2023 COASTAL MASTER PLAN

DIFFERENCES IN ORGANIC MATTER ACCUMULATION RATES ALONG THE LOUISIANA COAST

ATTACHMENT D2.2

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PREPARED BY: JENNEKE VISSER, DENISE REED, MADELINE FOSTER-MARTINEZ, ELIZABETH JARRELL

COASTAL PROTECTION AND
RESTORATION AUTHORITY
150 TERRACE AVENUE
BATON ROUGE, LA 70802
WWW.COASTAL.LA.GOV

COASTAL PROTECTION AND RESTORATION AUTHORITY

This document was developed in support of the 2023 Coastal Master Plan being prepared by the Coastal Protection and Restoration Authority (CPRA). CPRA was established by the Louisiana Legislature in response to Hurricanes Katrina and Rita through Act 8 of the First Extraordinary Session of 2005. Act 8 of the First Extraordinary Session of 2005 expanded the membership, duties, and responsibilities of CPRA and charged the new authority to develop and implement a comprehensive coastal protection plan, consisting of a master plan (revised every six years) and annual plans. CPRA's mandate is to develop, implement, and enforce a comprehensive coastal protection and restoration master plan.

CITATION

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- Coastal Protection and Restoration Authority (CPRA) of Louisiana – Stuart Brown, Ashley Cobb, Krista Jankowski (formerly CPRA), Elizabeth Jarrell (formerly CPRA), David Lindquist, Sam Martin, and Eric White
- University of New Orleans – Denise Reed

This document was prepared by the 2023 Coastal Master Plan ICM-Wetlands, Vegetation, and Soils Team:

- Denise Reed – University of New Orleans
- Jenneke Visser
- Madeline Foster-Martinez – University of New Orleans
- Elizabeth Jarrell – formerly CPRA

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LIST OF ABBREVIATIONS

AD .... ACTIVE DELTA

BD .... BULK DENSITY

CP .... CHENIER PLAIN

CPRA .... COASTAL PROTECTION AND RESTORATION AUTHORITY

CRMS .... COASTWIDE REFERENCE MONITORING SYSTEM

DP .... DELTA PLAIN

FFIBS ....FORESTED, FRESH, INTERMEDIATE, BRACKISH AND SALINE

ICM ....INTEGRATED COMPARTMENT MODEL

OMAR ....ORGANIC MATTER ACCUMULATION RATE

1.0 BACKGROUND AND CONTEXT

Primary production of higher plants is the main contributor of organic matter to the soil (Figure 1). Organic matter is derived from both aboveground plant material (leaves and stems) and belowground plant material (dead roots and rhizomes). Different plant species have different rates of primary production as well as different allocations between above and belowground biomass (Mitch & Gosselink, 2000). Within a plant species, both primary production and root/shoot allocation are affected by nutrient availability and stressors (salinity and flooding). Within the soil the organic matter contributed by the plants is decomposed by soil fauna, fungi, and microbes. The rate of decomposition is also affected by oxygen (flooding) and other terminal electron acceptors (salinity and mineral composition). Soil elevation relative to sea level is an important influence on many of the interactions shown in Figure 1 and is also influenced by soil compaction and deep subsidence.

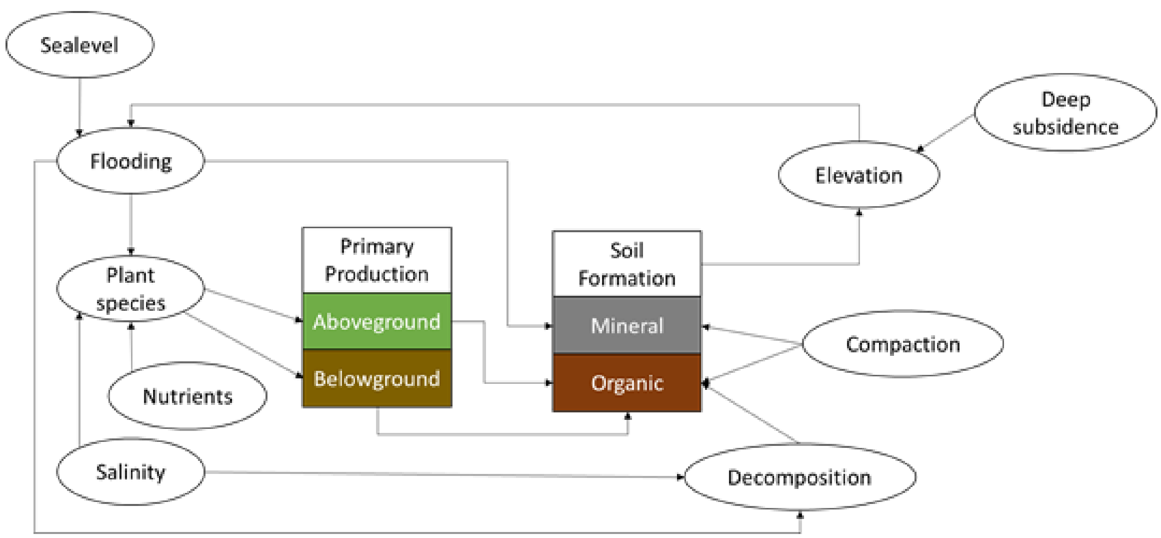

Figure 1. Conceptual model of soil formation.

The approach for calculating organic matter accumulation rate (OMAR) in the 2023 Integrated Compartment Model (ICM) utilizes OMAR data derived from coastwide reference monitoring system (CRMS) data (see Attachment D2: ICM-Wetlands, Vegetation & Soils Model Improvements) based on habitat types defined in LAVegMod. The categorization by type uses scores based on the occurrence of forested, fresh, intermediate, brackish and saline (FFIBS) species. OMAR rates are further separated by Chenier Plain (CP), Delta Plain (DP), and Active Delta (AD). OMAR rates vary by wetland type (Figure 2). For DP, lowest rates are found in brackish marshes (FFIBS scores $5 < x \leq 18$) and higher rates are found in saline marshes (FFIBS score >18) and fresh to intermediate wetlands (FFIBS scores <5). For CP there is little difference in OMAR rates among intermediate, brackish, and saline marshes (FFIBS scores >3) with higher rates for fresh marshes (Figure 2). CP rates for non-saline marshes are lower than DP. A single value forested wetland is used for both CP and DP derived from forested wetland sites in DP as no data is available for forested wetlands in CP. A single rate is used for AD (defined as areas within riverine input and FFIBS scores <3). This value, 0.145 g cm^{-2} yr^{-1}, is higher than any values used for CP or DP. This attachment explores why these differences occur in order to establish conceptual foundations for this aspect of the 2023 ICM.

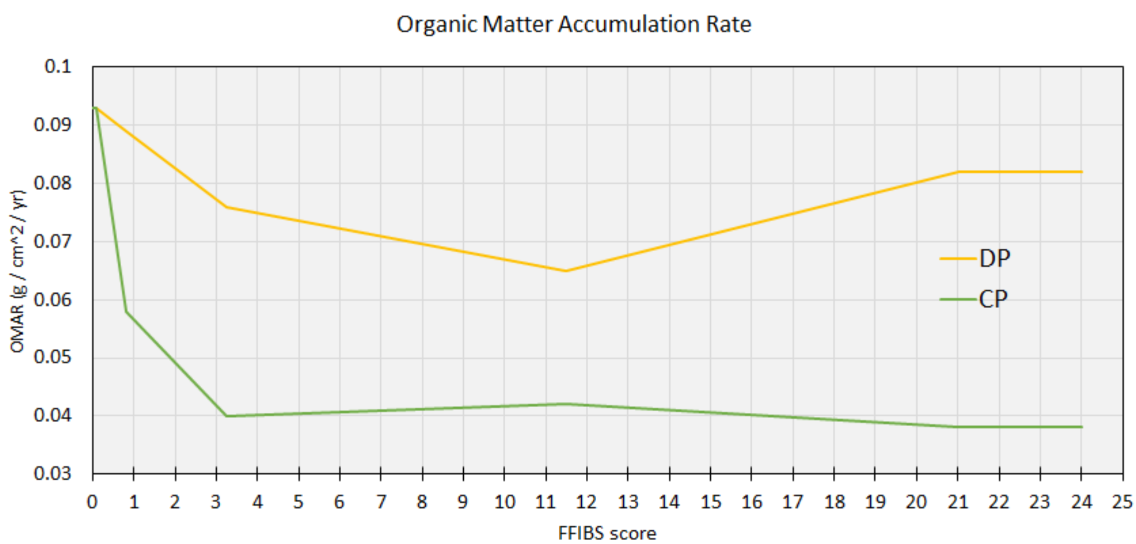

Figure 2. OMAR rates used in the 2023 ICM (see Attachment D2: ICM-Wetlands, Vegetation & Soils Model Improvements and Supplemental Material D2.1: Test Runs for Recommended Updates (G028-G031) for more information).

The following sections review variations in the data used to calculate the OMAR rates shown in Figure 2 and discuss vegetation distribution and soil processes in Louisiana which help explain the differences among habitat types and regions of the coast.

2.0 CALCULATING OMAR

OMAR rates shown in Figure 2 were calculated from core-averaged OM (%) and bulk density (BD; g cm^{-3}) determined from soil cores collected for CRMS in 2018 (2014 for swamp sites). These values were combined with vertical accretion rates calculated using regression analyses (using slope of the line and not forced through a zero intercept) for observed data from feldspar marker horizon plots established at the initiation of the CRMS sites (from years 2007 through 2010 for most sites). OMAR was estimated according to:

$$OMAR = OM \times BD \times VAR \qquad \text{Eq. 1}$$

Accretion data are not collected at flotant sites, therefore those habitats are not included in this analysis. See Attachment D2: ICM-Wetlands, Vegetation & Soils Model Improvements for more details.

Look up tables were created with the geometric means for each type/region combination using the CRMS data. Arithmetic means are inappropriate given the skewed distribution of these data (outliers on the right tail increase the arithmetic mean values). Following model test G031 (see Supplemental Material D2.1: Test Runs for Recommended Updates (G028-G031)) it was determined that the values from the look-up tables should be interpolated between habitat types by pinning the look-up table values to the midpoint of the range of FFIBS scores for each type. This interpolation is shown in Figure 2. For active delta sites OMAR values were calculated from four CRMS sites in active deltaic areas (see Supplemental Material D2.1: Test Runs for Recommended Updates (G028-G031) for more details).

Variations in OM, BD and VAR are explored to identify which, if any, of these three factors contributes to the patterns shown in Figure 2.

3.0 CHENIER PLAN VS. DELTA PLAIN

3.1 VARIATIONS IN OM AND BD

Data provided in Table 10 of Attachment D2: ICM-Wetlands, Vegetation & Soils Model Improvements can be used to explore whether there are obvious differences in OM or BD by habitat types or in CP vs. DP. FFIBS scores were based on the midpoints of ranges for each wetland type (see Supplemental Material D2.1: Test Runs for Recommended Updates (G028-G031) for more details). To calculate the soil properties by dominant species, we added the dominant species at each CRMS site in 2018 (marsh) and 2014 (forested) to the soils database. We limited soil property calculations to sites dominated by species that are included in the ICM. Table 1 shows the number of CRMS sites used in this analysis. CRMS sites in the MR[1] basin were excluded from the analysis and are discussed in the Active Deltaic Areas section below. The data for the CP consist of data from the CS and ME basins, all other basins were assigned to the DP. This includes the AT and TV basins, which both receive river water from the Atchafalaya River, but only two of these 60 sites are in the active delta area. Data from Table 10 of Attachment D2: ICM-Wetlands, Vegetation & Soils Model Improvements was used similarly.

Table 1. Number of CRMS sites by FFIBS score of its dominant species

FFIBS	CP	DP
0	0	44
0.25	4	23
1.5	10	19
2.75	11	9
7.15	58	73
11.5	2	1
17.5	6	9
24	3	42

For CP, as expected, there is an inverse relationship between OM and BD with higher OM in wetland

[1] See https://www.lacoast.gov/crms_viewer/Map/CRMSViewer for basin designations

soils associated with lower values for BD (Figure 3). Note that Figure 3 does not include values for forested wetlands (FFIBS score ≤ 0.15), because there are no CRMS stations in the CP swamps. This general pattern is also found in DP (Figure 4). However, forested wetlands show high OM and high BD in DP. Comparing across CP and DP, OM% is lower in DP for fresh marshes (61.6% in CP vs. 46.6% in DP) with a lesser difference for intermediate (47.6% in CP vs. 42.6% in DP) and brackish marshes (34.8% in CP vs. 30.7% in DP). For saline marshes OM% is slightly higher (22.2%) in DP vs. CP (20.5%). Higher OM% results in higher OMAR for the same BD and VAR values.

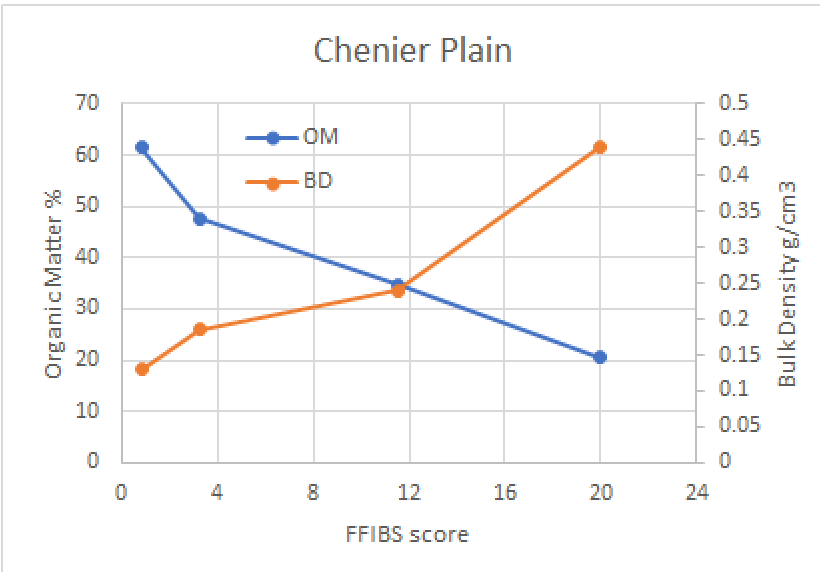

Figure 3. Organic matter and bulk density vs. FFIBS score for the Chenier Plain.

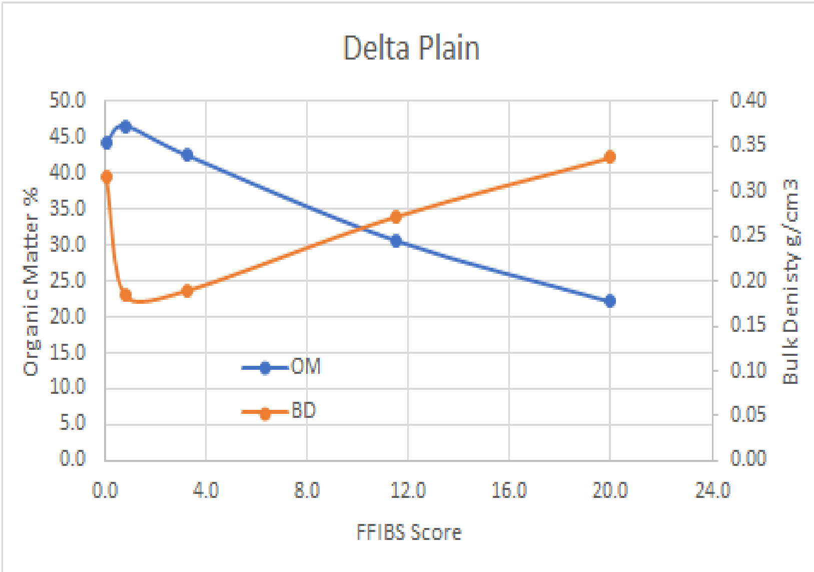

Figure 4. Organic matter and bulk density vs. FFIBS score for the Delta Plain.

BD is higher in DP than CP by 0.06 g cm^{-3}, 0.01 g cm^{-3}, and 0.03 g cm^{-3} for fresh, intermediate and brackish marshes respectively. BD is higher for saline marshes in both systems and substantially higher (0.1 g cm^{-3}) in CP vs DP. High BD will result in higher OMAR rates.

3.2 VARIATIONS IN VERTICAL ACCRETION

Baustian et al. (2021) note that there is little variation in organic matter density (the product of OM and BD) at CRMS sites, but there is wider variation in VAR. Patterns of VAR by FFIBS score can be examined using data from the CRMS sites separated for CP and DP. Figure 5 shows differences between CP and DP by wetland type where habitat types correspond to FFIBS scores as described in Supplemental Material D2.1: Test Runs for Recommended Updates (G028-G031). Note that VAR rates are not available for floating marshes, and, as these data are from CRMS sites, there are no swamp CRMS sites in CP.

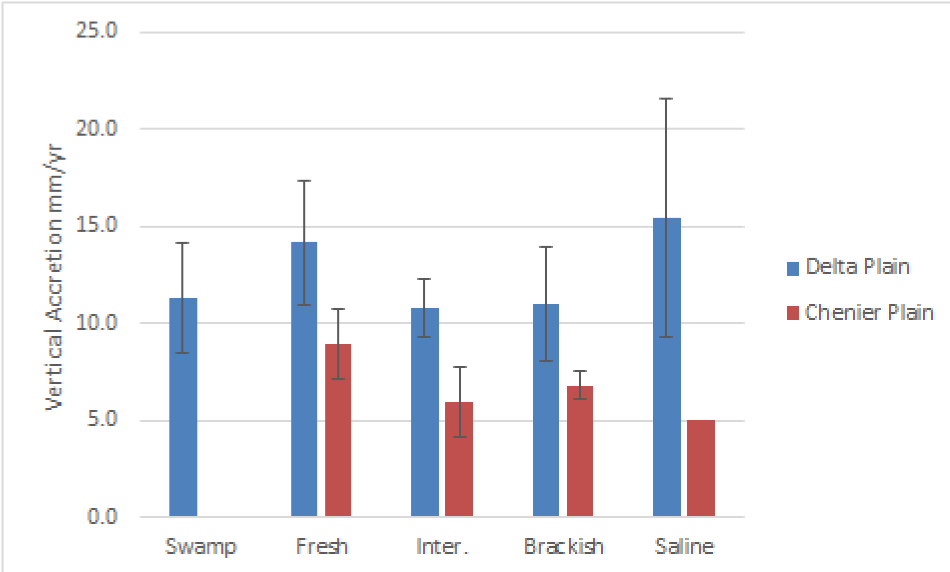

Figure 5. Vertical accretion rates for different habitat types for the Chenier Plain and Delta Plain (means +/- 1SD).

Figure 5 shows higher rates of VAR for DP vs. CP for all marsh types. In DP saline marshes (FFIBS score >18) mean VAR is higher than for brackish marshes but there is little difference between among the other habitat types. In CP, mean VAR in saline marsh is lower than the other habitat types but this is based on data from only three CRMS sites.

Higher rates of VAR in DP may be accounted for generally higher subsidence rates (see Fitzpatrick et al., 2021), which provide 'accommodation space' for both mineral and organic matter accumulation. Differences among types in DP may be accounted for by increased sediment deposition in salt marshes due to proximity to sources of sediment (see Soil Properties discussion below) and the proximity of some swamp sites to mineral sediment as discussed above. Within CP where there is little overall sediment input the variations in VAR among types may be driven by belowground organic contributions from different vegetation species.

3.3 DISCUSSION

Some of the differences in the OM% in the same wetland type among the two regions can be explained by the differences in vegetation composition of the CRMS stations in the different habitat types (Figure 6). Different species have different root:shoot ratios and plant allocation to roots or shoots can be altered by soil fertility and flooding regime (McConnaughay & Coleman, 1999; Miller & Zedler, 2003). Therefore different plant species could result in different OM%.

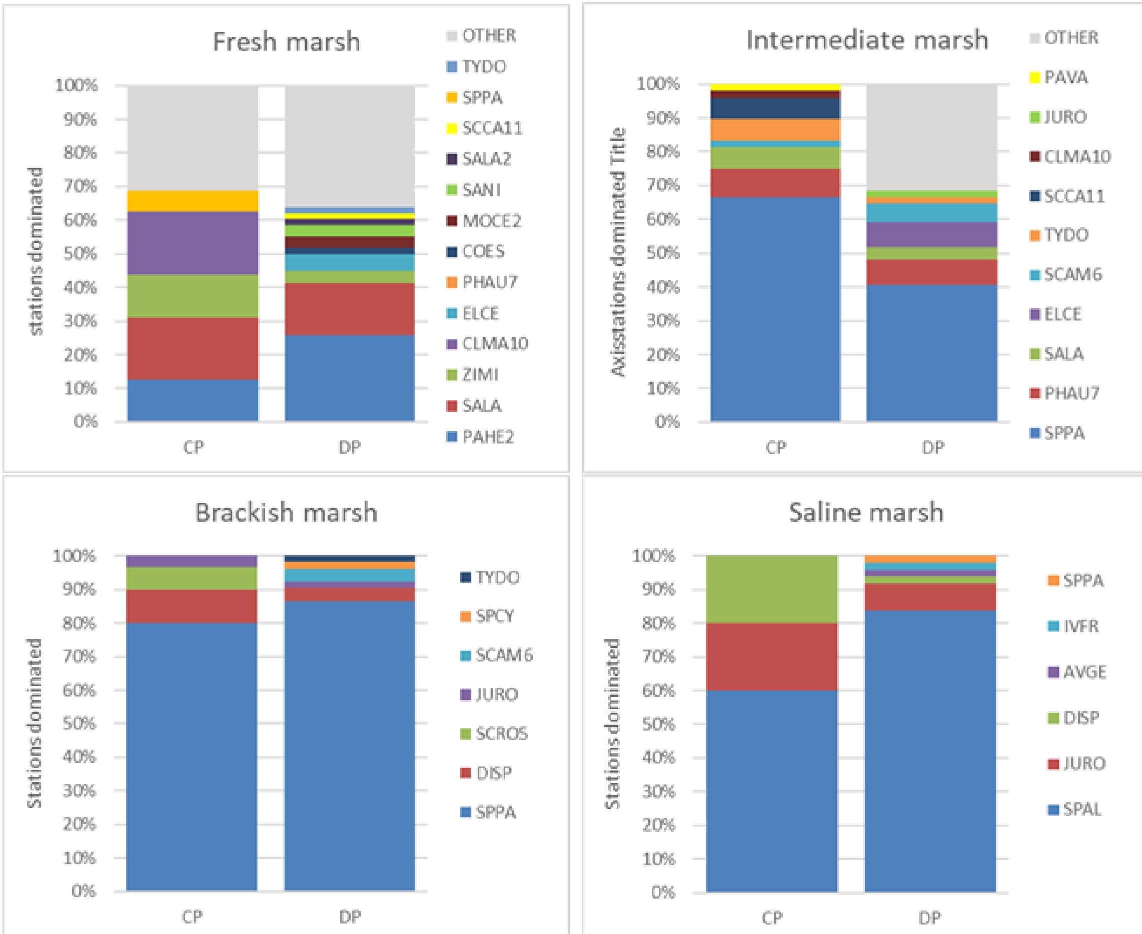

Figure 6. Distribution of dominant species observed at the CRMS stations in each marsh type by region in 2018. Species are ordered by coastwide abundance (bottom of stack). Please note that colors for species differ among graphs. OTHER represent dominant species.

In both regions, fresh and intermediate marshes show a high diversity of dominant plant species, with the DP being more diverse than the CP (Figure 5). In the fresh marsh, sawgrass (CLMA10) and bulltongue (SALA) are the dominant species in the CP, while maidencane (PAHE2) and bulltongue dominate the DP. These species all have similar soil properties (Table 2). It seems that the differences in OM among the fresh marsh soils in the two regions could be driven by soils of species not included in the ICM. Although intermediate marshes in both regions are dominated by wiregrass (SPPA), the CP has more wiregrass dominated stations than the DP. The differences in the intermediate marsh soils also seem to be driven by the species not included in the ICM. Differences in vegetation composition are smaller between the regions in the brackish and saline marshes. Brackish marsh sites are dominated by wiregrass (SPPA), but in the CP there are more sites dominated by saltgrass (DISP) and leafy threesquare (SCRO5), which have lower OM% than wiregrass (SPPA) (Table 1). The saline marshes are dominated by oystergrass (SPAL) but in the CP there are more sites dominated by saltgrass (DISP) and needlerush (JURO), which have lower OM% than oystergrass (SPAL).

Table 2. Soil properties based on dominant species determined from CRMS data

FFIBS score	Species	Common Name	N	OM%*	BD
0	NYAQ2	Tupelo	19	44.9 (O)	0.352
0	TADI2	Bald cypress	18	46.5 (O)	0.290
0	SANI	Black willow	7	22.3 (M)	0.464
0	QUTE	Texas red oak	1	16.3 (M)	0.565
0.25	PAHE2	Maidencane	17	66.0 (O)	0.096
0.25	ZIMI	Cutgrass	5	47.5 (O)	0.286
0.25	MOCE2	Waxmyrtle	3	67.4 (O)	0.082
0.25	COES	Elephant's Ear	2	8.9 (M)	0.599
1.5	SALA	Bulltongue	18	56.3 (O)	0.139
1.5	ELCE	Spikerush	7	73.3 (O)	0.074
1.5	CLMA10	Sawgrass	4	65.0 (O)	0.096
1.5	POPU5	Smartweed	1	43.7 (O)	0.159
2.75	PHAU7	Rouseaucane	17	19.4 (M)	0.411
2.75	TYDO	Cattail	6	57.6 (O)	0.119
2.75	SCCA11	Bullwhip	4	36.2 (O)	0.208
2.75	IVFR	Iva	1	30.0 (O)	0.286
2.75	PAVA	Paspalum	1	40.4 (O)	0.148
7.15	SPPA	Wiregrass	125	39.9 (O)	0.209
7.15	SCAM6	Threecorner	6	30.1 (O)	0.304
11.5	SCRO5	Leafy threecorner	2	31.7 (O)	0.296

FFIBS score	Species	Common Name	N	OM%*	BD
11.5	SPCY	Hogcane	1	26.4 (M)	0.272
17.5	JURO	Needlegrass	8	24.4 (M)	0.294
17.5	DISP	Saltgrass	7	22.1 (M)	0.420
24	SPAL	Oystergrass	44	21.4 (M)	0.342
24	AVGE	Mangrove	1	14.3 (M)	0.446
*Soils with greater than or equal to 30% OM are designated Organic (O) and those with less than 30% OM are designated Mineral (M).					

Table 2 shows there can be considerable differences in the OM for sites dominated by species with the same FFIBS score. These differences are not currently distinguished by species in the ICM but contribute to the differences in OMAR across CP and DP (and AD - see below). Future analysis focused on the relationship between FFIBS score of a CRMS site and its soil properties, as well as the dominant species could inform more refined application of the data in master planning work. This could allow the ICM to calculate weighted averages for OMAR based on abundance of the species within a box. Associating OMAR with dominant species may make it more responsive to changes in hydrology through water level variability that is used in LAVegMod to determine species distributions, which was one of the original motivations for reassessing calculation on OMAR for the 2023 Coastal Master Plan (see Attachment D2: ICM-Wetlands, Vegetation & Soils Model Improvements).

Examining the soil properties along the FFIBS gradient (Figure 7) shows that there is a lot more variation in soil properties for vegetation species with FFIBS scores below 5. For this analysis, we only used stations that were dominated by species that are included in the ICM. Species associated with river sedimentation such as willow (SANI), elephant's ear (COES), and Roseau cane (PHAU7) have soils with low OM% and high BD (Table 2). While species associated with low sediment input such as baldcypress (TADI2), maidencane (PAHE2), sawgrass (CLMA10), and spikerush (ELCE) have soils with high OM% and low BD.

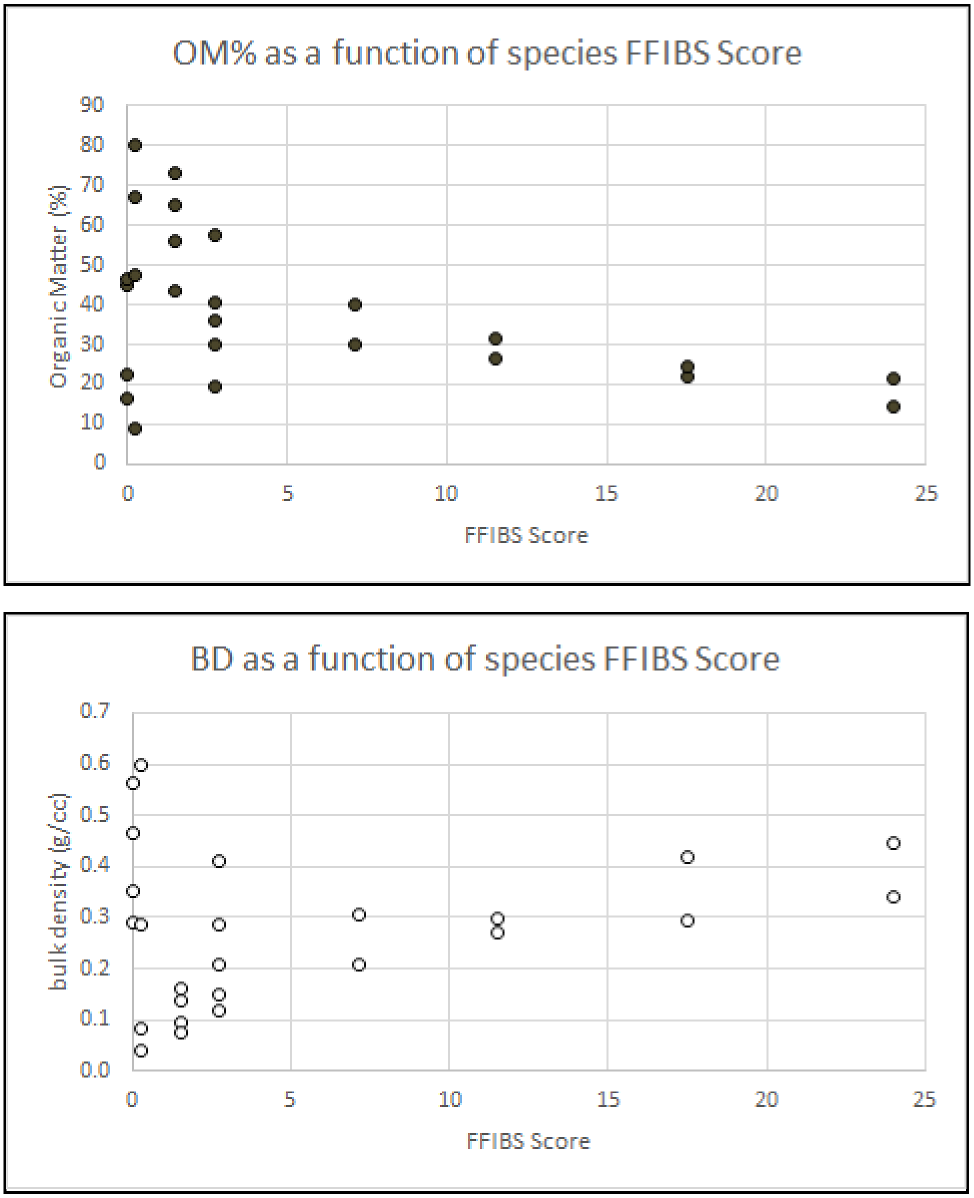

Figure 7. Percent Organic Matter (top) and Bulk Density (bottom), both as a function of species FFIBS score.

The general pattern of decreasing OM with increasing FFIBS score shown in Figure 7 is supported by several studies. In a meta-analysis of data from marshes in the northern Gulf of Mexico, Osland et al. (2018) found that estuaries with higher salinities had lower SOM and vice versa. Overall, they noted that the variable having the greatest effect on SOM is plant productivity, which is, in turn, influenced by salinity.

Within Louisiana, Baustian et al. (2017) found the mean percent total carbon varied among marsh types with the highest amount in fresh marshes (dominated by *Panicum hemitomon* and *Typha latifolia*). Intermediate (dominated by *Sagittaria lancifolia* and *Schoenoplectus americanus*) and brackish types were similar but significantly higher than the saline marshes. Overall % total carbon had a significant negative relationship with mean annual salinity. In contrast, Nyman et al. (1990) found that intermediate marsh had a higher percent of organic carbon than fresh marsh. The intermediate marsh site was in Barataria Bay (see Hatton et al., 1983) while fresh marsh sites were in western Terrebonne and upper Barataria (details of species at each site are not reported). Analyzing data from across the coast, Suir et al. (2019) found that fresh, intermediate, and brackish zones had greater percent carbon than the saline zone. However, the scatter shown in Figure 7 at low FFIBS scores shows that the sites within the same broad vegetation type could have diverse levels of soil OM. Variability in soil OM at higher salinity types was also found in Barataria Bay by Mariotti et al. (2020) where OM in salt marshes in Barataria Bay was 26% ± 8%, compared to 43% ± 18% in brackish marshes.

Several studies have looked at the mechanisms influencing organic matter accumulation and the role of salinity (Figure 1). Stagg et al. (2018) found that below-ground litter decay rates did not vary significantly among the fresh, mesohaline and polyhaline marshes sampled in the study, and that external drivers, including pore water salinity and flood duration, had no significant predictive capacity for either above-or below-ground litter decomposition. Williams and Rosenheim (2015) note that the addition of marine salts may alter the microbial processing of OM in ways that change its stability and/or may alter the organic carbon contribution of the dominant vegetation to the soil.

BD, the weight per unit volume of soil, is related to the amount of mineral sediment in the soil. The ICM calculates the mineral contributions of sediment separately from OMAR so its actual contribution to VAR in the modeling is dependent on processes controlling mineral sediment deposition rather than the BD data. Higher bulk densities in soils would be expected in areas with higher sediment deposition, and saline marshes closer to the coast are more exposed to sediment resuspended from coastal bays during frontal passage and storms, compared to more interior areas, i.e., brackish and fresher marshes. The high values for BD in swamps shown in Figure 7 are associated with CRMS swamp sites in Terrebonne and Barataria basins (Table 10 in Attachment D2: ICM-Wetlands, Vegetation & Soils Model Improvements). Some of these sites are in areas which may be subject mineral sediment input, i.e., in the Atchafalaya/Verret basins, and vertical accretion rates (see section below) reach 31 mm/yr at CRMS0403 and 25 mm/yr at CRMS 5770, which is potentially indicative of mineral sediment deposition,

Many of the studies discussed above also examined soil BD. Baustian et al. (2017) found that soil bulk density ranged between 0.07 to 0.19 g cm^{-3} among marsh types and had a positive relationship with salinity, generally matching Figure 7. Nyman et al. (1990) found that within inactive DP, bulk density increased from fresh (inland) to saline (seaward) marshes. They also note that saline marsh soils had more mineral matter and less water and gas than other marsh types. Suir et al. (2019) found that fresh, intermediate, and brackish zones had lower bulk density than the saline zone. Mariotti et al. (2020) also report substantial variability in BD in Barataria Bay with bulk density of salt marshes at 270 ± 110 kg m^{-3} and brackish marshes at 170 ± 70 kg m^{-3}. However, higher BD in salt marshes supports the pattern in Figure 7.

There have been few studies of soil bulk density in swamps in Louisiana and the highest values reported by Shaffer et al. (2009) for the Maurepas swamp (0.16 g/cm^3) are lower than those shown in Figure 4. However, those sites were not influenced by direct sediment input. Based on the species analysis (Table 1), forested wetlands dominated by willow (SANI) have significant higher BD than those dominated by bald cypress (TADI2) and tupelo (NYAQ2). The forested wetland CRMS sites in the Atchafalaya and Teche Vermillion basin are dominated by willow, which is associated with active river deposition, while the forested wetland CRMS sites in the Barataria and Pontchartrain basins are associated with backwater swamps dominated by cypress (TADI2) and tupelo (NYAQ2) which have much lower BD.

4.0 ACTIVE DELTA AREAS

As previously mentioned, a single rate of OMAR is used for AD (areas within riverine input and FFIBS scores<3). This value, 0.145 g cm^{-2} yr^{-1}, was derived from four CRMS sites that include locations in the Bird's Foot Delta, the Atchafalaya Delta, and the Wax Lake Delta (see Supplemental Material D2.1: Test Runs for Recommended Updates (G028-G031)). The value is much higher than for marshes with low FFIBS scores in DP or CP (Figure 2).

For the dominant species analysis only the MR Bird's Foot Delta was used for AD. In the Bird's Foot Delta, roseaucane (PHAU7) is the dominant species in both fresh and intermediate marsh stations (Figure 8), with bulltongue (SALA) and elephant's ear (COES) each dominating 20% of the fresh marsh stations.

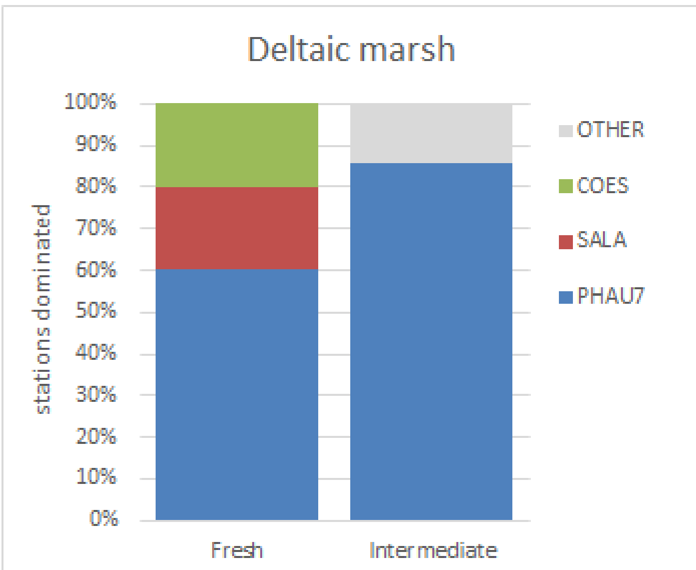

Figure 8. Species composition of CRMS stations in the Bird's Foot Delta (MR Basin).

Table 3 shows summary information for OM and BD for active delta areas of the coast. OM is substantially lower than for CP and DP, and BD is much higher (see Figure 3 and Figure 4). In an analysis of CRMS soil data collected in 2006-2009, Wang et al. (2016) found lowest SOM values (<10%) in the Mississippi River deltaic and the Atchafalaya deltaic marsh. Marsh types within the two active deltas also included mean BD larger than 0.6 g cm^{-3}.

Table 3. Mean OM and BD values for CRMS sites in Mississippi River and Atchafalaya Basins (Baustian et al., 2021 Table 10)

	Fresh	**Intermediate**
OM%	18.35	11.68
BD g/cc	0.42	0.49

The data in Table 3 include the entire Atchafalaya Basin – not only the active delta areas. DeLaune et al. (2016), working in the Wax Lake Delta and adjacent river-influenced marshes, identified that marshes adjacent and surrounding the delta benefit from sediment delivery from the river during flood stage. Results from that study also suggest that increased sediment inputs from river sediment diversions enhances vegetation growth leading to increased organic matter accretion, consistent with the high OMAR rates used in the 2023 ICM. Nyman et al. (1990) also noted, based on volumetric comparisons, that active delta fresh marsh soil had significantly more mineral and organic matter than inactive delta fresh marsh soil. Vertical accretion rates were also greatest in the Active Delta Zone. Fresh marsh in their Active Delta Zone contained 2.1 times more mineral matter than fresh marsh in the Inactive Delta Zone. In their coastwide analysis, Suir et al. (2019) showed that basins that receive larger river inputs (i.e., Atchafalaya, Mississippi River, Penchant, Vermilion-Teche) had significantly higher carbon accumulation rates than those with lower inputs (i.e., Biloxi Marsh, Calcasieu/Sabine, Mermentau). The Mississippi River basin had the highest mean carbon accumulation rate in their study.

5.0 CONCLUSIONS AND RECOMMENDATIONS

In general the differences in OMAR across vegetation types and coastal settings being used in the 2023 Coastal Master Plan analysis can be conceptually explained on the basis of variations in species distributions and the environments they are associated with. Physical processes such as sediment input and subsidence/flooding influence species distributions as well as aspects of wetland soils. The overall patterns found in how OM and BD vary with FFIBS score are similar to those found in previous studies. Similarly, while there are few mechanistic studies of the processes influencing soil organic matter accumulation, those available support the patterns shown in the data analysis represented in Supplemental Material D2.1: Test Runs for Recommended Updates (G028-G031).

For future model development of the ICM, it is recommended to examine the relationship between FFIBS and soil properties more carefully than was done in this report. Specifically:

- Examine the relationship between FFIBS score of a CRMS site and its soil properties.
- Examine soil properties of vegetation species included in the ICM with weighted averages based on abundance of the species at the site.

6.0 REFERENCES

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