Phase 1 Project Report

Optimizing Reforestation Strategy for Carbon Storage

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by
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This report summarizes the methods, data collected, and findings of Phase 1 of Carbon Sequestration in Reforestation. Included are reflections and lessons learned, feedback from a student intern, and goals for future work and research in Phase 2.

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Workplan Summary (April 2025 – June 2026)

Up to 200 soil samples were collected from existing reforested sites, unplanted areas, and high-quality forests. Each sample was analyzed for texture, total organic carbon (TOC), soil organic matter (SOM), and basic nutrient composition. These analyses help us better understand the relationship between SOM and TOC, determine differences between planting and management style, and establish a background and reference condition for coastal Delaware soil carbon.

Reforestation with the Delaware Center for the Inland Bays

Since 2014, The Center completed over 30 reforestation projects ranging in size from 0.1 acre to 80 acres (Figures 1 & 2). The Center primarily employs two planting styles: traditional forests with rows of trees and shrubs 10-12 feet apart and Mini-Forests with dense clusters of trees and shrubs and larger spaces between individual forests. Plants were generally planted at a density of 800-1000 stems per acre with bare root plants planted in the spring. Variations in the size of the initial planting material, season of the planting, and planting pattern are known to result in different efficacies as does weather, water availability, soil health, and the type of planter (professional vs. volunteer). The Mini-Forest planting method was not employed until 2023; therefore, those plantings are significantly younger than most of the traditional plantings. Documentation and monitoring of these sites provides The Center with valuable information on the health, success, and carbon storage potential of these sites. These data can be used to inform future reforestation goals and decisions to continue improving the health of the Inland Bays watershed.

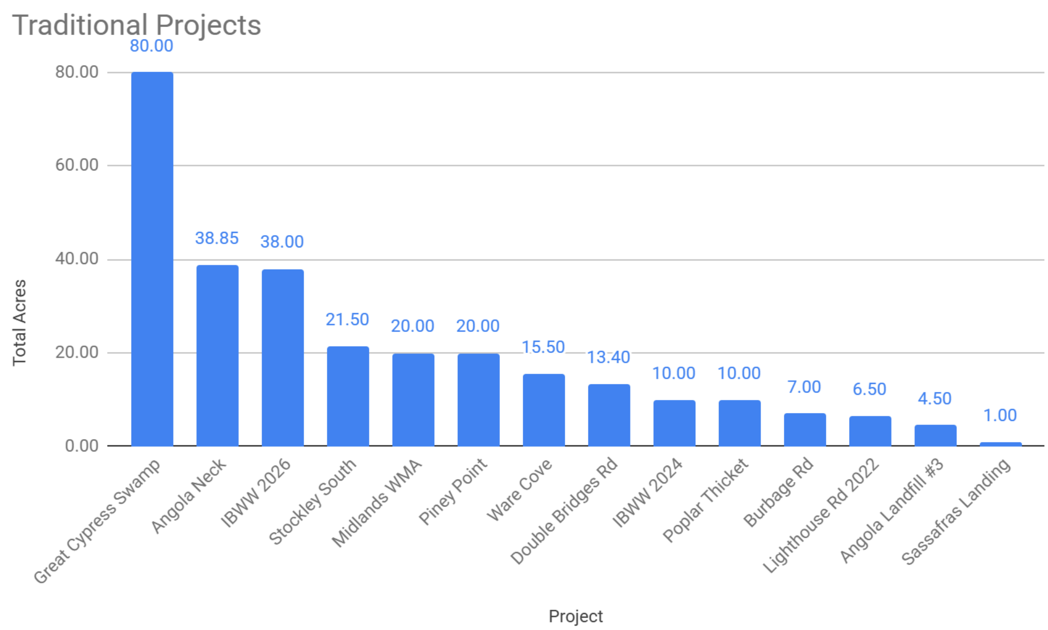

Figure 1. Acres per site for traditional plantings. Note: IBWW stands for Inland Bays Wastewater Treatment Plant and WMA stands for Wildlife Management Area.

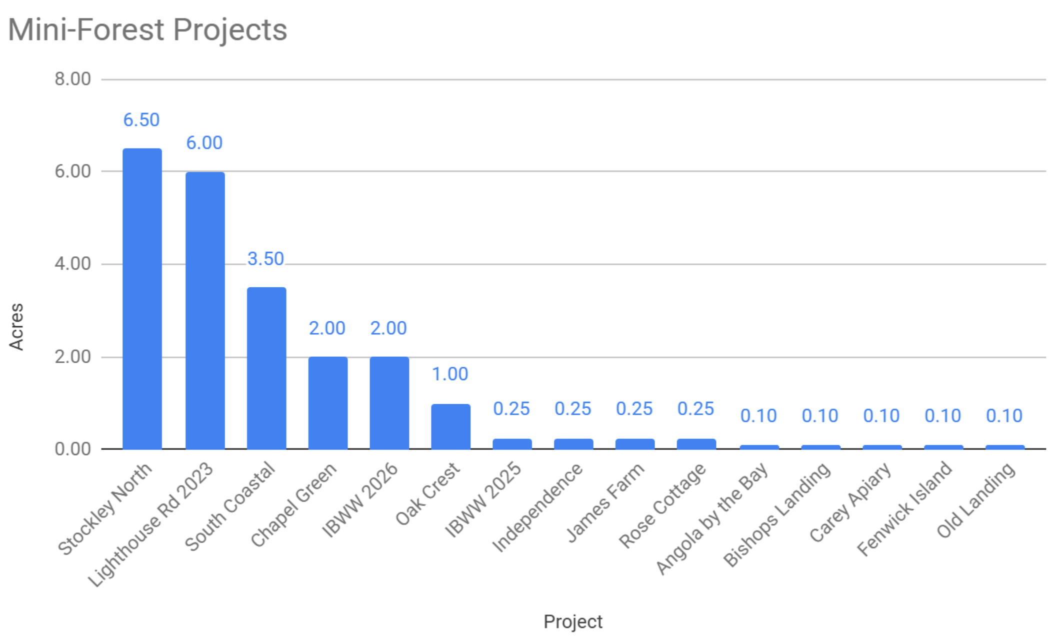

Figure 2. Acres per site for Mini-Forest projects. Total acreage includes the entire area to be reforested, including both the dense clusters of plants and the surrounding managed landscape. *Note: IBWW stands for Inland Bays Wastewater Treatment Plant.*

Reforestation Monitoring & Maintenance

Beginning in 2023, we attempted to revisit all previous plantings. Permanent monitoring plots within reforested areas are now designed to be visited at 0, 1, 2, and 6 years post-planting. Within each plot, we collect woody plant count, height, diameter at breast height (DBH), and species. Within three 1 m^2 subplots, we observe the canopy cover, invasive species, and leaf litter as well as collect soil cores to a depth of 15 cm.

Relationship Between Soil Organic Matter & Total Organic Carbon

Soil organic matter (SOM) is a standard low-tech approach to understanding fundamental soil health (NRCS Soil Organic Matter). Total organic carbon (TOC) is a metric used to understand carbon sequestration (NRCS Soil Quality Indicators). SOM is composed of more than just carbon, resulting in a linear but location-specific relationship with TOC. Variation in the relationship is generally due to underlying geology (Barre et al., 2017). Therefore, a location-specific relationship of SOM to TOC must be developed to calculate TOC from SOM. Based on about 50 soil samples (Figure 3) processed at the University of Delaware, we have established a relationship between SOM and TOC in the Inland Bays watershed (Figure 4).

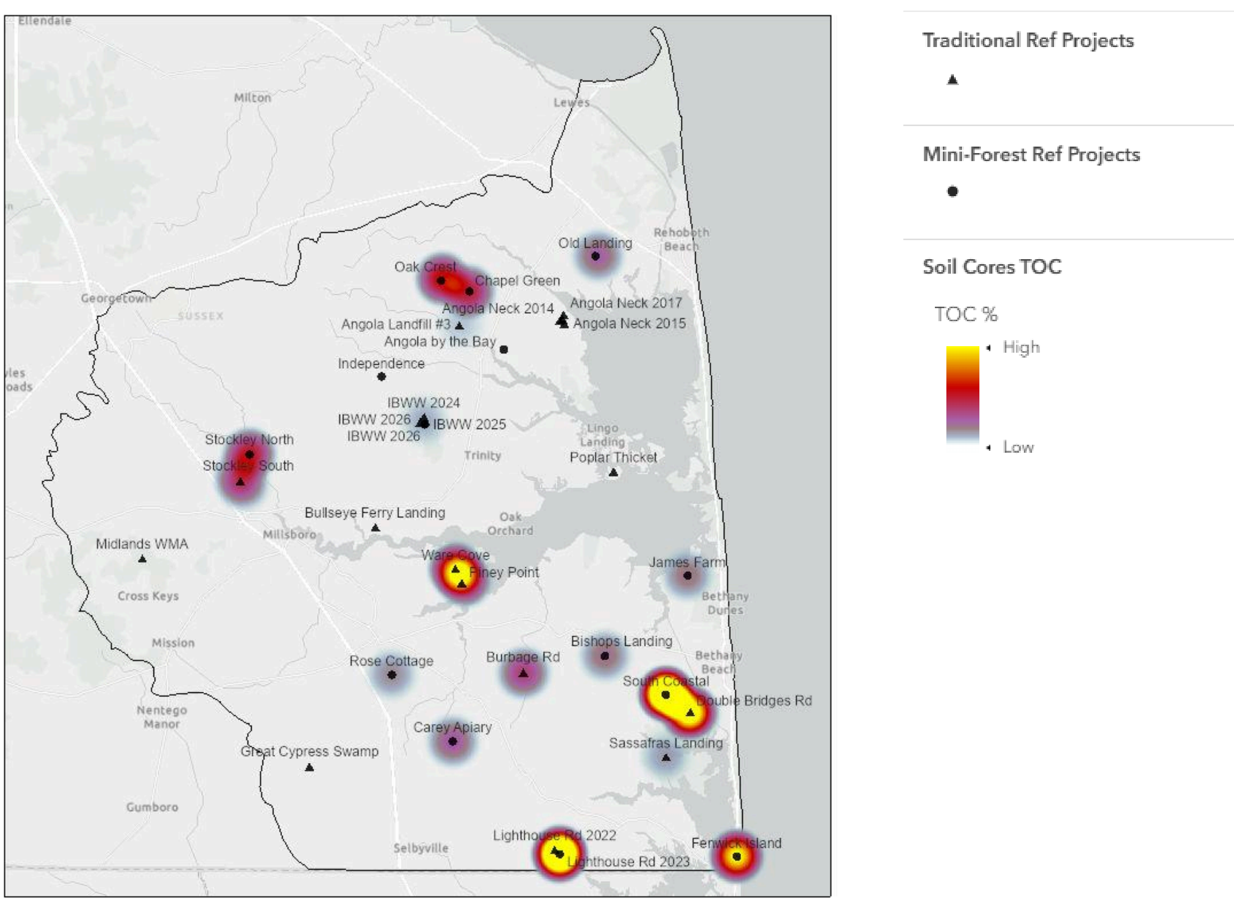

Figure 3. Spatial distribution of soil core samples and their relative measured TOC values.

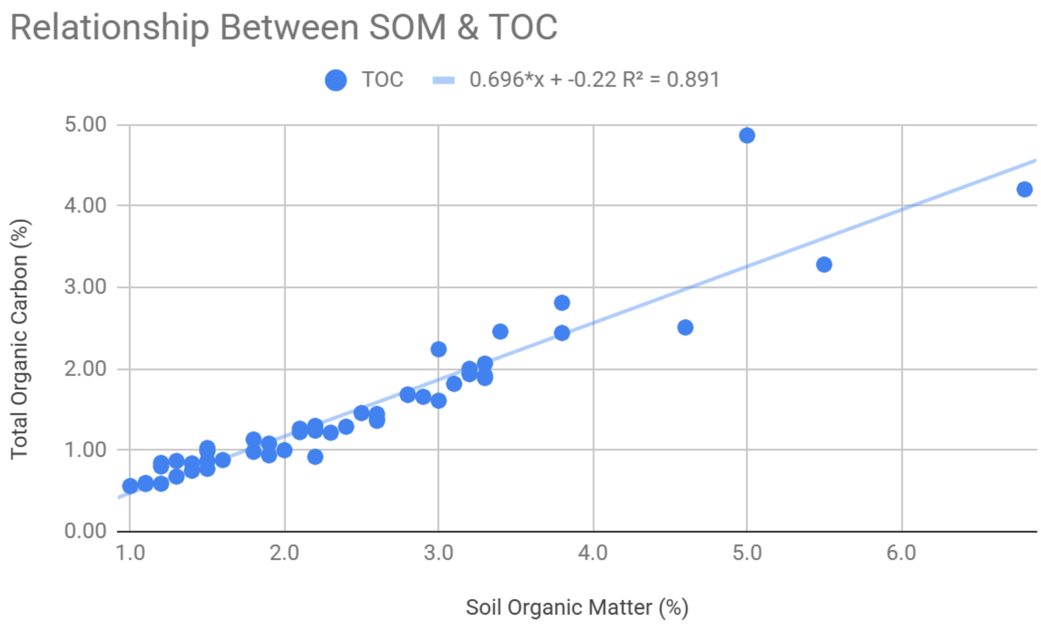

Figure 4. Relationship between SOM and TOC in the Inland Bays watershed.

We found that the Fenwick Island Mini-Forest site has the highest average TOC (13.13%) pre-planting while the Inland Bays Wastewater Treatment Plant 2025 Mini-Forest site has the lowest average TOC (0.63%) pre-planting. Both of these extremes are related to land use. The Fenwick Island site has 85% cover of invasive running bamboo which has created a thick duff layer. The IBWW site has been actively managed and recently undergone extensive clearing and land shaping which removed much of the topsoil. These two extreme conditions provide realistic bounds on the dataset with the median and average TOC across all soil samples being 1.22% and 1.54%, respectively.

As mentioned before, underlying geology is a strong location-specific driver of TOC. As land managers, we do not have much influence over this factor, but ground cover *is* within our control. Across all plantings, the number of trees per acre observed on site is strongly correlated with TOC with higher tree density resulting in higher TOC (Figure 5). The mechanism for this relationship is the higher rate of SOM incorporation through either root growth or aboveground cover (NRCS Soil Quality Indicators). We did not measure root growth; however, leaf litter shows a weak positive relationship with TOC (Figure 6). Many of the plantings showed low leaf litter coverage, in general, with the highest coverage being around 35%. This suggests leaf litter presence and decomposition rates may differ in the DelMarVa region compared to other physiographic provinces. For example, 5-year-old Mini-Forest plantings in the Piedmont have 75-95% leaf litter cover (Noe Fellows & Frederick, 2024). The Mini-Forest plantings in the DelMarVa region are all younger than the ones observed in the Noe Fellows & Frederick study and the smaller, immature trees may not be generating as much leaf litter.

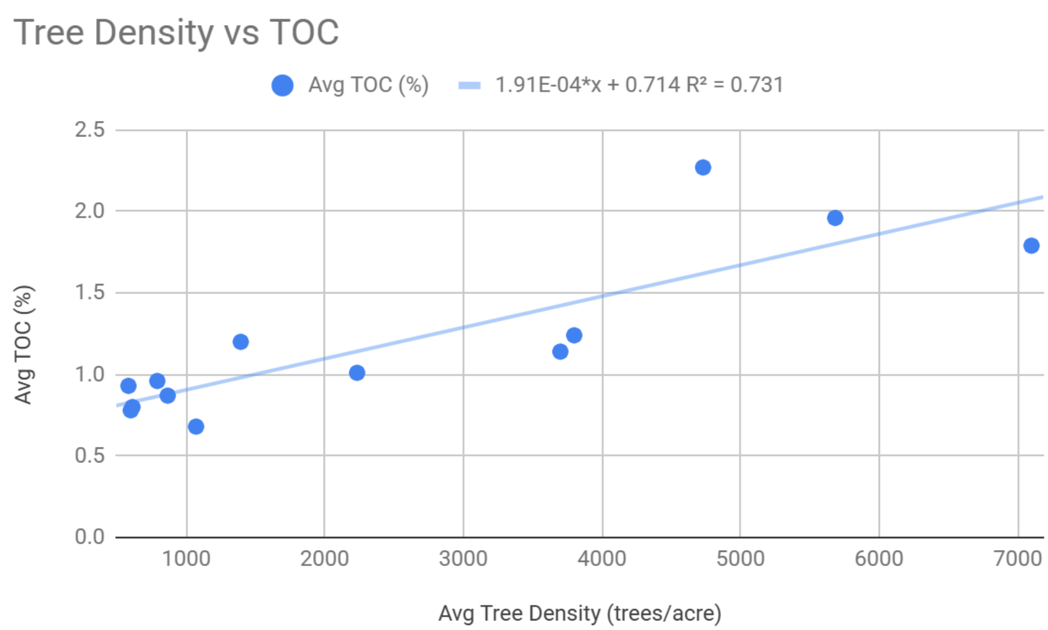

Figure 5. Average TOC as it relates to average tree density of observed trees during monitoring visits.

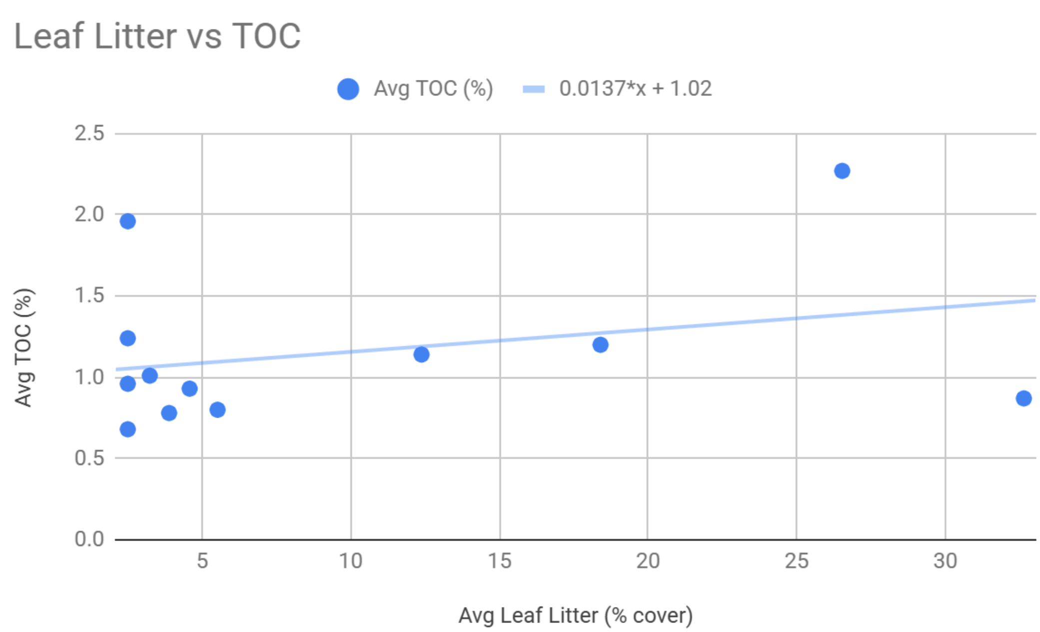

Figure 6. Average TOC as it relates to average leaf litter cover in 1 m^2 subplots within reforestation monitoring plots.

Relationship Between Soil Type & Total Organic Carbon

Soil carbon as it relates to soil type is under-reported in the literature with reports usually associated with highly disturbed lands like agricultural fields (Mathieu et al., 2015; Bruun et al., 2013; Lal, 2005). To understand the spatial distribution of TOC values within the Inland Bays, we overlaid our soil core data with the Sussex County Soils layer (FirstMap Delaware Soils 2.0, Figure 7). We identified the dominant soil type at each planting site to observe the relationship between soil type and carbon storage (Table 1 & Figure 8).

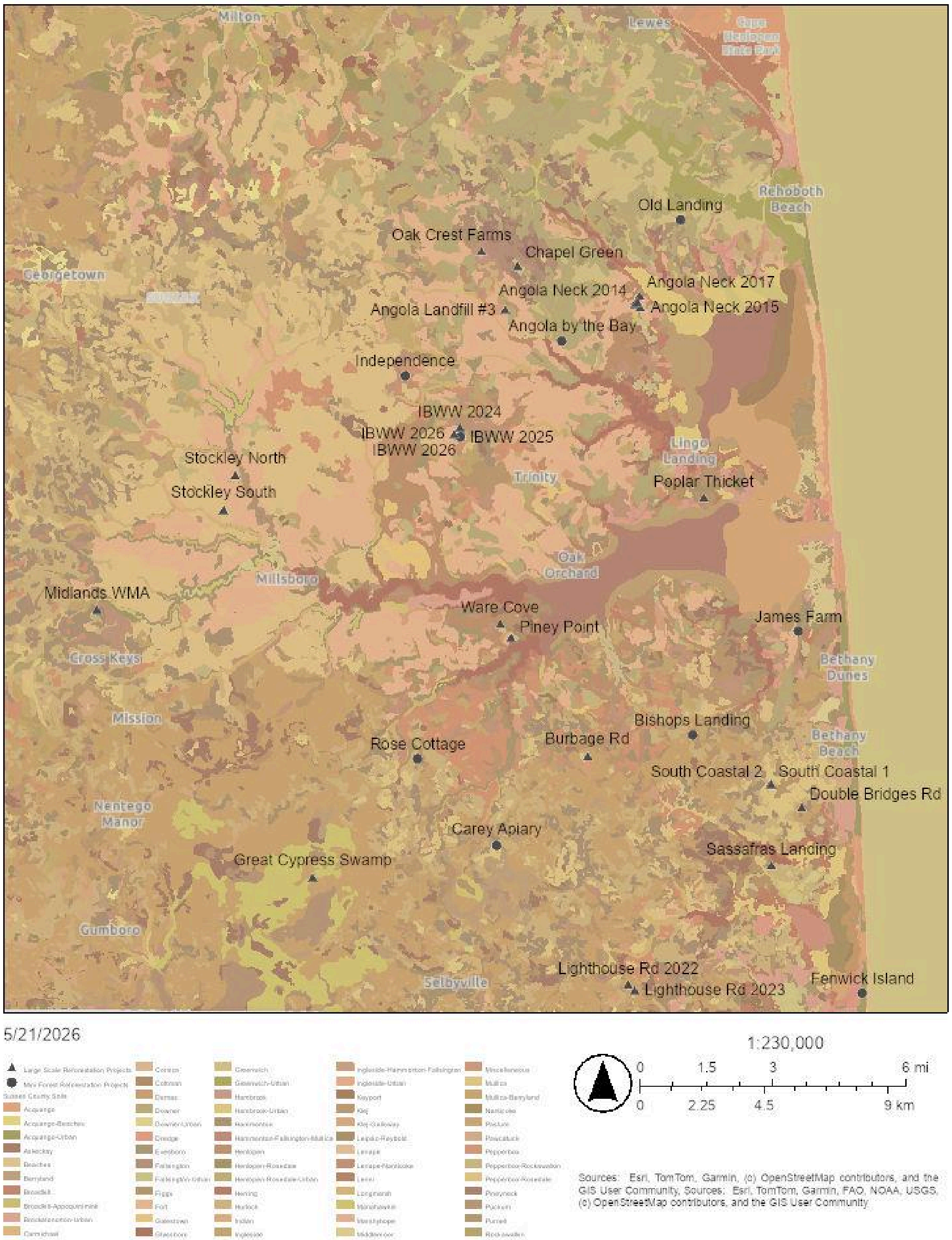

Figure 7. Spatial distribution of soil types and our reforestation sites.

Table 1. Dominant soil types within each reforestation site and average measured TOC % in 2025 (years since planting varies).

Site Name	Dominant Soil Type	Avg TOC (%)
Fenwick Island	Acquango-Urban land complex	13.13
Carey Apiary	Berryland mucky loamy sand	3.54
Angola Landfill	Downer sandy loam	0.87
Meadows at Old Landing	Downer sandy loam	3.19
James Farm Shelterbelt	Evesboro loamy sand	2.51
Piney Point	Fort Mott-Henlopen complex	0.96
Stockley North (background)	Fort Mott-Henlopen complex	0.77
Stockley North (nucleation)	Fort Mott-Henlopen complex	0.81
Chapel Green (background)	Greenwich loam	1.07
Chapel Green (nucleation)	Greenwich loam	0.95
Ware Cove	Henlopen loamy sand	1.20
Rose Cottage	Hurlock loamy sand	1.94
Burbage Rd	Hurlock sandy loam	1.14
South Coastal (background)	Hurlock sandy loam	2.35
South Coastal (nucleation)	Hurlock sandy loam	2.19
Sassafras Landing	Klej loamy sand	0.78
Bishops Landing	Mullica-Berryland complex	2.69
Double Bridges Rd	Mullica-Berryland complex	1.79
Lighthouse Rd 2023 (background)	Mullica-Berryland complex	1.92
Lighthouse Rd 2023 (nucleation)	Mullica-Berryland complex	1.99
Stockley South	Pepperbox-Rosedale complex	0.93
IBWW 2025 MF	Rosedale loamy sand	0.63
IBWW 2024	Runclint loamy sand	0.68
Oak Crest Farms (background)	Runclint loamy sand	1.29
Oak Crest Farms (nucleation)	Runclint loamy sand	1.18

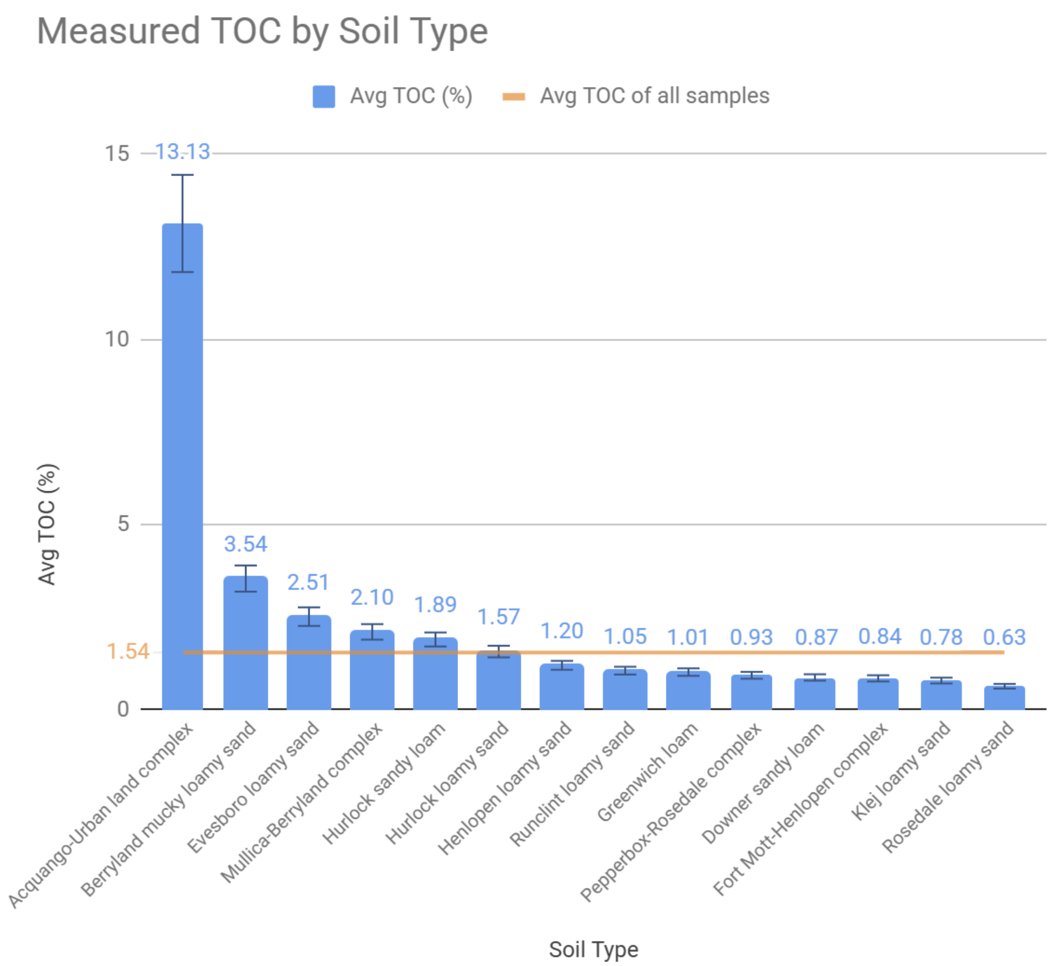

Figure 8. Average measured TOC (%) per soil type.

The soil types with the highest measured average TOC are Acuango-Urban land complex (13.13%), Berryland mucky loamy sand (3.54%), and Evesboro loamy sand (2.51%) (Figure 8). All three of these higher TOC values are in areas with Mini-Forest plantings (with soil samples collected before planting). For future reforestation projects, we may consider planting in areas with these soil types to maximize carbon storage. We must also consider the carbon storage potential of other soil types that may not have been taken advantage of in previous reforestation projects.

The NRCS houses a Soil Series Directory which includes known SOM values for some soil types (NRCS Official Soil Series Descriptions). Based on these known values, we were able to calculate the minimum and maximum TOC values (Table 2) using our SOM and TOC relationship from Figure 4. Not all soil types have SOM data available in this directory which explains the subset of soil types represented in Table 2.

Table 2. TOC range per soil type (NRCS Official Soil Series Descriptions).

Soil Type	Depth (cm)	TOC Minimum (%)	TOC Maximum (%)
Hurlock sandy loam	0-22	0	2.56
Runclint loamy sand	0-22	0.128	1.87
Pepperbox-Rosedale complex	0-10	0.476	1.87

When we compare our measured TOC values to Table 2, we can speculate whether we have achieved full carbon storage capacity in each planting location or if there is room to increase (Figure 9). On average, our measured TOC values from plantings in these soil types fall below the maximum possible TOC for each. This implies that there is a greater carbon storage potential in Hurlock sandy loam, Runclint loamy sand, and Pepperbox-Rosedale complex soils that has not been realized yet. We have planted in these soil types on many occasions, including Burbage Rd and South Coastal (Table 1). However, many of our measured TOC values exceed the average TOC found in Sussex County soils (1.15%) suggesting the plantings are having a positive effect on capturing carbon in the local landscape.

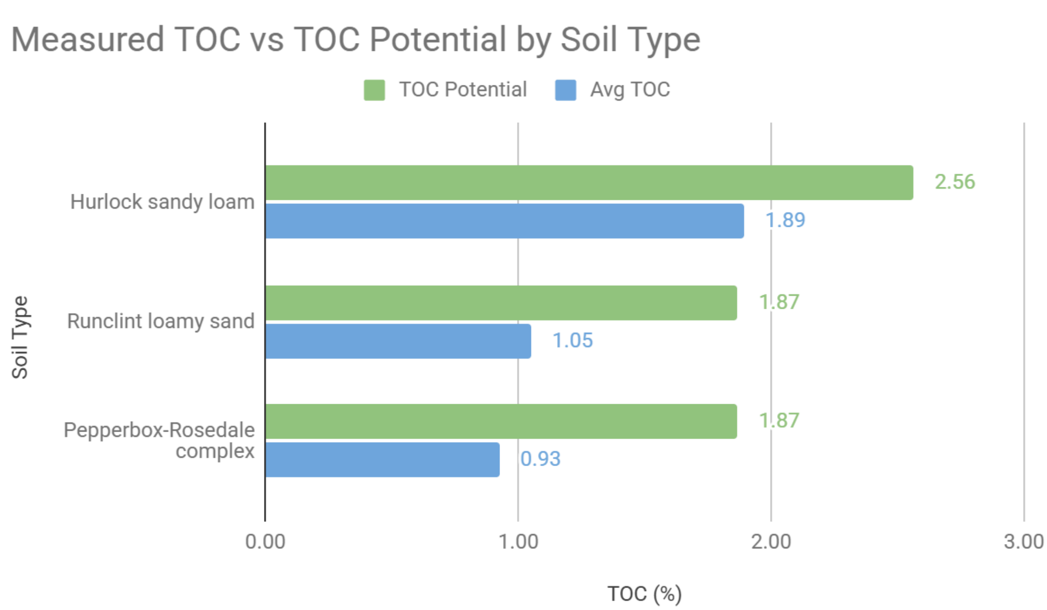

Figure 9. Measured TOC (%) and how it relates to known TOC values in the NRCS Soil Series Directory.

Increasing Total Organic Carbon Over Time

As a result of The Center's reforestation projects, we have witnessed changes to soil health and the landscape. In Figure 10, you can see the darkened color of additional organic matter in Mini-Forest plots (right) vs. "background" landscape (turf grass) plots (left). These are samples from one of our decommissioned septic drainfield restoration sites, Oak Crest Farms.

Figure 10. Soil core samples from the "background" landscape (turf grass) monitoring plots (left) and the Mini-Forest monitoring plots (right) at Oak Crest Farms.

We have more than one year of TOC data for sites like Lighthouse Rd Phase 2, South Coastal, Stockley North & South, and Chapel Green. TOC increased in both the Mini-Forests and background landscape at Lighthouse Rd, South Coastal, and Chapel Green over 1-2 years (Figure 11). For these sites, the background landscape was either left to grow naturally or amended with meadow mix. TOC decreased at Stockley North and South, regardless of planting style. Stockley South is the only traditional-style planting that we have before and after planting TOC values for. We are awaiting 2026 TOC results from Stockley North, Stockley South, Chapel Green, and Oak Crest which will provide a clearer picture of TOC as plants will be mature 2 years post-planting.

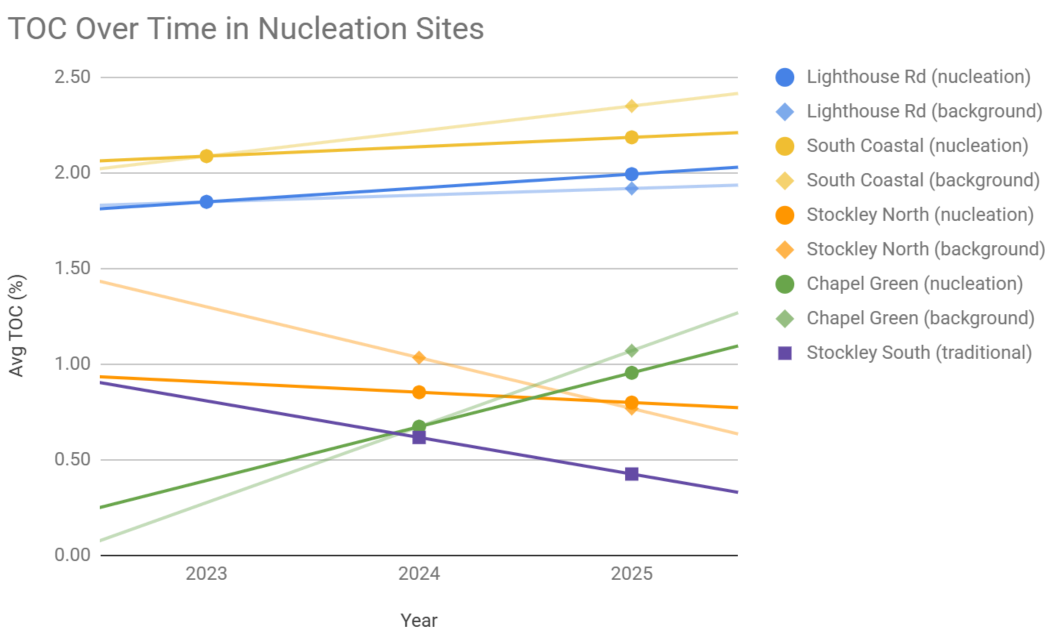

Figure 11. Average TOC over time in Mini-Forests (background vs. nucleation) and traditional plantings.

Phase 1: Conclusion

From our field and lab research completed during Phase 1, we believe that the Inland Bays coastal plain has an unrealized potential for soil carbon storage. Implementing soil carbon building practices such as Mini-Forests and widespread use of meadows can improve soil health. The lack of soil carbon data in this region (Coastal Carbon Atlas) is inhibitory to understanding best approaches, but the establishment of the SOM-TOC relationship is an important step in allowing research to continue at less cost.

Phase 2: Looking Ahead

This research has allowed us to better understand the scale of carbon storage in the Inland Bays soil and to identify the best places to plant next. Further research in Phase 2 of this program will improve our understanding of soil carbon per soil type for the Inland Bays, coordinate this study's results with results from national algorithms such as i-Tree and COMET-Farm, as well as looking at wetland and subaqueous sediments.

Potential Next Steps

Tracking the Mini-Forest plantings through time – especially as they approach 5 years – will provide a crucial pivot point in soil carbon storage. As full canopy is achieved, we would explore if the rate of carbon storage increases, decreases, or drops to zero as carbon storage potential is maxed out.

Additionally, two plantings have been amended with biochar which was initially a technique to help regulate soil moisture. We will review any changes in efficacy and/or soil carbon associated with biochar implementation.

Appendix A: Student Involvement Reflection

Dear Mrs. Fellows,

This internship was my first time being given the opportunity to do hands-on fieldwork. I am graduating from Cape Henlopen High School in 3 days, however this journey starts at the end of my junior year when I was looking for an internship for the following year. I wanted to pursue and experience my interest in environmental fieldwork. The Delaware Center for the Inland Bays allowed me to do just that.

On my first day I was handed real water samples from sites around Sussex County to take home and test their salinity. This was my first time handling something real–not something prepared in my chemistry class. I got to be part of truly impactful science. In the following months, I helped maintain mini-forest sites at Chapel Green and Oak Crest. I witnessed the miniforests impact, in real time, on the environment. I saw these baby trees grow and more bugs take habitat. In the winter, I entered real fish survey field notes into data tables. In the spring, I had the opportunity to attend multiple mini-forest monitoring sessions. There, I took samples of soil that would later be sent to the University of Delaware for analysis. I was shocked that so many factors are considered in field work like the weather, leaf cover, soil water concentration, invasive plant coverage, and so much more. I learned what mini-forests are and the real impacts they have, beyond listening to a classroom lecture.

This experience confirmed my love for working hands-on in both the field and the lab. This internship gave me experiences that helped me earn multiple competitive scholarships. I will be continuing my education this fall at Ursinus College, where I will be studying Biochemistry & Molecular Biology. Thank you for giving me the opportunity to take part in real science.

Sincerely,
Isabella Mekulski