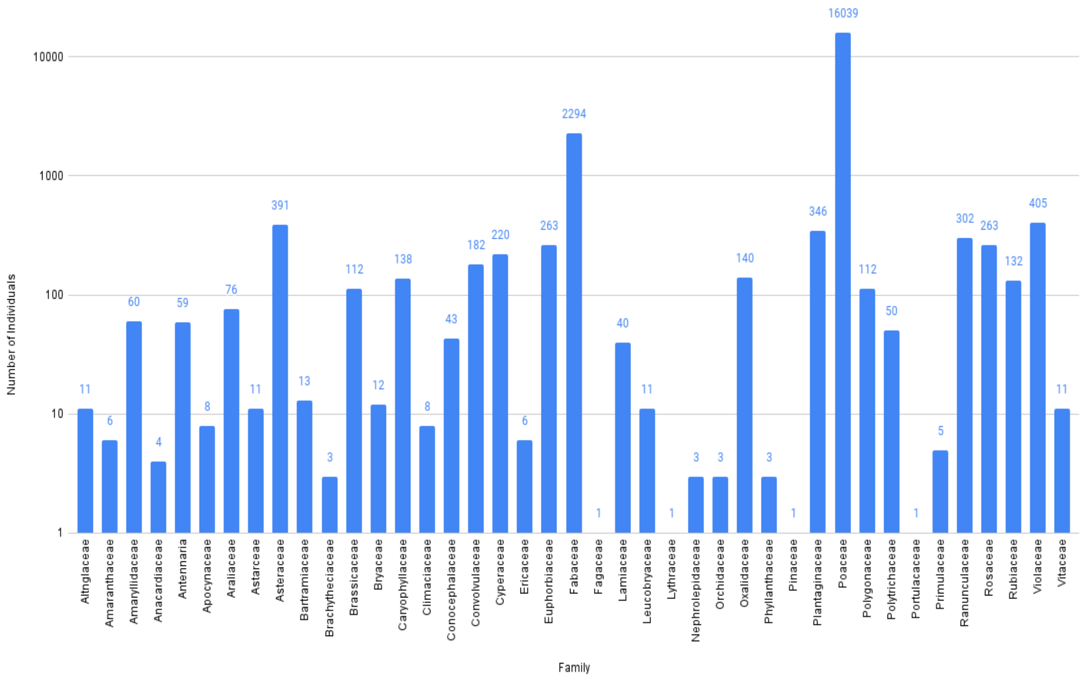

Figure 8. Bar graph of the number of individuals found from each order in all modern traditional burial sites. The y-axis is a log scale; the number of individuals from each family are above the columns.

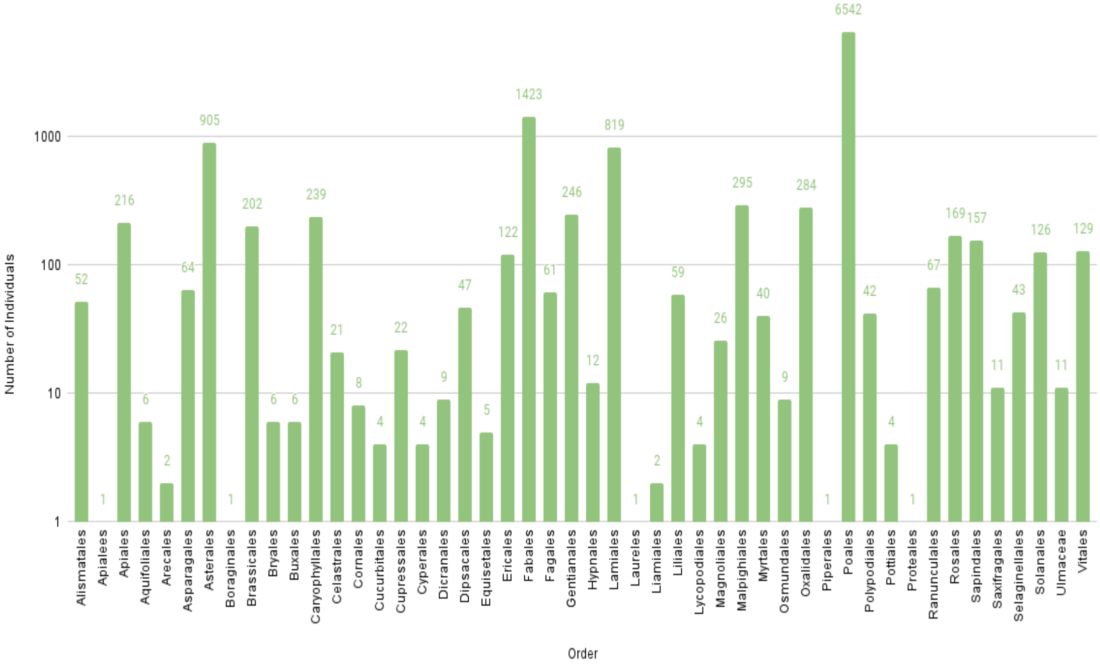

Figure 9. Bar graph of the number of individuals found from each order in all modern traditional burial sites. The y-axis is a log scale; the number of individuals from each order are above the columns.

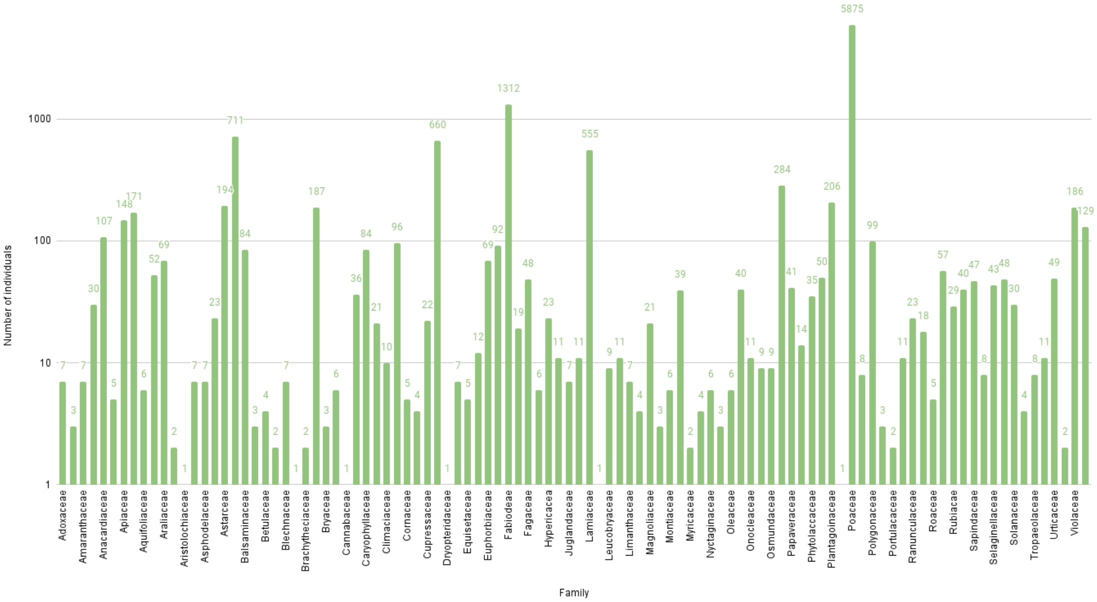

Figure 10. Bar graph depicts the number of individuals found from each family in all studied natural burial sites. The y-axis is a log scale; the number of individuals from each family are above the columns.

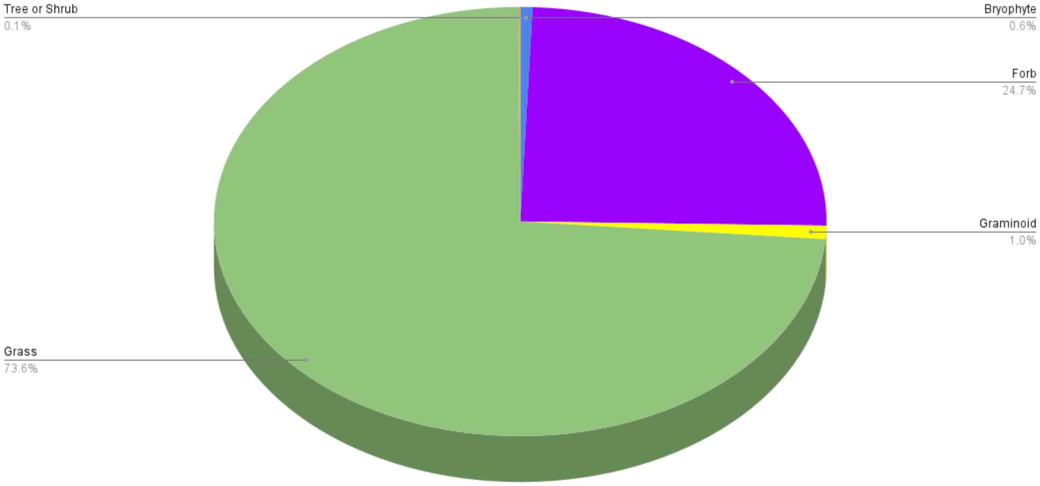

Figure 11. Pie chart depicting the floral category of modern traditional burial sites.

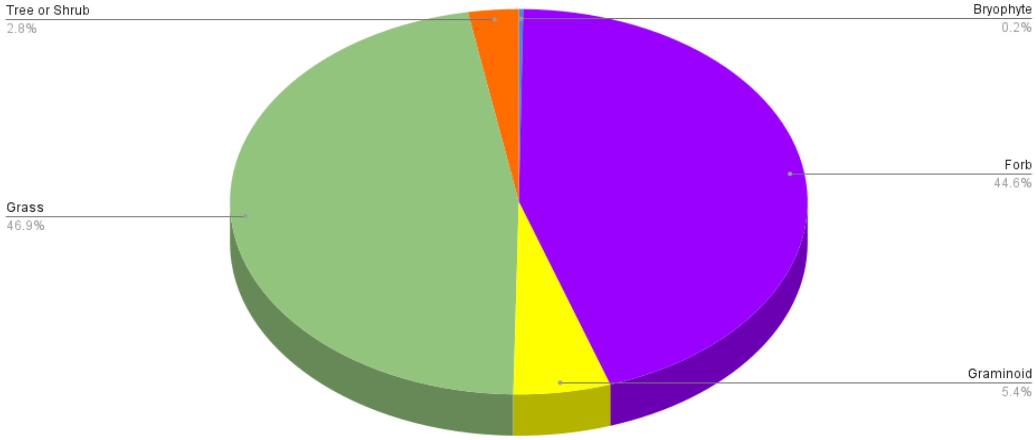

Figure 12. Pie chart depicting the floral category of natural burial sites.

While the common practice of intentionally planting and maintaining grasses at modern traditional burial sites was not part of this study, it is worth noting that some of the surprisingly rare studies that focus on American burial sites have recognized them as intermittently dispersed havens for local flora and fauna. (Löki et al., 2019). Recently published literature, however, has begun to push back on that contention (Cathcart-James et al., 2022). This thesis found that natural burial sites were easily more biodiverse than their modern traditional counterparts, but the latter still offered significant ecological benefits. Especially since they tend to go into periods of neglect over time, modern traditional sites can perform more ecological functions than the same parcel of ground would yield if it were used as a parking lot, or even as a sports field. Based only on my observations, it seems likely that the age of modern traditional burial sites could be useful as a predicter of their increasing biodiversity, but further study is needed before this can be stated with certainty.

The modern traditional sites used for this study had a mean SWDI of 1.45. This fits comfortably within the average SWDI of 1.2-1.6 that, without taking into account environmental and socioeconomic factors that might affect it, would be found in an average American front lawn in the eastern United States that was planted with dominant turfgrass (Wheeler et al., 2017). This comparison is especially appropriate when one considers that species richness in lawns is negatively correlated with the affluence of a household located in a typical metropolitan area in the eastern United States (Wheeler et al., 2017). It would be logical to infer that modern traditional burial sites that mow frequently and use chemical pesticides and fertilizers to maintain planted grasses would yield SWDI results similar to those of urban lawns with the same maintenance regimes.

The heightened biodiversity of natural burial sites as compared to their modern traditional counterparts when they were observed in the summer of 2022 makes it likely that ecological processes proximate to them will benefit in a number of ways, including increased soil protection, increased nutrient cycling, increased tolerance to grazing, and protection against the incursion of various noxious species (Pribyl, 2010). Future researchers may wish to consider the genetic variations among the different species present at natural and modern traditional burial sites. While it may seem axiomatic that burial sites that derive their floral communities largely from a deliberately homogenized source are likely to display less genetic diversity than burial sites that are often forested, a useful study could be done of the specific statistics associated with these factors. The environmental impact of the different burial styles becomes even more important when one considers that it is something that will ultimately affect every living person on Earth.

Invasive Species

Some of the important factors in this section of the analysis were not addressed by the performed paired t-tests. While it is indeed true that various species of invasive flora were more likely to be found at natural burial sites than at their modern traditional counterparts, their relative frequency and distribution tell a tale that was not reflected in the broader scope of this analysis.

I was surprised to find that regardless of the maintenance regime employed by modern traditional burial sites, invasive species were nearly absent; by contrast, natural burial sites frequently had a problem with the encroachment of invasive plants. The issue for natural burial sites is likely to be associated with a number of factors. But the main difference in the presence of invasive species between the two types of burial sites, however, had to do with the density of individual flora located within the single square meters that were studied.

The observed modern traditional burial site plant density per square meter was 61, while the observed natural burial site density was 35. This constitutes a mean increase of 57.3% (SE=6.7) (P=<.0001, n=360, paired t-test) in individuals at modern traditional sites as compared to those present in natural sites. It appears therefore that natural sites are much more biodiverse but plant distribution is much more spread out, which is partially why this section of the study showed an increased presence of invasive species in natural burial sites.

The number that would best seem to establish this trend best is simply the proportion of natural burial sites with invasive species as opposed to how frequently they were found at modern traditional burial sites. Only 30% of the studied modern traditional sites were host to at least one invasive species, but 85% of the natural sites had one or more. The fact that this did not return a statistically affirmative result indicates that there is a problem with the power of the study based on considering an insufficient number of samples. Future researchers may once again choose to incorporate longitudinal data into future data sets, and may also potentially wish to visit a greater number of sites.

Another problem regards the relative species richness of both styles of site. The mean richness of observed species as a whole at modern traditional burial sites was 12, while it was 35 for natural burial sites. This is at least partially why the relative abundance calculation failed. The denominator values for natural sites were much higher than those for modern traditional sites for nearly every paired observation. Additionally, when they were present, observed invasive species were far more dispersed in natural burial sites, and they exhibited clumped distributions when compared to their distribution at modern traditional sites. Although it was not a common occurrence, observed modern traditional burial sites were much more prone to being overrun with uniformly patterned invasive species than their natural counterparts.

The non-zero means and the invasive relative frequency by species paired t-tests both support these observations. These results imply that while invasive species may have some original difficulty in establishing themselves in modern traditional burial sites, once they are present, they are more able to exploit the proximate environment than they are in natural burial sites. If this is true, it further suggests that while natural burial sites tend to have a greater variety of invasive species present in their locations, their significantly increased biodiversity may make it more difficult for a given invasive species to find a vacant niche that will allow it to exploit the area. By contrast, modern traditional burial sites provide many more potentially vacant niches that are available for exploitation because of their relative lack of biodiversity, allowing individual invasive species enhanced opportunities to establish themselves and exploit the area. It is also likely that the practice of regular mowing at modern traditional sites disrupts the reproductive cycle of many invasive species by removing the above-ground biomass and preventing seed production, thereby reducing the ability of new invasive species to establish and spread within the local ecology.

I observed that noxious weeds were noticeably more present at modern traditional burial sites than at natural burial sites, but no formal analysis was performed to support this observation. Regardless of the intrinsic abilities of natural burial sites to combat invasive species, however, it seems likely that the biodiversity of these sites would benefit from more extensive homogenic attempts to control invasive species, especially if these could be undertaken by mechanical, rather than chemical means.

There are several other factors that may have some impact on the greater presence of invasive species in natural as opposed to modern traditional burial sites. One of these is the different maintenance regimes that the two kinds of sites employ. While modern traditional burial sites tend to maintain structured routines for mowing, fertilizing, and weeding, natural burial sites attempt to interfere with the local ecology to the least possible extent. The relaxed management method used by natural burial sites seems to offer several benefits to the ecology of the area as enumerated above, but it is likely to be accompanied by the risk of allowing natural burial sites to become vectors for invasive floral species to populate the surrounding area.

Another factor that may affect the presence of invasive floral species in burial sites is frequency of visitation. My observation of modern traditional burial sites was that they were visited much less frequently than their paired natural sites, although again this was not supported by data. What I was able to note with some confidence was that natural sites were often marked and used as hiking and recreational areas as well as sites for natural interment, especially when they were not directly adjacent to modern traditional burial sites. It was not uncommon to observe non-maintenance personnel with dogs present at the natural sites, as well as people casually walking in the adjoining forests. It is likely that at least in some instances such visitors might be agents for the accidental transmission of invasive species to the studied sites. This, along with the relaxed management style for such sites noted above, may allow invasive species to begin to colonize an area before they can be eradicated.

My theories concerning the relatively “lax management” style of natural burial sites is only anecdotally supported at this juncture, and would benefit from additional study and analysis. I observed several instances when clearly non-native ornamental vegetation had been planted on top of graves in sites that were designated as natural burial locations. These specific locations did not occur where I placed my quadrats, and thus were not accounted for in my formal analysis. However, I identified one species that I observed at a gravesite in North Carolina as *Senecio candicans,* and another I saw at a gravesite in Ohio as *Hemerocallis fulva*. It is notable that in both instances, the natural burial sites where these plants were observed were on-site paired with modern traditional sites. While it is understandable that people might wish to commemorate loved ones in this fashion, the planting of non-native vegetation is antithetical to the mission of natural burial sites. It is my opinion that continued accreditation by the GBC should be contingent upon monitoring and eliminating the deliberate introduction of non-native vegetation.

Soil Organic Carbon and Soil Organic Matter

I should have requested a full soil assay from Clemson for several factors including SOC, soil organic nitrogen, soil pH, and cation exchange capacity, rather than relying on a separate assessment of bulk density to test my hypotheses. Since it was at that point impossible to re-use the samples, I extracted relevant data by using WOSIS and Esri to further test my results. While these results were not completely satisfactory, they were useful in shedding light on how modern traditional and natural sites perform in their proximate ecologies.

The relationship between SOC and SOM is complex. While an increase in SOC will naturally lead to an increase in SOM, the inverse is not necessarily true. SOM and SOC are usually so highly correlated that it is common for soil scientists to use a conversion factor of 0.58 to translate SOM into SOC (Pribyl, 2010). For my purposes, however, it should be noted that the soil at both natural and modern traditional burial sites may have been managed in ways that affected their SOM content without affecting their SOC pools. It is for this reason that I am dubious about using the results of the standard 0.58 conversion factor.

Research has shown that the primary regulators of SOM stabilization and decomposition are climatic factors (Luo et al., 2016). In addition, the inclusion of nonorganic matter in soil composition, the spatial and temporal proximity and accessibility of SOM to decomposer organisms, and the interactions of those organisms with mineral surfaces in the soil can all significantly affect SOM composition and stabilization (Six et al., 2002).

Methods of land management, changes in the availability of nutrients due to fertilization or nutrient decomposition, and shifting environmental conditions have all been shown to affect SOM stability (Man et al., 2021). Differences in SOC between sites, therefore, may be indicative of the effects of any or all of these underlying factors on their respective soil ecologies. Since both modern traditional and natural burial sites are subject to inevitable repetitive stress, SOC is likely to be a more durable indicator than SOM of their relative ecological health. However, it is useful to be able to compare and contrast the two indicators to achieve a more complete understanding of the relative ecologies of the sites.

It is important to note that the method of measuring SOM in this study may also have affected the results. Specifically, Clemson University, using typical methodology for SOM analysis, may not have included leaf and dead vegetation litter in the calculation (USDA, n.d.). Because modern traditional graveyards are densely vegetated with intentionally planted grass flora , however, it is possible that their roots were included, which would have confounded the results. Frequent mowing in modern traditional graveyards may also have resulted in a higher density of decayed vegetation, which would have further skewed the data upon its comparison with results obtained from natural burial sites.

Modern traditional burial sites are typically composed of what is essentially a grassy field, where it is likely that SOM would be higher than that to be found in minimally maintained natural burial sites with numerous tall plants of different varieties. The grasses typical of modern traditional sites provide more organic material to the soil and decompose more quickly, releasing essential nutrients and thereby increasing SOM (Cambardella & Elliott, 1994). In natural burial sites, however, SOM would be more varied, because different plants require different types of nutrients and organic matter unlikely to be found in a broadly homogenized area that is routinely maintained with artificial substances.

Frequent digging, which is typical of both modern traditional and natural burial sites, has been shown to decrease levels of both SOM and SOC due to the trauma it causes to mycorrhizal connections and root structures as well as to its disruption of the micro-and mezzofaunal activity (Ross et al., 2019). Digging also has an inevitably deleterious effect on soil structure by compacting and fracturing its mineral constituents and subjecting them to erosion (Ross et al., 2019).

Since the soils of both modern traditional and natural burial sites are subject to similar repetitive stress caused by digging, the major factors affecting their relative SOM and SOC levels are likely to be most directly affected by their different maintenance regimes. These differences are particularly notable in the variance found between the 30cm and 2m SOC pools. Further refinement of these results yielding a more thorough understanding of the dynamics of SOM and SOC might be derived from a comparative analysis of particulate organic matter with mineral-associated organic matter, a study may be undertaken by future researchers in this area.

One of the factors with the most direct impact on SOM is mowing. Depending on its frequency and on the type of vegetation being mowed, it can have either a positive or a negative effect (Li et al., 2017). The soil in a relatively biodiverse modern traditional site can benefit from a nutrient-dense cocktail of plant matter being returned to it on an intermittent basis. However, if the site is mowed too often, mowing can reduce the amount of SOM because the soil will consistently be depleted of nutrients, and, in a modern traditional site, is likely to be supplemented with fertilizer to repair the perceived deficits in its aesthetic value (Li et al., 2017). If the mowed plant material is removed rather than being allowed naturally to decay, the problem is exacerbated.

On the other hand, the kind of infrequent mowing which is common at natural burial sites, may have a positive effect on SOM content by creating a more stable environment for microbial activity and by providing a layer of protection for the soil against erosion (Ontl, 2012). This can help to raise the SOM value of natural burial sites as compared to their artificially supplemented modern traditional counterparts (Ontl, 2012). SOM can further be increased by the presence of perennials, which are more common at natural burial sites. With their thicker foliage and deeper, thicker roots, perennials provide both more organic material and superior protection for decomposers in the soil (Ontl, 2012). In contrast, annuals have shallower roots and do not provide the same level of protection against water erosion when they die at the end of the season (Gyssels et al., 2005).

Fertilizer can, obviously, have both positive and negative effects on SOM. On one hand, when it is applied properly it can increase SOM by supplying essential nutrients for organic matter decomposition (Food and Agriculture Organization, n.d.).

Overapplication, however, can cause nutrients to leach from the soil, potentially reducing its associated carbon (FAO, n.d.). This is especially true if synthetic fertilizers are employed (FAO, n.d).

Synthetic nitrogenous fertilizers, commonly utilized in lawn maintenance as well as in modern traditional burial sites, have the ability to increase SOM content in the short-term by stimulating plant growth and thus increasing the amount of organic material entering the soil. However, these fertilizers do not necessarily lead to an increase in soil carbon, since the increased microbial activity they produce can also promote carbon leaching (Lazcano et al., 2021). The leaching is caused by the manner in which synthetic nitrogenous fertilizers disrupt the delicate balance of soil microorganisms, leading to an over-abundance of microbes that consume and release carbon from the soil at a faster rate than it can be stabilized and incorporated into the SOM pool (Ren et al., 2020).

High levels of SOC accompanied by low levels of SOM may be found at natural burial sites for a variety of reasons. One of these is the frequently forested nature of such sites, which promotes a high rate of decomposition and mineralization of organic matter (Quan et al., 2014). During this process, microorganisms such as bacteria and fungi consume organic matter and release CO2 and other gasses as byproducts, reducing SOM by breaking down organic compounds into smaller, more easily lost inorganic molecules and dispersing organic material throughout the environment as decomposition continues (Bridgham & Ye, 2015). However, more research on this topic would be needed to test the validity of this conjecture. Another factor that may contribute to the variance in the levels of SOC and SOM is that woody material such as fallen twigs and branches have high carbon content that takes some time to decompose and to be incorporated into the soil (Cragg et al., 2020). It is for this reason that SOM analyses do not account for woody vegetation (USDA, n.d.). This factor suggests a temporal aspect involved in calculations of SOM not previously accounted for in this analysis, which is compounded by the fact that natural burial sites are relatively new phenomena. It is quite possible that SOC levels in natural burial sites may not have had sufficient time to incorporate all the contributing factors as compared to their modern traditional counterparts.

The statistically significant 8.3% increase in SOC found in the Esri data at the 30cm depth in natural sites indicates that their ecologies have greater diversity in vegetation and greater complexity in their food webs than modern traditional sites, resulting both in an enhanced ability to store carbon and in high microbial activity and diversity in soil micro and mezzo fauna (Ontl, 2012). My biodiversity analysis also serves to confirm this assertion.

These factors indicate that natural burial sites have well-established food webs and are actively cycling nutrients from the top layer (Ontl, 2012). Further, they indicate that natural burial sites have well-developed soil structures and thus are less prone to erosion (Ontl, 2012). Future researchers may want to study potential erosion and possible desertification from both modern traditional and natural burial sites. It should be noted in context, however, that effluent from natural burial sites is likely to be less detrimental to the surrounding environment than that from modern traditional sites, since it does not carry the load of fertilizers and pesticides typical of the latter.

The difference in Esri data for the two-meter depth is not statistically significant, but the relative lack of variation between the results of natural and modern traditional sites was also interesting. It should be noted that Esri data is based on projection rather than specific sampling, which may become more difficult as depth increases. It is also notable that the average depth of burial varies considerably between the two types of sites. While there is no absolute standard for burial depth, bodies are generally interred in shallower graves at natural sites than they are in modern traditional burial places (Webster, 2016).

One possible explanation for the level of difference between the two types becoming insignificant at a greater depth is that the 30 cm depth has a higher rate of decomposition and mineralization of organic matter than the soil at the 2-meter depth. This is logical given the potential availability of organisms that can competently break down a body, regardless of whether or not it has been embalmed. Another possibility is that there may be physical, chemical, or energy conditions common to the soils of both modern traditional and natural sites at the 2m depth factoring into the decomposition of an embalmed or unembalmed decedent not accounted for in this section of the analysis. It is also quite possible that the relatively recent emergence of natural sites has not allowed them fully to develop edaphic factors that will be further established over the ark of time. Additional research on this matter is needed.

Bulk Density

My soil bulk density hypothesis was based on the supposition that natural burial sites would be more porous than their modern traditional counterparts because of the action of the numerous roots from the various plants that they contained holding soil together. However, in formulating the hypothesis I did not consider the fact that limiting my selections of paired sites to those located within the same zip code did not allow for a sufficient difference in the morphologies of the studied soils for it to be reflected in my findings. I also did not account for the fact that the soils in both types of burial sites were similarly stressed by frequent digging, which may have served further to normalize their morphologies. My initial assumption was that the bulk density of a given soil would be determined by a combination of its composition, its texture, and most importantly by its SOC. Even after realizing the problems with my initial hypothesis formulation, I am still surprised that the difference in bulk density between natural and modern traditional sites was so small, and the statistical noise so great.

One of the most important factors that influences a topsoil's bulk density is climate. The variations caused by different climates result in differences in soil temperature and moisture, both of which affect bulk density; conversely, when the climate is essentially identical, soil bulk density tends to be more closely matched (Upadhyay & Raghubanshi, 2020). I tried to control for climate variations by selecting paired sites within the same zip code, but in formulating my hypothesis I did not consider the role that matching climate would play in potentially normalizing the bulk density of modern traditional and natural burial sites.

Another important factor affecting bulk density is land use. The way land is used affects the fertility, the structure, and the SOM content of the soil, which can cause variations in its bulk density. Because soil bulk density is so closely linked to soil type, climate, and land use, it is understandable that the bulk densities of soils located within the same zip code that are both subjected to frequent digging would have similar bulk densities.

A final factor that may have tended to normalize bulk density findings between modern traditional and natural burial sites is the possibility that the former may have made use of aeration. Aeration is a landscaping technique that is used to promote good soil structure and root development. It involves making small holes throughout the soil to allow for better drainage and increased oxygen levels. This process can also reduce soil bulk density by improving soil structure and allowing for better movement of water and nutrients toward plant roots (Zeldovich, 2019). Plants with shallow root systems like many turf grasses that have been treated with fertilizers tend to receive the most benefit from aeration (Zeldovich, 2019). Since these are the types of plants that are most often found at modern traditional burial sites, it is likely the employment of aeration as part of a maintenance regime would tend to align soil bulk density results from modern traditional sites with those derived from natural burial sites.

Areas for Improvement of Burial Sites

The following section is not based on hard data. Rather, it is gathered from the observations I made while visiting forty modern traditional and natural burial sites located in the eastern United States. While many of the claims made by the GBC were validated by analysis of the data I was able to collect, others were subject to challenges that could be derived from the same data sets. The following observations are anecdotal. They do, however, provide some suggestions for ways in which both modern traditional and natural burial sites might be improved.

One of the most surprising things I encountered while visiting natural burial sites was the extent to which their quality varied. All of the natural burial sites I studied were at minimum licensed by the GBC, but it was unclear to me whether they were subject to any kind of routine inspection in order to maintain their status. If not, such inspections would seem to be advisable.

Especially when I was visiting on-site paired locations, it was not uncommon for me to observe items like plastic plants, dolls, food wrappers, and other detritus littering natural burial sites that were supposed to be maintained in pristine condition. While litter was less common at unpaired natural sites and at conservation sites, it was still present. Understandably, many natural burial sites operate with limited budgets and encounter challenges in managing biodiverse ecologies, but controlling the incursion of litter into natural burial sites should be prioritized.

I also observed several grave sites in natural burial grounds that were adorned with non-native charismatic vegetation or with non-native and slightly processed natural materials such as painted seashells or rocks. It is understandable that people may wish to commemorate their loved ones with such tokens, but it is central to the mission of the GBC and the natural burial movement that the environment in natural burial sites be maintained in pristine condition. It might be helpful for natural burial site locations to sell locally sourced charismatic natural flora for graves. They might also offer clients the option of using biodegradable chalk on locally sourced stones to mark gravesites.

In cases where modern traditional and natural burial sites are on-site paired, maintaining ecological health is essential to their mission and should to the extent possible be used in the maintenance regime for the modern traditional site as well as for the natural one. Using green manure and composted plant matter from the modern traditional site on the natural site, foregoing nutrient loading chemicals in favor of more environmentally sustainable soil amendments, and focusing on planting native grasses as opposed to grasses that may be engineered to remain green where other grasses do not would all help to achieve these goals. Such accommodations would obviously need to be weighed against potential issues associated with the potential release of GHG emissions from decaying plant matter, but they are nonetheless worthy of consideration.

Research Limitations

One of the primary limitations of this thesis is that it is broad, rather than deep. It is correlational in nature, and the methodology employed is insufficient to establish causation for the effects that it reports. Because ecosystems are complex, dynamic, and highly interconnected, there may be patterns affecting these systems that would not be apparent in the data collected and analyzed for this thesis. Rather, it should offer a starting point for future researchers to use methodologies that will allow them to explore specific topics in greater depth.

Sample size is another limiting factor to the usefulness of this thesis. I was able to visit only about half of the natural burial sites in the United States, and these were located in areas with widely divergent ecological characteristics that likely introduced significant variance. To mitigate against this factor, I compared the data collected from each natural burial site to that collected from a modern traditional site matched as closely as possible to it in size, elevation, location, and average rainfall and temperature. I am aware, however, that the sample size and the difference in situation of the data collection sites may have added significant noise to the data

Finally, the usefulness of this research may be limited by its lack of control settings for comparing natural and modern traditional burial sites. State and national parks have similar levels of human intrusion to those found in burial sites, and might have been useful for that purpose. However, such parks are relatively scarce in the same zip codes as modern traditional and especially as natural burial sites. A further limitation on the usefulness of parks as controls is that the microceres found in burial sites have unique qualities that are typically not found in other settings.

A small body of research contends that roadside verges, which are subject to the same kinds of maintenance and habitat fragmentation as modern traditional burial sites, serve an ecological role similar to that of floral habitats in urban and peri-urban settings (Fekete et al., 2017; Löki et al., 2019). Verges would not have been useful as control samples for this thesis, however, both because they do not occupy spaces that are readily comparable to burial sites, and, again, because they do not typically house human remains and thus incur the soil conditions resulting from the byproducts of decomposition. Future researchers who do similar studies may wish to formulate methodologies for establishing control variables in the same relative areas for both modern traditional and natural burial sites in order more directly to assess their environmental effects.

Conclusions

The research I conducted for this analysis serves to validate many of the natural death care industry’s assertions, and provides insights that should prove useful in planning future burial sites. The data supported my hypotheses regarding the relative verdancy and biodiversity of natural sites compared to their modern traditional counterparts, but findings concerning the presence and prevalence of invasive species in paired sites was more ambiguous. Analyses of the data indicate that natural burial sites have significant advantages over modern traditional sites in the areas of vegetation cover, of species diversity and composition, and of soil health and fertility, although some findings were not conclusive. My hypothesis regarding the organic carbon content of soil was confirmed, but the organic matter data made the results more confusing. The only hypothesis that did not render a particularly useful insight was the soil bulk density test, and the reasons why were easily understandable in retrospect.

Information was collected for this study with the hope that it would be useful to ecologically conscious individuals, to scientists, and to policy makers interested in the topic. Like natural burial sites themselves, our understanding of the ecological effects of burial sites is still in its infancy, and this study is intended to lay the groundwork for new research in more specialized areas. Despite the ubiquity of modern traditional burial sites, literature regarding their ecological impacts is surprisingly scarce, while scientific literature that examines the claims advanced by the natural death care industry is, at best, not readily available to the public.

The holistic approach that is central to the design of this study is intended to be wide rather than deep. I hope that the baseline data it provides will be useful as a springboard for more in-depth examination of specialized areas. It is also my hope that this study will serve to provide insight for the design, management, and regulation of future burial sites, and will help interested parties make informed decisions regarding end-of-life care for themselves and for their loved ones.

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