University of Houston Coastal Center

Soil Carbon Study of Remnant and Restored Prairies

April 14, 2023

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Introduction

On behalf of RES, we are pleased to provide the University of Houston Coastal Center (UHCC) with this report detailing the findings of the soil carbon and vegetation assessment activities of the remnant prairies and restored prairies at UHCC and Deer Park Prairie.

The University of Houston Coastal Center operates a science center that is within the context of former Texas coastal prairies bioregion of Southeast Texas. This center is also located within the vicinity of existing native prairie remnants including Nash Prairie, Deer Park Prairie, and Texas City Prairie. Remnant prairies within the center, which was the former Camp Wallace military base, include some areas of moderate to high quality, areas of very low quality, and fully degraded areas.

University staff and students engage in the center for academic research, training, and education, and have been focused on real world applied science to understand how to accelerate restoration of native coastal grasslands. As part of that effort, UHCC is interested in research into the ability of restored native prairie soils to accumulate, store, and sequester carbon, as well as the ancillary benefit of retaining and storing stormwater during flood events. This research will also serve to create a durable program of integrated science that attracts and retains staff and trains students with skills and passion to focus their careers on ecosystem restoration in general and the increasingly rare coastal prairie grasslands of Texas.

Seven separate units were included as part of the study: six units within the UHCC science center (hereafter referred to as UHCC) and one unit at the remnant Deer Park Prairie. The six units at UHCC are categorized as either remnant (Aumann Prairie, Southwest Prairie, and South Central Prairie) or tallow-dominated (Tallow Spray, Tallow Shred, and Tallow Priority). Figures 10 and 11 in Appendix E show the satellite imagery of both sites with unit names and boundaries.

The tallow-dominated units are expected to have the lowest floristic quality, as the namesake species, Chinese tallow, has heavily invaded these areas. However, some management actions have been performed on Tallow Spray (herbicide application) and Tallow Shred (mechanical mowing), so we may expect to see some effect of these actions within the given units. Tallow Priority has received no recent management at the time of this study.

This report is intended to summarize the distribution of soil carbon stocks in each study area, the floristic quality of each unit, attempt to identify factor potentially affecting soil carbon, and provide a list and summary of the plant species and functional groups found within each unit at the time of this study. This will provide baseline data which UHCC and their partners can track changes within these units over time and under different management actions to more fully understand carbon dynamics within the Texas coastal prairies bioregion. Ultimately, this understanding may drive improved methods of increasing soil carbon.

Methods and Materials

Sampling design

Soil core sample point allocation was done through a process of random point allocation with special attention paid to areas across the sites with distinct differences (See Figures 10 and 11 in Appendix E).

- Zone 1 – Aumann Reference/Remnant Prairie (Parade Ground) – 91.7 acres, 32 points (1 per 2.9 ac)
- Zone 2 – Southwest Prairie Remnant Prairie – 24.3 acres, 9 points (1 per 2.7 ac)

- Zone 3 – South Central Prairie Remnant Prairie – 48.4 acres, 17 points (1 per 2.8 ac)
- Zone 4 – Tallow Sprayed Areas – 38.0 acres, 13 points (1 per 2.9 ac)[1]
- Zone 5 – Tallow Shredded Areas – 2.5 acres, 2 points (1 per 1.3 ac)
- Zone 6 – Tallow Treatment Priority – 12.2 acres, 4 points (1 per 3.1 ac)
- Zone 7 – Deer Park Reference/Remnant Prairie – 53.6 acres, 15 points (1 per 3.57ac)

These distinct areas were identified due to their different management practices and history and the intent to evaluate these areas within the larger UHCC site for their potentially different rates of carbon accrual. All sample point locations were then randomly generated with ArcGIS for each of those distinct areas. A total of 92 soil sample locations were allocated across the distinct areas based on the acreage of each. The target soil sample to acreage ratio was approximately 1 sample per 2.5 acres, but this was not always possible due to site conditions.

Soil Carbon Sampling

During the week of October 10, 2022, a team of two RES field ecologists completed the soil carbon sampling on both the UHCC site and the Deer Park Prairie Preserve. After meeting with interested parties, the crew then deployed to the nearest point utilizing the ESRI Collector application with a sub-meter-accuracy Trimble R1 GPS unit. This ensures precision of sample collection and allows for revisiting and resampling the same points in future years.

Once a plan for sampling the points was in place, the crew navigated to each of the points with a Polaris Ranger 6x6 and completed soil sampling with a bed mounted Giddings hydraulic soil sampler. Once at each pre-determined sample point, the crew collected and labeled the soil core, then marked the actual collection point on the Collector application. Each core was taken down to 1m depth or less, in the event an impenetrable layer was reached.

In total, ninety-two (92) soil cores were collected from the UHCC site and the Deer Park Prairie Preserve. These samples were analyzed by Cquester Analytics for bulk density and soil carbon concentration over the winter months.

Vegetation Sampling

During the week of October 10, 2022, a RES ecologist with a specialty in botany completed the vegetation sampling at each of the 92 sample locations. At each location, both a soil sample and a vegetation sample were taken. The soil sample was geolocated and the vegetation samples were taken in the immediate vicinity. Due to the timing of the sampling (late in the growing season), an additional visit was completed during late spring 2023 to capture a fuller picture of species diversity.

Vegetation Composition

The vegetation composition sampling included measuring the cover and frequency of each plant species identified within a one square-meter (1m^2) quadrat, as well as other non-vegetative cover types such as fine litter, bare soil, and rock. A total of 92 quadrats were randomly allocated across the UHCC site and the Deer Park Reference Prairie. Upon arrival at each sample point, the botanist recorded the plant species present and their respective cover values and the non-vegetation cover. At each sample point, vegetation by plant species was ocularly estimated to the nearest 5% based on vertically projected photosynthetic cover in a one-meter circular quadrat centered over each sample point.

[1] One sampling point included in the Tallow Sprayed unit was located in a pocket of tallow in the middle of the Aumann unit (Zone 8, "the Wart")

The vegetative cover from both the 2022 and 2023 surveys were combined to calculate vegetation metrics. Vegetation data is summarized by data point, then management zone, with a focus on cover, frequency, and importance value of species present. Summary data has also been generated by physiognomy (grass, forb, shrub, etc.), native vs. non-native, level of conservatism, and other ways that may be of interest to UHCC.

Soil Data Analysis

Soil Carbon Summaries

Raw data for soil carbon were obtained as organic (SOC), inorganic, and total carbon concentration (%) values broken into soil depth increments: 0-15cm, 15-30cm, 30-50cm, and 50-100cm. Bulk density was provided with the carbon data for each depth increment in each core, allowing the calculation of the soil carbon stocks (in metric tonnes/hectare) of both fractions (organic and inorganic) for each depth increment. For each soil core, the sum of carbon stocks for all depth increments was calculated, and the mean and standard error were calculated for each unit.

Soil Carbon Map

To visually display the approximate distribution of soil carbon stocks within each site, maps for each site were created by interpolating the calculated organic carbon values at each observation point using the inverse distance weighted method (IDW (spatial analyst), n.d.). These interpolated values overlay satellite imagery.

Vegetation Data Analysis

Floristic Quality Index

COEFFICIENTS OF CONSERVATISM

The Floristic Quality Index (FQI) was developed by Swink and Wilhelm (1994) to provide a simple numerical index of site quality that could be used to make comparisons across sites. The main value of importance in the index is the Coefficient of Conservatism, commonly called the C value. C values range from 0 to 10 and, in a very rough sense, indicate the dependence of the given species on either highly disturbed (0) or very mature remnant (10) sites. There are some scientists who employ values below 0 for non-native invasive species but the more common practice, which was used in this report, is to assign a value of 0 to all non-native species. The C values for individual plant species are assigned either by a known botanist with expertise to assess them or by a panel of several botanists.

This method of site assessment is highly developed in the Chicago region, largely due to buy-in and guidance from the Chicago District US Army Corps of Engineers. Because the C values for each species will differ significantly in different regions, other areas of the country have begun to develop C values. Gulf coastal prairies have, fortunately, had some attention in this respect, but official guidance is limited. Ideally, a comprehensive list of C values specific to Texas gulf coast prairies would be used, but we were unable to locate one. However, an assessment of coastal prairies was made in Louisiana by the US Army Corps of Engineers (Suir and Sasser 2017). For the current assessment, a similar methodology was followed regarding assigning C values: values assigned by Cretini, et al. (2012) were prioritized as having the highest relevance. If a species did not have a value assigned, values from Allain, et al. (2004), Gianopulos (2014), or Reemts & Eidson (2019) were used, in order of preference based on relevance. The breakdown of sources was: 54% were taken from Cretini, et al., 31% from Allain, et al., 4% from Gianopulos, and 9% from Reemts & Eidson. C values for 2% of species could not be found within the given lists. The source for each value is listed on a per-species basis in the Supplementary Data file.

FLORISTIC QUALITY INDEX CALCULATIONS

To calculate the FQI for each quadrat, the modified FQI (Cretini, et al. 2012) was used as this was the method used in Suir & Sasser (2017), which evaluated similar ecosystems. This also makes comparisons with their data possible, if desired. The method takes a binary approach, with quadrats containing 100% cover or less using the following formula: $FQI_{mod} = \frac{\sum(cover_i \times C_i)}{100} \times 10$, where $cover_i$ is the percent areal cover for the i^{th} species and C_i is the C value for the i^{th} species. For quadrats containing more than 100% cover, the following formula was used: $FQI_{mod} = \frac{\sum(cover_i \times C_i)}{total\ cover} \times 10$. FQI_{mod} values range from 0 to 100, with low values representing highly disturbed/invaded systems, and high values indicating more mature systems.

Statistical Analysis

Floristic Quality Analysis

All statistics were analyzed using R version 4.3.1 (R Core Team 2023). FQI_{mod} values were compared between units to assess whether significant differences could be detected. A Bartlett's test was performed to ensure homogeneity of variance for the remaining units, since sample sizes differed. No significant departure from homogeneity was detected (bartlett.test in R; $K^2 = 5.03$, DF = 6, $p = 0.54$), so ordinary least squares ANOVA (aov in R) was performed. Post-hoc pairwise t-tests were performed to determine differences between individual units (glht in R), which were compiled into compact letter significance groups (cld in R).

Total Carbon Analysis

Because total soil carbon is not directly affected by short-term changes in vegetation cover, it was not included in the main body of this report. However, differences of potential interest were found, so the methods, results, and discussion of total soil carbon are included in Appendix B.

Soil Organic Carbon Analysis

Differences in SOC between remnant and tallow-dominated units were testing using ANOVA (aov in R). Individual units were also tested for differences in SOC using ANOVA, and post-hoc pairwise t-tests were performed (glht in R) and compact letter displays were calculated (cld in R).

Soil Organic Carbon Model

To explore additional potential causal factors, several variables were identified as possible influences on soil carbon stocks: total vegetation cover, SSURGO soil type (Soil Survey Staff 2023), floristic quality, average wetland indicator status, percent C4 species, and percent perennial species. A linear model (full total carbon stocks model; lm in R) was estimated with all variables and compared to more parsimonious models with likelihood ratio tests (lm.anova in R) to determine the optimal model.

Results

All soil carbon and vegetation data have been summarized below and are presented in a series of graphs, charts, and maps. Soil carbon is presented in total C, inorganic C, and organic C. Details of the variations of organic C are presented here, and details of total C and inorganic C are presented in Appendix B. The results of a selection process on a linear model relating SOC to site characteristics are presented. The vegetation data is presented using quality metrics, functional groups, and areal ground cover.

Table 1: Average carbon stocks (metric tonnes/hectare) for each unit. Numbers in parentheses indicate standard error of the mean. Significance groups (Sig. Group) indicate significant differences in total C among units (a = 0.05). Groups are remnant (Rt), restored (Rs), and tallow-dominated (T). No significant differences were found between group means.

Unit (Group)	Total C (t/ha)	Inorganic C (t/ha)	Organic C (t/ha)	Sig. Group (Organic)	Group Mean Organic C (t/ha)
Deer Park (Rt)	170.4 (37.3)	85.9 (34.2)	84.5 (9.2)	a	
Aumann (Rt)	147.3 (4.9)	0.1 (0.1)	147.3 (5.0)	b	
South Central Prairie (Rt)	133.1 (6.6)	1.9 (1.9)	131.3 (7.4)	ac	126.0 (4.4)
Southwest Prairie (Rt)	109.4 (6.8)	-	109.4 (6.8)	bc	
Tallow Priority (T)	107.6 (11.6)	3.5 (3.2)	104.1 (9.6)	bc	
Tallow Shredded (T)	143.0 (2.9)	-	143.0 (2.9)	†	119.7 (4.4)
Tallow Sprayed (T)	130.0 (8.1)	9.1 (5.1)	120.9 (4.6)	ac	

†Tallow Shredded omitted from analysis due to inadequate sample size.

Soil Organic Carbon

Table 1 provides the summaries of total, inorganic, and organic carbon stocks. Figure 1 presents the SOC summaries visually for each unit. SOC differed significantly among units ($F_{5,84} = 11.74$, $p < 0.001$) and was lowest at Deer Park and highest at Aumann. All intermediate units did not differ significantly. However, Southwest Prairie and Tallow Priority were grouped with Deer Park while South Central Prairie and Tallow Spray were grouped with Aumann (see Table 1; Figure 1). There was no significant difference between the remnant and tallow dominated units as a whole ($F_{1,90} = 0.483$, $p = 0.489$).

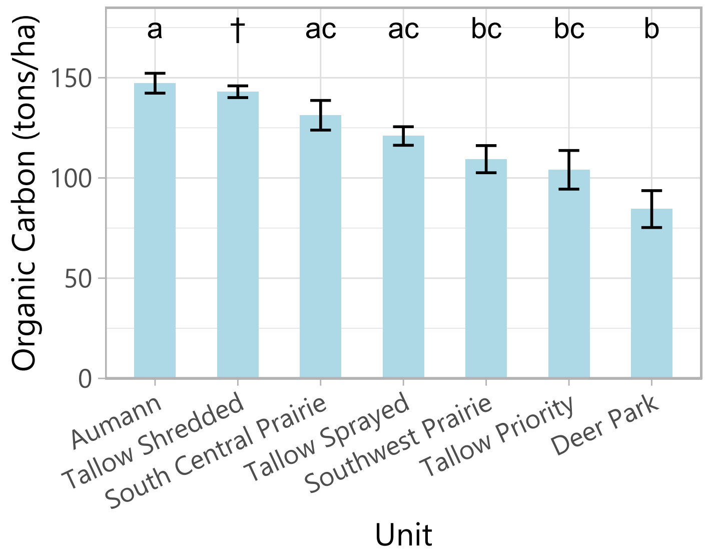

Figure 1: Total Organic Carbon stocks (metric tonnes/hectare) by unit. Error bars represent standard errors of the mean. †Tallow Shredded unit omitted from analysis due to inadequate sample size.

Organic Carbon Model

The full SOC linear model was estimated using all vegetative and groundcover variables and compared to more parsimonious models. We found that the model which included soil type, average wetland indicator status, and percent fine litter cover was the optimal model, but only some of the variation in the data is accounted for (model $F_{3,88} = 12.57$, $p < 0.001$, adj. $r^2 = 0.276$). The model's intercept, or base scenario corresponding to Soil Type = Bernard, Average Wet Indicator = 0, and Percent Fine Litter = 0%, is at 109.68 tonnes/ha (95% CI [83.29, 136.08]). Within this model, the effect of soil type is statistically significant and positive, with an estimated increase of 42.51 tonnes/ha when going from Bernard to Lake Charles soils (95% CI [19.11, 65.91], $t_{88} = 3.61$, $p < .001$). The effect of average wet indicator status is statistically non-significant, but marginally positive. The estimated increase is 7.63 tonnes/ha for every unit increase in average wetland indicator status (95% CI [-0.91, 16.17], $t_{88} = 1.78$, $p = 0.079$). The effect of fine litter percent cover is statistically significant and negative. For every additional percent fine litter, the estimated effect is a reduction of 1.71 tonnes/ha in SOC (95% CI [-2.51, -0.91], $t_{88} = -4.23$, $p < .001$). Table 2 provides a concise overview of the model variable estimates and significance values.

Table 2: Organic carbon/ecological characteristics model variable estimates and statistical values.

Variable	Estimate (t/ha)	Std. Error	t value	P (>t)
Intercept	109.6835	13.2814	8.258	<0.001
Soil Type (Lake Charles)	42.5108	11.7731	3.611	<0.001
Wetland Indicator	7.6277	4.2962	1.775	0.0792
% Fine Litter	-1.7076	0.4032	-4.235	<0.001

Spatial Distribution of Organic Carbon Stocks

The spatial distribution of SOC stocks can be seen in Figure 6 for Deer Park and Figure 7 for UHCC. Both Figures are shown in Appendix C.

Vegetation

Quality Metrics

Vegetation quality metrics summarized for each unit in the project include richness, native richness, FQI_{mod}, mean wetland indicator status, mean C value, mean C value of native species, and relative native species cover. Wetland indicator status ranges from -5 to 5, with more negative numbers indicating greater dependence on wetland conditions. Metrics are presented in Table 3. FQI_{mod} values differed significantly among units ($F_{6,85} = 5.69$, $p < 0.001$). Figure 2 shows how FQI_{mod} differed for each study area. If a site is labeled with a letter, it does not differ significantly from other sites with the same letter. When comparing remnant and tallow-dominated units as a whole, remnant prairies were significantly higher than tallow units ($F_{2,89} = 13.69$, $p < 0.001$).

Table 3: Site quality metrics, averaged over all quadrats within each unit.

Metric	Aumann	Southwest Prairie	Central Prairie	Tallow Spray	Tallow Shred	Tallow Priority	Deer Park
Richness	15.4	14.6	12.6	8.8	9.5	8.8	13.1
Native Richness	15.1	14.1	11.9	7.5	8.5	7.3	12.5
FQI_{mod}	56.45	50.53	52.92	42.01	46.49	27.78	53.42
Wetland Indicator	-0.8	-1.3	-1.0	-0.5	-2.0	-0.6	-1.58
C	5.27	4.68	4.88	3.98	4.26	2.85	5.86
Native C	5.37	4.83	5.22	4.66	4.66	3.66	5.86
% Native (by cover)	98.8	98.2	93.7	84.9	93.5	76.9	95.7
Total Quadrats	32	9	17	13	2	4	15

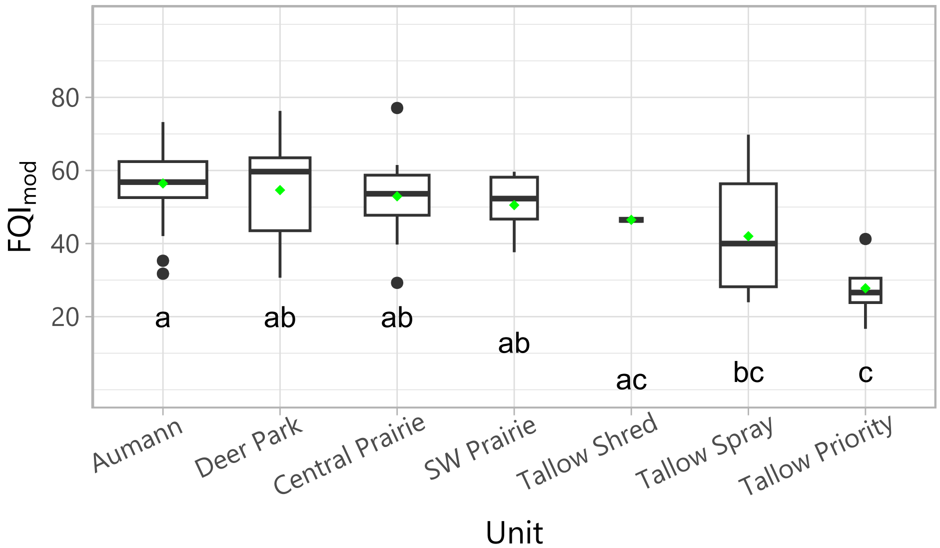

Figure 2: Boxplot of FQI_{mod} (Cretini, et al. 2012) for UHCC units and Deer Park. Unit of replication is individual quadrats. Median values are represented by horizontal bar, boxes indicate interquantile ranges, and whiskers represent range of values outside of interquantile range. Individual points represent possible outlier values. Sample sizes were unequal; box width indicates number of sampling points. Green points represent mean FQI_{mod} values.

Functional Groups

Plant species were grouped by growth habit (Forb, Grass, Grasslike [sedges and other non-grass graminoids], Shrub, and Vine), and duration (Annual or Perennial). Relative cover of each functional group was calculated and presented in Table 5 (in appendix A) and Figure 3 below.

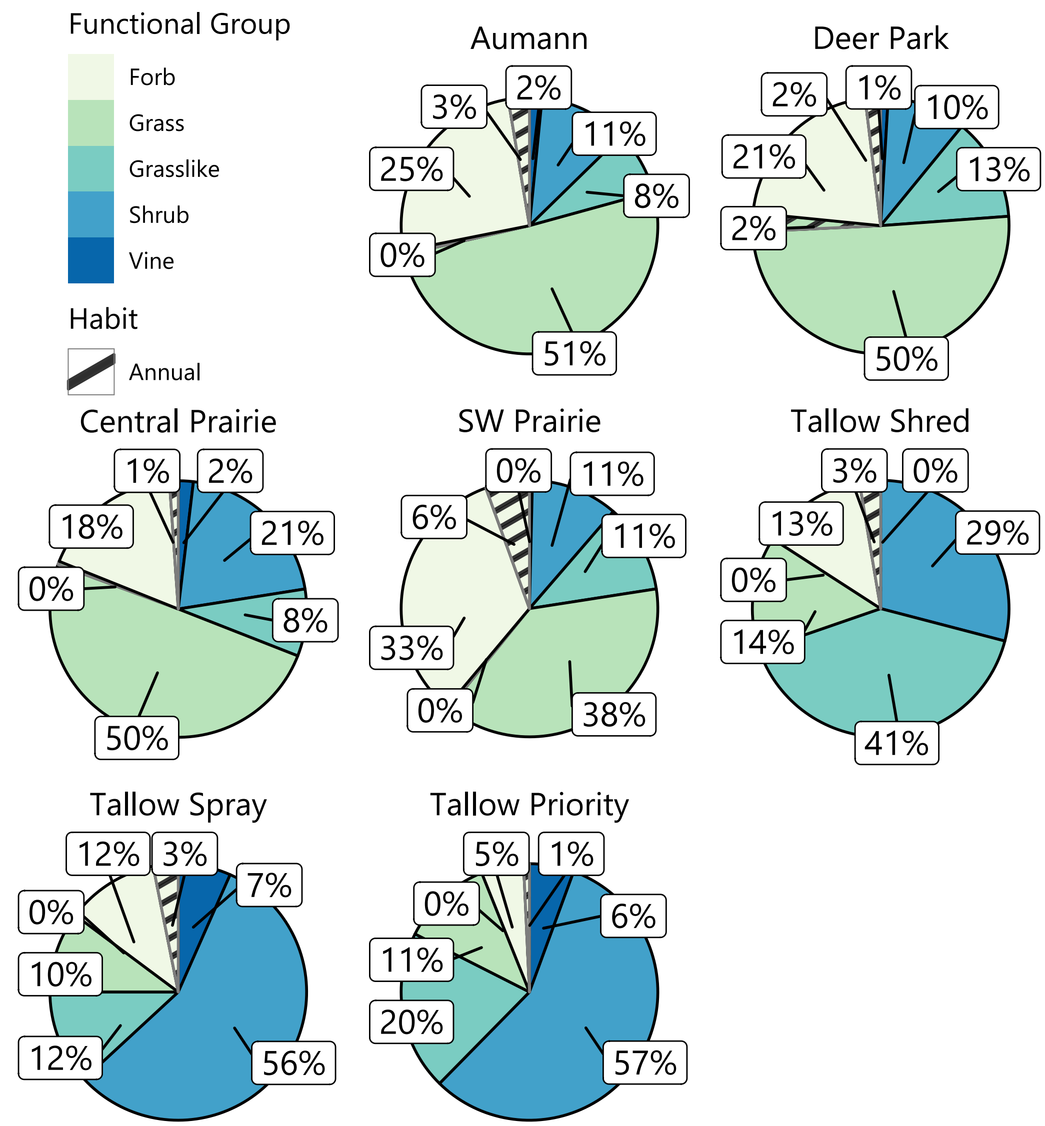

Figure 3: Breakdown of percent cover by functional groups in each unit. See Table 5 in Appendix A.

Areal Ground Cover

Areal cover was recorded for each quadrat, including total vegetation cover, native vegetation cover, bare soil, fine litter, coarse litter, and rock cover. Areal cover can be greater or less than 100% since layers may overlap. Values were calculated and presented in Table 6 (in Appendix A) and Figure 4.

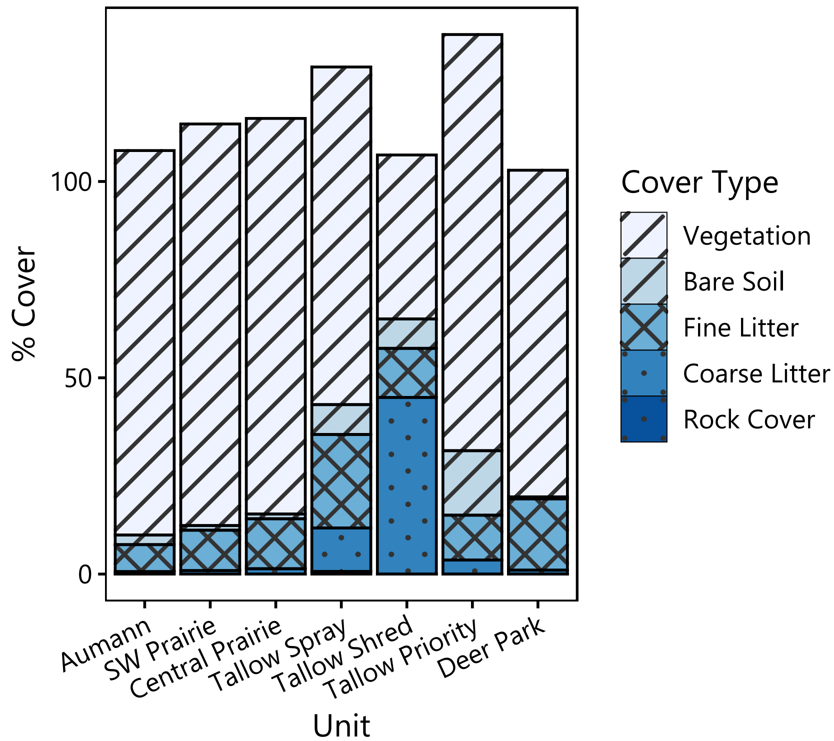

Figure 4: Percent Cover by type in each unit. Values are areal cover percents and may not add up to 100%.

Species Summaries

Data for each species were compiled and are available in the Supplemental Data file. For each species, the frequency (AF), relative frequency (RF), average cover (AC), relative cover (RC), Importance Value (IV), Relative Importance Value (RIV), and standard deviation of cover (STD) were calculated.

The dominant species in each area along with their associated importance value are noted below.

The dominant vegetation species in the Aumann management unit were the following: Little bluestem (IV 16.45), brownseed paspalum (IV 12.37), southern dewberry (IV 11.72), prairie blazingstar (IV 9.48), and Florida paspalum (IV 8.96)

The dominant vegetation species in the SW Prairie management unit were the following: swamp sunflower (IV 18.29), anglestem beaksedge (IV 11.82), sugarcane plumegrass (IV 10.94), longspike tridens (IV 9.20), and bushy bluestem (IV 8.98).

The dominant vegetation species in the Central Prairie management unit were the following: gulf cordgrass (IV 18.61), little bluestem (IV 18.58), southern dewberry (IV 16.92), wax myrtle (IV 11.62), and big bluestem (IV 10.19).

The dominant vegetation species in the tallow spray management unit were the following: southern dewberry (IV 27.48), Cherokee sedge (IV 18.61), Chinese tallow (IV 16.24), yaupon (IV 16.23), and Japanese honeysuckle (9.97).

The tallow shred had limited vegetation at the time of sampling. There were four species in the tallow shred area: anglestem beaksedge (IV 34.48), southern dewberry (IV 28.49), Cherokee sedge (IV 19.51), and groundseltree (IV 16.51).

The dominant vegetation species in the tallow priority management unit were the following: Cherokee sedge (IV 25.09), roughleaf dogwood (IV 22.55), Chinese tallow (IV 17.15), St. Augustinegrass (IV 14.29), and southern dewberry (IV 14.43).

The dominant vegetation species in Deer Park were the following: gulf cordgrass (IV 24.69), Florida Paspalum (IV 11.45), St. Augustinegrass (IV 11.24), wax myrtle (IV 9.32), and anglestem beaksedge (IV 9.16).

In summary, of the one-hundred-eighteen (118) plant species recorded in the 92 square-meter sampling quadrats at UHCC and Deer Park, one-hundred-six (106) were native plants – grasses, forbs, and shrubs of the Gulf Coast Prairies and Marshes vegetation communities.

Discussion

This baseline study provides a statistical analysis of soil carbon levels and vegetation quality and functional group metrics at the UHCC site and a reference remnant community at Deer Park. Because all soil sampling locations were recorded with GPS for relocation purposes, UHCC is positioned to monitor and document soil carbon and vegetation changes that occur at both sites over time.

Soil Carbon

Organic Carbon

Organic carbon results from living plants, microbes, and animals interacting within the rhizosphere and surface of the soil. It is therefore more reflective of current and recent ecological conditions. Our results found that the remnant and tallow-dominated units did not differ significantly. However, there were significant differences among the individual units. The pattern of statistically grouped units was not clear however: two remnant (Deer Park and Southwest Prairie) grouped with the (at the time) least managed site, Tallow Priority and the unit with the highest quality and highest organic carbon content, Aumann, was grouped with South Central Prairie and Tallow Sprayed units. Additionally, while it was not analyzed statistically due to lack of adequate replication, Tallow Shredded had high levels of organic carbon similar to Aumann. These results indicate that ecological quality metrics and level of management do not predict soil organic carbon very well in this study area.

Organic Carbon Model

In attempting to elucidate other possible factors affecting organic carbon, we found a significant correlation between soil type, average wetland indicator status, and percent fine litter cover and organic carbon stocks. Soil type had the strongest effect on soil organic carbon, with the Lake Charles clay exhibiting significantly higher SOC than Bernard clay loam. It is well known that higher clay content in soils tend to have higher organic carbon stocks than other soil types (Lal, 2018; Singh et al., 2018), so these results make sense. However, the effect is quite strong—42 tonnes/hectare more SOC for Lake Charles points compared to Bernard—considering the texture of the two soils is only minorly different. Further research may be needed to understand the SOC dynamics at the Deer Park reference site.

The effect of average wetland indicator status was positive, but marginal. A positive relationship between wetland indicator status is unexpected, because more anoxic conditions in the soil (which correlate with more negative wetland indicator) will cause slower breakdown of organic carbon. The p-value is greater than 0.05, however, so our baseline study does not provide significant evidence that this is a major factor at these sites.

The negative relationship between percent fine litter and SOC was somewhat unexpected and lacks obvious explanation. To see if this was a statistical fluke related to the lower SOC at Deer Park and perhaps incidental higher fine litter amounts at that site, a second model was tested which omitted Deer Park and confined data only to UHCC units. However, fine litter remained highly significant in this restricted dataset. The estimate in this limited model was similar to the model including both Deer Park and UHCC sites (-1.7 for the full dataset vs. -1.5 for UHCC alone), further suggesting that there may be a true negative correlation between fine litter and SOC at these sites. While fine litter has been indicated as a potentially important driver of SOC stocks in other ecosystems, the relationship is normally expected to be positive (e.g., Craig et al., 2022). A mechanistic explanation of this correlation is not immediately apparent and suggests that additional research is needed.

Vegetation

The floristic quality of remnant units was significantly higher than those of tallow-dominated units, as expected. The two tallow-dominated units that recieved management activities, Tallow Shredded and Tallow Sprayed, had slightly but non-significantly higher floristic quality compared to Tallow Priority, which had not yet been managed at the time of observation. This appears to indicate that the management actions are having the desired effect. The floristic quality map provided in Figures 8 & 9 show the spatial distribution of floristic quality indices and can serve as a rough guide to identify areas requiring management.

One area of potential valuable research would be the creation of a single comprehensive list of gulf coastal plain coefficients of conservatism. The references used in this assessment showed moderate agreement where overlapping species were seen, but there were many discrepancies nonetheless. The priorities described in the Methods section were chosen based on similarity of ecosystems to the current study areas for which the C values were assigned. However, even the most relevant from the perspective of ecosystem similarity were values assigned within Louisiana (Cretini et al 2012 and Allain et al 2004). Similar attempts to provide C values for Texas coastal plains and marshes were not found during the course of our research here.

Within the remnant units, perennial grasses and forbs dominate the functional group breakdown, while the tallow-dominated units were composed of shrubs and vines to a much greater extent, as expected. These observations indicate that, in the absence of continued maintenance, invasive vegetation will change the functional characteristics of these coastal plains ecosystems.

Conclusions

The baseline data presented here provides the groundwork to build further research into soil carbon and vegetation relationships on these sites. When comparing the remnant units and tallow-dominated units collectively, there were no significant differences in either total carbon or organic carbon. Differences were seen among the units, but these did not follow any pattern related to remnant status nor floristic quality. Relationships between other variables and SOC were weak and somewhat unexpected in this baseline study. There is much that is not clear about why these unexpected trends were seen. However, this study and the work done to record sampling locations have paved a way to conduct long-term ecological research on the UHCC units and at the Deer Park reference unit. Repeated-measures analysis can be a powerful tool to understanding the changes occurring in ecosystems. The work being done on the UHCC site also has the potential to demonstrate the power that active restoration and management has for improving soils, sequestering carbon, increasing the floristic quality and diversity, and maintaining functional characteristics of invaded or degraded systems.

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Appendices

Appendix A – Vegetation Details

*Table 4: The Floristic quality indices ranged from 27.78 for Tallow Priority to 56.45 for Aumann. FQImod differed statistically significantly between sites marked with * (p <0.05), ** (p < 0.01), and highly significant with *** (p < 0.001). Comparison column shows the sites being compared. Mean columns show the mean value of each of the two units being compared. Estimate shows the estimated FQI_{mod} difference between the two stated sites. P (>| t |) shows the probably obtaining the observed difference by random chance.*

Comparison	Mean (1)	Mean (2)	Estimate	Std. Error	t value	P(>|t|)	
SW Prairie - Aumann	50.53	56.45	-5.923	4.304	-1.376	0.79513	
Central Prairie - Aumann	53.92	56.45	-3.524	3.423	-1.029	0.93897	
Tallow Spray - Aumann	42.01	56.45	-14.441	3.751	-3.849	0.00348	**
Tallow Shred - Aumann	46.49	56.45	-9.955	8.314	-1.197	0.88151	
Tallow Priority - Aumann	27.78	56.45	-28.669	6.049	-4.739	< 0.001	***
Deer Park - Aumann	53.42	56.45	-3.0278	3.518	-0.861	0.97417	
Central Prairie - SW Prairie	53.92	50.53	2.398	4.702	0.51	0.99843	
Tallow Spray - SW Prairie	42.01	50.53	-8.518	4.946	-1.722	0.57713	
Tallow Shred - SW Prairie	46.49	50.53	-4.033	8.917	-0.452	0.99921	
Tallow Priority - SW Prairie	27.78	50.53	-22.746	6.854	-3.319	0.01902	*
Deer Park - SW Prairie	53.42	50.53	2.8948	4.740	0.611	0.99574	
Tallow Spray - Central Prairie	42.01	53.92	-10.917	4.202	-2.598	0.12625	
Tallow Shred - Central Prairie	46.49	53.92	-6.431	8.527	-0.754	0.98684	
Tallow Priority - Central Prairie	27.78	53.92	0 -25.145	6.339	-3.967	0.00251	**
Deer Park - Central Prairie	53.42	53.92	0.497	3.983	0.125	1.00000	
Tallow Shred - Tallow Spray	46.49	42.01	4.486	8.664	0.518	0.9983	
Tallow Priority - Tallow Spray	27.78	42.01	-14.228	6.522	-2.182	0.2929	
Deer Park - Tallow Spray	53.42	42.01	11.413	4.260	2.679	0.10429	
Tallow Priority - Tallow Shred	27.78	46.49	-18.714	9.878	-1.894	0.46248	
Deer Park - Tallow Shred	53.42	46.49	6.9275	8.463	0.819	0.97993	
Deer Park - Tallow Priority	53.42	27.78	25.6411	6.326	4.053	0.00179	**

Table 5: Average percent relative cover by functional groups in each unit.

Functional Group	Aumann	SW Prairie	Central Prairie	Tallow Spray	Tallow Shred	Tallow Priority	Deer Park
Total Forb (%)	26.31	35.43	18.11	12.04	13.59	5.38	22.45
Total Grass (%)	52.30	40.64	50.46	10.52	14.82	11.55	52.66
Grasslike (%)	8.30	11.90	8.58	12.27	41.74	20.26	13.50
Shrub (%)	11.48	11.64	20.94	58.33	29.86	57.18	10.42
Vine (%)	1.61	0.39	1.91	6.84	0.00	5.64	0.98
Annual Forb (%)	2.74	5.86	1.11	3.23	2.72	0.74	2.02
Annual Grass (%)	0.49	0.29	0.43	0.00	0.00	0.00	2.42
Perennial (%)	96.77	93.85	98.46	96.77	97.29	99.26	95.56

Table 6: Average cover by type in each unit. Values are areal cover and may not add up to 100%.

Cover Type	Aumann	SW Prairie	Central Prairie	Tallow Spray	Tallow Shred	Tallow Priority	Deer Park
Vegetation Cover (%)	98	97	98	83	42	93	82
Native Cover (%)	97	95	91	70	39	76	79
Bare Soil (%)	2.5	1.1	1.2	7.3	7.5	14.4	0
Fine Litter (%)	6.9	9.7	12.4	22.9	12.5	10	7.3
Coarse Litter (%)	0.6	0.8	1.3	10.7	45	3.1	1
Rock Cover (%)	0	0	0	2.8	0	0	0

Appendix B – Total Carbon Analysis

Methods

Total soil carbon data failed assumptions of ANOVA, due to the non-normal distribution of the data (shapiro.test in R; $W = 0.416$, $p < 0.001$), so a non-parametric Kruskal-Wallis rank sum test was performed to test for differences between groups. This test was also used to determine if there was a significant difference between units. With a significant test result, a post-hoc Dunn-Bonferroni test was used to compare individual units.

Results

Soil Total Carbon

We found that total carbon stocks did not differ between the remnant and tallow-dominated groups (Kruskal-Wallis $\chi^2 = 1.1$, df = 1, $p = 0.30$). Figure 1 shows the total carbon stocks across each study area and the fraction of total carbon made up of inorganic and organic carbon. When comparing individual units, a significant effect was found (Kruskal-Wallis $\chi^2 = 19.5$, df = 6, $p = 0.003$). However, a post-hoc Dunn's test revealed that only Aumann and Southwest Prairie differed significantly ($z = 3.28$, $p = 0.02$).

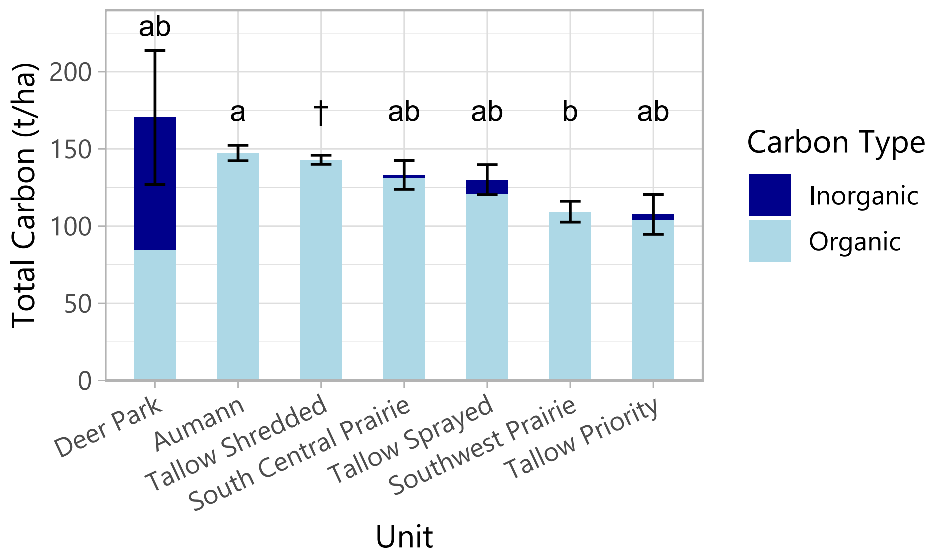


Figure 5: Total stocks (metric tonnes/hectare) of inorganic and organic carbon by unit. Error bars represent standard errors of the mean. †Tallow Shredded unit omitted from analysis due to inadequate sample size.

Discussion

Total Carbon and Inorganic Carbon

While the total carbon density was slightly higher at the remnant units compared to the tallow dominated units (see Table 1), this difference was not statistically significant. This was due to the wide variability among remnant units in total carbon. Between individual units, Aumann was significantly higher than Southwest Prairie, but no other differences between units were statistically significant.

Interestingly, a large proportion of the total carbon density was made up of inorganic carbon, while UHCC units were dominated by organic carbon. This is most likely due to differences in soil types. All of UHCC is made up of Lake Charles clay soils, and while half of UHCC is the same soil type, the other half is Bernard clay loam. Both soil series are mapped by SSURGO as having calcium carbonate concentrations; however, the carbonates in Bernard are mapped starting at 79cm in depth whereas Lake Charles starts around 135cm. If these SSURGO series are accurate, the deeper calcium carbonates in Lake Charles would have been missed by our 1-meter sampling protocol, leading to much greater quantities at Deer Park in our measurement. SSURGO data can often be approximate, so there may be additional factors creating this difference, but our data suggest that this is the most likely cause of the discrepancy.

Inorganic carbon forms over time when water containing dissolved calcium percolates down through the soil profile. This calcium combines with C02 gases that are being respired by roots and water in the subsoil. This process occurs over long timescales and is affected by rainfall, soil parent material, and geological history, making inorganic carbon an impractical target for management.

Appendix C – Soil Organic Carbon Stocks Mapping

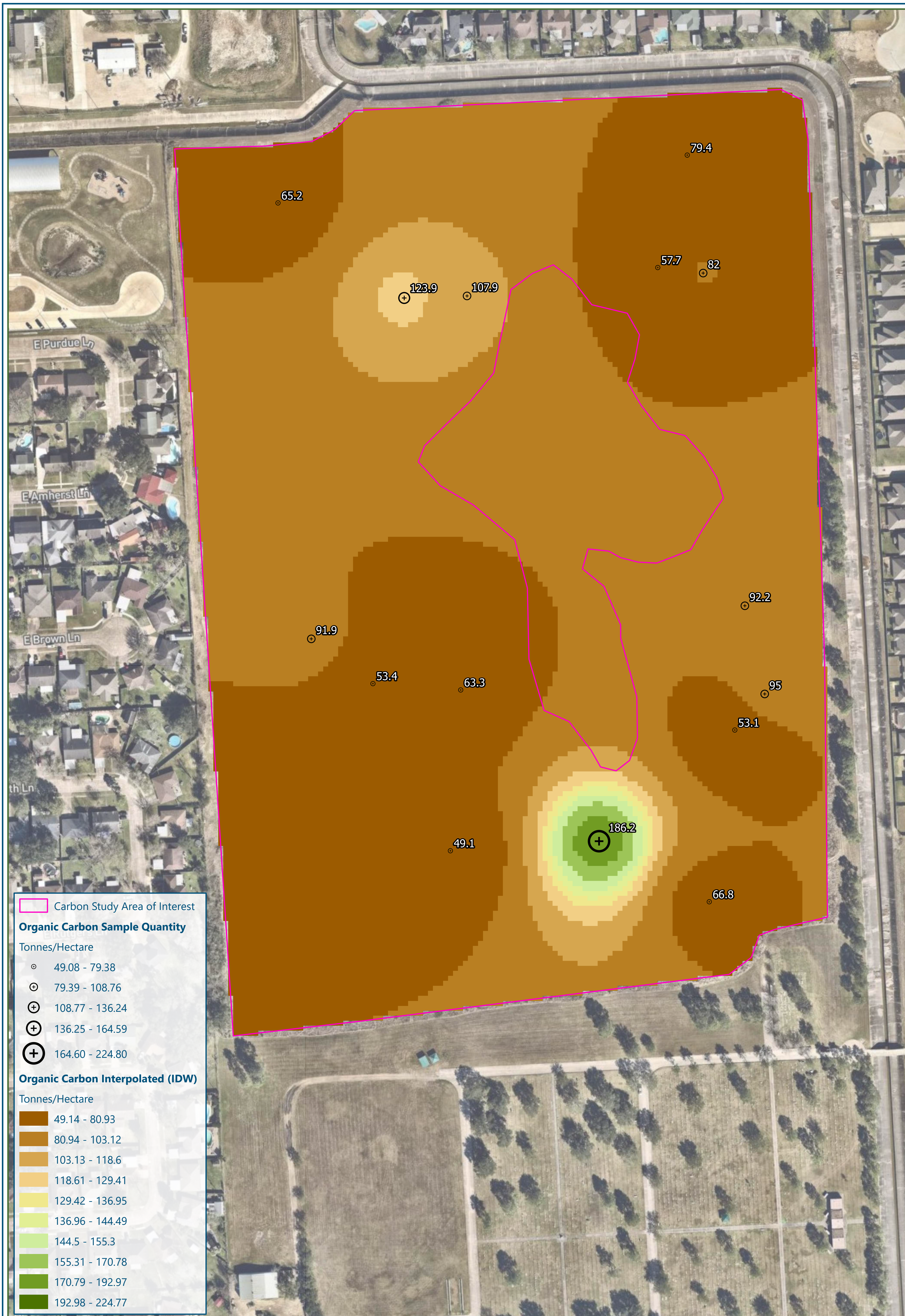
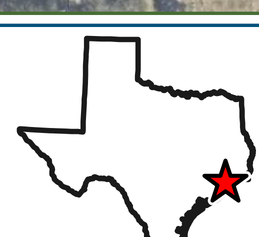


Figure 6
Organic Carbon Lab Results

UHCC
Galveston County, Texas
95.1085°W 29.67°N

N
0 100 200
Feet

Reference: Project limits are approximate. This information is not to be used as final legal boundaries.
Data Source: RES Survey
Spatial Reference:
NAD 1983 StatePlane Texas South Central FIPS 4204
Feet
Date Exported: 12/4/2023
Project Number: 107680, 105740



res
www.res.us

Cartographer: jtouzel | POC: M. Szuter | Path: R:\Resgis\Projects\TX\107680_UHCC_Soil_Carbon_Study\PRO\107680_UHCC_Soil_Carbon_Study.aprx | Layout: UHCC_SoilCarbon_Organic_SamplingInterpolation_North

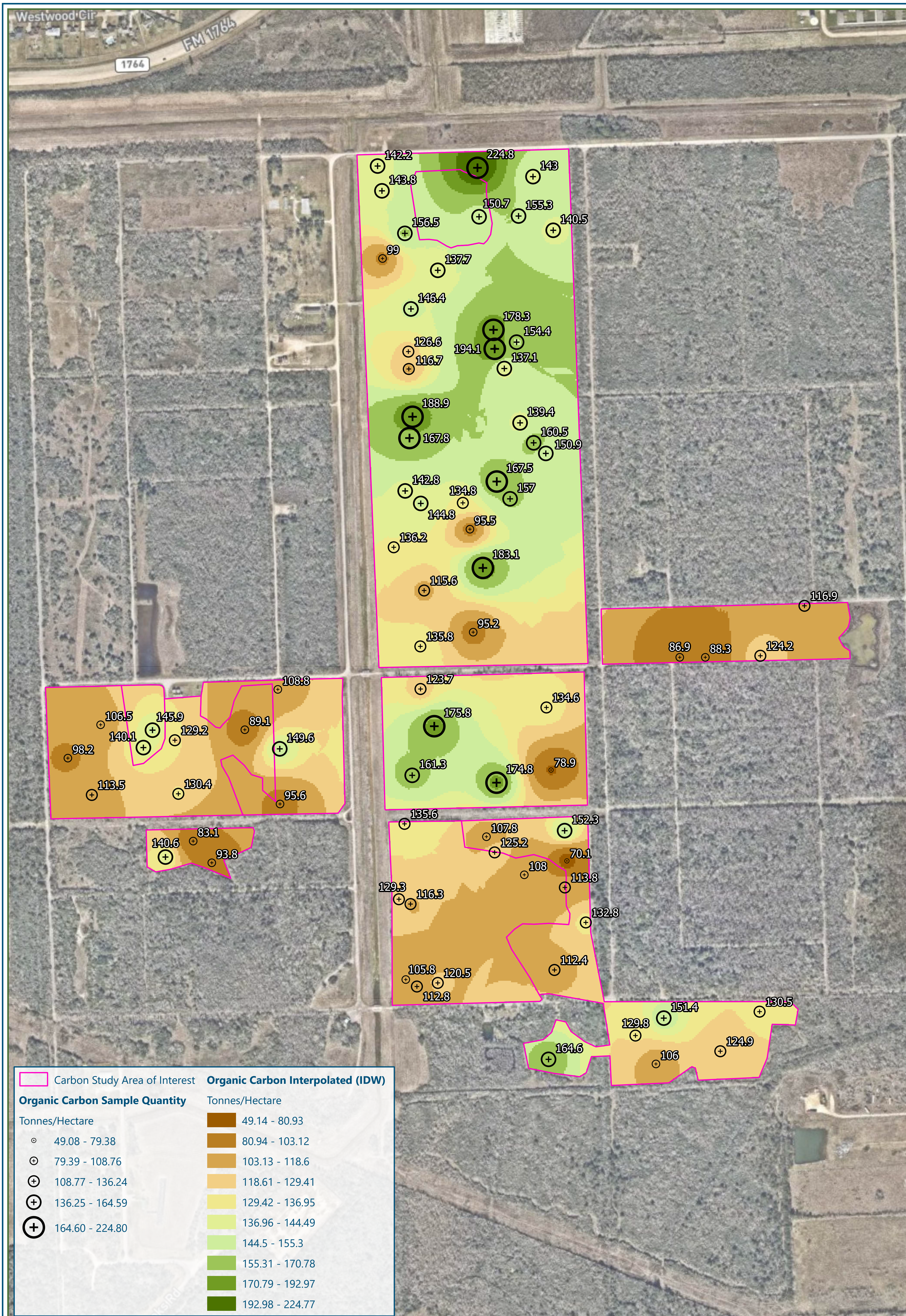
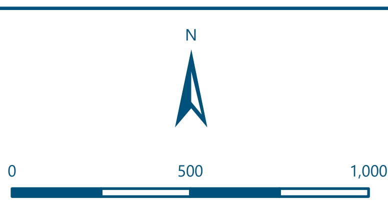


Figure 7
Organic Carbon Lab Results

UHCC
Galveston County, Texas
95.0413°W 29.3821°N



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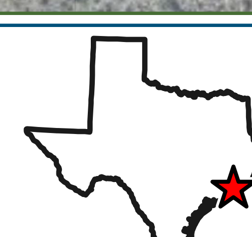
Date Exported: 12/4/2023
Project Number: 107680, 105740



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Appendix D – FQI Mapping

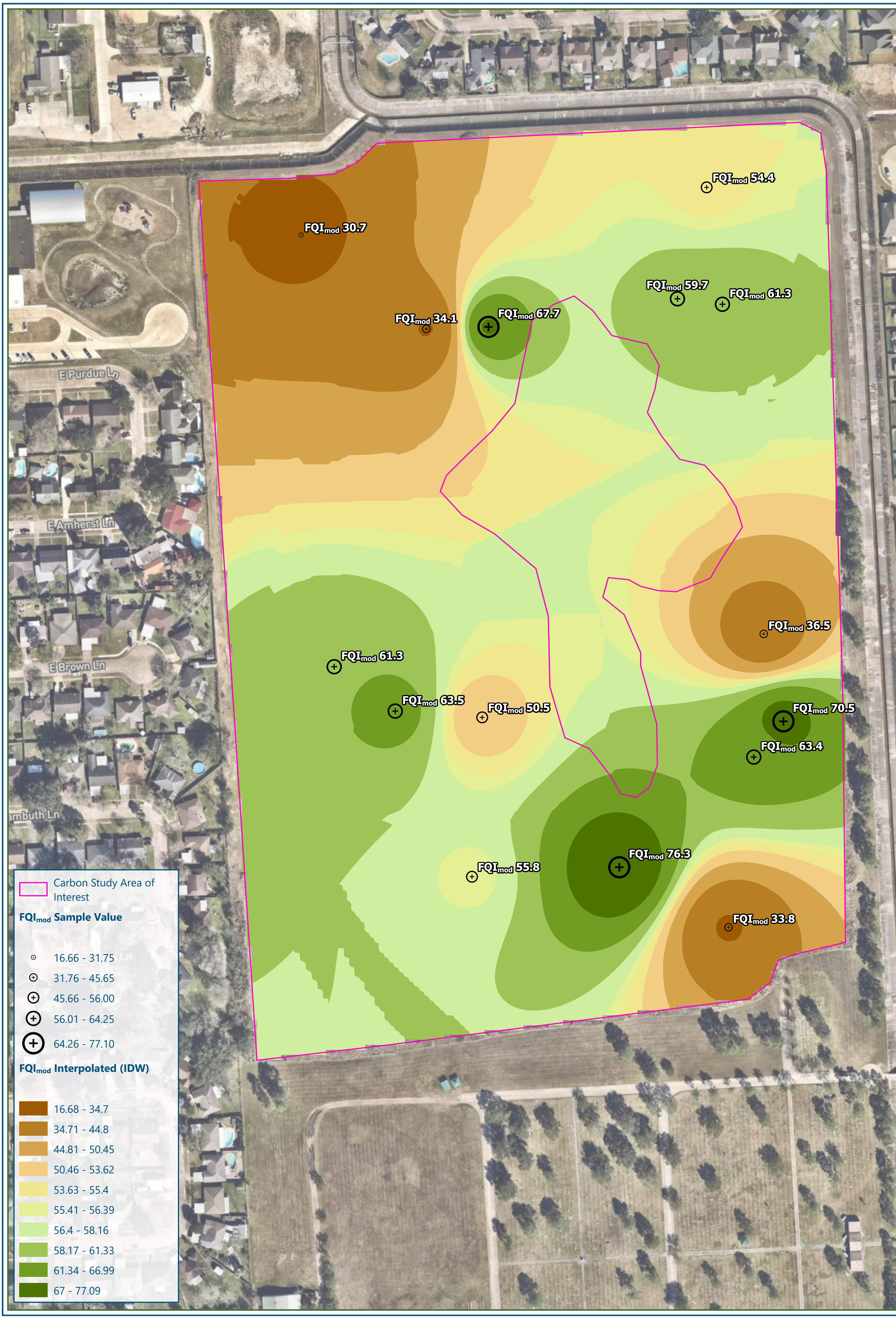


Figure 8
FQI_{mod} Results

Deer Park
Galveston County, Texas
95.1087°W 29.6702°N

N

0 80 160
Feet

Reference: Project limits are approximate. This information is not to be used as final legal boundaries.
Data Source: RES Survey
Spatial Reference:
NAD 1983 StatePlane Texas South Central FIPS 4204
Feet
Date Exported: 10/12/2023
Project Number: 107680, 105740

www.res.us

Cartographer: jtouzel | POC: M. Szuter | Path: R:\Resgis\entgis\Projects\105740_UHCC_Soil_Carbon_Sampling\PRO\105740_UHCC_Soil_Carbon_Sampling.aprx | Layout: UHCC_SoilCarbon_FQI_SamplingInterpolation_North

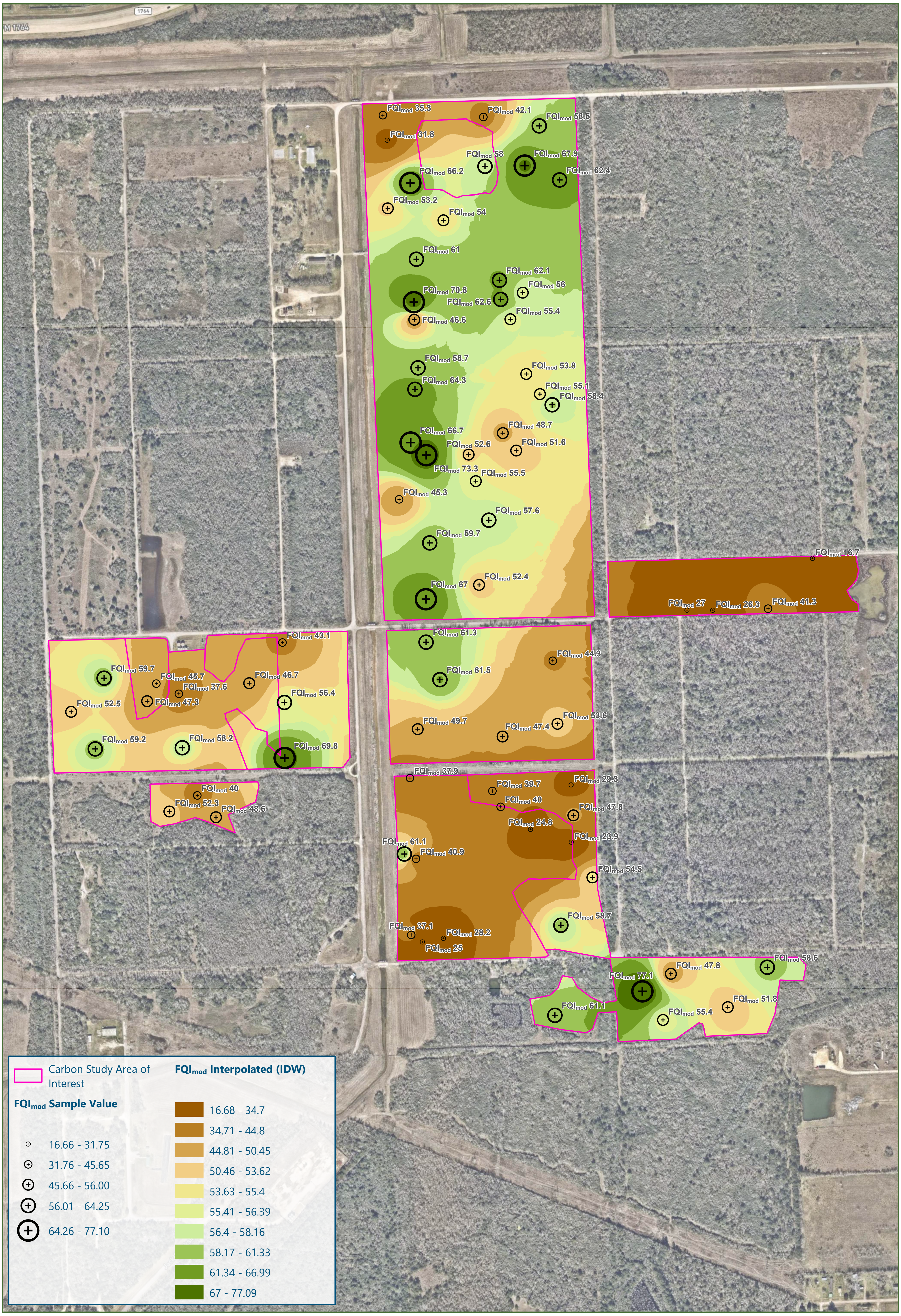


Figure 9
FQI_{mod} Results

UHCC
Galveston County, Texas
95.0416°W 29.3814°N

N

0 250 500
Feet

Reference: Project limits are approximate. This information is not to be used as final legal boundaries.
Data Source: RES Survey
Spatial Reference:
NAD 1983 StatePlane Texas South Central FIPS 4204
Feet
Date Exported: 10/12/2023
Project Number: 107680, 105740

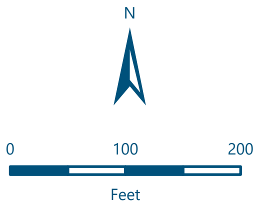
www.res.us

Cartographer: jtouzel | POC: M. Szuter | Path: R:\Resgis\entgis\Projects\105740_UHCC_Soil_Carbon_Sampling\PRO\105740_UHCC_Soil_Carbon_Sampling.aprx | Layout: UHCC_SoilCarbon_FQI_SamplingInterpolation_South

Appendix E – Unit Map

Figure 10
Carbon Study Units

UHCC
Galveston County, Texas
95.1082°W 29.6705°N



Reference: Project limits are approximate. This information is not to be used as final legal boundaries.
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Date Exported: 12/5/2023
Project Number: 107680, 105740

www.res.us

Cartographer: jtouzel | POC: M. Szuter | Path: R:\Resgis\Projects\TX\107680_UHCC_Soil_Carbon_Study\PRO\107680_UHCC_Soil_Carbon_Study.aprx | Layout: UHCC_SoilCarbon_Units_North

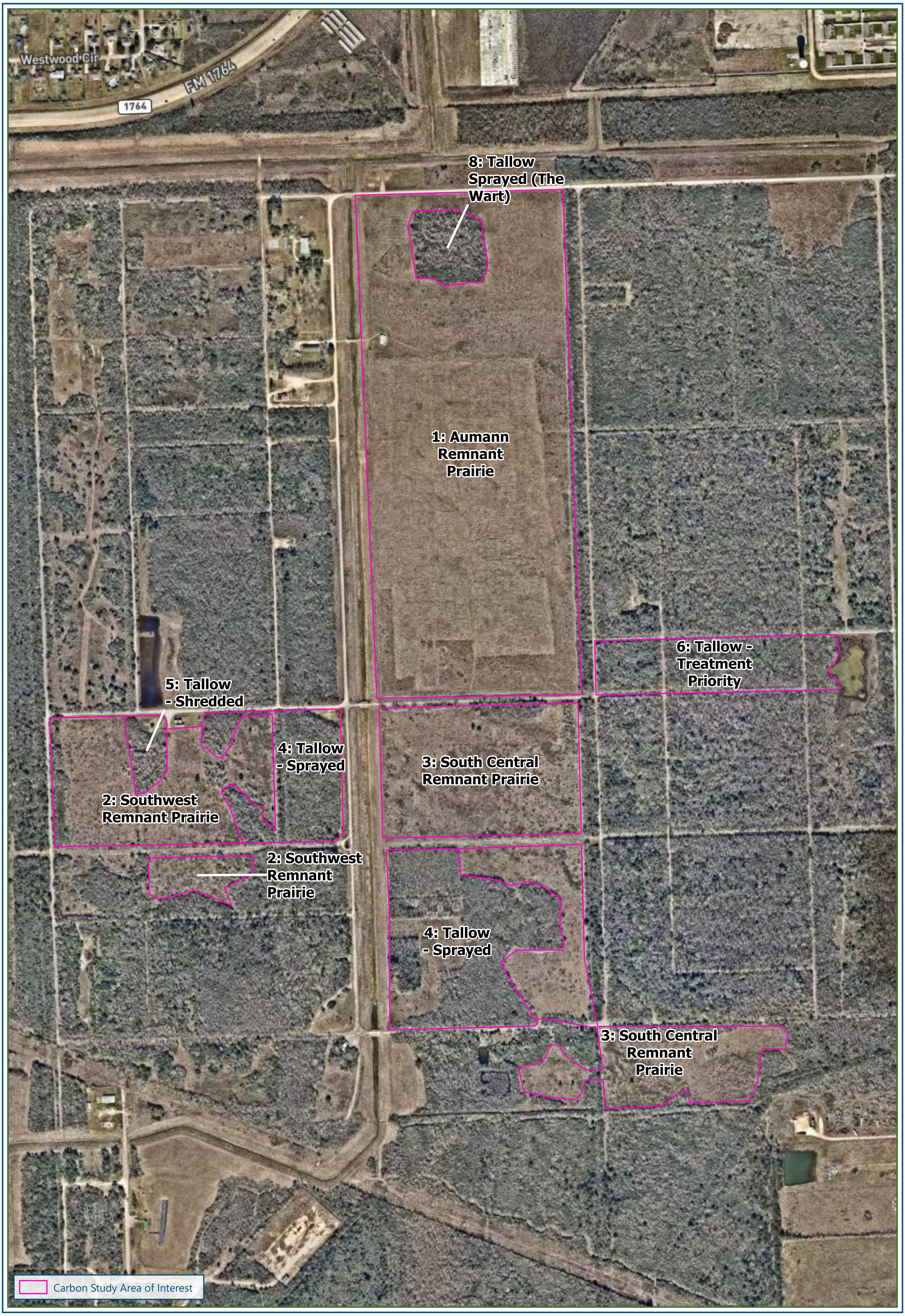

Figure 11
Carbon Study Units

UHCC
Galveston County, Texas
95.0413°W 29.3827°N

N

0 500 1,000
Feet

Reference: Project limits are approximate. This information is not to be used as final legal boundaries.
Data Source: RES Survey
Spatial Reference:
NAD 1983 StatePlane Texas South Central FIPS 4204 Feet
Date Exported: 12/5/2023
Project Number: 107680, 105740

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Cartographer: jtouzel | POC: M. Szuter | Path: R:\Resgis\Projects\TX\107680_UHCC_Soil_Carbon_Study\PRO\107680_UHCC_Soil_Carbon_Study.aprx | Layout: UHCC_SoilCarbon_Units_South