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Soil Carbon Sequestration and Carbon Market Potential of a Southern California Tidal Salt Marsh Proposed for Restoration

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Soil Carbon Sequestration and Carbon Market Potential of a Southern California Tidal Salt Marsh Proposed for Restoration

A dissertation submitted in partial satisfaction

of the requirements for the degree

Doctor of Environmental Science and Engineering

by

Todd Michael Bear

2017

ABSTRACT OF THE DISSERTATION

Soil Carbon Sequestration and Carbon Market Potential of a Southern California Tidal Salt Marsh Proposed for Restoration

by

Todd Michael Bear

Doctor of Environmental Science and Engineering

University of California, Los Angeles, 2017

Professor Richard F. Ambrose, Chair

Without a substantial reduction in the billions of tons of anthropogenic greenhouse gases emitted annually our planet can expect a wide variety of deleterious effects. The restoration, enhancement, and conservation of coastal "blue carbon" habitats, including tidal salt marshes, have received increasing attention as a potential component of climate change mitigation because of their high carbon storage capacity.

This study presents the results of an investigation of soil carbon sequestration within a degraded Mediterranean-type climate tidal salt marsh in southern California, the Ballona Wetlands. Results from the Ballona Wetlands soil analyses and data from existing tidal marsh studies are used to estimate the change in soil carbon accumulation resulting from the proposed Ballona Wetlands Restoration Project (Ballona Project) as compared to the existing condition. Finally, this study demonstrates the process of using an existing carbon market methodology,

VCS Methodology for Tidal Wetland and Seagrass Restoration VM0033 (2015, V 1.0), to calculate the number of carbon credits that could potentially be generated for the Ballona Project.

The results presented in Chapter 3 show that the existing tidal marsh habitats of the Ballona Wetlands contain soil organic carbon densities ranging from 0.018 to 0.030 g/cm^3. Averaging SOC densities by habitat type resulted in a range of 0.022 to 0.027 g C/cm^3, which is similar to natural tidal marshes around the world. Percent organic carbon is highest in low marsh habitat and decreases with increasing marsh habitat elevation (low > mid > high). However, carbon density is lowest in low marsh habitat and increases with increasing habitat elevation (low < mid < high). Carbon content is highest near the soil surface in all vegetated habitats and decreases rapidly due to decomposition of organic matter near the surface before stabilizing at lower soil depths. Higher levels of carbon at the soil surface of the existing habitats shows that even in its degraded condition the soils continue to accumulate organic carbon.

Chapter 4 presents a method to calculate carbon accumulation rates using the soil carbon densities measured in Chapter 3 along with soil accretion rates estimated from data in existing studies of tidal marsh habitat. Carbon accumulation rates estimated for habitats of the proposed Ballona Project are similar to rates reported in other tidal marsh studies. Results showed that the proposed restoration of a 600-acre degraded tidal marsh would increase the amount of carbon the habitats accumulate and store by an estimated 286 metric tons of carbon dioxide equivalents (CO_2e) per year (range 110 – 680 mt CO_2e/yr). This represents a 270% increase from the carbon accumulation estimated for the existing habitats.

The evaluation presented in Chapter 5 indicates that depending on project area, scope of restoration activities, and market value of a carbon credit (where 1 carbon credit = 1 mt CO_2e), restoring tidal marsh habitat in general could be a viable component in a carbon trading market and climate change mitigation. However, due to its small area, high construction costs and emissions, and the currently low value of a carbon credit (approx. $13.50 in early 2017), the Ballona Project is not by itself financially feasible in a carbon market. The annual funding from carbon credit generation of the Ballona Project is estimated at approximately $2,538 per year (range $420 – $7,338) and is unlikely to even cover the monitoring and reporting costs associated with carbon market participation.

The dissertation of Todd Michael Bear is approved.

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Kyle Cavanaugh

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LIST OF ABBREVIATIONS

ac	Acre
AFOLU	Agriculture, Forestry and Other Land Uses
A/R	Afforestation/Reforestation
BSL	Baseline Scenario
BWER	Ballona Wetlands Ecological Reserve
C	Carbon
CAR	Carbon Accumulation Rate
CARB	California Air Resources Board
CDM	Clean Development Mechanism
CH_4	Methane
CO_2e	Carbon Dioxide Equivalent
EIS/EIR	Environmental Impact Statement / Environmental Impact Report
FRP	Fire Reduction Premium
GHG	Greenhouse Gas
ha	Hectare
LK	Leakage
MLLW	Mean Lower Low Water
mt	Metric Ton
NAVD	North American Vertical Datum
NER	Net Emission Reductions and Removals
N_2O	Nitrous Oxide
OC	Organic Carbon
OM	Organic Matter
PDT	Peat Depletion Time
ppt	Parts per thousand
SAR	Soil Accretion Rate
SBD	Soil Bulk Density
SDT	Soil Organic Matter Depletion Time
SOC	Soil Organic Carbon
UNFCCC	United Nations Framework Convention on Climate Change
VCS	Verified Carbon Standard
VCU	Verified Carbon Unit
WPS	With Project Scenario

ACKNOWLEDGEMENTS

This dissertation process was a long endeavor and would not have been possible without the support and encouragement of many people. My parents, Ken and Sandy, and my sister Kristin and brother-in-law Jeffrey provided encouragement and much appreciated confidence in me throughout the years. Collecting and processing tidal marsh soil samples is hard and dirty work. Thanks to colleagues Jim Burton and Carlos Carreon for sacrificing their time to collect soil cores from the Ballona Wetlands over long days, although the weather and scenery were beautiful. Carlos Carreon, Stephen Holle, and Nicole Tachiki deserve my utmost thanks for the hours upon hours of triceps-developing grinding and meticulous wieghing of hundreds of soil samples for analysis. Without them, I would still be in the laboratory.

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1 INTRODUCTION

The continuing increase of greenhouse gas (GHG) emissions from human activities worldwide has resulted in the highest concentrations of GHG in our atmosphere in at least the last 800,000 years (Luthi et al., 2008; Jouzel et al., 2007; EPA, 2016). Carbon dioxide is the most important greenhouse gas emitted by humans and represents over 64% of the amount of warming caused by emissions. The pre-industrial era (pre-c.1750) concentration of atmospheric CO_2 averaged approximately 280 parts per million (ppm) (IPCC, 2013). In early 2017, NOAA's Mauna Loa Observatory measured the daily mean concentration of carbon dioxide in the atmosphere at over 405 ppm, a 45% increase from pre-industrial levels.

Scientists have understood since the 19th century that carbon dioxide absorbs heat radiated from the Earth in a process we now refer to as the greenhouse effect. Svante Arrhenius was the first scientist to attempt to calculate how changes in atmospheric CO_2 alter the surface temperature of the earth (Arrhenius, 1896). Today, warming of the climate system is unequivocal; the atmosphere and oceans have warmed, the volumes of snow and ice have diminished, and sea level has risen. Without a substantial reduction in the billions of tons of greenhouse gases emitted annually our planet can expect a wide variety of deleterious effects.

Several approaches are available and being implemented to mitigate the increasing levels of CO_2 in the atmosphere including: government regulation of fossil fuel emissions from industries and automobiles, renewable energy, GHG emission offset programs, agricultural and forestry management, urban tree planting projects; afforestation/reforestation, and coastal habitat restoration. Of these mitigation efforts, the restoration, enhancement, and conservation of coastal habitats have received the least attention. The carbon stored in coastal habitats such as seagrass beds, mangroves, and tidal marshes is referred to as "blue carbon" and is recognized as a potential driver of coastal conservation and restoration because of these habitats' high carbon storage capacity (Mcleod et al., 2011; Sifleet et al., 2011; Emmer et al., 2015). Tidal salt marshes in particular have been shown to accumulate and store substantial amounts of blue carbon (Chmura et al., 2003; Pidgeon, 2009).

1.1 Tidal Salt Marsh Blue Carbon

Tidal marshes accumulate and sequester significant amounts of CO_2 from the atmosphere due to high sediment deposition, saturated soils that result in low decomposition rates, and high primary productivity (Chmura et al., 2003; Ouyang & Lee, 2014; Bridgham et al., 2006; Li et al., 2010). Organic matter from the above-ground biomass and the below-ground root zone accumulates in the soil over time. As plant matter dies it begins to decompose; however, not all of the organic matter is lost to decomposition due to the saturated soils and rapid soil accretion present in tidal marshes. Many tidal marshes also trap sediment containing organic matter from natural and anthropogenic watershed sources, adding to the carbon accumulation (Mitra et al., 2005). Saturated soils create an anaerobic environment that slows decomposition rates due to a chemically reduced condition for microbial respiration (Mitsch & Gosselink, 2007; Li et al., 2010). In addition, some recalcitrant organic molecules can avoid microbial decomposition and accumulate in the soil (Valiela et al., 1985; Callaway et al., 1996; Kirwan & Megonigal, 2013). Organic carbon is sequestered in marshes when soil organic matter decomposition has slowed to the point that further loss of carbon is negligible and conditions favor long-term carbon storage.

The global extent of coastal blue carbon ecosystems makes up only approximately 0.3% (0.2-0.8%) of the total land area of the Earth but are believed to contain a disproportionate amount of the global soil carbon (Pendleton et al., 2012; Bridgham et al., 2006; Mitra et al., 2005). Coastal habitats contribute about half of the total carbon sequestration in all ocean sediments even though they account for less than 2% of the ocean surface (Duarte et al., 2005). In addition, carbon burial in these habitats can be sustained over millennia and be as deep as 8 meters (Pidgeon, 2009; Chmura et al., 2003; Brevik & Homburg, 2004). Tidal marsh soils have higher soil carbon accumulation rates than any other ecosystem (Ouyang & Lee, 2014), approximately 10 times the rate of freshwater peatlands (Roulet, 2000), 10 times the rate of temperate forests and 50 times the rate of tropical forests (Pidgeon, 2009). Additionally, tidal marshes have been found to emit a small to negligible amount of methane (CH_4), a powerful greenhouse gas, as compared to freshwater wetlands due to the presence of sulfate in salt water causing the suppression of methanogenic bacteria in anaerobic conditions (Bartlett et al., 1987; Bartlett & Harris, 1993; Keller et al., 2012). Although the exact amount of carbon stored in coastal habitats is still an area of active research, annual carbon sequestration in coastal ecosystems globally is estimated between approximately 327 and 856 million metric tons of carbon dioxide equivalents (Mcleod et al., 2011; Pendleton et al., 2012; Ouyang & Lee, 2014). This represents a removal of between 4.8% and 12.5% of the total U.S. emissions of 6,870 million metric tons of carbon dioxide equivalents for the year 2014 (EPA, 2016).

1.2 Tidal Marsh Restoration and Carbon Accumulation

Many of the historical tidal marsh systems in North America have been filled and/or degraded to the point where their ability to sequester carbon and keep it sequestered is compromised. Changes in land use such as the conversion of wetlands to upland habitat, agricultural land, and development projects, can affect the ability of wetlands to remove CO_2 from the atmosphere and can lead to substantial loss of carbon stored in their soils (EPA, 2013; Mitsch & Gosselink, 2007). The draining and destruction of wetlands through land-use changes has contributed a large and steady flux of carbon back to the atmosphere (Bridgham et al., 2006;

Mitra et al., 2005; Maltby & Immirzi, 1993). This occurs when buried wetland soils are exposed to the air by excavation or by draining, thereby allowing aerobic oxidation to occur and converting organic matter in the soil to CO_2 emissions.

The estimated loss of vegetated coastal ecosystems over the last 50-100 years ranges from 25-50% of the total global area and at current conversion rates, 30-40% of global tidal marshes and seagrasses and 100% of mangroves could be lost in the next 100 years (Mcleod et al., 2011; Pendleton et al., 2012). In California, only 5% of the state's coastal wetlands remain intact (CERES, 2015). It is estimated that prior to about 1850 there were approximately 20,000 ha (49,400 acres) of estuarine habitats along the southern California coast alone (Grossinger et al., 2011) with an overall loss today estimated at 9,317 ha, or 48% of the historical habitat (Stein et al., 2014). Remaining coastal wetlands are often degraded by decades of anthropogenic impacts, yet are highly valued due to their ecological functions and ecosystem services.

Increased interest is being given to restoring wetlands for their well-known ecosystem benefits. Numerous projects around the U.S. have focused on conserving, enhancing, and restoring tidal marsh habitat and function, although typically not for the purpose of carbon sequestration. In California alone, millions of dollars have been invested to protect and restore wetlands and riparian habitats. The restoration of these habitats has substantial ecological, socio-economic, and environmental benefits. However, soil carbon sequestration as a benefit of wetland restoration has been gaining attention only recently. The restoration of tidal marsh habitats offers significant potential for increasing carbon sequestration and natural carbon sinks (Crooks et al., 2010; Chmura, 2009; Pidgeon, 2009) and studies have shown substantial increases in soil carbon accumulation following restoration (Burden et al., 2013; Spencer et al., 2008; Craft et al., 1988; Craft et al., 1999; Craft et al., 2000; Craft et al., 2002; Craft et al., 2003).

1.3 Blue Carbon in Carbon Markets

Carbon emission trading is a market-based approach that provides economic incentives for reducing GHG pollution. Today's carbon markets have foundations in earlier emissions trading systems, including the U.S. Acid Rain Program, which successfully reduced acid rain-causing emissions from power plants. Similarly, carbon markets are designed to work by assigning a price to GHG emissions and then establishing a cap on the total amount of emissions allowed. Carbon emitters must acquire permits to cover the emissions they produce and can purchase carbon credits, also known as carbon offsets, to cover some of the emissions above what they are permitted to release. Projects that reduce GHG emissions can generate carbon offsets and sell them to emitters through an offset program.

Various GHG offset accounting programs exist, including the American Carbon Registry (ACR), Climate Action Reserve (CAR), and Verified Carbon Standard (VCS). Scientifically credible methodologies or protocols are provided by these programs to properly measure a project's GHG offset and verify the actual carbon sequestration. The ACR and VCS have both developed protocols for the generation of carbon offsets through wetland restoration projects for sale on carbon markets.

In 2006, California passed AB-32, the California Global Warming Solutions Act, which requires California to reduce its greenhouse gas emissions to 1990 levels by 2020, a reduction of approximately 15% below emissions expected under a "business as usual" scenario, and ultimately achieve an 80% reduction below 1990 levels by 2050. The AB-32 Scoping Plan identifies a cap-and-trade program as one strategy to reduce GHG emissions in California. A cap-and-trade program was designed by the California Air Resources Board (CARB) and began on January 1, 2012, with an enforceable compliance obligation beginning with 2013 GHG emissions. American Carbon Registry (ACR), Climate Action Reserve (CAR), and Verified Carbon Standard (VCS) have all been approved by CARB as Offset Project Registries, which allows them to issue Registry Offset Credits for California's cap-and-trade program.

Given the high carbon sequestration rates measured in tidal marsh soils, tidal marsh restoration projects may be viable components of GHG offset programs. As of early 2017, California has not approved carbon offset credits from wetland restoration projects in its trading program; however, it is anticipated that these projects will be included in its program in coming years.

Despite existing data showing the carbon sequestering potential of wetlands, the limited emission of CH_4 in tidal salt marshes, and the growing interest in promoting and protecting natural carbon sinks, there have been few studies focused on carbon sequestration in tidal marshes. Additional carbon studies and further comprehensive sampling are needed to advance the understanding of carbon sequestration in tidal marshes. This study contributes valuable data to the existing literature related to carbon sequestration in these understudied habitats.

1.4 Outline of Dissertation Chapters

This chapter provides an introduction to the dissertation, while Chapter 2 presents information about the study area, the Ballona Wetlands, a degraded Mediterranean-type climate tidal marsh in southern California.

Chapter 3 of this study investigates the carbon content of the Ballona Wetlands. Soil core samples were collected and analyzed to determine how the soil carbon content varies spatially and with depth across the marsh habitats and results are compared to other tidal marsh studies. The results of this analysis help us understand how much carbon is being stored across tidal marsh habitats and where carbon is being stored in the highest densities. Additionally, contributing to the limited data available for Mediterranean-type climate tidal marshes facilitates the comparison of soil carbon with coastal wetlands in other regions of the nation and the world.

In Chapter 4, the change in soil carbon accumulation resulting from restoration of a tidal marsh is estimated prior to its construction using the proposed Ballona Wetlands Restoration Project (Ballona Project) as a case study. By increasing the area of tidally influenced marsh habitat and improving hydrology to these habitats, the Ballona Project is anticipated to increase the net carbon sequestration. To estimate this change in soil carbon prior to construction, the net change in carbon sequestration is calculated using available data from existing studies along with site-specific soil data collected in Chapter 3. The calculation of the net change in carbon sequestration due to the restoration consists of estimating carbon sequestration of the existing and restored habitats. This analysis can be applied to other tidal marsh restoration projects during the planning process to determine if a proposed restoration alternative will increase the amount of carbon sequestered in its soils, and by how much, compared to the existing condition. Understanding the benefits of the carbon sequestration potential of restored wetlands may encourage the development of more restoration projects, in part, for their carbon storage component. Or similarly, proposed restoration project plans could be modified to further enhance carbon sequestration based on the results of a net carbon balance analysis.

Finally, Chapter 5 of this study illustrates the calculation of carbon credits potentially generated in a carbon market for the Ballona Project using an existing emissions accounting methodology. In late 2015, VCS approved a GHG accounting methodology for tidal marsh restoration projects to earn carbon offset credits for carbon markets. The methodology is the first to provide the procedures for how to calculate, report, and verify GHG reductions for tidal marsh restoration projects anywhere in the world. The information applied to the VCS methodology in

Chapter 5 includes Ballona soil data presented in this study as well as available information relating to the Ballona Project. This case study is not intended to represent a comprehensive evaluation of the entire VCS program or all components of the methodology process, but as an initial feasibility evaluation of a tidal marsh restoration project to determine if the project could benefit by registration in a carbon market.

This evaluation of the Ballona Project case study provides an estimate of carbon credits to assess if tidal marsh restoration projects similar to Ballona would produce enough carbon credits to be viable components of a carbon market such as the California cap-and-trade program. The evaluation will also demonstrate the feasibility of the methodology and provide insight into any challenges or issues associated with the overall process.

2 STUDY SITE – BALLONA WETLANDS ECOLOGICAL RESERVE

The Ballona Wetlands (Ballona) is the largest remaining tidal wetland in Los Angeles County and is located along the coast of Los Angeles County where Ballona Creek discharges to the Pacific Ocean. According to the Los Angeles County Department of Public Works, the Ballona Creek Watershed covers approximately 130 square miles located in the western portion of the Los Angeles Basin and is comprised of approximately 64% residential, 8% commercial, 4% industrial, and 17% open space (Figure 2-1).

History

The Ballona Wetlands previously covered approximately 2000 acres of coastal area and included a variety of habitats with over 1200 acres of vegetated wetland (Dark et al., 2011). The historical wetlands extended from the base of the bluffs to the south up to the intersection of modern-day Main Street and Abbot Kinney to the north. Prior to 1825, the Los Angeles River flowed through the Ballona Wetlands. However, following consecutive years of heavy rains the river shifted course to the south altering the hydrology of the wetlands. This shift of the Los Angeles River removed a major, however sporadic, source of freshwater flow and sediment to the Ballona Wetlands (PWA et al., 2006).

From 1851 – 1900 the US Coast Survey produced maps of coastal features which were referred to as topographic sheets, or T-sheets. Recently, Dark et al. (2011) obtained and interpreted these T-sheets and, along with the aid of other historical texts and drawings, have provided data on historical wetland habitat types (Figure 2-2 and Figure 2-3). Historical habitat of the coastal Ballona Wetlands consisted of substantial amounts of brackish to salt marsh/tidal marsh habitat as well as salt flat/tidal flat habitat. Open water made up less than 3 percent of the wetlands with a long but narrow strip of open water where the Del Rey/Ballona Lagoon is now located (Dark et al., 2011). Dark et al. found no evidence of a permanent opening from the lagoon to the ocean from approximately 1850 – 1900, instead finding that connection to the ocean depended on the hydraulic forces of any given year. After the Los Angeles River diverted course to the south in the 1820s, the wetlands received lower freshwater flows and only on rare storm occasions was there enough flow to break through to the ocean. As a result, sediment built up along the coast and formed dunes that further limited tidal access. Over the next two centuries, significant land use changes altered the Ballona Wetlands dramatically. These alterations to the landscape resulted in major changes in the size and function of the wetlands.

Around the 1820s, ranchers utilized land in and around the Ballona Wetlands to graze cattle on what was then known as Rancho La Ballona. From the middle of the 1800s, farming began replacing cattle ranching and urban development began in the early 1900s. Also in the early 1900s the Pacific Electric Railroad was extended to Playa Del Rey through the wetland and included the creation of an elevated railroad berm using fill material. Today the railroad berm's fill remains, creating upland habitat within the wetlands. Lincoln and Jefferson Blvds were constructed in 1918, bisecting the wetlands both north and south as well as east and west. Oil fields then sprang up in and around Ballona in the 1920s and 30s with the construction of oil derricks and support facilities. Fill was placed throughout the wetland for the construction of raised platforms to protect the rigs and facilities from tides. These facilities were connected by access roads throughout the area and also elevated with fill (PWA et al., 2006; EPA, 2012). The Gas Company still has active operations and access roads in Area B.

Gas production was followed by agriculture in Area B from the 1930s to 1985. Crops were grown in Area B east of the Gas Company road as well as the entirety of Area C by 1933. Many tidal channels were filled for agricultural land (PWA et al., 2006).

Ballona Creek was channelized in the 1930s to help control surface runoff during substantial rainfall events. The creek channelization and growing urban development of the watershed resulted in increased impermeable surfaces, which reduced rain infiltration and began to funnel runoff through the creek more quickly and in greater volume than during pre-development (Bergquist et al., 2012). Channelization of Ballona Creek effectively eliminated almost all tidal connectivity between the ocean and wetland habitats. Culverts with flap-gates were installed in the south bank of the channel to accommodate drainage from Area B. However, leakage and occasional blockage of the flap-gates allowed some limited tidal exchange to continue (PWA et al., 2006). Dredge materials from the channel construction were placed mostly north of the channel in Area A in a broad band approximately 300 – 400 feet wide (PWA et al., 2006).

Sometime before 1950, Centinela Ditch was excavated through Area B, channelizing freshwater flows from east of Lincoln Blvd. In 1962, Centinela Creek was also channelized and connected to Ballona Creek, diverting freshwater flows that previously flowed into Area B (Straw, 1987).

The single most devastating impact came in the 1960s with the construction of Marina del Rey and the subsequent disposal of the dredge spoils onto the northern portion of the wetland habitats (Areas A and C), raising the surface elevation by an estimated 12 – 15 feet (PWA et al., 2006). Over 900 acres of wetlands were destroyed for the marina's construction, playing a major role in converting the former marsh habitat to a system dominated by upland habitats interspersed with seasonal, depressional wetlands (Johnston et al., 2015).

Finally, and more recently, two projects have altered flows within Area B. In 2003 the Freshwater Marsh, constructed directly west of Lincoln Blvd and south of Jefferson Blvd, diverted freshwater flows into the Freshwater Marsh and then directly into Ballona Creek, bypassing Area B altogether. In the same year, flap-gates installed on the Ballona Creek Channel to Area B were replaced with self-regulating tide-gates (SRTs) to provide control and increase tidal flushing to a portion of the wetland in Area B (PWA et al., 2006).

Current Conditions

Today, approximately 600 acres remain within the historical wetland footprint, entirely surrounded by the extensively developed metropolitan area of Los Angeles. The property was purchased by the State in 2004 and designated as a reserve, with the California Department of Fish & Wildlife (CDFW) owning 523 acres and the State Lands Commission (SLC) owning another 60 acres. Of the 60 acres owned by the SLC, 24 acres are included in Ballona and the remaining 36 acres is the Freshwater Marsh mitigation site constructed for the Playa Vista Development and managed separately from Ballona (EPA, 2012). Approximately 543 acres are open-space habitat. The remaining area consists of the Freshwater Marsh, Gas Company parcel, roads, parking lots, etc.

In previous studies the current wetlands have been divided into three areas designated as Areas A, B, and C, as shown in Figure 2-4. Area A lies north of Ballona Creek, west of Lincoln Blvd, east of Marina del Rey, and south of Fiji Way and currently comprises approximately 139 acres. Area B is approximately 338 acres and lies south of Ballona Creek, west of Lincoln Blvd, and is buttressed by the Playa Del Rey Bluffs to the south. Finally, Area C is approximately 65 acres and lies north of Ballona Creek, east of Lincoln Blvd, southwest of the Marina Freeway (SR 90), and is bifurcated by Culver Blvd.

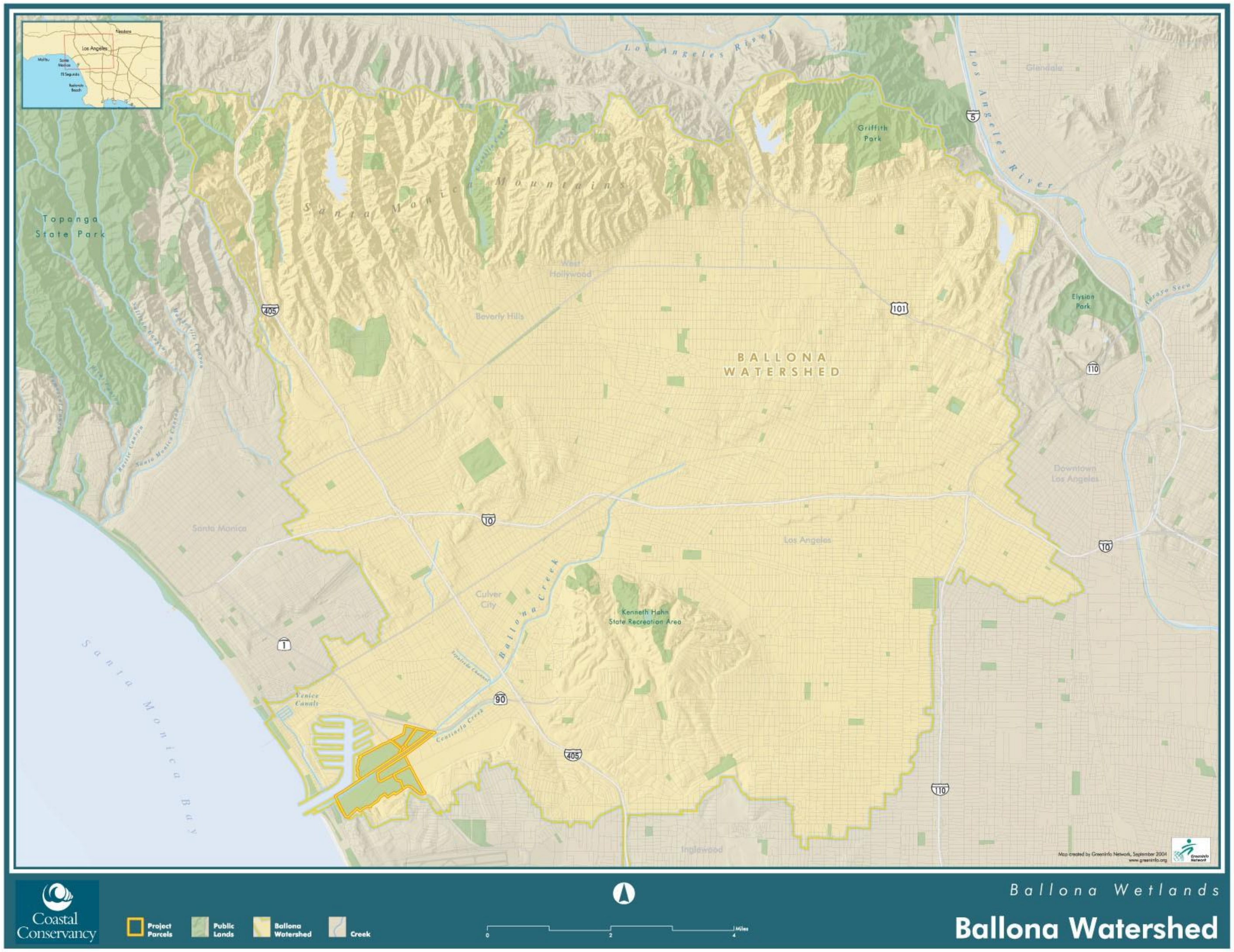
Ballona receives flows from Ballona Creek, direct runoff from the bluffs to the south, and overflow runoff from the Playa Vista Development as well as from parts of Jefferson and

Lincoln Boulevards (EPA, 2012). The self-regulating tide gates located within the south levee of Ballona Creek limit tidal inundation in Area B to an elevation of between approximately 3.6 and 4 feet MLLW (PWA et al., 2006). This muted tidal flow results in a more limited tidal range in Ballona than a fully tidal wetland. The elevation of low marsh habitat at Ballona ranges from 3.8 and 4.8 feet MLLW (ESA PWA, 2012). Therefore, tidally inundated habitat within Area B in the existing condition is confined to mudflat and low marsh habitat and likely totals no more than 24 acres. Johnston et al. (2015) estimate the existing habitat still exposed to tidal influence at approximately 15 acres. The tidal prism is the volume of water entering a wetland on each tide and is a function of the topography and tidal range of the site. The existing muted tidal wetland of Area B of Ballona has a tidal prism of about 45 acre-feet (PWA et al., 2008). Existing habitats of Ballona are shown in Figure 2-5 based on a survey performed in 2007 by the CDFW.

The State Coastal Conservancy, along with the CDFW, SLC, and a wide range of stakeholders, has worked over several years to develop a restoration plan for the Ballona Wetlands. A 2008 Feasibility Report (PWA et al., 2008) characterized and contrasted five preliminary project alternatives for restoration of Ballona. Revisions and refinements to two preferred alternatives (Alternatives 4 & 5) were documented in a 2010 Preferred Alternatives Memorandum (PWA et al., 2010). Further refinements to a single preferred alternative (Alternative 5) were presented in a 2012 Draft Memorandum to the Ballona Wetlands Science Advisory Committee (ESA PWA, 2012). The most recent (2012) Ballona restoration project alternative (Alternative 5) is shown in Figure 2-6. A joint draft Environmental Impact Statement / Environmental Impact Report (EIS/EIR) document is currently under preparation by the Army Corp of Engineers and CDFW and is anticipated to be released for public review in late 2015.

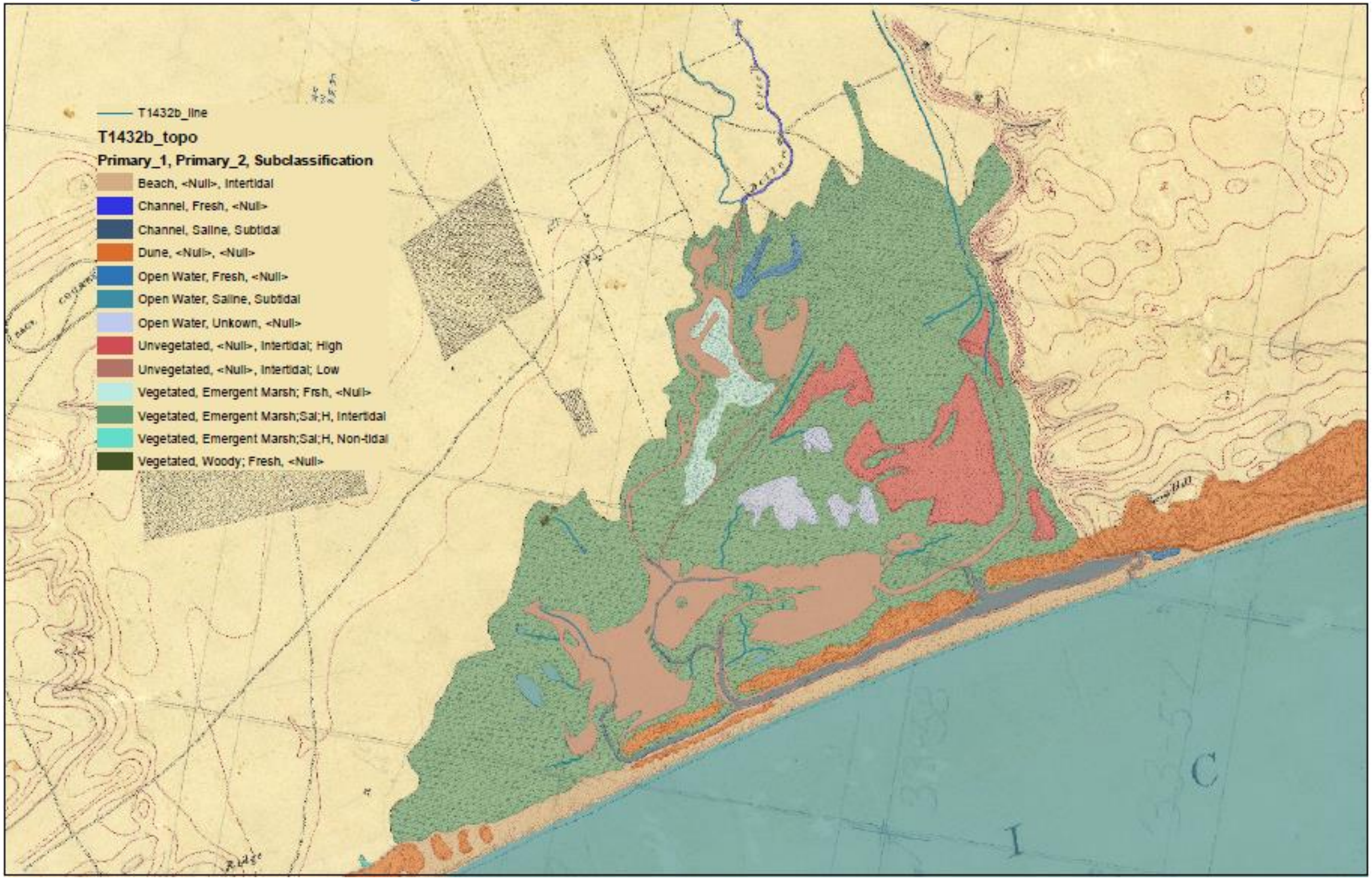
Table 2-1, summarizes area by habitat type for the Ballona Wetlands existing condition and the proposed restoration alternative. Elevation ranges for each tidal marsh habitat type are shown in Table 2-2, and dominant vegetation of each habitat type is presented in Table 2-3.

Figure 2-1 – Ballona Creek Watershed



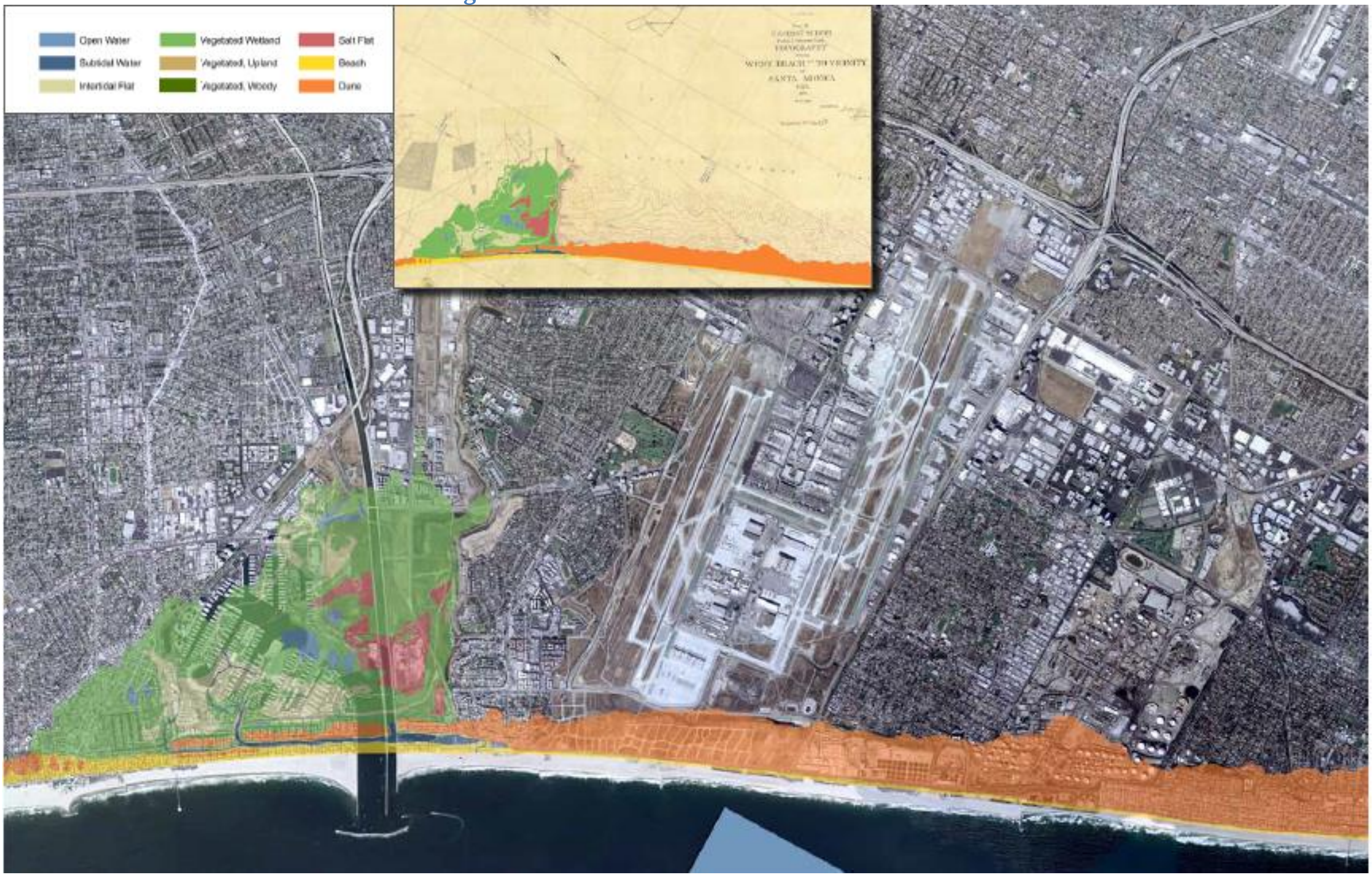
Source: Coastal Conservancy

Figure 2-2 – 1876 T-Sheet – Historical Ballona Wetland



Source: Grossinger et al., 2011

Figure 2-3 – Historical Habitats from T-Sheet



Source: Grossinger et al., 2011

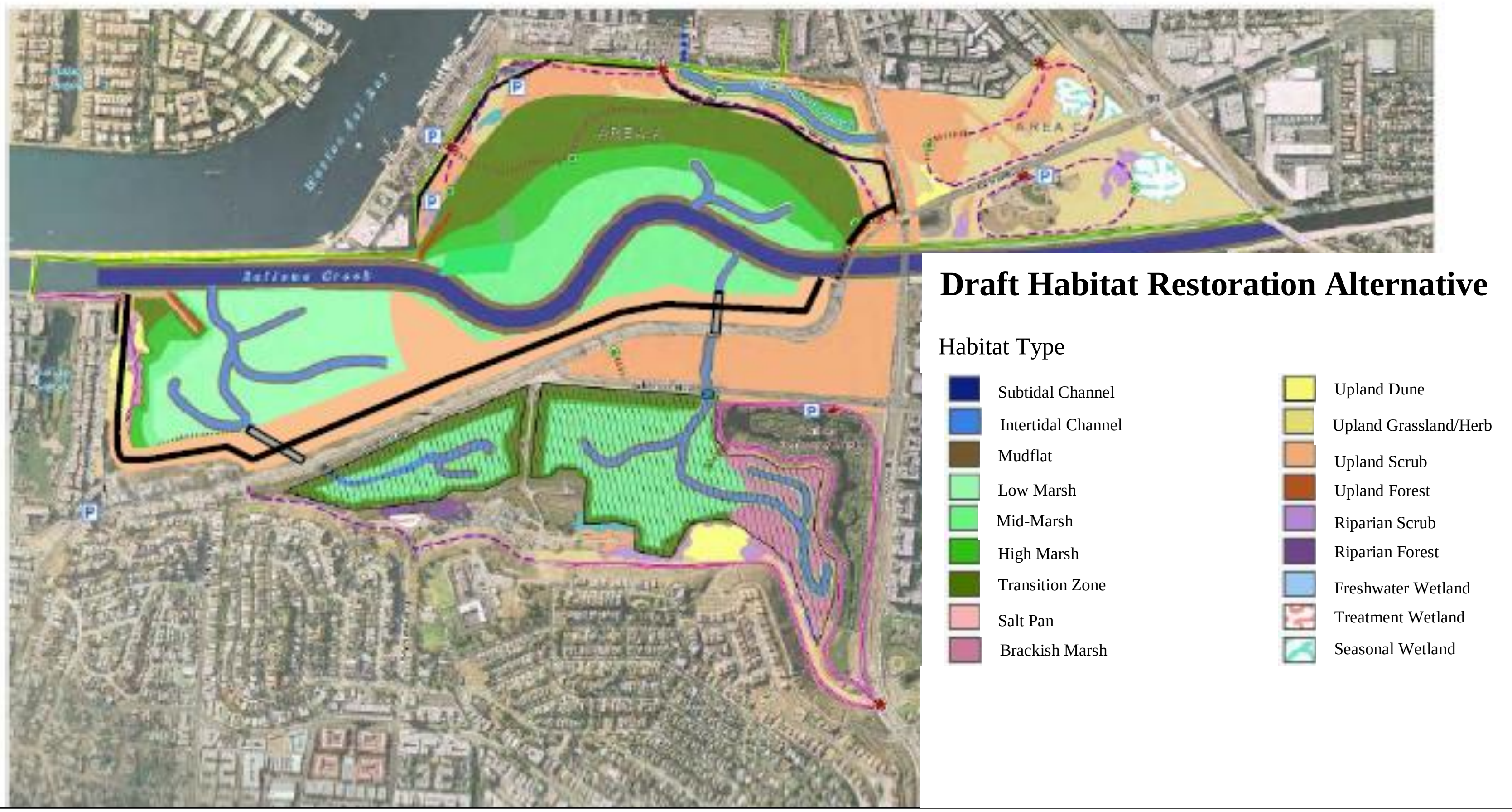
Figure 2-4 – Ballona Wetlands; Areas A, B, and C

Source: PWA et al., 2008, Ballona Wetlands Feasibility Study

Figure 2-5 – Existing Ballona Wetlands Habitats

Source: California Department of Fish & Wildlife, 2007.

Figure 2-6 – Proposed Draft Ballona Wetlands Restoration Alternative



Adapted from ESA PWA, 2012. Preferred Alternative Memorandum

Table 2-1 – Area by Habitat Type, Existing and Alternative 5

Habitat Type	**Area (Acres)[1]**	
Estuarine Habitats	Existing	Alternative 5
Vegetated Marsh		
Low	9	49
Mid	18	103
High	41	34
Seasonal	86	4
Brackish	3	13
Salt Pan	22	20
Subtidal	40	43
Mudflats[1]	15	40
Estuarine Total	**234**	**306**
Other Habitats		
Transition Zone	0	51
Upland	283	171
Freshwater/Riparian	26	26
Other Total	**308**	**248**
Habitat Total	**543**	**554**
Other: Freshwater Marsh, Gas Co. parcel, roads, parking lots, etc…	123	111
TOTAL AREA	**665**	**665**

1: ESA PWA 2012, Table 3, Habitat acreage estimates and projections

Table 2-2 – Tidal Ranges by Habitat Type

Habitat Type	NAVD (m)[1,3]	NAVD (ft)[1]	MLLW (ft)[1,2,4]	MLLW (m)[1,2]
Upland	3.35	10.99	11.2	3.41
Transition/Salt Pan	2.93	9.61	9.80	2.99
High Marsh	2.23	7.32	7.50	2.29
Mid Marsh	1.92	6.30	6.50	1.98
Low Marsh	1.40	4.59	4.80	1.46
Intertidal Channel / Mudflat	1.11	3.64	3.80	1.16
Subtidal	-0.06	-0.20	0.00	0.00
	-0.91	-2.99	-2.8	-0.85

1: PWA et al., 2006, Existing Conditions, Fig 4-5 (NAVD & MLLW datums)

2: ESA PWA 2012, Table 3, Projected Habitat Acreages (habitat MLLW elevs)

3: Bergquist et al., 2012, Ballona CRE Study, Table 5.1 (habitat NAVD elevs)

4: PWA et al., 2010, Preferred Alternative Memo - (Upland upper & Intertidal Channel/Mudflat lower elevs)

Table 2-3 – Dominant Vegetation by Habitat Type

Habitat Type	Dominant Vegetation[1] (% Cover of spp. >10%)
Salt Pan	Bare ground (92.2)
High Marsh	*Salicornia pacifica* (29.6) *Arthrocnemum subterminale* (11.1) *Distichlis spicata* (11.0)
Mid Marsh	*Salicornia pacifica* (39.2) *Jumea carnosa* (17.4) *Distichlis spicata* (14.6)
Low Marsh	*Salicornia pacifica* (63.8) *Jumea carnosa* (14.5)
Brackish Marsh	*Schoenoplectus* spp. (25.6)
Freshwater Wetland	*Anemopsis californica* (30.0) *Juncus mexicanus* (12.4) Non-native (32.6)
Seasonal Wetland (Area A)	*Salicornia pacifica* (12.0) Dead unknown grass (28.5)
Seasonal Wetland (Area B)	*Salicornia pacifica* (41.9) *Cressa truxillensis* (11.8) Non-native (20.8) Bare ground (10.2)
Upland	
Dune	Non-native (27.9) Bare ground (19.9)
Grassland	Non-native (46.1) Bare ground (17.9)
Scrub	Wood/non-vegetated branches (10.5) Non-native (49.8) Bare ground (14.3)

1: Johnston et al., 2012. BWER Baseline Assessment Program: Second Year Report

3 SOIL CARBON CONTENT IN THE EXISTING HABITATS OF THE BALLONA WETLANDS

3.1 INTRODUCTION

Wetlands have long been known to provide valuable ecological and economic benefits including improvement of water quality, providing habitat for native species, public open space, protected nurseries for fisheries, and flood control. More recently, the carbon stored in soils of coastal ecosystems, also known as "blue carbon", has been of increasing interest to scientists and policymakers as a potential component of climate change mitigation (Crooks et al., 2011; Mcleod et al., 2011; Sifleet et al., 2011; Crooks et al., 2010). Estimated at approximately one to ten billion metric tons of carbon globally (Pendleton et al., 2012), tidal marsh blue carbon represents a major carbon sink to be investigated and managed responsibly.

Coastal habitat, including tidal marshes, store more soil carbon per unit area than any other ecosystem on the planet and their global importance as carbon sinks is widely recognized (Pidgeon, 2009; Mitsch & Gosselink, 2007; Chmura et al., 2003; Ouyang & Lee, 2014). Many studies have provided corroborating evidence showing high carbon densities in tidal marsh soils from various regions around the world. However, the existing literature contains few studies focused on soil carbon in tidal wetlands within Mediterranean-type climates, such as those of southern California. Because soil carbon content can be highly variable between regions, as well as within regions, due to differences in sediment supply, tidal flooding, and average temperatures (Chmura et al., 2003), the deficiency of soil studies in southern California tidal marshes provides many opportunities to fill data gaps. In addition, by collecting only a few samples and presenting soil data as core averages, many tidal marsh studies provide only a limited view of the soil carbon profile of a wetland.

Tidal marsh habitats contain high soil carbon densities because they have high biomass production, trap large amounts of sediments, have high rates of soil accretion, and contain saturated soils (Chmura et al., 2003; Ouyang & Lee, 2014; Bridgham et al., 2006; Li et al., 2010). Over time the organic-rich surface layers become buried by rapid soil accretion and saturated soils limit the oxygen needed for aerobic bacteria respiration, leading to carbon sequestration in the soil (Li et al., 2010). In contrast to freshwater wetlands, the presence of sulfate in salt water wetlands is known to suppress the production of methane by bacteria in anaerobic conditions (Bartlett et al., 1987; Bartlett & Harriss, 1993). This is an important distinction because methane is a greenhouse gas approximately 25 times more potent than carbon dioxide (EPA, 2010).

Loss of historical coastal ecosystems in the U.S. due to anthropogenic impacts has been extensive. Wetland area in the coastal watersheds of the U.S. declined by more than 360,000 acres between 2004 and 2009 alone, a 25% increase in the rate of loss from the previous reporting period (Dahl & Stedman, 2013). More than 90% of the historical tidal wetlands in California alone have been lost since the mid-19th Century (CERES, 2015). Vertical soil accretion and/or landward migration are necessary to avoid further loss of coastal wetlands due to submergence by projected sea level rise. Projected sea level rise is anticipated to flood portions of remaining west coast marshes, particularly in areas with low sediment supply and infrastructure barriers to inland migration (Morris et al., 2002; Thorne et al., 2014; Thorne et al., 2013). Because of the threats to these few remaining coastal wetlands, investigating the soil carbon sequestration potential of these habitats is essential to future conservation, restoration, and land use planning. However, much remains to be learned about these important habitats and the carbon stored in their soils. Fully understanding the soil carbon content of a tidal wetland includes investigating how soil carbon content varies spatially across the wetland, between habitat types, and with depth beneath the soil surface.

The Ballona Wetlands is the largest tidal wetland ecosystem in Los Angeles County and is one of the largest remaining in California, yet little is known about its existing carbon pool. This study presents the investigation of soils in the Ballona Wetlands in an effort to better understand the soil carbon content of this important wetland and to add to the existing data for tidal marshes globally and Mediterranean-type climate marshes particularly.

This study addresses the questions: *How does soil carbon content vary spatially and with depth across the Ballona Wetlands and how does it compare to other tidal marsh studies?* The results of this analysis will help us understand how much carbon is being stored across tidal marsh habitats and where that carbon is being stored in the highest densities. Additionally, filling data gaps in Mediterranean-type climate tidal marshes of southern California will facilitate the comparison of soil carbon with tidal wetlands in other regions of the nation and the world. The data provided in this study and others may also assist policymakers with decisions regarding future restoration, conservation, land use, and climate mitigation planning by highlighting the value and importance of these ecosystems.

3.2 METHODS

3.2.1 Study Site – Ballona Wetlands

The Ballona Wetlands is a tidal marsh system located along the coast of Los Angeles County, near the community of Playa del Rey, north of the Los Angeles International Airport (Figure 3-1). The pre-settlement Ballona Wetlands ecosystem was approximately 2000 acres and included a variety of habitats (Grossinger et al., 2011). Approximately 600 acres remain within the historical wetland footprint, entirely surrounded by the extensively developed metropolitan area of Los Angeles. Wetlands at the site have been degraded and reduced to approximately 67 acres of subtidal and muted intertidal salt marsh and mudflat habitat, with the remaining area largely converted to seasonal wetland or upland habitats (Johnston et al., 2012). The property was purchased by the State of California in 2004 and designated as an ecological reserve.

The Ballona Wetlands are commonly divided into three areas designated as Areas A, B, and C. Area A lies north of Ballona Creek, west of Lincoln Blvd, east of Marina del Rey, and south of Fiji Way and currently comprises approximately 139 acres. Area B is approximately 338 acres and lies south of Ballona Creek, west of Lincoln Blvd, and is buttressed by the Playa Del Rey Bluffs to the south. Finally, Area C is approximately 65 acres and lies north of Ballona Creek, east of Lincoln Blvd, southwest of the Marina Freeway (SR 90), and is bifurcated by Culver Blvd. Major habitats of the existing Ballona Wetlands include salt marsh habitat (low, mid-, and high elevation), salt pan, seasonal wetland, brackish marsh, and upland habitat (Figure 3-2). Low marsh, mid-marsh, high marsh, and seasonal wetland in Area B are dominated by *Salicornia pacifica* (pickleweed), a perennial salt-tolerant plant. Brackish marsh, seasonal wetland in Areas A and C, and upland habitat are dominated by native and non-native grasses, herbs, and shrubs (CDFG, 2007; Johnston et al., 2015).

Anthropogenic disturbances throughout the Ballona Wetlands have been documented for a period of nearly 200 years. Around the 1820s, ranchers utilized land in and around the Ballona Wetlands to graze cattle. From the middle of the 1800s farming began replacing cattle ranching with urban development beginning in the early 1900s. Also in the early 1900s the Pacific Electric Railroad was extended to Playa Del Rey through the wetland and included the creation of an elevated railroad berm using fill material. Today the railroad berm's fill remains, creating upland habitat within the wetlands. Lincoln and Jefferson Blvds were constructed in 1918, bisecting the wetlands both north and south as well as east and west. Oil fields sprang up in and around Ballona in the 1920s and 30s with the construction of oil derricks and support facilities. Fill was placed throughout the wetland for the construction of raised platforms to protect the rigs and facilities from tides. These facilities were connected by access roads throughout the area and also elevated with fill (PWA et al., 2006; EPA, 2012). The Gas Company still has active operations and access roads in Area B. Gas production was followed by agriculture from the 1930s to 1985. Crops were grown in Area B east of the Gas Company road as well as the entirety of Area C by 1933. Many tidal channels were filled for agricultural land (PWA et al., 2006).

Channelization of Ballona Creek in the 1930s effectively eliminated almost all tidal connectivity between the ocean and wetland habitats. Culverts with flap-gates were installed in the south bank of the channel to accommodate drainage from Area B. Dredge materials from the channel construction were placed mostly north of the channel in Area A in a broad band approximately 300 – 400 feet wide (PWA et al., 2006).

Sometime before 1950, Centinela Ditch was excavated through Area B, channelizing freshwater flows from east of Lincoln Blvd. In 1962, Centinela Creek was also channelized and connected to Ballona Creek, diverting freshwater flows that previously flowed into Area B (Straw, 1987).

The single most devastating impact came in the 1960s with the construction of Marina del Rey and the subsequent disposal of the dredge spoils onto the northern portion of the wetland habitats (Areas A and C), raising the surface elevation by an estimated 12 – 15 feet (PWA et al., 2006). Over 900 acres of wetlands were destroyed for the marina’s construction, playing a major role in converting the former marsh habitat to a system dominated by upland habitats interspersed with seasonal, depressional wetlands (Johnston et al., 2015).

In 2003 the Freshwater Marsh, constructed directly west of Lincoln Blvd and south of Jefferson Blvd, diverted freshwater flows into the Freshwater Marsh and then directly into Ballona Creek, bypassing Area B altogether. In the same year, flap-gates installed on the Ballona Creek Channel to Area B were replaced with self-regulating tide-gates to provide control and increase tidal flushing to a portion of the wetland in Area B (PWA et al., 2006).

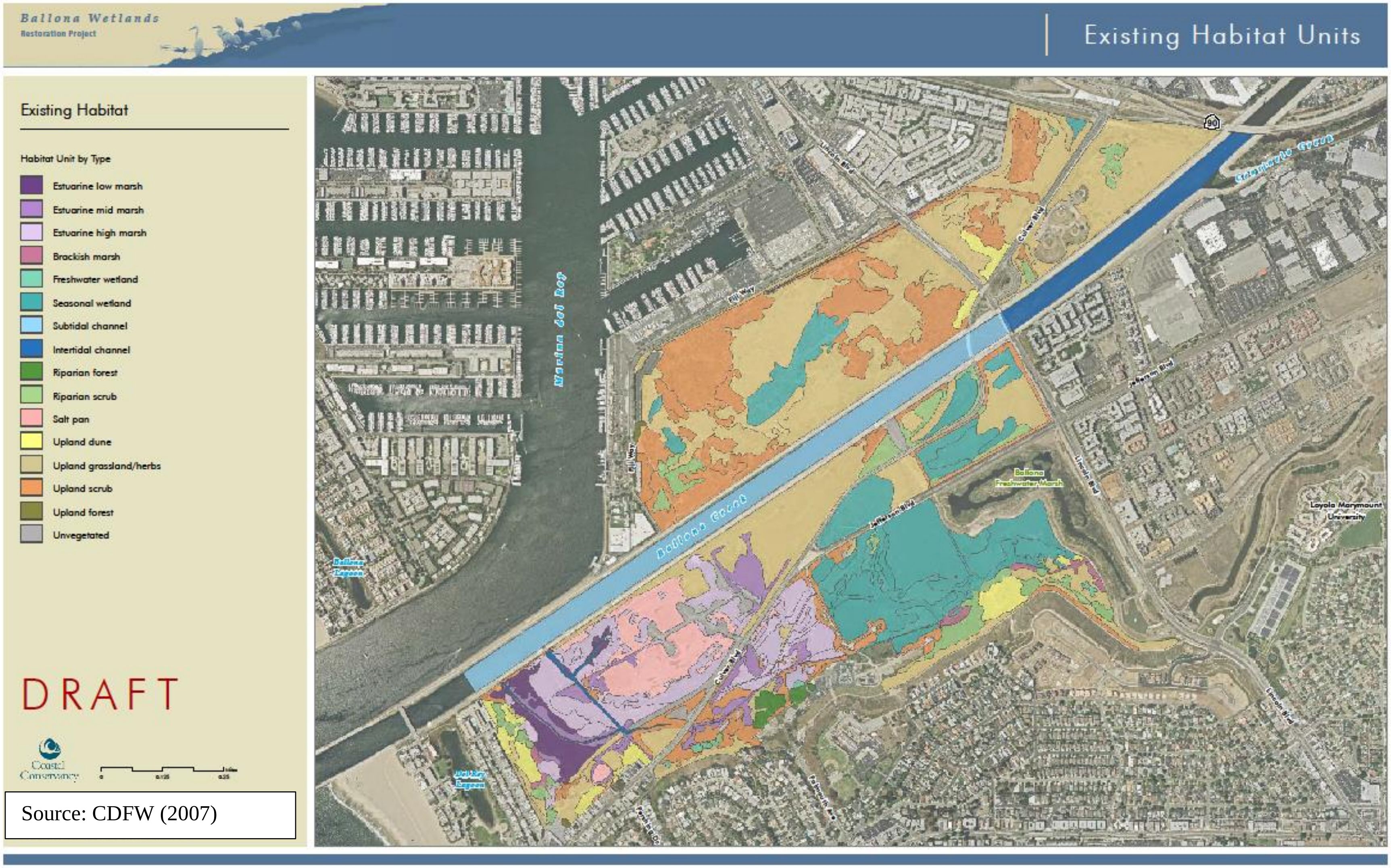
Tidal inundation in Area B of Ballona is limited to an elevation of between approximately 3.6 and 4 feet MLLW due to regulating tide gates (PWA et al., 2006). The elevation of low marsh habitat at Ballona ranges from 3.8 and 4.8 feet MLLW (ESA PWA, 2012). Therefore, tidally inundated habitat within Area B in the existing condition is confined to mudflat and low marsh habitat and likely totals no more than 24 acres. Johnston et al. (2015) estimate the existing habitat still exposed to tidal influence at approximately 15 acres.

The State Coastal Conservancy (SCC), along with the California Department of Fish & Wildlife (CDFW – previously California Department of Fish & Game), State Lands Commission (SLC), and a wide range of stakeholders, have developed a restoration plan for the Ballona Wetlands. A combined Draft Environmental Impact Report/Environmental Impact Statement (EIR/EIS) is anticipated to be released for public review sometime in 2017.

Figure 3-1 – Ballona Wetlands Location and Areas A, B, and C

Source: PWA et al., 2008

Figure 3-2 – Habitats of the Existing Ballona Wetlands



Source: CDFW (2007)

3.2.2 Soil Sampling

Twenty-five (25) soil cores were collected across various habitat types (low marsh, mid marsh, high marsh, seasonal wetland, and salt pan) and at various locations throughout the wetland. Salt marsh habitat is generally defined by tidal elevation. Typically, low marsh is inundated regularly and daily by tides, mid-marsh habitat irregularly but at greater frequency than higher elevations, and high marsh and salt pan habitat are irregularly inundated only during the highest tides. Salt pan alternates between flooded and drought conditions, which prevents most plants from occurring. Seasonal wetlands are non-tidal wetlands and transitional habitats that are flooded to varying degrees by seasonal rainfall and runoff (Ferren et al., 2007). The goal is to collect samples representative of the marsh habitats of the wetland and provide spatial coverage across the wetland. Table 3-1 shows the number of cores collected for each habitat type.

Samples were collected from September – October 2012. Figure 3-3 shows the locations within the Ballona Wetlands where soil sampling was conducted for this study. Detailed figures with labeled core locations in Areas A and B are presented in Appendix A. Due to restrictions in ground disturbing activities within the wetland implemented by the CDFW, access to coring locations for this study was limited to the general areas being sampled by a geotechnical crew approved to perform an investigation unrelated to this study. This allowed CDFW-mandated environmental monitors to observe and monitor both the geotechnical work as well as the coring activities of this study. However, due to the restriction of coordinating with the geotechnical work, some habitats and areas of the wetland are less represented, with only a few core samples possible. For instance, coordination & scheduling constraints restricted the collection of cores in seasonal wetland habitat in Area A and seasonal wetland in Area B to two cores apiece. Due to similar constraints, only four cores were collected in high marsh habitat. Three cores were deemed sufficient in salt pan habitat due to the relatively small area and limited distribution of this habitat type. Coordination allowed for seven cores to be collected in both low marsh and mid-marsh habitats (Table 3-1).

The coring locations were selected within the accessible areas by reviewing aerial photography (Google Earth imagery), existing habitat maps (CDFG, 2007), as well as on-site determination of characteristics such as vegetation type, relative elevation, soil saturation, and tidal inundation. Habitats (i.e., low, mid, high marsh) were sampled at various locations where they occurred throughout the wetland. Once a habitat was identified, the specific coring location was chosen arbitrarily by tossing an object blindly into the vicinity of the habitat and sampling where it landed.

Any vegetation at the surface of the coring location was removed to the soil surface with garden shears. Soil cores were typically collected to depths of 40-50 cm below ground surface (bgs) using a 15.25 cm diameter by 57 cm long stainless steel tube corer equipped with cutting teeth along the bottom edge. The corer was pushed into the ground using a twisting motion in conjunction with downward pressure until a core length of approximately 50 cm was reached or until the corer could be pushed no further. Compaction of the soil in the corer was determined in the field by comparing the depth to soil inside the corer versus depth to soil outside the corer. Cores were kept if it was determined that the difference between the inside and outside was within 2 cm. The soil cores were extracted in the field and sliced into 2 cm depth increments using a knife. Each 2 cm section was bagged separately, labeled, and delivered to a laboratory freezer the same day as collection.

Table 3-1 – Number of Cores per Habitat Type

Wetland Habitat	# Cores
Low Marsh	7
Mid-Marsh	7
High Marsh	4
Salt Pan	3
Seasonal Area A	2
Seasonal Area B	2

Figure 3-3 – Ballona Wetlands Coring Locations

Overview of all Ballona Wetlands Coring Locations. Yellow circles are approximate coring locations. Detailed Figures of Core Locations in Area A and Area B in Appendix A. Images from Google Earth.

3.2.3 Sample Analysis

After slicing into 2 cm increments, the 25 soil cores totaled 566 sections. For analysis, each soil section was weighed wet, dried at 50–70 ºC to a constant weight for 5-7 days, and then weighed again. Analyses were performed on each soil section to determine soil bulk density and organic carbon content, the two factors needed to calculate soil organic carbon (SOC). Soil grain size measurements were performed on each section to better understand the contribution of sand, silt and clay to observed soil bulk density, to compare between habitat types, and help explain any unusual changes in SOC with sample depth.

Bulk density (g dry mass cm^{-3}) is determined by dividing the dry mass of each soil section by the volume of the pre-dried section (~365 cm^3).

Organic matter content of each section is determined using Loss on Ignition (LOI) to determine the percent mass of organic matter. Precisely 50 grams of dried soil from each soil section was ground to a fine powder using a mortar and pestle. Each 50 gram sample was placed in an oven at 400 ºC for 10 hours, allowed to cool in a desiccant chamber, and weighed again to determine LOI. The percent mass organic matter is converted to percent mass organic carbon using the quadratic relationship described by Craft (1991): $OC = (0.40 \pm 0.01) * LOI + (0.0025 \pm 0.0003) * LOI^2$, where LOI is the percent organic matter in the sample.

To determine the density of carbon of each soil sample, soil bulk density of each sample (g dry mass cm^{-3}) is multiplied by the percent of soil carbon.

Grain size of each 2 cm soil section was determined using the hydrometer methodology (Bouyoucos 1962). Approximately 50 grams of dried soil from each soil section was carefully crushed, but not ground to a fine powder, and weighed. Any non-soil debris such as shell, stems, or plastic was removed from the sample. Each sample was then placed in a 600 mL beaker with

5 grams of sodium metaphosphate and 300 mL of deionized (DI) water. The beakers were placed on a shaker table at 125 rpm for at least 24 hours. The contents of each beaker were transferred to a 1L cylinder and filled to the 1L line with DI water. Each cylinder was inverted several times in order to ensure the suspension of all soil in the cylinder. Once mixing was complete, the cylinder was placed on a table and the hydrometer was inserted. The hydrometer reading was taken after 40 seconds to determine sand content and again after 2 hours to determine silt content. Temperature of the mixture was recorded just prior to the initial mixing and again after two hours of settling.

Grain size of each sample was determined using the following methodology (Bouyoucos, 1962):

- Corrected hydrometer reading = hydrometer reading –hydrometer reading of the blank (grams of particles per liter of suspension; g/L)
- TAHR = [(temperature – 20 degrees)*0.35] + corrected hydrometer reading
    - Note: TAHR (Temperature Adjusted Hydrometer Reading)
- TAHR (g/L) at 40 seconds * Volume (L)/grams of dry soil = % silt and clay
- 100 – % silt and clay = % sand
- TAHR (g/L) at 2 hrs * Volume (L)/grams of dry soil = % clay
- % silt and clay - % clay = % silt

3.2.4 Data Analysis

Differences in soil organic carbon (SOC) density between habitat types and between core depths were analyzed using a statistical analysis program (Systat 13) to perform two-way Analysis of Variance (ANOVA) and post-hoc Tukey tests.

Seasonal wetland cores collected in Area A and Area B of the Ballona Wetlands differed from each other substantially in average soil carbon content and represented the lowest and highest SOC densities of all habitats. Therefore, a two-way ANOVA was performed between six habitat types (low marsh, mid-marsh, high marsh, salt pan, seasonal wetland Area A, and seasonal wetland Area B). The two-way ANOVAs were performed in each of the above scenarios with habitat type and depth as independent variables at a 95% confidence level ($p=0.05$). The two-way ANOVA is presented in the Results section. Significant results ($p \leq 0.05$) were followed with a post-hoc Tukey analysis. Soil carbon density data for all habitat types and across depths were determined to be normal and of equal variance following log transformation of the data.

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3.3 RESULTS

All soil results for each core collected in Ballona Wetlands are presented by depth increments in Table B-1 in Appendix B. Average values for all soil parameters by habitat type are summarized in Table B-2 and are summarized in the sections below.

3.3.1 Soil Grain Size

Low marsh habitat contains the highest average proportion of sand, particularly nearer to the surface, followed by mid-marsh, seasonal wetland, salt pan, with high marsh containing the lowest proportion (Table 3-2). Low marsh habitat contains the highest proportion of sand in the 0 to 10 cm and 10 to 20 cm depths and is second only to seasonal wetland Area A in the 20 to 40 cm depth (29.6 ± 2.8% vs 31.6 ± 2.1%). The sand content in the 0 to 10 cm depth of low marsh (60.5 ± 6.2%) is nearly double the amount at the same depth in the habitat types with the next highest percent; 32.4 ± 1.7% and 31.7 ± 3.1% for seasonal wetland Area A and mid-marsh, respectively. Mid-marsh cores generally contain more sand than high marsh cores with core averages of 25.3 ± 1.8% and 16.5 ± 1.4%, respectively. The high marsh cores show a similar profile with depth as the mid-marsh cores, but overall have a lower proportion of sand at all depths.

The high proportion of sand in the combined seasonal wetland cores can be explained by the 2 cores collected from Area A north of the Ballona Creek channel. The average % sand for all 4 seasonal wetland cores is 23.3 ± 4.9%, however, the 2 cores from Area A average 31.2 ± 1.2% and the 2 cores from Area B average 15.5 ± 4.1%. In general, seasonal wetland Area A cores are more similar in sand content to mid-marsh cores, although mid-marsh cores have considerably more clay than Area A cores, while Area B cores are more similar to high marsh cores. Cores from both seasonal wetland areas show a fairly consistent distribution of sand with depth with no distinct difference between the upper and lower soils in the cores. One exception is the 0-2 cm layer of Area B cores, which shows a considerably higher percent of sand than any other layer in the cores. Also, seasonal wetland cores from Area B have higher proportions of clay while cores of Area A have higher proportions of silt.

The three cores of salt pan habitat show little difference in sand proportion with depth, similar to those of seasonal wetland and high marsh habitats (Table B-1 in Appendix B). However, similar to seasonal wetland Area B and high marsh, salt pan cores have lower overall sand proportions than seasonal wetland Area A. Area A cores contain the second highest proportion of sand in the 0 to 10 and 10 to 20 cm depths, after low marsh, and have the highest proportion in the 20 to 40 cm depth, (Table 3-2).

Table 3-2 – Grain Size
Average Sand Proportions by Depth and Range of Low and High Core Averages[1]

Habitat	% Sand (± 1SE)			
	0 to 40 cm (Range)	0 to 10 cm	10 to 20 cm	20 to 40 cm
Low Marsh	39.3 ± 3.5 (26.0–55.8)	60.5 ± 6.2	38.0 ± 4.9	29.6 ± 2.8
Mid-Marsh	25.3 ± 1.8 (16.8–30.1)	31.7 ± 3.1	22.3 ± 2.2	23.6 ± 3.5
High Marsh	16.5 ± 1.4 (13.3–19.8)	18.5 ± 2.3	13.3 ± 0.3	17.1 ± 1.9
Salt Pan	20.0 ± 2.8 (14.6–24.0)	22.3 ± 3.5	18.8 ± 4.6	19.4 ± 2.2
Seasonal (Area A)	31.2 ± 1.2 (30.0 & 32.4)	32.4 ± 1.7	29.2 ± 1.1	31.6 ± 2.1
Seasonal (Area B)	15.5 ± 4.1 (11.4 & 19.5)	19.2 ± 3.1	10.8 ± 3.1	15.9 ± 5.0
Seasonal (All Cores)	23.3 ± 4.9 (11.4–32.4)	25.8 ± 4.1	20.0 ± 5.5	23.7 ± 5.0

1: Remainder of soil grain proportion is composed of silt & clay

3.3.2 Soil Organic Carbon Percent

The average %OC (0 to 40 cm) is highest in low marsh and seasonal wetland Area B habitats at 3.3 ± 0.2% and 3.3 ± 0.1%, respectively. Mid-marsh and high marsh habitats are similar at 2.7 ± 0.2% and 2.6 ± 0.2%, respectively, followed by salt pan and seasonal wetland Area A with the lowest %OC at 2.1 ± 0.0% and 1.3 ± 0.1%, respectively (Table 3-3). Although the two cores from seasonal wetland Area A contained the lowest organic carbon content of all the cores analyzed and the two seasonal wetland cores from Area B contained some of the highest organic carbon content measured, when all cores for areas A and B are averaged the organic carbon content is 2.3 ± 0.6%.

Percent OC in the top 10 cm of soil is highest in low marsh habitat at 5.6 ± 0.8%, followed by seasonal wetland Area B (4.1 ± 0.4%), mid-marsh (3.9 ± 0.4%), high marsh (3.0 ± 0.2%), salt pan (2.3 ± 0.2%), and lowest in seasonal wetland Area A (1.8 ± 0.2%). This pattern is generally consistent in the 10 to 20 cm soil depth, however, in the deepest soil depth (20 to 40 cm) the pattern is different with the highest %OC in seasonal wetland Area B, followed by high marsh, low marsh, mid-marsh, salt pan, and lowest in seasonal wetland Area A. Organic carbon percent is consistently lowest in seasonal wetland Area A for all soil depths.

Profiles of %OC with depth for all cores by habitat type are shown in Figure 3-4. In most cores organic carbon content is highest at the surface, declined rapidly over a depth of approximately 6-10 cm and then remained relatively stable or declined only slightly with depth. This is the prominent pattern in all low marsh cores, six of the seven mid-marsh cores, and all of the high marsh cores. This pattern is slightly more prominent in seasonal wetland cores of Area B than those of Area A. None of the three salt pan cores showed distinctly higher %OC at the surface and the %OC profile is fairly consistent with depth. The mid-marsh core (BW-23) that did not show distinctly higher %OC at the surface was collected further from a marsh channel than all other cores, except seasonal wetland cores, and has probably not experienced tidal flooding for an extended period. The average %OC of this core is the smallest of all mid-marsh cores (1.4%) and is more similar to %OC of seasonal wetland Area A cores. The %OC profile with depth for BW-23 appears more similar to salt pan and seasonal wetland Area A cores.

The graphs in Figure 3-4 show a wide variation in %OC near the surface among low marsh cores that lessens with increasing elevation from mid-marsh to high marsh. Graphs of profiles for all 25 soil cores showing %OC, SOC density, and soil bulk density plotted together with depth are presented in the figures in Appendix C.

Table 3-3 – Soil Organic Carbon

Average Soil Organic Carbon Percent by Depth and Range of Low and High Core Averages

Habitat	%OC (± 1SE)			
	0 to 40 cm (Range)	0 to 10 cm	10 to 20 cm	20 to 40 cm
Low Marsh	3.3 ± 0.2 (2.6–4.1)	5.6 ± 0.8	2.8 ± 0.2	2.3 ± 0.2
Mid-Marsh	2.7 ± 0.2 (1.4–3.2)	3.9 ± 0.4	2.5 ± 0.2	2.2 ± 0.2
High Marsh	2.6 ± 0.2 (2.2–2.9)	3.0 ± 0.2	2.6 ± 0.2	2.4 ± 0.3
Salt Pan	2.1 ± 0.0 (2.0–2.1)	2.3 ± 0.2	2.2 ± 0.2	1.9 ± 0.1
Seasonal (Area A)	1.3 ± 0.1 (1.2 & 1.3)	1.8 ± 0.2	1.2 ± 0.2	1.0 ± 0.1
Seasonal (Area B)	3.3 ± 0.1 (3.2 & 3.5)	4.1 ± 0.4	3.2 ± 0.0	3.0 ± 0.1
Seasonal (All Cores)	2.3 ± 0.6 (1.2–3.5)	3.0 ± 0.7	2.2 ± 0.6	2.0 ± 0.6

Figure 3-4 – Core Profiles of %OC by Habitat Type

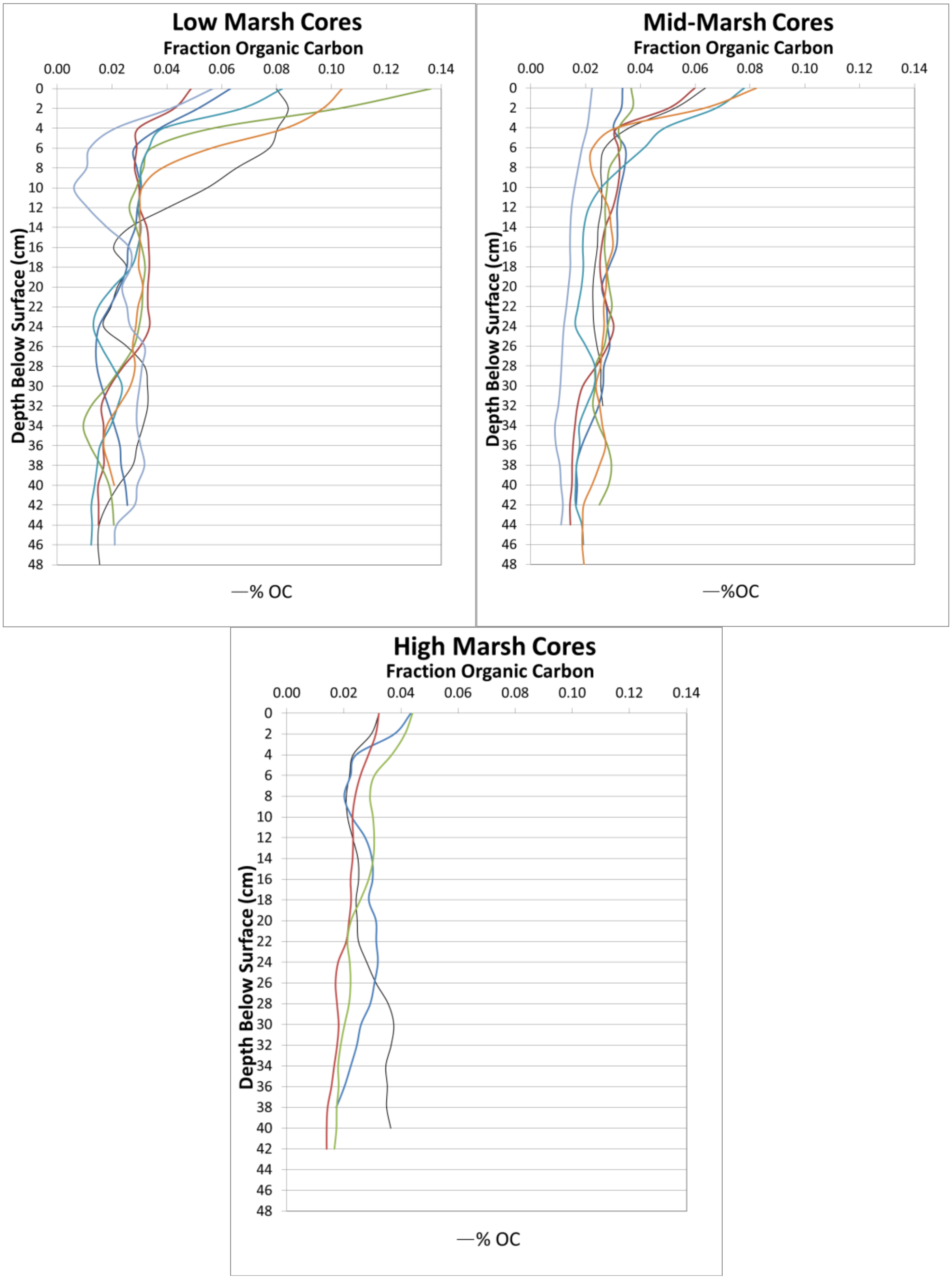
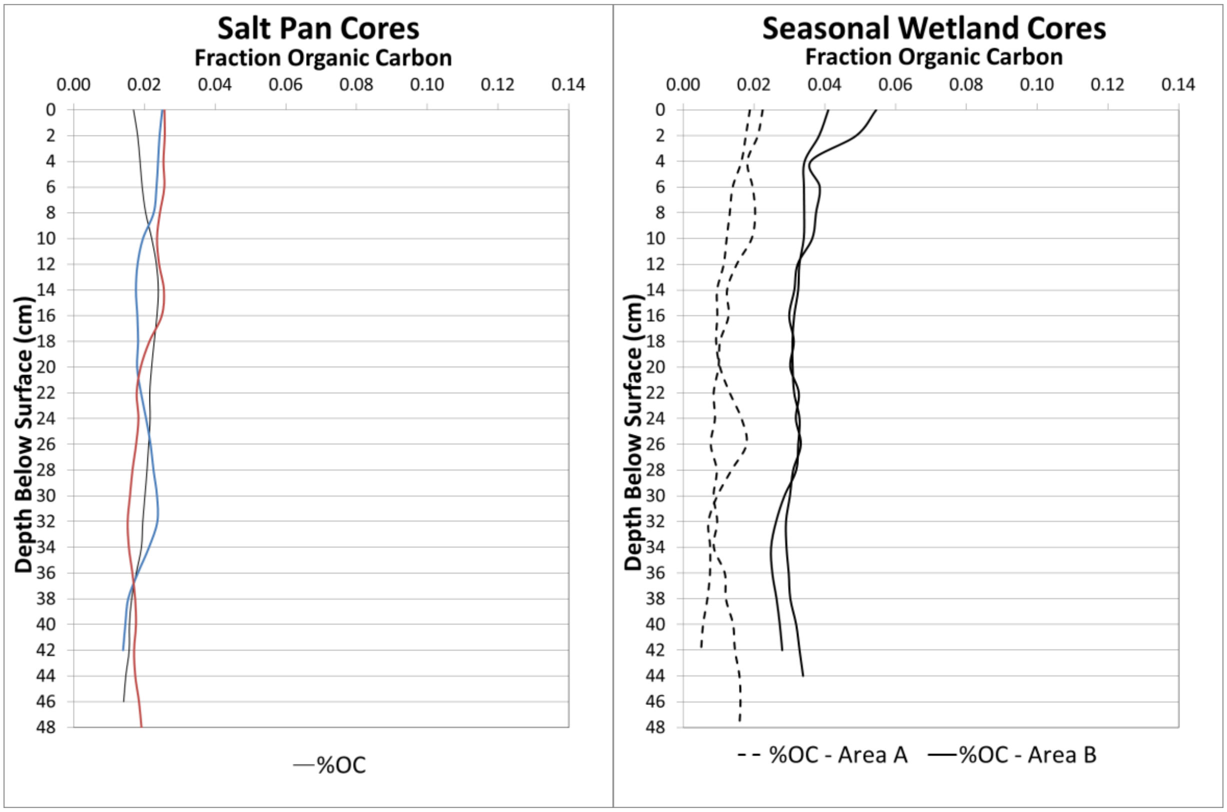


Figure 3-4 – Core Profiles of %OC by Habitat Type, Continued…



3.3.3 Soil Bulk Density

Low marsh habitat shows the lowest average soil bulk density of 0.813 ± 0.050 g/cm^3 and is the only habitat with an average density below 1.0 g/cm^3. Although mid-marsh and high marsh habitats had similar average bulk densities (1.005 ± 0.052 & 1.041 ± 0.033 g/cm^3), as did the salt pan and seasonal wetland habitats (1.142 ± 0.039 & 1.192 0.039 g/cm^3), the general trend is increasing bulk density with habitat elevation from low marsh to seasonal wetland (Table 3-4).

Generally, soil bulk density is lower near the surface where there is typically higher organic matter in the soil. This is seen most prominently in the low marsh cores where bulk density is 0.634 ± 0.094 g/cm^3 at the surface and then increased with depth. Bulk density also is lowest in the mid-marsh habitat surface at 0.949 ± 0.90 g/cm^3 and increased with depth. This pattern is also observed in some cores of other habitat types (core BW-04 & 05-high, BW-14 & 15-salt pan, and BW-25-seasonal) but not as prominently as in low marsh and mid-marsh cores. Graphs of profiles of bulk density, along with %OC and SOC density data, with depth are presented in the graphs of Appendix C for all 25 soil cores.

While grain size is higher in the surface layer (0-10 cm) of many cores (more sand content), bulk density is often lower in those same surface layers, particularly in low marsh. Below a depth of approximately 10 cm, the bulk density profile is irregular in many cores, increasing and decreasing with depth and with little observable relation to changes in soil grain size.

Table 3-4 – Soil Bulk Density
Average Soil Bulk Density by Depth and Range of Low and High Core Averages

Habitat	Soil Bulk Density g/cm^3 (± 1SE)			
	0 to 40 cm (Range)	0 to 10 cm	10 to 20 cm	20 to 40 cm
Low Marsh	0.813 ± 0.050 (0.682–1.062)	0.634 ± 0.094	0.813 ± 0.062	0.902 ± 0.042
Mid-Marsh	1.005 ± 0.052 (0.830–1.266)	0.949 ± 0.090	1.003 ± 0.046	1.038 ± 0.064
High Marsh	1.041 ± 0.033 (0.959–1.123)	1.111 ± 0.029	1.056 ± 0.013	0.999 ± 0.055
Salt Pan	1.142 ± 0.039 (1.090–1.218)	1.122 ± 0.035	1.180 ± 0.082	1.133 ± 0.040
Seasonal (Area A)	1.255 ± 0.024 (1.232 & 1.279)	1.220 ± 0.011	1.283 ± 0.073	1.259 ± 0.005
Seasonal (Area B)	1.129 ± 0.021 (1.108 & 1.151)	1.104 ± 0.090	1.141 ± 0.017	1.137 ± 0.006
Seasonal (All Cores)	1.192 ± 0.039 (1.108–1.279)	1.162 ± 0.050	1.212 ± 0.051	1.198 ± 0.035

3.3.4 Soil Organic Carbon Density

The SOC densities of all Ballona tidal marsh habitat cores (low, mid-, high marsh) ranged from 0.018 to 0.030 g/cm^3. The average SOC density of marsh habitats increases incrementally with elevation from low marsh to high marsh resulting in a narrow average carbon density range. Overall, the SOC densities averaged by habitat type for the 0 to 40 cm depth in the five habitat types sampled resulted in a range of 0.022 to 0.027 g/cm^3 (Table 3-5). The marsh habitats had average SOC densities of 0.022 ± 0.001, 0.025 ± 0.002, and 0.027 ± 0.001 g/cm^3 for low, mid, and high marsh, respectively. However, the range of average carbon densities within low and mid-marsh cores is greater than the range of average SOC densities between habitats. Core averages from each marsh habitat type overlap with the other marsh habitats (Table B-1 in Appendix B).

Although average %OC is highest in the low marsh soils, due to generally lower bulk density at lower elevation, average SOC density is lowest in the low marsh habitat and increases with elevation to mid-marsh and is greatest in the high marsh habitat. Salt pan and seasonal wetland habitats show SOC densities within the range of the marsh habitats at 0.023 ± 0.001 and 0.026 ± 0.006 g/cm^3, respectively. If seasonal wetland Areas A and B are separated, the two cores from Area A contained the lowest average SOC density at 0.015 and 0.017 g/cm^3 and the two cores from Area B contained the highest average SOC density at 0.037 and 0.038 g/cm^3.

The mid- and high marsh habitats have considerably higher SOC in the surface layer (0-10 cm) compared to low marsh and salt pan habitats, but carbon content subsequently decreases rapidly with depth in mid- and high marsh. With the exception of salt pan habitat, SOC density is highest near the surface in all habitat types and then decreased with depth. Salt pan averages are similar at 0.025, 0.026, and 0.022 for the 0 to 10, 10 to 20, and 20 to 40 cm depths, respectively. The difference in average SOC density between the top depth (0 to 10 cm) and the lowest depth (20 to 40 cm) between the cores of each habitat type is greatest in mid-marsh cores and lowest in salt pan cores at 0.005, 0.011, 0.009, 0.003, and 0.010 g/cm^3 for low, mid, high, salt pan, and seasonal wetland, respectively. When separated into Area A and Area B, the ranges of the individual seasonal wetland areas are similar to the combined seasonal wetland at 0.009 and 0.010 g/cm^3, respectively.

SOC density profiles are highly variable with depths within individual cores, between cores, and between habitats (Appendix C). SOC density at the surface does not always display the same pattern as %OC in the same core. This is due to the lower bulk densities near the surface in many cores and because SOC density is the product of %OC and bulk density. Below the surface layer, however, SOC density and %OC profiles show more similar patterns in many cores and often increase and decrease together with depth.

The ranges of average core SOC density (0-40 cm) between cores of each habitat type in Table 3-5 are relatively narrow in all habitats with a difference of 0.006 g/cm^3 in low marsh, 0.012 g/cm^3 for mid-marsh, 0.004 g/cm^3 for high marsh, 0.003 g/cm^3 in salt pan, and just 0.002 g/cm^3 and 0.001 g/cm^3 for seasonal wetland Area A and Area B, respectively. These ranges show that all 5 habitats overlap in at least one core value. Low and high marsh habitats each have one core with a SOC density of 0.024 g/cm^3. Both low and mid-marsh habitats have a low core value of 0.018 g/cm^3 and more than one core value of 0.024 g/cm^3. Mid-marsh has the highest SOC density for a single core (0.030 g/cm^3), with the exception of seasonal wetland Area B cores. If separated into Area A and Area B, neither seasonal wetland habitat overlaps SOC density values with any other habitat type.

Table 3-5 – Soil Organic Carbon Density

Average Soil Organic Carbon Density by Depth for Each Habitat and Range of Low and High Core Averages

Habitat	SOC g/cm^3 (± 1SE)			
	0 to 40 cm (Range)	0 to 10 cm	10 to 20 cm	20 to 40 cm
Low Marsh	0.022 ± 0.001 (0.018–0.024)	0.025 ± 0.001	0.022 ± 0.001	0.020 ± 0.002
Mid-Marsh	0.025 ± 0.002 (0.018–0.030)	0.033 ± 0.003	0.024 ± 0.002	0.022 ± 0.002
High Marsh	0.027 ± 0.001 (0.024–0.028)	0.033 ± 0.002	0.027 ± 0.002	0.024 ± 0.002
Salt Pan	0.023 ± 0.001 (0.022–0.025)	0.025 ± 0.002	0.026 ± 0.001	0.022 ± 0.001
Seasonal (Area A)	0.016 ± 0.001 (0.015 & 0.017)	0.022 ± 0.003	0.016 ± 0.003	0.013 ± 0.001
Seasonal (Area B)	0.037 ± 0.000 (0.037 & 0.038)	0.044 ± 0.000	0.036 ± 0.000	0.034 ± 0.001
Seasonal (All Cores)	0.026 ± 0.006 (0.015–0.038)	0.033 ± 0.006	0.026 ± 0.006	0.023 ± 0.006

The six habitat two-way ANOVA showed a significant difference ($p<0.001$) in average SOC densities between the six habitats (low, mid, high, salt pan, seasonal Area A, seasonal Area B) and a significant difference ($p<0.001$) between the three depths (Table 3-6). Tukey testing of habitats resulted in a p-value of 0.057 between low and mid-marsh habitats, showed a significant difference between low and high marsh habitats ($p=0.006$), showed significant differences between seasonal wetland Area A and all other habitat types, including Area B, and showed significant differences between seasonal wetland Area B and all other habitat types, including Area A (all $p<0.005$). Tukey testing of depths showed SOC density is significantly higher in the 0 to 10 cm depth compared to 10 to 20 cm depth ($p=0.002$), significantly higher in the 0 to 10 cm compared to 20 to 40 cm depth ($p<0.001$), and significantly higher in the 10 to 20 cm compared to 20 to 40 cm depth (p=0.047). There is no significant interaction between habitat and depth in the two-way ANOVA.

Table 3-6 – ANOVA Table for SOC Density

Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
Habitat	0.483	5	0.097	18.413	<0.001
Depth	0.192	2	0.096	18.324	<0.001
Habitat*Depth	0.035	10	0.003	0.665	0.752
Error	0.299	57	0.005		

3.4 DISCUSSION

Tidal wetlands are well known as effective carbon sinks globally (Chmura et al., 2003; Ouyang & Lee, 2014), yet remarkably little is known about the soil carbon in tidal marshes of Mediterranean-type climates such as those along the southern California coast. Through field sampling and laboratory analyses this chapter determined average soil organic carbon densities for habitats of the Ballona Wetlands. These results are discussed in detail for SOC densities by habitat type and by depth in the sections below. However, prior to discussing the SOC results from Ballona, the first section below presents the results of a literature review of tidal marsh soil carbon densities from other studies in various geographic regions.

3.4.1 Soil Organic Carbon in Other Tidal Marsh Studies

A literature search was performed of peer-reviewed studies that reported soil organic carbon density in tidal salt marsh soils. An emphasis was placed on studies of marshes along the west coast of North America, particularly of southern California. However, studies from other regions were also included in the review for comparison to Ballona and to west coast studies.

The range of average SOC densities of the Ballona Wetlands tidal marsh habitats determined in this study is strikingly similar to soil carbon determined in other tidal marsh studies in different parts of the world, including studies of other southern California tidal marshes. Although the range of SOC densities determined for Ballona in this study is lower than the global average determined by Chmura et al. (2003), the values at Ballona are very similar to most of the other existing studies reviewed.

SOC densities reported in the existing tidal marsh studies ranged from 0.009 to 0.054 g/cm^3 for all of the studies reviewed and 0.009 to 0.043 g/cm^3 for studies in California tidal marshes (Table 3-7). These ranges are similar to the range of SOC densities in tidal marsh habitat cores at Ballona (0.018 to 0.030 g/cm^3). SOC data from various regions are similar and no region stands out with remarkably different values. Chmura et al. (2003) reported an average soil carbon density for global tidal marsh studies of 0.039 g/cm^3 but included only one study from a Mediterranean climate tidal marsh.

Averaging all of the SOC density values reported in the existing studies in Table 3-7 results in a general estimate of approximately 0.027 g/cm^3 for tidal marsh habitats. Interestingly, when the existing study data is averaged by low, mid-, and high tidal marsh habitats, the resulting SOC densities are similar at 0.026, 0.026, and 0.027 g/cm^3, respectively. Averaging existing data for only California tidal marsh studies by habitat type results in values with a wider range of 0.019, 0.027, and 0.029 g/cm^3, for low, mid-, and high marsh habitat, respectively. These average values of existing study data are similar to the average densities estimated in this study for the low, mid-, and high marsh habitats in Ballona of 0.022, 0.025, and 0.027 g/cm^3. The marshes in southern California studies by Keller et al. (2012) and Elgin (2012) show similar SOC densities to Ballona and are similar to Ballona in habitat and proximity, supporting an assumption that the Ballona SOC density range determined in this study is representative of southern California salt marshes.

In the only other known soil carbon study conducted within the historical extent of the Ballona Wetlands, Brevik & Homburg (2004) collected cores prior to the development of much of the eastern portion of the historical wetland and estimated average soil carbon in historical salt marsh habitat at 0.043 g/cm^3. This value from Brevik & Homburg is higher than the soil carbon density values found at Ballona, but is similar to values for seasonal wetland Area B cores (0.037 & 0.038 g/cm^3). The SOC density value reported by Brevik & Homburg (2004) represents salt marsh habitat up to 5,000 years before present and may be high due to compaction and soil consolidation known to occur in deep soils (Callaway et al., 1996; Swanson et al., 2013).

The review of existing marsh studies shows that the soil carbon content between marshes is variable. Other marsh studies, including this one, have shown that soil carbon can also vary within an individual marsh across habitat types and with depth due to differing rates of carbon accumulation throughout the marsh (Hussein & Rabenhorst, 1999; Tucker, 2016). This variability within Ballona is discussed further in the following sections.

Table 3-7 – SOC Density from Existing Studies

Average Soil Organic Carbon Densities of Salt Marsh Habitat by Region from Existing Studies

Reference	Soil Organic Carbon Density (g/cm^3)	Region
Chmura et al. 2003	0.039 mixed marsh habitats	Global
Burden et al. 2013	0.014 low marsh 0.031 high marsh	UK
Adams et al., 2012	0.012 mid-marsh 0.023 high marsh	UK
Connor et al., 2001	0.035 low marsh 0.042 high marsh	Bay of Fundy, Canada
Craft et al. 2003	0.020 low marsh	North Carolina
Elsey-Quirk et al., 2011	0.054 low marsh 0.053 mid-marsh 0.031 high marsh	Delaware/Maryland
Choi & Wang 2004	0.052 low marsh 0.025 mid-marsh 0.025 high marsh	NW Florida
Choi et al. 2001	0.034 low marsh 0.017 mid-marsh 0.015 high marsh	NW Florida
Loomis & Craft, 2010	0.023 low marsh	Georgia
Thorne et al., 2015	0.015 low marsh 0.017 mid-marsh 0.020 high marsh	Oregon & Washington
Patrick & DeLaune 1990	0.009 low marsh 0.014 low marsh	SF Bay
Callaway et al. 2012	0.027 low marsh 0.026 mid-marsh 0.027 high marsh	SF Bay
Callaway et al. 2012b	0.027 & 0.021 low marsh 0.033 & 0.021 mid-marsh 0.031 & 0.029 high marsh	SF Bay
Cahoon et al. 1996	0.018 low marsh	Tijuana Estuary
Cahoon unpublished (referenced in Chmura et al., 2003)	0.017 & 0.040 unknown	Tijuana Estuary
Keller et al. 2012	0.023 mid-/high marsh 0.034 mid-/high marsh	Huntington Beach
Elgin 2012	0.022 mixed marsh habitat	Mugu Lagoon, Tijuana, Carpinteria
Brevik & Homburg 2004	0.043 mixed marsh habitat	Ballona
Average of Existing Studies	**0.027 all** **0.026 low marsh** **0.026 mid-marsh** **0.027 high marsh**	**Various**
This Study	**0.022 low marsh** **0.025 mid-marsh** **0.027 high marsh**	**Existing Ballona Wetland**

3.4.2 SOC Density and Habitat Type

The major influencing factor between marsh habitats is generally tidal elevation (Ferren et al., 2007). Since the construction of the Ballona Channel in the 1930s, tidal inundation to the Ballona Wetlands was essentially halted until installation of the self-regulating tide gates in 2003 (PWA et al., 2006). Due to the muted tidal flow in Ballona, only mudflat channels and low marsh habitat currently receive tidal inundation even at the highest tides. However, average SOC density in Ballona soils is greater in higher elevation habitats. Given the considerable difference in tidal inundation between marsh habitats in Ballona and the substantial anthropogenic disturbances across the wetland over time, it may be surprising that the range of SOC densities between low marsh, mid-marsh, high marsh, and salt pan is so narrow (0.022 – 0.027 g/cm^3). However, the range of average carbon densities within both sets of low and mid-marsh cores is greater than the range of average SOC densities between habitats. SOC densities from each marsh habitat type overlap with cores in each of the other marsh habitats. The range of average SOC densities may be narrow because each individual core is averaged over 40 centimeters of soil and all cores of a habitat type are averaged together, while the greatest difference in SOC between habitats is in the surface layer (0-10 cm). Even with this narrow range, SOC density in Ballona is significantly different between low marsh and high marsh habitats and nearly significantly different between low marsh and mid-marsh.

There have been few studies comparing SOC density between low, mid-, and high marsh habitats, providing little data for comparison with Ballona. Some of these studies showed a similarly narrow range of SOC density between low and high marsh habitats (Callaway et al., 2012; Callaway et al., 2012b; Connor et al., 2001; Elgin, 2012). Other studies showed a substantial difference in densities between habitat elevations with some habitats having up to twice the SOC density as other habitats (Adams et al., 2012; Burden et al., 2013; Elsey-Quirk et al., 2011; Choi & Wang, 2004; Choi et al., 2001). Like Ballona, some studies showed SOC density increase with elevation from low to high marsh (Burden et al., 2013; Adams et al., 2012; Connor et al., 2001; Callaway et al., 2012b) while other studies showed SOC density decrease with habitat elevation (Elsey-Quirk et al., 2011; Choi & Wang, 2004; Choi et al., 2001). When the cores collected by Elgin (2012) in southern California marshes similar to Ballona are categorized as lower and higher marsh elevations, the average SOC densities showed a narrow range of values similar to Ballona, but with no consistent pattern with elevation. Callaway et al. (2012) also showed no distinct pattern of SOC density with habitat elevation.

The finding that SOC density in Ballona is lowest in low marsh habitat and generally increases with elevation is notable since %OC is highest in low marsh habitat and decreases with increasing elevation. Few of the studies reviewed presented data for soil bulk density and %OC. Unlike Ballona soils, most of the existing studies that did report bulk density and %OC showed SOC density and %OC either increasing or decreasing together with elevation (Adams et al., 2012; Burden et al., 2013; Connor et al., 2001; Elsey-Quirk et al., 2011; Choi et al., 2001). The reason that SOC density increases with elevation in Ballona, despite decreasing %OC, is due to the greater soil bulk density at higher elevations. Of the existing studies that reported soil bulk density with SOC, only one (Callaway et al., 2012b) showed SOC density and soil bulk density increase together with elevation while %OC decreased, as seen in Ballona. Elgin (2012) also reported bulk density increasing and %OC decreasing slightly with increasing elevation in cores from three southern California marshes. However, the average SOC densities reported by Elgin for lower and higher marsh cores are similar. Elsey-Quirk et al. (2011) showed bulk density increase with elevation, similar to Elgin (2012) and Ballona, however, SOC density was shown to decrease with elevation, unlike Ballona. With such little data from existing studies reporting bulk density and %OC with depth, it is unclear if the soils at Ballona represent typical salt marsh characteristics of southern California tidal marshes.

Although low marsh cores were collected at various locations of Ballona, no substantial difference in SOC density is obvious between cores based on location in the wetland or on distance from the Ballona Channel tide gate. The low bulk density in low marsh at Ballona is presumably due to relatively high organic matter and sand content in this habitat. A higher proportion of sand is found throughout all low marsh cores and sand content declined with increasing elevation to mid- and high marsh habitats. This higher proportion of sand at lower elevation may be surprising since low marsh is the only habitat presumably receiving fine sediments from tidal flow. However, the existing muted tidal flow to the low marsh has only occurred since installation of the self-regulating tide gates in 2003, prior to which Area B received no regular tidal flow. Elgin (2012) also reported sand content and, unlike Ballona, showed generally higher average sand content in higher elevation marsh habitat, but sand content varied widely among the cores.

Mid- and high marsh habitats at Ballona no longer receive tidal flow that typically carries fine sediments, however, these habitats have low sand content, high soil bulk densities, and continue to accumulate plant matter in their root zones, accounting for the relatively high SOC densities. The high marsh cores are relatively similar to each other in soil characteristics and do not show any discernable differences based on general location in the wetland. One mid-marsh core (BW-23) showed notably lower SOC density than the other six mid-marsh cores. BW-23 has the lowest %OC and the highest soil bulk density of all mid-marsh cores and has a SOC density more similar to low marsh habitat or seasonal wetland Area A. Other soil characteristics of BW-23 are more like those of seasonal wetland habitat in Area A and suggest that perhaps the area at BW-23 contains fill material deposited during the excavation of the adjacent Ballona Channel.

The low %OC in salt pan habitat is likely because salt pan habitat is unvegetated and in Ballona receives little to no tidal inundation, except occasionally along the far northern portion adjacent to the tidal outflow gate. One salt pan core, collected south of the other two cores and separated from them by a utility road, had a slightly higher SOC density and a much lower sand proportion. Because sand proportion in all salt pan cores is relatively consistent through the entire core depth, the difference in sand proportions between the cores may be due to natural variation within the habitat, rather than from relatively recent disturbances. Historical aerial photographs of the Ballona Wetlands show that the existing salt pan habitat is similar to its historical footprint and has remained relatively untouched over decades. None of the existing studies reviewed reported SOC in salt pan habitat for comparison.

Portions of Areas A and B were both classified as seasonal wetland by CDFW in a 2007 survey. However, locality, site history, and soil characteristics are considerably different between the two areas due to past anthropogenic disturbances. SOC densities of seasonal wetland Area A and Area B are significantly different from all other habitat types, including each other, and represented the habitats with the lowest and highest SOC densities, respectively. Although seasonal wetland in Area A and in Area B are both represented by only two cores, the two cores from each area are very similar to one another with little variation in soil characteristics. Interestingly, both areas have similar soil bulk densities even though Area A soil has approximately twice the sand proportion of Area B. Area A has much lower %OC than Area B which explains the significant difference in SOC density between these areas.

The higher proportion of sand and lower %OC in Area A is due to the fill material deposited there during construction of the marina and the lack of tidal inundation for many decades. The relative consistency in soil characteristics with depth in Area A is likely due to an even spreading of the fill material from the construction of the marina. The higher proportion of silt and clay and higher %OC in Area B is likely due to the presence of historical marsh soils and possibly from decades of organic matter addition to the soil from past agricultural operations. The relative consistency in soil characteristics with depth in Area B soils may be due to tilling of the soils that occurred during agricultural periods. Soil disturbance and increased oxidation due to agricultural activities in Area B does not appear to have caused a decrease in soil organic matter since the average %OC in seasonal wetland Area B and in low marsh habitat is the same at 3.3%. However, the SOC densities between low marsh and seasonal wetland Area B are very different (0.022 vs 0.037 g/cm^3, respectively) because low marsh has a much lower soil bulk density, likely because of its higher sand proportion and higher water content compared to seasonal wetland Area B (Table B-2 in Appendix B). It is possible that increased aerobic decomposition from ground disturbance due to farming activities in Area B may have been offset by the addition of plant matter from crops in the soils. None of the existing studies reviewed sampled seasonal wetland in a tidal marsh ecosystem.

3.4.3 SOC Density and Depth

SOC density in Ballona is found to not only vary between habitats, but also with depth. Generally, the results of this study show that organic carbon in all Ballona habitats is substantially higher near the soil surface, decreases rapidly through approximately the top 10 centimeters, and then becomes relatively stable with depth. This pattern is seen clearly in low marsh, mid-marsh, high marsh, and seasonal wetland Area B habitats and not as prominently in salt pan and seasonal wetland Area A habitats. The pattern of high organic carbon at the surface and then declining with depth has been reported in many other tidal marshes (Keller et al., 2012; Keller et al., 2015; Elgin, 2012; Callaway et al., 2012; Cahoon et al., 1996; Patrick & DeLaune, 1990; Craft et al., 1993; Choi & Wang, 2001; Bricker-Urso et al., 1989; Elsey-Quirk et al., 2011). This pattern appears to be typical of salt marsh habitat due to high biomass production at the surface and because wetlands trap sediment containing variable amounts of organic matter from natural and anthropogenic watershed sources, adding to the carbon accumulation at the surface (Mitra et al., 2005). Over time the organic-rich surface layers become buried by the rapid soil accretion typical of tidal marshes. The subsequent loss of organic carbon with depth is due to steady decomposition by bacteria and other organisms near the soil surface, which is typically better aerated. However, not all of the organic matter is lost to decomposition because rapid soil accretion and saturated soils create an anaerobic soil condition that slows aerobic decomposition (Li et al., 2010).

Only a few of the existing studies reviewed reported soil bulk density and %OC data with depth along with SOC density (Elgin, 2012; Connor et al., 2001; Callaway et al., 2012; Callaway et al., 2012b; Elsey-Quirk et al., 2011). Although soil bulk density is lower near the surface in Ballona marsh habitats, particularly in low and mid-marsh, %OC is highest at the surface and SOC density is still generally highest near the surface in all habitats. Similar to Ballona, marshes of southern California (Elgin, 2012) and the Bay of Fundy (Connor et al., 2001) show higher %OC and lower bulk density at the surface. However, two studies of San Francisco Bay tidal marshes (Callaway et al., 2012; Callaway et al., 2012b) and one marsh in Delaware (Elsey-Quirk et al., 2011) show the opposite pattern with lower %OC and higher soil bulk density near the surface. Differences in bulk density and %OC with depth between marshes is likely due to local differences in suspended sediment concentration and size, storm deposits, and the organic matter content of sediments. Nevertheless, because SOC density is the product of %OC and soil bulk density, whether %OC is high and bulk density low or %OC low and bulk density high, the SOC densities in these studies are all generally similar to Ballona.

3.4.4 Conclusions

The existing literature contains relatively few studies reporting SOC data in tidal marshes globally and only a handful of studies report data from tidal marshes of Mediterranean-type climates, including the marshes of southern California. This study contributes important soil carbon data from a southern California tidal marsh; however, considerably more data is needed to better understand carbon accumulation in these important ecosystems.

Most of the existing studies reviewed present SOC density as a core average, combining both surface and deeper soil, and many do not show how SOC density, or other soil characteristics, change with depth. In addition, many studies do not present the %OC and soil bulk density data used to calculate the SOC density and even fewer studies show how these data change with soil depth. These data are important because although the SOC densities of two marshes can be similar, it can be the result of either low %OC and high bulk density or high %OC and low bulk density. Additionally, most existing studies do not sample marsh habitat at different elevational habitats and many do not report the general habitat type (e.g., low, mid, high marsh) where their samples were collected. Reporting these data will help to show how these soil characteristics differ with tidal elevation and how they change spatially throughout a wetland. It is highly recommended that future tidal marsh carbon studies report the %OC and soil bulk density data along with SOC density, present changes in these soil characteristics with depth, and sample cores at different marsh elevations to capture differences in soil characteristics across the wetland.

Finally, if feasible, it is recommended that tidal marsh studies, including subsequent studies at Ballona, collect additional marsh-specific data for other parameters necessary to calculate and understand carbon accumulation rates such as suspended sediment concentration, above-ground and below-ground biomass production, soil accretion rates, and allochthonous carbon content. Understanding these parameters of a tidal marsh along with SOC density will help define how much carbon is being accumulated and sequestered in marsh habitat as well as the origin of that carbon.

Although tidal marshes are known as important carbon sinks globally, tidal marsh studies are relatively limited. The data presented for Ballona in this study helps to fill an important data gap and has important practical uses. Because of the staggering loss of natural tidal marsh habitat throughout the west coast of the U.S., and particularly in California, understanding soil carbon content in the remaining marshes, such as Ballona, provides valuable data representing a historical condition of natural tidal marsh habitat. In addition, recognizing that tidal marsh soils contain large quantities of carbon should discourage future changes in land use that would lead to the oxidation and release of tidal marsh soil carbon to the atmosphere.

The data in this study can also be used to estimate the SOC content in a future tidal marsh restoration project. SOC densities are necessary to estimate the soil carbon sequestration potential for tidal marsh restoration projects, as discussed in the next chapter of this study. Estimating the future carbon sequestration of a tidal marsh restoration project can provide valuable insight to climate change mitigation and potential financial benefits such as the participation in carbon trading markets. It is expected that as the body of tidal marsh soil data grows, it will assist policymakers with important decisions regarding land use, restoration, and climate mitigation planning.

4 CHANGE IN SOIL CARBON SEQUESTRATION OF A TIDAL MARSH RESTORATION PROJECT

4.1 INTRODUCTION

Warming of the global climate system is unequivocal; the atmosphere and oceans have warmed, the volumes of snow and ice have diminished, and sea level has risen (IPCC, 2013). Efforts to mitigate the increasing concentration of CO_2 in the atmosphere include: government regulation of fossil fuel emissions from industries and automobiles, research and investment in renewable energy, GHG emission offset programs, agricultural and forestry management, afforestation/reforestation, and restoration, enhancement, and conservation of natural habitat sinks. Of these mitigation strategies, the restoration, enhancement, and conservation of natural habitats, such as coastal wetlands, have received the least attention.

Recent studies and international climate change forums have highlighted the potential role of restoring, creating, and enhancing coastal wetland ecosystems as a means to reduce greenhouse gas emissions and mitigate climate change (Crooks et al., 2011; Pendleton et al., 2012; Sifleet et al., 2011; Restore America's Estuaries et al., 2010; Paris Climate Conference, 2015). Carbon stocks in coastal habitats are referred to as "blue carbon" and despite their relatively small global extent coastal wetlands contribute a disproportionate amount to long-term soil carbon sequestration compared to other ecosystems (Mcleod et al., 2011). This is because tidal marsh soils have higher soil carbon accumulation rates than any other ecosystem (Ouyang & Lee, 2014), approximately 10 times the rate of freshwater peatlands (Roulet, 2000), 10 times the rate of temperate forests and 50 times the rate of tropical forests (Pidgeon, 2009).

Carbon accumulation in marsh soils is the product of the soil accretion rate (SAR) and soil organic carbon (SOC) density, and coastal wetlands have high values of both for several reasons. The accumulation of organic matter is generally enhanced in wetlands due to the high productivity of wetland ecosystems. Organic matter from the above-ground biomass and the below-ground root zone accumulates in the soil over time. As plant matter dies it begins to decompose; however, not all of the organic matter is lost to decomposition due to the saturated soil and rapid soil accretion present in wetlands. In addition, many coastal wetlands trap sediment containing organic matter from natural and anthropogenic watershed sources, adding to the carbon accumulation (Mitra et al., 2005). Saturated soil creates an anaerobic environment that slows decomposition rates due to a chemically reduced condition for microbial respiration (Mitsch & Gosselink, 2007; Li et al., 2010). Some recalcitrant organic molecules avoid microbial decomposition and they accumulate in the soil as well (Valiela et al., 1985; Callaway et al., 1996; Kirwan & Megonigal, 2013). Organic carbon is considered sequestered in soil when organic matter decomposition has slowed to the point that further loss of carbon is negligible and conditions favor long-term carbon storage. Saltwater wetlands have also been found to emit low to negligible amounts of methane (CH_4), a powerful greenhouse gas, compared to freshwater wetlands due to the presence of sulfate in sea water (Bartlett et al., 1987; Bartlett & Harriss, 1993; Keller et al., 2012).

Because of their exceptional carbon storage capabilities, all remaining global tidal marshes should be rigorously conserved and protected from degradation. In addition, restoring already degraded tidal marsh habitat is likely to increase the amount of carbon sequestered in the soils of these wetlands. Future tidal marsh restoration projects could benefit from measuring this increase in carbon sequestration, for example by helping to meet carbon emission reduction goals or by receiving financial incentives in a carbon trading market. However, wetland restoration projects can take many years to plan and implement and may require a number of additional years after restoration before monitoring will show any measurable changes in carbon accumulation. Therefore, estimating the net change in carbon sequestration of a restoration project prior to investing time and resources could prove valuable to project proponents. Understanding the potential change in carbon sequestration could lead to revisions in restoration planning prior to construction in order to optimize carbon accumulation in the restored wetland.

In this study, the Ballona Wetlands Restoration Project (Ballona Project) is used as a case study to estimate the potential change in soil carbon sequestration in a tidal marsh proposed for restoration. By increasing the area of tidally influenced marsh habitat and improving tidal inundation to these habitats, the restoration of the Ballona Wetlands is anticipated to result in an increase in soil carbon sequestration. Although not estimated in this chapter, construction-related emissions from work vehicles and exposure of organic soil to oxygen may result in an unintended and substantial input of carbon to the atmosphere. Therefore, emission sources related to restoration construction activities such as fossil fuel use and organic matter oxidation of disturbed marsh soils should be considered by project proponents if determining a restoration project's total net carbon balance, such as for a carbon cap-and-trade program.

Using the Ballona Project as a case study, this chapter investigates the question; *what is the estimated net change in soil carbon sequestration resulting from the restoration of a tidal marsh ecosystem?* To answer this question prior to the years of planning, construction, and monitoring needed before any change in soil carbon could be directly measured, it is necessary to estimate the net change in carbon sequestration using available data from existing studies along with site-specific soil data. To estimate the net change in carbon sequestration between the restored and existing wetland conditions, this chapter presents a method to calculate carbon sequestration in both the existing and proposed restored habitats. With these results it is possible to estimate, prior to implementation of the project, how much additional carbon would be sequestered in the restored wetland and which habitats would sequester the most carbon. This analysis can be applied to other tidal marsh restoration projects during the planning process to determine if a proposed restoration alternative will increase the amount of carbon sequestered in its soils, and by how much, compared to the existing condition.

4.2 METHODOLOGY

The methodology developed in this study to determine the net change in carbon sequestration of the Ballona Project consists of estimating carbon sequestration for existing and restored wetland habitats from available data. Values are estimated for; 1) carbon sequestration of the existing Ballona marsh habitats (C_{exist}/yr), and 2) carbon sequestration of the restored Ballona marsh habitats following construction (C_{rest}/yr). The net change in carbon sequestration can be represented by:

$$C_{net}/yr = C_{rest}/yr - C_{exist}/yr,$$

4.2.1 Study Site – Ballona Wetlands

The Ballona Wetlands is a tidal marsh system located along the coast of Los Angeles County, near the community of Playa del Rey, north of the Los Angeles International Airport (Figure 4-1). The pre-settlement Ballona Wetlands ecosystem was approximately 2000 acres and included a variety of habitats (Grossinger et al., 2011). Approximately 600 acres remain within the historical wetland footprint, entirely surrounded by the extensively developed metropolitan area of Los Angeles. Wetlands at the site have been degraded and reduced to approximately 67 acres of subtidal and muted intertidal salt marsh and mudflat, with the remaining area largely converted to seasonal wetland or upland habitats (Johnston et al., 2012).

The property was purchased by the State of California in 2004 and designated as an ecological reserve.

The Ballona Wetlands are commonly divided into three areas designated as Areas A, B, and C. Area A lies north of Ballona Creek, west of Lincoln Blvd, east of Marina del Rey, and south of Fiji Way and currently comprises approximately 139 acres. Area B is approximately 338 acres and lies south of Ballona Creek, west of Lincoln Blvd, and is buttressed by the Playa Del Rey Bluffs to the south. Finally, Area C is approximately 65 acres and lies north of Ballona Creek, east of Lincoln Blvd, southwest of the Marina Freeway (SR 90), and is bifurcated by Culver Blvd.

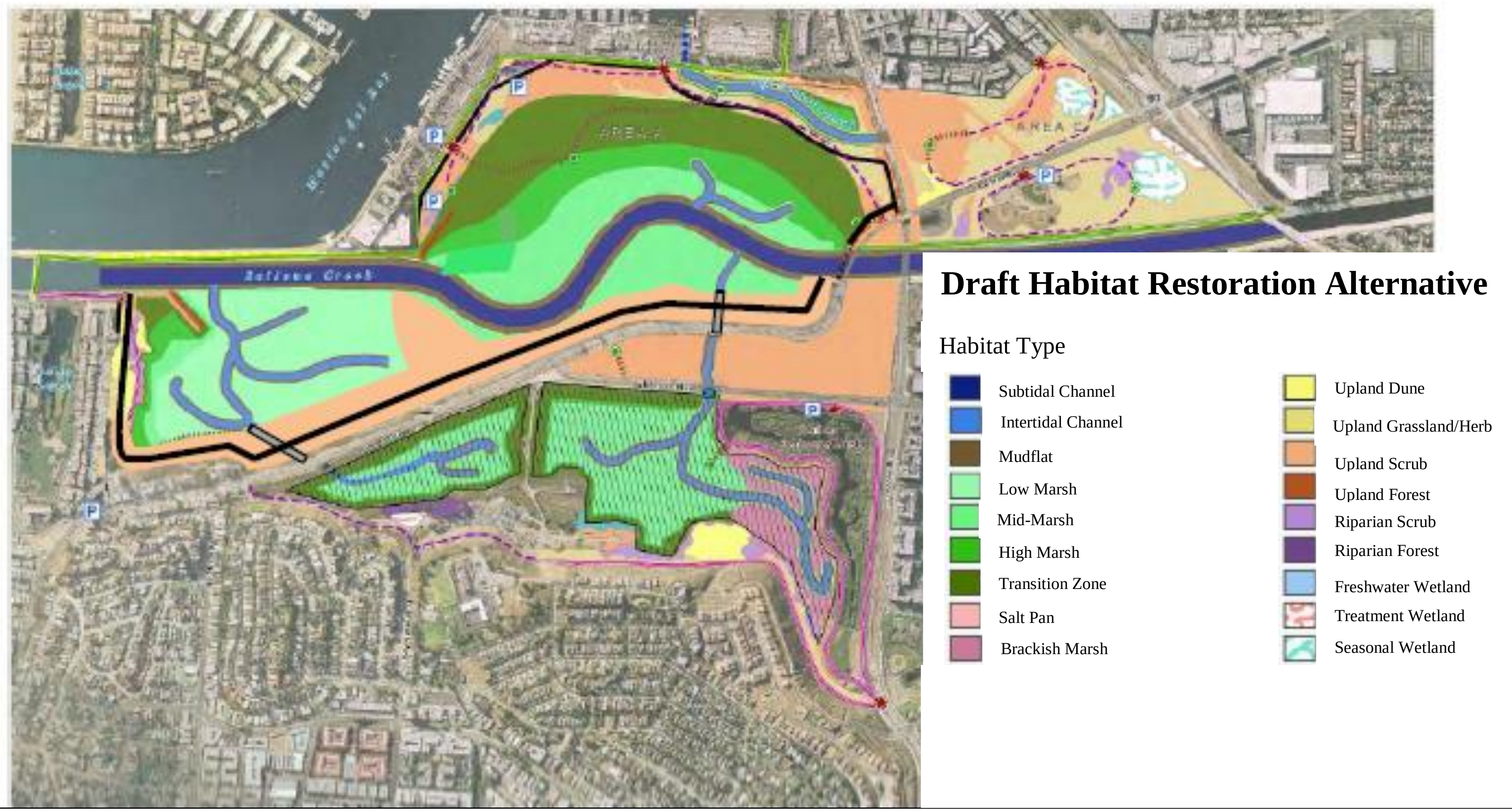
Tidal inundation in Area B of Ballona is limited to a maximum elevation of between approximately 3.6 and 4 feet MLLW due to regulating tide gates (PWA et al., 2006). The elevation of low marsh habitat at Ballona ranges from approximately 3.8 and 4.8 feet MLLW (ESA PWA, 2012). Therefore, tidally inundated habitat within Area B in the existing condition is confined to mudflat and low marsh habitat and likely totals no more than 24 acres based on habitat area estimates from ESA PWA (2012). Johnston et al. (2015) estimate the existing habitat still exposed to tidal influence at approximately 15 acres.

The State Coastal Conservancy (SCC), along with the California Department of Fish & Wildlife (CDFW – previously California Department of Fish & Game), State Lands Commission (SLC), and a wide range of stakeholders, have developed a draft restoration plan alternative for the Ballona Wetlands (ESA PWA, 2012; PWA et al., 2010; PWA et al., 2008). The overall goal of the project is to restore, enhance, and create estuarine habitat and processes in the Ballona ecosystem to support a range of natural habitats and functions. This will be achieved primarily by restoring tidal marsh habitats and by improving tidal circulation and enlarging the amount of area that is tidally inundated.

The proposed draft restoration alternative is shown in Figure 4-2. Although the final restoration design may differ from the proposed draft alternative, this alternative is the basis for the analyses in this study. A combined Draft Environmental Impact Report/Environmental Impact Statement (EIR/EIS) outlining a preferred restoration design for the Ballona Project is anticipated to be released for public review in 2017.

Figure 4-1 – Ballona Wetlands Existing Condition: Areas A, B, and C

Figure 4-2 – Proposed Draft Ballona Wetlands Restoration Alternative



Adapted from ESA PWA, 2012

4.2.2 Estimation of Carbon Accumulation Rates for Existing and Restored Habitats

Carbon accumulation rates (CAR) are calculated for both the existing and restored Ballona Wetland habitats using estimated values for soil accretion rates (SAR) and measured soil organic carbon (SOC) densities. SAR values are estimated by selecting data from existing studies that are determined to represent the existing and restored Ballona habitats. SOC density of wetland habitats is determined from analyses of soil collected from the existing Ballona Wetland habitats presented in the previous chapter of this study.

Soil accretion is described as the increase in surface elevation due to mineral sediment accumulation and organic matter accumulation and both components have been found to be important to soil accretion rates (Nyman et al., 2006; Nyman et al., 1993; Morris et al., 2016; Neubauer, 2008; Baustian et al., 2012; Turner et al., 2000; Callaway et al., 1997; Patrick & DeLaune, 1990). The presence of salt marsh vegetation has been shown to increase sedimentation on the marsh surface compared to unvegetated plots at the same tidal elevation (Baustian et al., 2012; Morris et al., 2002). Soil accretion via organic matter accumulation has been termed "accretion via vegetative growth" and consists primarily of the accumulation of organic matter resulting from belowground growth and decay of roots and rhizomes of wetland vegetation (McCaffrey and Thomson, 1980; Nyman et al., 2006).

Soil carbon density is a product of soil bulk density and the percent of carbon in the soil. Carbon accumulation refers to the mass of carbon added per year to the marsh surface or produced in situ (e.g., belowground biomass production) (Neubauer, 2008). Carbon accumulation rate (CAR) is a product of the soil accretion rate (SAR), soil bulk density (SBD), and percent organic carbon (%OC) and can be expressed with the following equation: CAR = SAR x SBD x %OC, or CAR = SAR x SOC density. Soil accretion is presented as centimeters per year (cm/yr), soil carbon density as grams of carbon per cubic centimeters (g C/cm^3), and carbon accumulation as grams of carbon per square meter per year (g C/m^2*yr).

A literature review was performed to compile a representation of soil accretion rates, soil carbon densities, and carbon accumulation rates from other studies. The search consisted of peer-reviewed studies that reported data from tidal salt marsh soils and certain upland habitats in various regions. An emphasis was placed on studies of marshes along the west coast of North America, particularly of California. However, studies from other regions are also included in the review for comparison to Ballona and to other west coast studies. Where SOC densities or accumulation rates are not explicitly provided in a particular study, they are calculated from the study data, when possible. In studies that specified marsh habitat elevation or where marsh habitat could be inferred, data are categorized as low, mid-, and high marsh habitat, based primarily on tidal elevation and vegetation dominance. For example, low marsh is typically inundated regularly and daily by tides, mid-marsh habitat irregularly but at greater frequency than higher elevations, and high marsh and salt pan habitat are irregularly inundated only during the highest tides (Ferren et al., 2007).

On the Atlantic and Gulf coasts of the U.S., *Spartina alterniflora* typically dominates low marsh habitat and species such as *Spartina patens, Distichlis spicata,* and *Salicornia* spp. occupy higher marsh habitats (McKee and Patrick, 1988; Callaway et al., 1997; Craft et al., 1993). On the west coast of the U.S., *Spartina foliosa* tends to dominate low marsh habitat while *Salicornia pacifica*, other *Salicornia* spp., and *D. spicata* dominate in mid- and high marsh habitat (Callaway et al, 2012; Johnston et al., 2011; Zedler, 2001; Zedler, 1982). In southern California salt marshes where *S. foliosa* is absent (e.g., Ballona Wetlands, Carpinteria Marsh, Mugu

Lagoon), *S. pacifica* and *Jaumea carnosa* tend to dominate the low marsh with *S. pacifica* and *D. spicata* dominating mid- and high marsh (Chan et al., 2010; Johnston et al., 2012).

Soil accretion rates were not measured for the existing Ballona habitats in this study because direct measurement and soil dating were beyond the scope of this project. Instead, soil accretion rates are compiled from 35 sources of published literature and reports on coastal salt marshes. Accretion in these studies was measured using a variety of markers (radioisotopes, radiocarbon, pollen, feldspar, plates, or surface elevation tables). Some of the studies provided estimates of the contribution of organic matter accumulation to overall soil accretion. Estimates of accretion via vegetative growth are used in the estimation of soil accretion rates for some non-tidal vegetated habitats of the existing Ballona Wetlands as described in the Results section. Average SAR values, along with a range of low and high values, are selected from the existing data to represent each habitat type. Because SAR was not directly measured at Ballona and rates are estimated using existing study data, a range of rates is presented for each habitat type to help moderate uncertainties in the data.

Average SOC densities for low marsh, mid-marsh, high marsh, seasonal wetland, and salt pan habitats of the existing Ballona Wetlands are presented in a previous chapter of this study. Many of the existing studies reviewed provided SOC density and others provided data from which SOC density could be calculated. Many existing studies calculated SOC density by averaging it over the entire core depth. The aggregation of deeper soils with surface soils likely overestimates the amount of carbon that will ultimately be sequestered because much of the organic matter near the surface will be oxidized. Soils nearer to the surface are typically exposed to factors that tend to increase the rate of decomposition of organic matter, such as tidal flushing, exposure to oxygen, greater temperature variations, and the presence of roots and rhizomes and fossorial organisms (Mitsch & Gosselink, 2007). Greater exposure to these factors near the surface tends to increase the rate of microbial decomposition and loss of organic matter in the soil. When a soil layer is buried sufficiently by accretion and experiences saturation with low water exchange, the factors influencing decomposition may be reduced to a level where additional loss of organic carbon is negligible (Valiela et al., 1985). The soil carbon below this depth is considered sequestered and the depth at which this occurs depends on soil conditions.

Elgin (2012) found that organic matter content decreased with soil depth and became relatively uniform at a depth of approximately 14 to 20 cm. To determine a depth at which soil carbon is sequestered in Ballona cores, SOC depth profiles are analyzed to evaluate the depth at which decomposition had generally slowed and organic matter became relatively uniform. These profiles show a similar trend as observed by Elgin. Most core profiles show that organic carbon becomes relatively uniform at a depth of approximately 14 to 20 cm (Appendix C).

Therefore, SOC densities for soil cores are conservatively calculated from deeper soils in the 20 to 40 cm depth, where the carbon is considered sequestered. An average SOC density for each habitat type is calculated from all the cores of that habitat type (i.e., low, mid-, high marsh). SOC density data from this study are compared to SOC densities reported in previous studies to check that they are reasonable. Because the SOC densities used in the calculations are based on data collected directly from the existing Ballona study site, no ranges are presented for SOC values as was done for SAR values, which are determined entirely from data from other studies.

4.2.3 Net Change in Soil Carbon Sequestration in the Restored Ballona Wetlands

Carbon accumulation rates (CAR) are multiplied by the areas of each existing and proposed restored habitat to calculate annual carbon sequestration. Carbon sequestration, like greenhouse gas emissions, is typically presented as carbon dioxide equivalents (CO_2e). The change in carbon sequestration is calculated by converting carbon to carbon dioxide equivalents using the molecular weight ratio for carbon dioxide to carbon of 44/12 (CO_2/C) and the mass of carbon from grams to metric tons. Annual carbon sequestration from the existing habitats is subtracted from sequestration of the restored habitats and summed over the entire wetland. The change in annual carbon sequestration is presented as metric tons CO_2e (mt CO_2e/yr) as represented by the general equation:

$$C_{net}/yr = C_{rest}/yr - C_{exist}/yr;\ mt\ CO_2e/yr$$

4.3 RESULTS AND DISCUSSION

4.3.1 Soil Accretion Rates (SAR)

Soil accretion rate values are estimated for the Ballona Wetlands habitats that were sampled in the previous chapter of this study and include mudflat, low marsh, mid-marsh, high marsh, salt pan, and seasonal wetland. Rates are selected based on the evaluation of 35 existing studies that presented SAR data for marsh habitat. SAR data from studies in the literature reviewed are discussed in the sections below for the respective habitat types and are presented in Table 4-1. Estimated SARs for the existing and proposed restored Ballona Wetlands habitats are presented in Table 4-2 as average SAR values with estimated ranges of low and high values for the restored habitats.

Three of the sources reviewed present summaries of average soil accretion rates compiled from various tidal marsh studies around the conterminous United States as well as from other regions of the world (Craft, 2007; Ouyang & Lee, 2014; Zedler, 2001). The range of SARs presented in each of these studies was similar. Zedler (2001) compiled SARs from 38 studies along the U.S. Atlantic, Gulf, and Pacific coasts and from European coasts and found that annual rates of accretion generally ranged from 0.1 to 1.0 cm/yr. Craft (2007) presented SARs reported in over 40 studies from the NE Atlantic coast, SE Atlantic coast, Gulf coast of Louisiana, and the Gulf coast of Texas ranging from 0.14 – 0.84 cm/yr. More recently, Ouyang & Lee (2014) compiled SAR data from 143 sites from over 50 published studies in various global regions of the northern and southern hemispheres that resulted in a range of SARs of 0.49 – 1.15 cm/yr.

Although habitat types (i.e., low, mid-, high marsh) are not specified in these summary studies, the ranges of rates presented in them are similar to the rates of SAR values for low, mid-, and high marsh habitats in other studies presented in Table 4-1, suggesting that perhaps the average rates presented in the summary studies include a mixture of habitat types. Interestingly, an evaluation of the data compiled in various regions by Ouyang & Lee (2014) and Craft (2007) shows that SAR values of salt marsh habitat are very similar in all regions of the world both in the average rates and in the ranges of low and high values (Table 4-1). Tidal marshes of the U.S. west coast had the highest average accretion rate and the highest range values of the Ouyang & Lee (2014) data and a close second highest after the Gulf coast of Louisiana in Craft (2007).

In many soil accretion studies, vertical accretion is measured but the mechanisms controlling accretion are rarely explored and have largely been assumed to be controlled primarily by mineral sedimentation (Nyman et al., 2006). However, soil accretion is understood to consist of both mineral sedimentation and organic matter accretion via vegetative growth (McCaffrey and Thomson, 1980; Nyman et al., 2006; Nyman et al., 1993; Morris et al., 2016; Neubauer, 2008; Turner et al., 2000; Callaway et al., 1997; Patrick & DeLaune, 1990). Therefore, soil accretion in intertidal marsh habitats is considered to be the result of a combination of mineral sedimentation deposited by tides and organic matter accretion via vegetative growth. These intertidal habitats are discussed in Section 4.3.1.1. Some vegetated habitats within the Ballona Wetlands are not subject to tidal inundation and any soil accretion in these habitats is considered to be due solely from organic matter accumulation via vegetative growth. Soil accretion in non-tidal vegetated habitats is discussed below in Section 4.3.1.2.

4.3.1.1 Intertidal Habitats

Low Marsh

Soil accretion rates for low marsh habitat are reported in 23 of the studies reviewed. Low marsh SAR values ranged from 0.23 – 9.1 cm/yr. Rates from U.S. Gulf coast and Northern Europe studies (0.56 – 1.0 cm/yr) are similar to U.S. west coast studies. Two study sites with rates at the lower end of the range, Thorne et al. (2014) and Cornu & Sadro (2002), are reported to have qualities that do not represent typical low marsh habitat. Thorne et al. (2014) recorded a SAR of 0.24 cm/yr in a marsh with "very low organic matter contribution to the soil and marsh accretion processes". Similarly, a SAR value of 0.23 cm/yr was recorded in a recently constructed marsh site in Oregon that began unvegetated and had only 53% vegetation cover at the end of the 3-year study (Cornu & Sadro, 2002). At the other end of the range, several studies reported unusually high rates due to specific circumstances such as large storm events, newly formed low-elevation marshes, or areas of unusually high subsidence (Patrick & DeLaune, 1990; Cahoon et al., 1996; Ward et al., 2003; He et al., 2016). Disregarding the outlying low and high values from these studies results in a SAR range of 0.36 – 1.9 cm/yr for low marsh with an average of 0.84 cm/yr. This range of SARs includes 78% of the low marsh SARs reported in the existing literature reviewed and is similar to the global ranges reported by Zedler (2001), Craft (2007), and Ouyang & Lee (2014).

Therefore, a SAR range of 0.4 – 1.9 cm/yr and an average of 0.8 cm/yr is chosen to represent the low marsh habitat in the restored Ballona Wetlands. Because existing low marsh habitat in Ballona is located in the tidally muted portion of Area B, a SAR value of 0.4 cm/yr from the lower end of the SAR range is applied.

<u>Mid-Marsh</u>

Twelve of the studies reviewed provided SAR data for mid-marsh habitat. SAR values for mid-marsh ranged from 0.12 – 1.06 cm/yr and averaged 0.5 cm/yr. All mid-marsh SAR values except two are reported from west coast regions. Callaway et al. (1997) reported a rate of 0.5 cm/yr in the Gulf coast of Louisiana and Erwin et al. (2006) reported a rate of 1.06 from mid-Atlantic marshes. Two low values stand out in the data; 0.12 and 0.13 cm/yr from Thorne et al. (2014) and Cornu & Sadro (2002), respectively. If the results of these two studies are not included for the same reasons provided above for their low marsh habitat, the range of SAR values for mid-marsh habitats is 0.35 – 1.06 with an average SAR of 0.57 cm/yr. This range of SARs includes 83% of the mid-marsh SARs reported in the existing literature reviewed and are similar to ranges reported by Zedler (2001), Craft (2007), and Ouyang & Lee (2014).

The range of estimated SAR values for restored mid-marsh habitat is 0.3 – 1.0 with an average SAR of 0.5 cm/yr. The average SAR of 0.5 cm/yr is rounded down to provide a more conservative estimate for mid-marsh habitat. The low range value for mid-marsh (0.3 cm/yr) is rounded down so that it would be below the lower range value for low marsh (0.4 cm/yr), which will receive more inundation than mid-marsh and is expected to have a higher SAR range. Because existing mid-marsh habitat in Ballona is located in the tidally muted portion of Area B, and currently does not receive any tidal inundation, the SAR value determined below in Section 4.3.1.2 for accretion via vegetative growth (0.18 cm/yr) is applied to existing mid-marsh habitat.

High Marsh

High marsh habitat SARs are reported in 16 of the studies reviewed and ranged from 0.11 – 1.0 cm/yr and averaged 0.34 cm/yr. All high marsh SAR values except three are reported from west coast regions. Callaway et al. (1997) reported an average SAR of 0.40 cm/yr in a Gulf coast study, Erwin et al. (2006) reported an average high marsh SAR of 0.31 cm/yr from mid-Atlantic marshes, and Callaway et al. (1996b) reported a similar average value of 0.45 cm/yr in high marsh habitats of Northern Europe. The rates in these three studies are similar to rates from west coast studies. Two of the studies provided relatively high SAR values for high marsh; 0.70 cm/yr in Cornu & Sadro (2002) and 1.0 cm/yr in PWA & PFA (2002). Although there appears to be no reason to suggest that these SAR rates are unnaturally high (due to some factor such as large storm deposits or marsh surface subsidence), if these two high values are conservatively removed from the data set the range of high marsh SARs becomes 0.11 – 0.45 cm/yr with an average of 0.27 cm/yr. This range of SARs includes 88% of the high marsh SARs reported in the existing literature reviewed. The average SAR for only west coast high marsh studies, also excluding the values of 0.70 and 1.0 cm/yr, is similar at 0.24 cm/yr. Chan et al. (2010) reported an average high marsh SAR value of 0.29 cm/yr from three southern California salt marshes that are similar to the Ballona Wetlands in proximity and habitat.

The accretion rate for only vegetative organic matter accumulation determined for high marsh habitat in the following section (Section 4.3.1.2) is slightly larger (0.18 cm/yr) than the low range SAR of 0.11 cm/yr in existing high marsh studies. Because accretion via vegetative growth is considered in this study to be a minimum accretion rate for vegetated tidal marsh habitats, the rate of 0.18 cm/yr replaces 0.11 cm/yr as the low range value for high marsh habitat. Therefore, a range of 0.18 – 0.5 cm/yr and average of 0.3 cm/yr is applied to the restored high marsh habitat for Ballona. Similar to mid-marsh habitat, high marsh in the existing Ballona Wetlands is located in the tidally muted portion of Area B, and currently does not receive any tidal inundation. Therefore, the SAR value of 0.18 cm/yr described below in Section 4.3.1.2 for organic matter accretion via vegetative growth in high marsh habitat is applied to the existing high marsh habitat.

Mudflats

Very few studies have measured vertical accretion rates in mudflats. Mudflat habitat is inundated by tidal water containing suspended sediment longer than any of the vegetated marsh habitats. Flow and sediment dynamics within mudflats are complex and highly variable between and within coastal wetlands due to factors such as suspended sediment concentration, tidal prism, tidal currents, wind-generated waves, and biological activity (Anderson et al., 1981; Ward et al., 2003; Wallace et al., 2005). Although cyclical patterns of erosion and deposition occur on intertidal mudflats, they are primarily considered to be depositional environments and, in general, accretion rates are assumed to be within the same general range as those found in adjacent vegetated areas (Zedler, 2001; Anderson et al., 1981).

Only four studies in the literature review provided measured accretion rates for mudflat habitat. Ward et al. (2003) and Wallace et al. (2005) measured mudflat accretion rates in Tijuana Estuary at 1.4 and 2.2 cm/yr, respectively. Yuknis (2012) measured rates of 1.46 and 5.6 cm/yr in mudflats of the Liaohe Delta in China. Erwin et al. (2006) measured an average mudflat SAR of 1.45 cm/yr from four salt marshes along the mid-Atlantic coast. The higher SAR of 5.6 cm/yr in Yuknis (2012) was from a mudflat with a low elevation and directly adjacent to a river mouth. If the high SAR of 5.6 cm/yr is disregarded, the average value from these four mudflat studies is

1.6 cm/yr. This value is within the general range of SARs determined for adjacent low marsh habitat.

Because only four studies in the literature review provided SARs for mudflat habitat, the average SAR of 1.6 cm/yr from those four studies is applied to the upper range value for mudflats. Mudflat accretion rates at Ballona may be generally similar to the adjacent low marsh accretion rates as suggested by Zedler (2001). Although mudflat habitat may be exposed to more sedimentation than low marsh due to longer inundation by tidal water, it does not experience accretion via vegetative matter accumulation as low marsh does. Therefore, the low range and average SAR values for low marsh of 0.4 cm/yr and 0.8 cm/yr is applied to mudflats as well. A representative range of 0.4 – 1.6 cm/yr with an average value of 0.8 cm/yr is used in this study for mudflats of the restored Ballona Wetlands. Because existing mudflat habitat in Ballona is tidally muted, this study applies the low range SAR value of 0.4 cm/yr to mudflats of the existing Ballona Wetlands to reflect the expected lower sedimentation.

Salt Pan

None of the literature reviewed provided data on salt pan habitat soil accretion. Salt pan is typically an unvegetated habitat that receives tidal inundation at only the highest tides, similar to high marsh. Therefore, all soil accretion in salt pan habitat would be expected to be from mineral sedimentation deposited by flooding. Although the rationale for estimating soil accretion via organic matter vegetative growth is discussed in the following section (Section 4.3.1.2), the discussion is relevant here for salt pan as well. As discussed below, the accretion via vegetative growth is estimated as 60% of the total accretion in intertidal marsh habitats. Salt pan habitat typically receives a level of tidal inundation similar to high marsh habitat, but would not have a contribution of accretion via vegetative growth. In Section 4.3.1.2, the organic matter component of the average soil accretion rate of 0.3 cm/yr for high marsh habitat is estimated at 0.18 cm/yr (0.6 x 0.3 cm/yr). Because all soil accretion in salt pan habitat presumably comes from sedimentation, the SAR for salt pan might be expected to be equal to the remaining 40% of the high marsh average SAR, or 0.12 cm/yr (0.3 cm/yr – 0.18 cm/yr). The 40% rationale is also applied to the upper and lower range values of the high marsh SAR to calculate a range of SAR values for salt pan.

Therefore, this study applies an average SAR value of 0.12 cm/yr and range of 0.04 – 0.2 cm/yr to restored salt pan. The existing salt pan habitat in Ballona does receive some tidal inundation along the northern-most portion of the habitat at the highest tides and a larger portion of the existing habitat accumulates stormwater runoff from adjacent habitats (Johnston et al., 2015). However, due to the muted inundation of the existing Ballona Wetlands, this study applies the low range SAR value of 0.04 cm/yr for existing salt pan habitat.

4.3.1.2 Non-tidal Vegetated Habitats

Non-tidal vegetated habitats occur at elevations that are higher than the tidal range in the wetland and are not inundated by tides. Non-tidal vegetated habitats of the existing Ballona Wetlands include mid-marsh, high marsh, brackish marsh, seasonal wetland, and upland habitat. Although mid- and high marsh habitats typically experience tides, the existing mid-marsh and high marsh habitats in Ballona are located in the tidally muted portion of Area B, and currently do not receive any tidal inundation. In the restored Ballona Wetlands, non-tidal vegetated habitats include transition zone, brackish marsh, seasonal wetland, and upland habitat. Any soil accretion in these habitats is therefore assumed to be the result of organic matter accretion via vegetative growth only. Because SOC density in brackish marsh, transition zone, and upland habitat was not measured at Ballona, soil accretion rates are not estimated for these habitats.

Carbon accumulation rates for these habitats are estimated in Section 4.3.3.2 using carbon accumulation rate data from existing studies.

The contribution of vegetative matter accumulation to overall soil accretion has not been measured in the Ballona Wetlands. However, organic matter can be a substantial component of soil accretion in marsh soils and can improve soil structure by contributing to the aggregation of fine particles, adding to soil stability and decreasing soil bulk density (Ward et al., 2003; Tate, 1987). Several studies have found organic matter accumulation to be a major component of overall soil accretion (McCaffrey and Thomson, 1980; Bricker-Urso et al., 1989; Craft et al., 1993; Callaway et al., 1997; Culberson et al., 2004; Nyman et al., 2006; Nyman et al., 1993; Turner et al., 2000; Chmura and Hung, 2004; Neubauer, 2008; Morris et al. 2016; Baustian et al., 2012). When the water associated with the organic component of soil is considered, Bricker-Urso et al. (1989) determined that organic matter accounts for an average of 91% of vertical accretion in the low marsh and 96% in the high marsh. Craft et al. (1993) found that organic matter accounted for 47% – 57% of accretion in an irregularly flooded tidal marsh. Neubauer (2008) and Morris et al. (2016) determined in separate studies that organic matter probably contributes about 60% to vertical accretion of tidal marshes along the Atlantic Coast, Gulf Coast, and San Francisco Bay.

Most of the studies of vegetative matter contribution to marsh soil accretion are from *Spartina*-dominated tidal marshes while the Ballona Wetlands is a *Salicornia*-dominated marsh. Because of the difference in species composition, climate, and other factors between studies, what has been learned about *Spartina* wetlands may not be directly applicable to Mediterranean-type tidal wetlands of the southern California coast (Callaway et al., 2012). However, in studies comparing above- and belowground biomass between *Spartina*- and *Salicornia*-dominated marshes, *S. pacifica* was similar to *Spartina* species in both above and belowground biomass production (Mahall and Park, 1976; Zedler et al., 1980; Keller et al., 2015; Gallagher and Plumley, 1979).

Because vegetative matter accretion is driven by plant matter accumulation and *Spartina* and *Salicornia*-dominated marshes are similar in biomass production, this study applies the approximate 60% contribution of organic matter to vertical accretion of marsh habitats determined by Craft et al. (1993), Neubauer (2008), and Morris et al. (2016).

Multiplying the 60% contribution by the average SAR values of marsh habitat results in accretion rates via organic matter accumulation of 0.48 cm/yr (0.6 x 0.8 cm/yr) for low marsh, 0.3 cm/yr (0.6 x 0.5 cm/yr) for mid-marsh, and 0.18 cm/yr (0.6 x 0.3 cm/yr) for high marsh habitats. Because existing mid-marsh, high marsh, and seasonal wetland Area B are more similar in elevation and vegetation composition to restored high marsh than to other marsh habitats, the high marsh organic matter accretion rate of 0.18 cm/yr is applied to the these existing habitats. The estimate of 0.18 cm/yr for these existing non-tidal habitats may be an overestimate because, unlike restored high marsh, they do not receive any tidal water saturation that could slow decomposition of organic matter, as described further in a later section.

Table 4-1 – SAR from Existing Studies

Average Salt Marsh Soil Accretion Rates from Existing Literature

Reference	SAR (cm/yr) by Salt Marsh Habitat					Dating Method	Region
	Low	Mid	High	Mean	Range		
Summary References							
Zedler, 2001				0.50	0.1 – 1.0	Various	Various
Craft, 2007				0.14	0.03-0.19	^{137}Cs	Georgia
				0.34	0-0.65	Various	NE Atlantic coast
				0.23	0.03-0.27	Various	SE Atlantic coast
				0.84	0.56-1.78	Various	Gulf Coast – LA

Reference	SAR (cm/yr) by Salt Marsh Habitat					Dating Method	Region
	Low	Mid	High	Mean	Range		
				0.53	0.44-0.62	Various	Gulf Coast – TX
				0.60	0.23-1.2	Various	West Coast
Ouyang & Lee 2014				0.80	0.08-3.5	Various	Tropical West Atlantic
				0.89	0.19-3.25	Various	N. Europe
				0.92	0.11-2.2	Various	S. Europe
				1.15	0.25-4.2	Various	NE Pacific (U.S. west coast)
				0.49	0.07-3.87	Various	NW Atlantic
Various Regions							
Erwin et al. 2006		1.06	0.31	0.61	0.23-1.27	Surface Elevation Table	Mid-Atlantic Coast
Loomis & Craft 2010				0.19		^{137}Cs	Georgia
Smith et al. 1983	0.76			0.76		^{137}Cs	Gulf Coast – LA
Nyman et al. 1993	1.0			1.0	0.55-1.78	^{137}Cs	Gulf Coast – LA
Nyman et al. 2006	0.79			0.79	0.59-0.98	^{137}Cs	Gulf Coast – LA
Callaway et al. 1997	0.70	0.50	0.40	0.54	0.18-0.89	^{137}Cs	Gulf Coast – LA
Spencer et al. 2008				0.75		Direct Measure	UK
Callaway et al. 1996b	0.56		0.45	0.51		^{137}Cs	N. Europe
He et al. 2016	3.5					Feldspar	Georgia
West Coast North America							
Thom 1992	0.36			0.36	0.20-0.70	^{137}Cs	Oregon & Washington
Thorne et al. 2015	0.46	0.49	0.36	0.44	0.17-0.89	^{137}Cs	Oregon & Washington
Cornu & Sadro 2002	0.23	0.13	0.24 0.70	0.19 0.70	0.13-0.70	Feldspar	Oregon
Patrick & DeLaune 1990	0.50 0.80 3.90			1.70	0.50–3.90	^{137}Cs	San Fran Bay
Callaway et al. 2012	0.61	0.35	0.35	0.44	0.35-0.61	^{137}Cs	San Fran Bay
Callaway et al. 2012b	0.44	0.41	0.36	0.40	0.30-0.60	^{137}Cs and ^{210}Pb	San Fran Bay
Watson 2004	1.0			1.0		Various	San Fran Bay

Reference	SAR (cm/yr) by Salt Marsh Habitat					Dating Method	Region
	Low	Mid	High	Mean	Range		
PWA and PFA 2002	1.8		1.0		0.8-6.6 (low) 0.5-1.3 (high)	Feldspar	San Fran Bay
Ingram et al. 1998			0.13		0.13	^{14}C	San Fran Bay
Byrne et al. 2001			0.11	0.11	0.06-0.16	^{14}C	San Fran Bay
Goman and Wells 2000			0.11	0.11		^{14}C	San Fran Bay
Orr et al. 2003	0.7			0.7		Model results	San Fran Bay
Watson 2008	0.6	0.35	0.30	0.42	0-2.1	Plates	San Fran Bay
Watson et al. 2011	0.42			0.42	0.30 – 0.54	^{137}Cs	Elkhorn Slough
Mudie & Byrne 1980		0.50		0.50	0.10-1.0	Pollen & ^{14}C	Southern California
Chan et al. 2010	0.67	0.70	0.29	0.55	0.29-0.70	Stakes	Southern California
Thorne et al. 2014	0.24	0.12	0.16	0.16		^{137}Cs	San Diego Bay
Weis et al. 2001	1.15	0.86		0.95	0.71-1.23	^{137}Cs	Tijuana Estuary
Wallace et al. 2005	1.0	0.50		1.30	NA	Feldspar	Tijuana Estuary
Cahoon et al. 1996	1.9 5.90		0.15	5.90	0.1-0.2 (high) 1.9-8.5 (low)	Feldspar & ^{14}C	Tijuana Estuary
Ward et al. 2003	9.1 1.4				4-12.7	Feldspar	Tijuana Estuary
Ruiz-Fernandez et al. 2016			0.29	0.19-0.39		^{210}Pb	Gulf of California
Brevik & Homburg 2004				0.09		^{14}C	Ballona
Representative Values from Study Summary	**0.80**	**0.50**	**0.30**	**0.53**	**0.30-0.80**	**NA**	**Various**

Table 4-2 – Estimated SARs for Ballona Habitats

Habitat Type	Average SARs (cm/yr) (Range)	
	Existing	Restored
Mudflat	0.4	0.8 (0.4 – 1.6)
Low Marsh	0.4	0.8 (0.4 – 1.9)
Mid-marsh	0.18	0.5 (0.3 – 1.0)
High Marsh	0.18	0.3 (0.18 – 0.5)
Salt Pan	0.04	0.12 (0.04 – 0.2)
Seasonal Wetland Area B	0.18	NE

NE: Non-existent in the restored condition

4.3.2 SOC Densities (SOC)

SOC densities for Ballona Wetland habitats are determined from soil sampling and laboratory analyses presented in the previous chapter of this study. Sampling did not include brackish marsh, freshwater/riparian habitat, transition zone, or upland habitats because sampling was focused primarily on tidal marsh habitats and transition zone habitat is not represented in the existing Ballona Wetlands. SOC densities are averaged over each 20 to 40 cm core depth and are presented in Table 4-3. A review of existing studies reporting SOC density data for similar habitats is summarized in Table 4-4.

Mudflat

Broad plains of mudflat do not occur in the existing Ballona Wetlands. However, the channels of the existing wetland provide narrow, sinuous corridors of intertidal mudflat habitat. Channel beds, banks and benches exposed at low tide conditions have similar functions to mudflats (Ferren et al., 2007) and are presented in Ballona Wetlands Restoration Plan documents as mudflat habitat (ESA PWA, 2012). One core in this study was collected in a mud-bottom channel of the Ballona Wetlands. Because the core was determined to be slightly compacted and partially mixed during extraction it was not presented in the previous chapter of this study and no other channel cores were attempted. The core was sliced into samples as well as could be accomplished and analyzed in the laboratory along with the other cores. Although the mudflat core was not presented in the previous chapter, average SOC density in the 20 to 40 cm depth was measured at 0.013 g/cm^3.

Few existing studies provide SOC density of mudflat habitat. He et al. (2016) reported SOC density in a newly-formed (9 year-old) natural mudflat in Georgia of 0.003 g/cm^3. Crawford et al. (2015) determined an average SOC density of 0.027 g/cm^3 for mudflats also in Georgia. Mudflats sampled in the Liaohe Delta in China contained an average SOC density of 0.015 g/cm^3 (Yuknis, 2012) and mudflats in the Blackwater Estuary of the UK reported 0.016 g/cm^3 (Adams et al., 2012). The average SOC density for mudflat habitat in these existing studies is 0.015 g/cm^3, similar to the Ballona mudflat SOC density of 0.013 g/cm^3. Because mudflat habitat was directly measured from the Ballona project site, and the value is similar to existing study data, the SOC density of 0.013 g/cm^3 is used to represent mudflat habitat in this study.

Salt Marsh and Salt Pan Habitats

Low marsh, mid-marsh, high marsh, and salt pan SOC data from the existing Ballona habitats are presented in the previous chapter of this study and ranged from 0.020 – 0.024 g/cm^3 for the 20 to 40 cm depth. Although averaged over the deeper 20 to 40 cm soil depth, the SOC densities of the Ballona marsh habitats have similar values to SOC densities for salt marsh habitat reported in many of the existing studies reviewed (Table 4-4). SOC densities reported in existing studies ranged from 0.009 to 0.054 g/cm^3 and many reported data for low, mid-, and high marsh habitats. Like SAR values, SOC data from different regions are similar and no region stands out with substantially different values. Some studies show SOC density decreasing with habitat elevation (Elsey-Quirk et al., 2011; Choi & Wang, 2004; Choi et al., 2001) while other studies, like Ballona, show SOC density increase with elevation (Burden et al., 2013; Adams et al., 2012; Connor et al., 2001; Thorne et al. 2015).

Averaging all SOC density values reported in these existing studies results in a general estimate of 0.027 g/cm^3 for salt marsh habitat. When existing study data is averaged for low, mid-, and high marsh habitats, the resulting SOC densities are all similar at 0.026, 0.026, and 0.027 g/cm^3, respectively. Although the SOC density values at Ballona are lower than the global average of 0.039 g/cm^3 calculated by Chmura et al. (2003), they are similar to many other studies, including studies from California salt marshes (Callaway et al., 2012; Keller et al., 2012; Elgin, 2012). The marshes in studies by Keller et al. (2012) and Elgin (2012) are similar to Ballona in SOC density, habitat, and proximity, supporting an assumption that the SOC values from Ballona in this study are representative of southern California salt marshes. The SOC density value of 0.043 g/cm^3 reported by Brevik & Homburg (2004) for the historical Ballona Wetlands complex, representing salt marsh habitat up to 5,000 years before present, may be high due to compaction and soil consolidation known to occur in deep soils (Callaway et al., 1996; Swanson et al., 2013).

Because the SOC density values determined for the existing Ballona habitats in Table 4-3 were measured directly from Ballona soils and are very similar to values from existing studies, they are used in the subsequent calculation of carbon accumulation in both the existing and restored Ballona conditions, except as discussed below. Although the restored Ballona habitats may ultimately accumulate more organic matter than the existing condition due to increased tidal influence and soil saturation, the SOC densities of the existing Ballona habitats are used to calculate CAR in the restored habitats as well.

Seasonal Wetland

The seasonal wetland habitat in Area B is substantially different in soil characteristics (grain size, bulk density, %OC) and historical impacts from Area A. Existing seasonal wetland habitat totals 86 acres and is presented in Table 4-3 as an average of all seasonal habitat areas combined and is also separated into Areas A and B.

Table 4-3 – Estimated SOC Densities for Ballona Habitats (20 to 40 cm)

Wetland Habitat	# Cores	Ave SOC (g/cm^3)	
		Existing	Restored
Mudflat	1	0.013	0.013
Low Marsh	7	0.020	0.020
Mid-marsh	7	0.022	0.022
High Marsh	4	0.024	0.024
Salt Pan	3	0.022	0.022
Seasonal All Cores	4	0.023	NA
Seasonal Area A	2	0.013	NA
Seasonal Area B	2	0.034	NA

NA = Not Applicable

As discussed previously, the existing studies in Table 4-4 present carbon data averaged over the entire core sample. The inclusion of these surface soils likely overestimates the amount of carbon that will ultimately be sequestered over the long term. Therefore, SOC density from Ballona habitats is averaged over the more conservative 20 to 40 cm depth.

Similar to Elgin's (2012) data, average SOC densities in Ballona are lower in the 20 to 40 cm depth than when averaged over the entire core. SOC densities are between 4 – 19% lower in the deeper soils with an average around 12%. The biggest percent change between the 0 to 40 cm and the 20 to 40 cm depths is in seasonal wetland Area A (19%) and the least change is in salt pan habitat (4%). Mudflat SOC density did not change over depth and may be due to the complete saturation of the soils and possibly some mixing of mud layers during extraction of the core.

Because SOC densities for Ballona habitats are based on soil cores collected directly from the study site and values from the study site are similar to other regional salt marsh soils, no ranges are presented for SOC values as was done for SAR values, which are determined entirely from existing data of other studies.

Table 4-4 – SOC Densities from Existing Studies

Reference	Soil Organic Carbon Density (g/cm^3)	Region
	Mudflats	
He et al. 2016	0.003	Georgia
Adams et al., 2012	0.016	UK
Yuknis 2012	0.015	China
Crawford et al. 2015	0.027	Georgia
Average Mudflat Habitat	**0.015**	**Various**
This Study	**0.013**	**Existing Ballona Wetlands**
	Vegetated Salt Marsh	
Chmura et al. 2003	0.039 mixed marsh habitats	Global
Burden et al. 2013	0.014 low marsh 0.031 high marsh	UK
Adams et al., 2012	0.012 mid-marsh 0.023 high marsh	UK
Connor et al., 2001	0.035 low marsh 0.042 high marsh	Bay of Fundy, Canada
Craft et al. 2003	0.020 low marsh	North Carolina
Elsey-Quirk et al., 2011	0.054 low marsh 0.053 mid-marsh 0.031 high marsh	Delaware/Maryland
Choi & Wang 2004	0.052 low marsh 0.025 mid-marsh 0.025 high marsh	NW Florida
Choi et al. 2001	0.034 low marsh 0.017 mid-marsh 0.015 high marsh	NW Florida
Loomis & Craft, 2010	0.023 low marsh	Georgia
Thorne et al., 2015	0.015 low marsh 0.017 mid-marsh 0.020 high marsh	Oregon & Washington
Patrick & DeLaune 1990	0.009 low marsh 0.014 low marsh	SF Bay
Callaway et al. 2012	0.027 low marsh 0.026 mid-marsh 0.027 high marsh	SF Bay

Reference	Soil Organic Carbon Density (g/cm^3)	Region
Callaway et al. 2012b	0.027 & 0.021 low marsh 0.033 & 0.021 mid-marsh 0.031 & 0.029 high marsh	SF Bay
Cahoon et al. 1996	0.018 low marsh	Tijuana Estuary
Cahoon unpublished (see Chmura et al., 2003)	0.017 & 0.040 unknown	Tijuana Estuary
Keller et al. 2012	0.023 mid-/high marsh 0.034 mid-/high marsh	Huntington Beach
Elgin 2012	0.022 mixed marsh habitat	Mugu Lagoon, Tijuana, Carpinteria
Brevik & Homburg 2004	0.043 mixed marsh habitat	Ballona
Average of Existing Studies	**0.027 all** **0.026 low marsh** **0.026 mid-marsh** **0.027 high marsh**	**Various**
This Study	**0.020 low marsh** **0.022 mid-marsh** **0.024 high marsh**	**Existing Ballona Wetland**

4.3.3 Carbon Accumulation Rates (CAR)

Carbon accumulation rates are calculated by multiplying the estimated SAR values in Table 4-2 by the measured SOC densities in Table 4-3 for the habitats sampled at Ballona, except as discussed below. For habitats not sampled at Ballona; brackish marsh, transition zone, and upland, CARs are estimated using carbon accumulation data from existing studies. The CAR values estimated in this study for Ballona habitats are presented in Table 4-5.

Carbon accumulation is generally highest in habitats that have both tidal inundation and vegetation, and is higher in habitats that are inundated longer by tides. For habitats of the proposed restored Ballona Wetlands the CAR values ranged from 16 g C/m^2*yr in upland, transition zone, and seasonal wetland Area C to 160 g C/m^2*yr in low marsh habitat. CAR values for the existing Ballona habitats ranged from 9 g C/m^2*yr in salt pan to 80 g C/m^2*yr in low marsh. Carbon accumulation for each habitat type is discussed in the sections below and organized by intertidal and non-tidal habitat.

4.3.3.1 Intertidal Habitats

Intertidal habitats of the Ballona Wetlands include low marsh, mid-marsh, high marsh, salt pan, and mudflat. Because mid-marsh and high marsh habitats in the existing wetland do not currently receive tidal influence due to a regulating tide gate, these habitats are discussed along with the non-tidal habitats in the following section. The same SOC density values are used for the same habitats in both the existing and restored wetland, so any difference in CAR values is due to a difference between the SAR values. The lower SARs in the existing wetland are chosen from the lower end of the range of estimated restored habitat rates due to the muted tidal influence for these habitats. Ranges of CARs are not presented for existing habitats because ranges of SAR values are not applied to these habitats.

Due to the muted tidal influence in the existing wetland, carbon accumulation rates are higher for all restored intertidal habitats compared to their existing habitat counterparts. The estimated CAR values of restored habitats are approximately 2 to 3 times higher than those of the existing habitats. CAR of the intertidal habitats is highest in the low marsh and is followed by mid-marsh, mudflat, high marsh, and salt pan. Salt pan has the lowest CAR of marsh habitats due to its lack of vegetation and little tidal inundation. Low marsh habitat has the highest CAR in both the existing and restored habitats because of its high SAR resulting from greater vegetation cover and tidal inundation. While SOC densities decrease with lower elevation habitat, carbon accumulation rates increase with lower elevation. The higher CAR in lower elevation marsh is due to the higher SARs estimated for the lower elevation habitats.

The high SAR and low SOC density values of lower elevation habitats might appear to indicate that their high CAR is due primarily to soil accretion by mineral sedimentation as suggested by some researchers (Chmura et al. 2003, Callaway et al. 2012, Patrick & DeLaune 1990; Craft, 2007; Wallace et al., 2005). However, the high SAR values of lower elevation habitats may be due to both higher mineral sedimentation and organic matter accumulation. Although SOC density is smaller at lower elevations, this does not necessarily mean there is less organic matter accumulation in the soil. In fact, in the low marsh the percent of organic matter is highest (7.7%) and decreased in mid-marsh and high marsh habitats (both 6.5%). This higher proportion of organic matter in lower elevations could be from deposits of allochthonous matter brought in with tidal inundation; however, some researchers believe that increased tidal flow actually removes organic matter deposited on soils (Craft et al., 1993; Craft, 2000).

Alternatively, the higher amount of organic matter in low marsh habitat is likely due to a higher level of vegetation production. Low marsh habitat of the existing Ballona Wetlands has the highest average cover of native plants (92.5 ± 2.6%), followed by mid-marsh (77.7 ± 8.2%) and high marsh (65.1 ± 8.8%) where the remaining cover consists of non-native species and bare ground. In addition, low marsh has the highest percent cover of the dominant and highly productive salt marsh plant, *S. pacifica* (63.8% vs 39.2% and 29.6%, for low, mid-, and high marsh) (Johnston et al., 2012). These factors suggest a higher biomass productivity, and potentially more organic matter accumulation, in the lower elevation habitats. Thus, the higher CARs in lower elevation vegetated habitats is likely driven by higher soil accretion from both sedimentation and organic matter accumulation from vegetative growth.

The existing mudflat habitat has a relatively high CAR of 52 g C/m^2*yr yet has the lowest organic matter content (3.7%) suggesting that CAR in this habitat is driven by its high SAR due to sedimentation. Salt pan habitat has a low CAR of 9 g C/m^2*yr and also has a low organic matter content of 5%. Like mudflats, salt pan habitat is unvegetated with a low CAR driven by sedimentation, but typically receives only minor tidal inundation at the highest tides.

4.3.3.2 Non-Tidal Habitats

Non-tidal habitats of the Ballona Wetlands include existing mid-marsh and high marsh, brackish marsh, seasonal wetland, transition zone, and uplands. Although brackish marsh typically receives some tidal influence along with freshwater flow it is unclear how much, if any, tidal inundation the brackish marsh of the proposed restored Ballona Wetlands will receive. Therefore, this study considers brackish marsh in the Ballona Wetlands to be non-tidal.

Existing non-tidal habitats occur in each of Areas A, B, and C. The proposed restoration alternative (ESA PWA, 2012) shows transition zone and seasonal wetland will occur primarily in Areas A and C. Upland habitat will be created in the restored Area B from fill material excavated from Area A (Figure 4-2). Because of the similarity in habitat elevation, soil origin, soil characteristics, and a lack of tidal inundation, carbon accumulation is anticipated to be equal in upland habitat, transition zone, and seasonal wetland Areas A and C (seasonal wetland Area B is discussed below). Each habitat type is discussed below.

Upland Habitat

Upland habitat in the existing Ballona Wetlands consists almost entirely of grassland and scrubland. Studies of carbon accumulation in grasslands and scrublands are limited. A few studies report carbon accumulation in grasslands decades after the reestablishment of grassland following prolonged land disturbance (Post & Kwan, 2000; IPCC, 2000; Conant et al., 2001; Potter et al., 1999). These studies' CAR values ranged from 27 – 304 g C/m^2*yr with an approximate average of 44 g C/m^2*yr. One study by Hungate et al. (1996) reported a high CAR value in naturally occurring annual grassland in central coastal California at 266 and 303 g C/m^2*yr. Schlesinger (1990) on the other hand, reported an average long-term CAR of 2.2 g C/m^2*yr in temperate grassland soils over a period of 9,000 years.

Studies reporting carbon accumulation rates in scrub habitats are even fewer. Luo et al. (2007) reported an average CAR in southern California chaparral of 117 g C/m^2*yr with a range of 96 – 155 g C/m^2*yr and Hastings et al. (2005) reported CARs of 39 and 52 g C/m^2*yr at two desert scrub study sites in Baja, Mexico. The Luo et al. (2007) average CAR of 117 g C/m^2*yr may be higher than expected for the coastal scrub habitat found at Ballona. Chaparral communities have been found to have higher aboveground biomass (~200%) and higher net primary productivity (~300%) than coastal scrub communities (Gray, 1982). Based on these indicators, if coastal scrub is assumed to accumulate ⅓ to ½ of the carbon as the chaparral in the Luo et al. (2007) study, the resulting average CAR would be approximately 39 – 59 g C/m^2*yr, similar to the average CAR of 44 g C/m^2*yr reported for grasslands and for the scrubland in Hastings et al. (2005). In addition, coastal scrub has been found to have similar soil carbon density and net primary production as grasslands (Silver et al., 2010; Jobbagy & Jackson, 2000; Gray & Schlesinger, 1981; Gray, 1982; Sims & Singh, 1978). The CAR values of 39 and 52 g C/m^2*yr reported by Hastings et al. (2005), although in a region further south of Ballona, are similar to the range of CARs reported for grasslands.

Unlike the scrub studies of Luo et al. (2007) and Hastings et al. (2005), the scrub habitat at Ballona includes 50% non-native species and is therefore potentially not comparable to these studies. Because upland habitat in the existing Ballona Wetlands is highly disturbed and data for carbon accumulation in upland habitats is very limited, especially for California habitats, carbon accumulation for upland habitat at Ballona is estimated from among the lower end of the values in the upland habitat studies discussed above. The lowest value, a CAR rate of 27 g C/m^2*yr presented by Post & Kwan (2000) is the average for temperate grasslands throughout the U.S. that have been established for between 5 to 80 years following an extended period of disturbance. Similarly, upland habitats at Ballona have likely been established since the completion of the Ballona Channel in the 1930s. The value of 27 g C/m^2*yr is an average of several studies compiled by Post & Kwan (2000) and is skewed high by a single data point of 110 g C/m^2*yr, where the remaining values range from 3.1 to 34.2 g C/m^2*yr. If the high data point is removed from the data set, the average CAR is approximately 16 g C/m^2*yr . Therefore, the CAR of 16 g C/m^2*yr is applied to upland habitat for both the existing and restored Ballona Wetland conditions.

Because of the similarity in elevation and habitat, carbon accumulation in transition zone and in seasonal wetland in Areas A and C is anticipated to be the same value as upland habitat at 16 g C/m^2*yr.

Existing Mid-Marsh, High Marsh, and Seasonal Wetland Area B

Multiplying the accretion rate of 0.18 cm/yr determined for organic matter accumulation by the SOC densities measured in the existing mid-marsh, high marsh, and seasonal wetland Area B habitats results in CARs of 40 g C/m^2*yr, 43 g C/m^2*yr, and 61 g C/m^2*yr, respectively. Though, these CARs may overestimate the amount of organic matter accumulation because these habitats are not inundated in the existing wetland and therefore do not receive allochthonous organic matter in tidal water and organic matter oxidation may be higher than in saturated soils. However, unlike the soils of upland habitat and seasonal wetland Area A, the soils of mid-marsh, high marsh, and seasonal wetland Area B consist of historical marsh soils (higher in organic matter, clay and water content) and are dominated by highly productive salt marsh vegetation. Therefore, their CARs may be higher than for upland habitats. Due to the uncertainty of actual carbon accumulation, CARs for these existing habitats are estimated as the average of the rates shown above and the upland CAR of 16 g C/m^2*yr. This results in average CAR values of 28 g

C/m^2*yr, 30 g C/m^2*yr, and 39 g C/m^2*yr for mid-marsh, high marsh, and seasonal wetland Area B, respectively (Table 4-5).

Brackish Marsh

Few studies have reported carbon accumulation in brackish marshes (Smith et al., 1983; Craft, 2007; Loomis & Craft, 2010; Callaway et al., 2012; Craft et al., (2002). These studies reported CARs from brackish marshes ranging from 59 g C/m^2*yr in an upland brackish marsh in North Carolina (Craft et al., 2002) to a high of 296 g C/m^2*yr in brackish Louisiana marshes (Smith et al., 1983). Callaway et al. (2012) reported CARs of 105 and 156 from brackish marshes in the upper San Francisco Bay and was the only study reviewed from California marshes. All of these studies represented brackish marshes that received some combination of both tidal and freshwater flows. The brackish marsh of the existing Ballona Wetlands receives no tidal flow and limited freshwater storm runoff. Brackish marsh of the restored Ballona Wetlands may or may not receive tidal inundation and an unknown amount of freshwater runoff from the adjacent Freshwater Marsh. However, the brackish marsh in the restored wetland will be created within the area of the existing seasonal wetland Area B, which consists of soils similar in characteristics to existing marsh habitat at Ballona, and will likely be subject to some wetting. Therefore, CAR in the brackish marsh might be expected to be greater than the CAR for upland habitats but is unlikely to reach levels of carbon accumulation found in the existing studies where brackish marsh is exposed to both tidal and freshwater influence. The CAR of 59 g C/m^2*yr reported by Craft et al. (2002) may be most similar to Ballona brackish marsh because it was from a high elevation brackish marsh that was infrequently inundated by tides. If the CAR for Ballona brackish marsh is assumed to be an average of 59 g C/m^2*yr and the upland habitat CAR of 16 g C/m^2*yr, this results in a CAR of 38 g C/m^2*yr. If instead the organic matter accretion rate of 0.18 cm/yr and the mid-marsh SOC of 0.022 g/cm^3 are used to calculate CAR for brackish marsh, the result would be very similar at 40 g C/m^2*yr.

Two other habitat types are represented in both the existing and restored Ballona conditions: subtidal habitat and freshwater/riparian habitat. No data on SARs or SOC densities were identified for these habitats in the literature review. These habitats have similar areas in both the existing and restored Ballona conditions; 40 vs 43 acres of subtidal and 26 vs 26 acres of freshwater/riparian in the existing and restored conditions, respectively. No CAR values are calculated for these habitats in this study and any differences in contribution from these habitats to net carbon accumulation and sequestration is considered negligible.

The total annual carbon accumulation in each habitat type is determined in Section 4.3.4 using the CARs determined for each habitat type.

Table 4-5 – Estimated CARs for Ballona Habitats (based on SOC densities of 20 to 40 cm)

Habitat Type	Ave CAR (g C/m^2*yr) (Range)	
	Existing	Restored
Mudflat	52	104 (52 – 221)
Low Marsh	80	160 (80 – 380)
Mid-marsh	28	110 (66 – 198)
High Marsh	30	72 (43 – 120)
Salt Pan	9	26 (9 – 44)
Seasonal Area A	16	NA
Seasonal Area B	39	NA
Seasonal Area C	16	16
Brackish	38	38
Transition Zone	NA	16
Upland	16	16

4.3.3.3 Comparison with Existing Study Carbon Accumulation Rates

A review of existing literature for carbon accumulation rates of tidal marsh habitat was conducted and is presented in Table 4-6 for comparison to the CARs estimated for Ballona habitats in this study. Two studies are summaries of existing data (Chmura et al., 2003; Ouyang & Lee, 2014) while the majority of the studies reviewed present original data from various regions of the world, with a focus on the U.S. Atlantic and west coasts. Many studies presented average CARs from unknown marsh habitat elevation, while some of the studies presented CARs by marsh habitat type (low, mid-, high marsh). Only two of the studies presented data for mudflat habitat, five for brackish marsh, and no studies that were reviewed reported CAR for salt pan, seasonal wetland, or transition zone habitat. Seven studies reported CARs for upland grassland and scrubland habitats.

Overall, the evaluation of CAR data from existing studies supports the rates estimated in this study for the Ballona Wetlands habitats. Although the CAR values estimated for Ballona are lower than estimated global averages of 210 g C/m^2*yr (Chmura et al., 2003) and 245 g C/m^2*yr (Ouyang & Lee, 2014), the value of 174 g C/m^2*yr reported by Ouyang & Lee (2014) for the NE Pacific (U.S. west coast) is similar to the restored low marsh estimate of 160 g C/m^2*yr for Ballona. In addition, the Craft (2007) CAR value of 75 g C/m^2*yr for west coast tidal marsh habitat is comparable to the estimated rate of 72 g C/m^2*yr for high marsh habitat of the restored Ballona Wetlands. The CAR values of both the existing and restored Ballona habitats are very similar to many of the other marsh studies summarized in Table 4-6. Although Choi & Wang (2004) studied marshes in Florida, Craft et al. (1993 & 2002) in North Carolina, and Callaway et al. (2012 & 2012b) in San Francisco Bay, the low, mid-, and high marsh values from their studies are comparable to the values for the Ballona habitats estimated in this study. Similar to the values estimated for Ballona, the CARs in existing studies generally decrease from low to high marsh habitat.

Two studies of southern California tidal marshes nearby and similar to the Ballona Wetlands (Elgin, 2012; Keller et al., 2012) also provided data similar to Ballona. Keller et al. (2012) did not present CAR values because SAR was not measured in their study. Keller et al. reported that soil cores were collected from mid/high marsh habitat in southern California. If the high marsh SAR of 0.3 cm/yr estimated for the restored Ballona Wetlands is applied to the Keller et al. SOC density data, the resulting CARs for their two study sites are 69 and 102 g C/m^2*yr, similar to Elgin and Ballona. Elgin used a higher SAR of 0.6 cm/yr calculated from average rates of Chan et al. (2010) from southern California marsh habitat and resulted in slightly higher CAR values than Keller et al.

Only two of the existing studies reviewed reported CAR for mudflat habitat. Adams et al. (2012) reported an average CAR for mudflats in the U.K. of approximately 84 g C/m^2*yr and Yuknis (2012) reported an average CAR of 218 g C/m^2*yr from a mudflat study site in China. The average CAR of 104 g C/m^2*yr estimated for restored mudflat in Ballona falls between these two existing study values but is closer to the lower value of the U.K. marsh. The CAR estimated for upland habitat in this study (16 g C/m^2*yr) falls between the range of long-term rate values from Schlesinger (1990) and studies reporting rates of grassland and scrubland habitats (Post & Kwan, 2000; IPCC, 2000; Conant et al., 2001; Potter et al., 1999; Hungate et al., 1996; Luo et al., 2007; Hastings et al., 2005).

The carbon sequestration rates determined for Ballona and presented in existing soil studies closely correspond to carbon sequestration rates presented in a meta-analysis of eddy covariance data (Lu et al., 2017). Estimating carbon sequestration by measuring CO_2 fluxes in various studies showed annual sequestration for coastal wetlands of approximately 208 g C/m^2*yr, similar to rates determined by soil sampling.

Table 4-6 – CARs from Existing Studies

Carbon Accumulation Rates by Habitat Type as Best Determined from Existing Literature

Reference	Carbon Accumulation Rate (g C/m^2*yr)				Region or Ecosystem
	Low	Mid	High	Mean or Range[1]	
Chmura et al. 2003				210	Global Average (arithmetic mean)
Ouyang & Lee, 2014				245 global (174 NE Pacific)	Global Average (area-weighted mean)
Smith et al. 1983	183			183	Gulf Coast (LA)
Choi & Wang 2004[3]	117 25	101 22	65 20	94 (short-term) 22 (long-term)	NW Florida

Reference	Carbon Accumulation Rate (g C/m^2*yr)				Region or Ecosystem
	Low	Mid	High	Mean or Range[1]	
Connor et al. 2001	58		191	124	Bay of Fundy, Canada
Craft et al. 1993	40		126	83	North Carolina
Craft et al. 2002	142	113	59	105	North Carolina
Craft et al. 1999				99-125 (Constructed) 115-159 (Natural)	North Carolina
Craft 2000	90 – 140			115 (Created)	North Carolina
Craft et al. 2003				42 (Constructed) 43 (Natural)	North Carolina
Craft 2007				170 70 310 200 75	NE Atlantic Coast SE Atlantic Coast Gulf Coast (LA) Gulf Coast (TX) West Coast
Loomis & Craft 2010	40			40	Georgia
Crooks et al. 2014				90-352	Puget Sound, WA
Patrick & DeLaune 1990	54 & 385			220	No Cal – SF Bay
Callaway et al. 2012	120	86	93	72-144	No Cal – SF Bay
Callaway et al. 2012b	126	123	98	89-107	No Cal – SF Bay
Callaway & Drexler (unpublished)				180-200	No Cal – SF Bay
Cahoon et al. 1996				343	Tijuana Estuary
Cahoon unpublished (see Chmura et al. 2003)				43	Tijuana Estuary
Keller et al. 2012			69 & 102[4]	86[4]	Huntington Beach
Elgin 2012				132 & 103[2]	Mugu Lagoon, Tijuana, Carpinteria
Brevik & Homburg 2004				39	Ballona
Adams et al. 2012				84	Mudflats in UK
Yuknis 2012				218	Mudflats in China
Schlesinger 1990				0.2 – 12 (long-term)	Various Upland Habitat

Reference	Carbon Accumulation Rate (g C/m^2*yr)				Region or Ecosystem
	Low	Mid	High	Mean or Range[1]	
Post & Kwan 2000				27	Grasslands
IPCC 2000				30-80 (ave 50)	Grasslands
Conant et al. 2001				11-304 (ave 54)	Grasslands
Potter et al. 1999				45	Grasslands
Hungate et al. 1996				266 & 303	Grasslands
Luo et al. 2007				96-155 (ave 117)	Scrublands
Hastings et al. 2005				39 & 52	Scrublands
Lu et al. 2017				208	CO_2 flux meta-analysis
This Study (Existing & Restored)	**80 & 160**	**28 & 110**	**30 & 72**	**46 & 114**	**Ballona Estimates**

1: Natural, Constructed, and Restored refer to the study sites sampled.
2: Second data point corresponds to the 20-30 cm soil depth layer in Elgin 2012.
3: Top numbers short-term rate (1985-1997), bottom numbers long-term rate (400-600 yrs).
4: CAR values calculated using high marsh SAR of 0.3 cm/yr from this study.

4.3.4 Net Change in Soil Carbon Sequestration in the Restored Ballona Wetlands

The net change in soil carbon sequestration between the existing and restored Ballona Wetlands, using the more conservative SOC densities in the 20 to 40 cm soil depth, is calculated in Table 4-7. The estimated CARs are multiplied by the area of each habitat type for both the existing and restored wetland and converted to carbon dioxide equivalents (CO_2e) using the ratio of molecular weights for CO_2 and C (44/12). These calculations result in an estimated annual mass of carbon dioxide equivalents (metric ton CO_2e/yr) sequestered in each habitat type for each wetland condition (existing vs. restored). The estimated CO_2e sequestered in the existing wetland is subtracted from the estimated CO_2e sequestered in the restored wetland to give the net difference in soil carbon sequestration attributable to the restoration: $CO_2e_{(net)}/yr = CO_2e_{(rest)}/yr$ -

$CO_2e_{(exist)}$/yr. Table 4-7 presents these calculations for the existing habitats and for the average, low range, and high range values of the restored habitats.

The overall area of the Ballona Project does not change from the existing condition and both comprise 665 acres of land. The planned restored wetland will contain 12 acres more total habitat compared to the existing condition, but will contain 72 acres more estuarine habitats than the existing wetland (306 vs 234). The restoration project will transition 112 acres of existing upland habitat and 85 acres of seasonal wetland habitat to other types of marsh habitat. Areas of salt pan, subtidal, and freshwater/riparian habitats will not change substantially. The area of tidally inundated habitat in the existing condition is confined to mudflat and low marsh habitat and totals no more than 24 acres. The restored wetland by contrast will have approximately 226 acres of tidally inundated habitat including low, mid-, high marsh, and mudflat; an increase of over 800%.

Total annual sequestration calculated for the existing wetland is approximately 165 metric tons CO_2e per year. This represents the estimated amount of carbon the wetland would continue to sequester into the future without implementing the restoration project and with other conditions unchanged. The total average annual carbon sequestration in the restored wetland is estimated at approximately 452 metric tons CO_2e per year with a range of 276 – 845 metric tons CO_2e per year. The average restored sequestration rate is nearly three times the amount (272%) of the sequestration estimated annually in the existing wetland. To calculate the net sequestration due to the restoration, the existing sequestration amount is subtracted from the restored values in the last column of Table 4-7.

The net change in carbon sequestration calculations in Table 4-7 result in an increase in sequestered carbon of between approximately 110 and 680 metric tons CO_2e per year with an average of approximately 286 metric tons CO_2e per year. This means that more carbon is anticipated to be sequestered in the restored wetland, compared to the existing wetland, even at the lowest range of rates estimated for the restored Ballona habitats. The restored habitat types contributing the largest increase in soil carbon include mid-marsh, low marsh, and mudflats with smaller contributions from transition zone, high marsh, brackish marsh, and salt pan. The habitat types contributing the most to soil carbon increases did so not only because of higher sequestration rates but because the restored wetland is designed to increase the area of these habitats as well. The habitat types that sequester less total soil carbon in the restored wetland include seasonal wetland (-44.8 metric tons CO_2e/yr) and upland habitat (-26.6 metric tons CO_2e/yr) because both have substantially less area in the restored wetland. Only 4 acres of seasonal wetland remain in the restored condition compared to 86 acres in the existing wetland, and upland habitat decreased from 283 acres to 171 acres.

This analysis shows that restoration of a coastal wetland can increase the total amount of soil carbon sequestration, as estimated by the net change in carbon sequestration calculations demonstrated here. The results of this study provide a means for planners to estimate changes in soil carbon of a restored wetland prior to implementation of a project. From a purely carbon perspective, it is tempting to suggest that revising the proportions of habitat areas in the restored wetland could further increase the amount of carbon sequestration. For instance, further reducing the area of upland habitat, a very low CAR, with an intertidal marsh habitat with a high CAR could further increase the amount of annual carbon storage. Or increasing the amount of low marsh habitat (49 acres) and reducing the amount of mid-marsh (103 acres) to take advantage of low marsh's higher sequestration rate. However, other considerations must be taken into account such as habitat diversity, constraints in restoration design, and future habitat flooding due to sea level rise. Tidal marshes are particularly threatened by sea level rise as many lower elevation vegetated habitats are predicted to be submerged in the near future (Kirwan & Megonigal, 2013; Ganju et al., 2015). A study of tidal marshes along the northern and southern California coastlines determined that under low sea level rise scenarios, most study sites maintained their elevation. However, under mid and high sea level rise rates, marsh vertical growth did not keep pace and habitat shifted from high and mid-marsh to low marsh or mudflat and all vegetated habitat is lost at all sites by 2110 under a high sea level rise scenario (Thorne et al., 2016). Therefore, designing a wetland restoration project initially with a large area of low marsh habitat to increase carbon storage could lead to early submergence of the habitat following moderate sea level rise. Restoration planners could consider multiple options when presenting restoration alternatives by applying the methodology presented in this chapter to their own wetland restoration projects.

The calculations presented in this chapter assume immediate functional equivalency of carbon accumulation. In practice, the amount of carbon a restored wetland will sequester over time will depend on the subsequent structural and functional development of the restored marsh habitats. Previous studies have found that ecological attributes of constructed marshes exhibit three trajectories toward equivalency to natural marshes during development: 1) processes related to hydrology, such as sedimentation and soil carbon accumulation rates, developed equivalency to natural marshes almost instantaneously following construction; 2) attributes related to heterotrophic processes, vegetation biomass and primary production, benthic invertebrate density and diversity, and soil microbial processes reached equivalency within approximately 5 to 15 years following construction; and 3) development of wetland soils, SOC and nitrogen pools, do not achieve full equivalency within 3 to 4 decades after construction

(Craft et al., 2003; Craft, 2000; Zedler and Callaway, 1999; Zedler, 2000). Therefore, although organic carbon accumulation rates in restored marshes may immediately reflect the rates of natural marshes, a restored marsh may not reach carbon pool equivalency to natural marshes for many years to decades following restoration. However, the studies describing these marsh trajectories measured soil attributes in marshes that were restored primarily on dredge spoils, upland soils, and sandy fill material, whereas the marsh habitats of the Ballona Wetlands Restoration Project will be constructed largely within the existing historical wetland soils.

Table 4-7 – Net Change in Carbon Sequestration

Annual Carbon Sequestration Calculations and Net Change in Carbon Sequestration between Existing and Restored Conditions

Habitat Type	CAR ($g C/m^2*yr$)				Area (Acres)[1]		Annual Sequestration (metric ton CO_2e/yr)				Net Difference from Existing Condition (metric ton CO_2e/yr)		
Estuarine Habitats	Existing	Restored			Existing	Restored	Existing	Restored			Average	Low Range	High Range
Vegetated Marsh		Average	Low	High				Average	Low	High			
Low	80	160	80	380	9	49	10.7	116.4	58.2	276.5	**105.7**	**47.5**	**265.9**
Mid	28	110	66	198	18	103	7.5	168.3	101.0	302.9	**160.8**	**93.5**	**295.4**
High	30	72	43	120	41	34	18.3	36.4	21.7	60.6	**18.1**	**3.4**	**42.3**
Seasonal Area A	16	0	0	0	11	0	2.6	0.0	0.0	0.0	**-2.6**	**-2.6**	**-2.6**
Seasonal Area B	39	0	0	0	74	0	42.9	0.0	0.0	0.0	**-42.9**	**-42.9**	**-42.9**
Seasonal Area C	16	16	16	16	1	4	0.2	1.0	1.0	1.0	**0.7**	**0.7**	**0.7**
Brackish	38	38	38	38	3	13	1.7	7.3	7.3	7.3	**5.6**	**5.6**	**5.6**
Salt Pan	9	26	9	44	22	20	2.9	7.7	2.7	13.1	**4.8**	**-0.3**	**10.1**
Subtidal	NA	NA	NA	NA	40	43	NA	NA	NA	NA	NA	NA	NA
Mudflats	52	104	52	221	15	40	11.6	61.8	30.9	131.3	**50.2**	**19.3**	**119.7**
Estuarine Total					**234**	**306**	**98.4**	**398.9**	**222.7**	**792.7**	**300.5**	**124.4**	**694.3**
Other Habitats													
Transition Zone	0	16	16	16	0	51	0.0	12.1	12.1	12.1	**12.1**	**12.1**	**12.1**
Upland	16	16	16	16	283	171	67.2	40.6	40.6	40.6	**-26.6**	**-26.6**	**-26.6**
Freshwater/Riparian	NA	NA	NA	NA	26	26	NA	NA	NA	NA	NA	NA	NA
Other Total					**309**	**248**	**67.2**	**52.8**	**52.8**	**52.8**	**-14.5**	**-14.5**	**-14.5**
Habitat Total					**543**	**554**	**165**	**452**	**276**	**845**	**286**	**110**	**680**
Other: Freshwater Marsh, Gas Co. parcel, roads, parking lots, etc...					122	111							
TOTALS					**665**	**665**					**286**	**110**	**680**

1: Areas from ESA PWA, 2012.
NA: Not Applicable

4.4 CONCLUSIONS

Our planet will face formidable challenges due to climate change if greenhouse gas emissions are not mitigated. The potential role of natural ecosystems in climate change mitigation is becoming increasingly recognized throughout the scientific community (Crooks et al., 2011; Howard et al., 2017; Mcleod et al., 2011; Sifleet et al., 2011; PWA & SAIC, 2009; Pendleton et al., 2012). Although the increase in carbon sequestration due to the Ballona Project is substantial at 270% of the existing sequestration, it is not as clear what role the Ballona Project or similar restoration projects would play in climate change mitigation.

The amount of additional carbon sequestration estimated in this study for the Ballona Project is minor in light of the 6,870 million metric tons of carbon dioxide equivalents emitted in the U.S. for the year 2014 alone (EPA, 2016). At 8.89 x 10^{-3} metric tons of CO_2 per gallon of gasoline combustion and an average annual fuel use of 480 gallons for a typical car in the U.S. (Federal Highway Administration), the Ballona Project would only mitigate for the annual gasoline usage of between approximately 26 and 160 automobiles. However, the Ballona Project is a relatively small restoration project and it wasn’t originally designed with increasing carbon sequestration as an objective. Changes to habitat proportions in the restoration design could increase carbon sequestration in the wetland, at least in the short term. For instance, increasing the extent of marsh habitat with higher carbon accumulation rates, while decreasing the amount of upland habitat, would increase the amount of annual carbon sequestration. Though doing so could lead to earlier submergence of low marsh habitat by sea level rise and increase costs and emissions from hauling upland soil off-site for disposal. The goal of increasing carbon sequestration must be balanced with other equally important ecosystem goals. Restoring the wetland as proposed provides many other ecosystem benefits including habitat diversity, improved water quality, habitat for native and special-status species, nurseries for fisheries, and valuable open-space habitat for the community of an urban area.

The estimated carbon accumulation rates for the existing and restored Ballona habitats in this study could be further refined by additional on-site measurements and applying more tidal marsh data from other studies. Unlike carbon density, soil accretion rates were not measured for the existing Ballona habitats and there are limited studies reporting rates in other marshes. The average SAR values estimated for Ballona may not ultimately reflect the actual existing and future soil accretion because the Ballona Watershed is highly developed (>80%), perhaps resulting in lower sediment supply to the wetland from watershed erosion. Investigation of sediment supply in the Ballona Creek and within the existing wetland channels could improve these estimates. However, presenting the estimated SAR values as ranges for the restored habitats helps compensate for the uncertainties in actual rates of accumulation in the restored wetland.

Estimates of carbon accumulation in the existing Ballona Wetlands could be substantially improved by direct measurement of soil accretion in these habitats. Ideally, future investigation of the existing habitats would include measurement of soil accretion using surface elevation tables (SET) along with surface horizon markers such as feldspar. The combination of these techniques would also help quantify the contributions to surface elevation changes due to sedimentation, soil organic matter accumulation, and subsidence.

There are relatively few studies providing data on carbon accumulation dynamics in tidal marshes. Additional studies that measure parameters including soil accretion, carbon density, sediment supply, and biomass production in tidal marshes would help to fill information gaps and provide additional data points to refine the estimates for habitats in this and other studies.

As more studies provide data for these parameters in tidal marshes throughout a variety of regions, project proponents will be better able to estimate ranges of values for these parameters in their own tidal marsh projects when sampling and measurement is not feasible for them.

As additional data becomes available, the estimations made in this chapter for Ballona habitats could perhaps be revised prior to restoration construction. Following the restoration of the Ballona Wetlands, direct measurement of soil accretion and long-term changes in SOC density in the restored habitats over time will determine if the wetland habitats are accumulating and storing the amount of organic carbon estimated in this study.

Even small tidal marsh restoration projects like Ballona could potentially generate financial compensation in existing carbon markets depending on carbon market price and any monitoring costs. A removal of one metric ton of CO_2e from the atmosphere will generate one carbon credit in a carbon trading market. The price of a carbon credit in the California market in early 2017 was approximately $13.50 and had been trading between approximately $12 and $13 for the previous two years. Based solely on the estimates in this study, at the price of $13.50 per credit the Ballona Project could theoretically generate approximately $3,861 per year from the estimated average net sequestration of 286 mt CO_2e/year, without any other factors considered. Notably, the United States Environmental Protection Agency (EPA) released an updated report in 2015 that estimates the real cost of carbon to society at $42 per metric ton of CO_2e in the year 2020 and increasing to $69 per metric ton of CO_2e by the year 2050 (EPA, 2015). At 286 mt CO_2e/year, this would result in annual funding from carbon credit generation at Ballona of $12,012 and $19,734 in the years 2020 and 2050, respectively. However, emissions due to construction activities, including fossil fuel use and oxidation of exposed organic soils, can be substantial for a marsh restoration project and it could take years to decades for the restored habitat to compensate for those emissions. Carbon market accounting protocols would need to be consulted to estimate potential net emission reductions and carbon credit generation. The next chapter of this study investigates the Ballona Project in a carbon market protocol.

Because of their high rate of carbon accumulation and capacity for carbon storage, coastal blue carbon ecosystems offer important opportunities for climate mitigation activities such as conservation, restoration, and creation and some organizations are beginning to evaluate these benefits for their regions.

For example, an evaluation of the commercial potential of blue carbon restoration throughout all of coastal Louisiana identified approximately 1.4 million acres of coastal wetlands with potential for restoration or enhancement. Opportunities for coastal wetland restoration have the potential to produce over 1.8 million carbon credits per year, potentially generating millions of dollars each year to support wetland restoration projects (Mack et al., 2015). In another example along the west coast of the U.S., Crooks et al. (2014) evaluated several proposed restoration projects within the Snohomish Estuary of the Puget Sound and determined that approximately 4,749 hectares (11,730 acres) of converted and drained wetlands exist with 1,353 hectares (3,342 acres) currently in planning or construction. The additional carbon sequestration from all potential wetland restoration in the Snohomish Estuary is estimated to total 4.4 to 8.8 million metric tons of carbon dioxide equivalents after just 20 years.

Even local community-based projects have been initiated in order to determine the potential benefits and opportunities for climate change mitigation through blue carbon management. The Tampa Bay Blue Carbon Assessment studied the contributions and opportunities of coastal wetlands for carbon sequestration in Tampa Bay blue carbon ecosystems. The study found that by 2100 these ecosystems in Tampa Bay alone would remove about 74 million metric tons of CO_2, the equivalent of removing approximately 15.5 million vehicles from the roads (ESA, 2016). Similarly, the K'omoks and Squamish Estuaries Blue Carbon Pilot Project developed a community-based initiative for carbon assessment in estuaries along the Pacific coast of British Columbia. The purpose of the project was to measure the carbon sequestration rates of blue carbon ecosystems to assist in estimating the benefits of future conservation and restoration projects (Hodgson & Spooner, 2016). The data presented in this study for the Ballona Wetlands could similarly contribute to a regional-wide assessment of the current contributions and opportunities of blue carbon ecosystems in California.

By applying the methodology outlined in this study, the potential change in carbon accumulation of coastal wetlands can be estimated prior to investing time and money into restoration projects. The evaluation of carbon sequestration rates by habitat types also provides a basis for planners to incorporate the types and areas of habitats that would optimize carbon sequestration. While further study is necessary to refine the estimates of carbon accumulation in Ballona soils, this study demonstrates how restoring tidal marsh habitat could substantially increase carbon sequestration in these ecosystems. Although carbon sequestration is not a goal of the Ballona Wetlands Restoration Project, if desired, the results of this study could be considered to propose revisions to the restoration plan to further increase the amount of carbon sequestration. However, the emissions related to construction activities must be considered if carbon offset trading is a project goal. Global efforts to create, restore, and enhance these highly productive tidal marsh habitats on a large scale may collectively offer an additional approach to climate change mitigation. Questions remain whether societies are capable and motivated to invest the resources necessary to make a difference.

5 TIDAL MARSH RESTORATION IN THE CARBON MARKET

5.1 INTRODUCTION

Warming of the climate is unequivocal, reservoirs of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases (GHG) have increased (IPCC, 2013). The Intergovernmental Panel on Climate Change (IPCC) concluded in their Fifth Assessment Report that it is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century. However, the predicted rate and magnitude of warming and sea-level rise could be lessened by reducing or removing GHG emissions, and the earlier this occurs the smaller and slower the projected warming and sea level rise is likely to be.

Various strategies exist to mitigate the effects of increasing GHG emissions and include, among others, government regulation of fossil fuel emissions from industries and automobiles, increasing renewable energy, GHG emission offset programs, improving agricultural and forestry management, and promoting afforestation/reforestation and coastal habitat restoration. The carbon sequestered and stored in coastal habitats such as seagrass beds, mangroves, and tidal wetlands is referred to as “blue carbon” and is recognized as a potential driver of coastal conservation and restoration because of these habitats’ high carbon storage capacity (Crooks et al., 2011; Mcleod et al., 2011; Sifleet et al., 2011; Emmer et al., 2015).

One tool intended to limit the amount of GHG emissions is the carbon trading market, such as the California emissions trading program, also known as cap-and-trade. The California Air Resources Board (CARB) trading program, which began in 2012, sets a statewide limit on annual emissions of GHGs from a variety of sources. CARB then assigns a price to the allowable emissions and carbon emitters must acquire permits to cover the emissions they produce. Emitters can purchase carbon credits, also known as carbon offsets, to cover some of the emissions above what they are permitted to release. A carbon credit represents a reduction or removal of GHGs by an activity that can be measured, quantified, and verified. Each offset credit is equal to one metric ton of carbon dioxide equivalent (1 mt CO_2e). Many projects that reduce GHG emissions can apply to generate carbon credits and sell them to emitters through an offset program.

Due to the high carbon sequestration rates of tidal marsh habitat, tidal marsh restoration projects may be viable components of GHG offset programs. Voluntary carbon markets have only recently begun to include wetland restoration as offset projects and it remains unclear if carbon credits are easily calculable and verifiable and if restoration projects are a viable component in the carbon market (Emmett-Mattox et al., 2010). As of early 2017, CARB has not approved carbon offset credits from wetland restoration projects in its trading program; however, existing voluntary GHG offset programs have already developed methodologies for calculating and verifying carbon credits for such projects. It is anticipated that CARB will accept one or more of these methodologies in its program in coming years.

Existing GHG offset accounting programs include the American Carbon Registry (ACR), Climate Action Reserve (CAR), and Verified Carbon Standard (VCS). The ACR, CAR, and VCS have all been approved by CARB as Offset Project Registries, which allows them to issue Registry Offset Credits for California's cap-and-trade program. CARB has approved protocols for six offset project types for the compliance market: Forestry, Urban Forestry, Livestock Methane, Ozone Depleting Substances, Mine Methane Capture, and Rice Cultivation. CARB has not yet included any wetland restoration protocols for offset projects in the California market.

In late 2015, VCS approved a GHG accounting methodology for coastal wetland restoration projects to earn carbon offset credits in carbon markets. The methodology is the first to provide the procedures for how to calculate, report, and verify GHG reductions for tidal wetland restoration projects anywhere in the world. Project activities may include creating, restoring, and/or managing hydrological conditions, sediment supply, salinity characteristics, water quality, and/or native plant communities. Two assessment reports of the VCS methodology have been completed (Environmental Services, Inc., 2015; DNV GL, Inc., 2015) and both conclude that the methodology provides clear, appropriate and adequate procedures and parameters for calculating emissions. However, neither of these reports demonstrates the process with real case study data to determine if the process is straightforward and feasible for project proponents to effectively complete.

This chapter demonstrates the VCS GHG accounting methodology to calculate carbon credits using a California tidal marsh restoration project as a case study. The results illustrate the feasibility of the process and identify information gaps while addressing the question: *Can California tidal marsh restoration projects produce enough carbon credits to be viable components of a carbon market?* This question is answered by applying data specific to the proposed Ballona Wetlands Restoration Project (Ballona Project) as a case study.

The Ballona Wetlands is a tidal marsh system located along the coast of Los Angeles County, near the community of Playa del Rey and north of the Los Angeles International Airport (Figure 5-1). Wetlands at the site have been degraded and reduced to approximately 67 acres of subtidal and muted intertidal salt marsh and mudflat, with the remaining area largely converted to seasonal wetland or upland habitats (Johnston et al., 2012). In 2004, the State of California took title to over 600 acres of the remaining Ballona Wetlands. State agencies are working with stakeholders, scientists, and other agencies to develop a plan to restore the Ballona Wetlands for future generations. Planning phases for the proposed alternative of the Ballona Project are currently underway with an unspecified project start date.

Information applied to the VCS methodology includes Ballona soil data presented in the previous chapters of this study as well as available information relating to the Ballona Project. This case study is not intended to represent a comprehensive evaluation of the entire VCS program or all components of the methodology process. Rather, it is an initial feasibility evaluation of a tidal marsh restoration project to determine if the project could benefit in a carbon market prior to registering with an offset program. This evaluation of the Ballona Project case study provides an estimate of carbon credits potentially produced from tidal marsh restoration projects and provides insight into any challenges or issues associated with the methodology process.

Figure 5-1 – Ballona Wetlands Location and Areas A, B, and C

5.2 METHODS

This section outlines the methods used in this study to estimate net emission reductions/removals and the potential carbon credits associated with the Ballona Project case study by applying data and information to the *VCS Methodology for Tidal Wetland and Seagrass Restoration VM0033* (2015, V 1.0) (Methodology).

The purpose of this study is not to demonstrate the entire VCS process from project registration through project monitoring, but to present the requirements for a project to qualify for participation, demonstrate the carbon credit calculations, and discuss the general feasibility of the overall process. Therefore, various mapping and other supporting documentation required by the VCS Program for project registration will not be produced by this study but will be referred to as appropriate.

VCS provides documents to assist project proponents with the project registration process including: VCS Program Guide, VCS Standard, VCS AFOLU Requirements, VCS Registration and Issuance Process, and report templates for a Project Description and a Monitoring Report. A project must be registered with the VCS within five years after the project start date. Before the project can be registered and begin generating carbon credits, the project must be validated and initial monitoring results verified by a VCS-accredited verification/validation body. Validation occurs to confirm that all project requirements are met and that the project is expected to result in net emission reductions. Verification is an audit of all emission measurements and carbon credit calculations performed for each field monitoring event. VCS estimates that the process of registration, validation, and initial verification can take as long as two years and should therefore be started within 3 to 4 years of the project start date. Validation and verification are discussed further in a following section.

The main steps of the Methodology include determining applicability, setting the project boundary, determining the baseline scenario, determining additionality and permanence, quantifying GHG emissions and reductions, calculating carbon credits, and monitoring. Details of each of these Methodology steps are summarized below.

5.2.1 Applicability Conditions

The Methodology applies to tidal wetland restoration activities intended to reestablish ecological conditions that are not expected to occur in the absence of the project. Certain initial project conditions must be met in order to use the Methodology to estimate net GHG emission reductions and removals for a project. These conditions include general rules on what types of projects are eligible, conditions designed to exclude leakage (defined below), and conditions for other situations for which the Methodology does not provide procedures (Emmer et al., 2015).

The Methodology incorporates a broad definition of restoration and includes a wide variety of eligible restoration activities. First, projects must fit the definition of tidal wetlands or seagrass meadows. The Methodology defines tidal wetlands as a subset of wetlands under the wetting and drying cycles of the tides. Sub-tidal seagrass meadows are not subject to drying cycles, but are still included in the definition. Activities generally include any projects that create, restore, or manage hydrological conditions, alter sediment supply, change salinity, improve water quality, improve native plant communities, and/or improve management practices. The project proponent must demonstrate that the land is degraded and would remain degraded in the absence of the project activity. This may require documented evidence and/or studies that demonstrate the area is degraded or is degrading.

GHG leakage occurs when project activities cause additional GHG emissions or relocate emissions to areas outside of the project boundaries. Applicability conditions are incorporated to restrict projects that cause leakage. These include restrictions on current and past land use, hydrologic connectivity with adjacent areas that leads to an increase in emissions outside the project, and the degradation of other wetlands to replace agricultural sites. In other words, the project area must be free of any land use such as commercial forestry or agriculture that could be displaced outside the project area or must have been abandoned for two or more years prior to the project start date.

Other applicability conditions exclude activities for which the Methodology does not provide procedures to estimate the associated emissions. These conditions are: 1) burning of organic soils is not allowed, 2) application of nitrogen fertilizers may not occur, and 3) projects that lower the water table without maintaining or improving wetland conditions are not allowed. If a project meets all of the applicability conditions, project proponents may proceed with the Methodology.

5.2.2 Project Boundaries

Various project boundaries must be clearly defined and/or mapped and include temporal, geographic, carbon pools, and greenhouse gases.

Temporal boundaries refer to the crediting period of the project, the longevity of the project, and the peat or soil organic matter depletion time (PDT or SDT). The crediting period is 30 years based on VCS non-permanence risk rules set out in the VCS Standard (VCS Non-Permanence Risk Tool). A project proponent therefore needs to show that the longevity of their project will be maintained for a minimum of 30 years. The crediting period can be renewed up to four times, but the total crediting period may not exceed 100 years. The VCS has developed a Non-Permanence Risk Tool (discussed in a following section) to assess the risk of a potential loss in carbon stock in the project over a period of 100 years. According to the Non-Permanence

Risk Tool, for projects with lifetimes of less than 30 years the risk is deemed too high to warrant project registration at all.

Depletion times, SDT for soil organic matter depletion in mineral soils and PDT for peat depletion in organic soils, can be estimated for projects that claim reductions in baseline GHG soil emissions through the prevention of oxidation of organic material such as rewetting of soils (i.e., avoided losses). SDT is the time it would have taken for all soil organic carbon to oxidize to CO_2 or to reach a point where no further losses occur. PDT is the time it would have taken for the peat in a soil to be completely lost due to oxidation or to reach a depth where no further losses occur. Project proponents must decide whether to account for these emission reductions or to conservatively assume that emissions are zero in the baseline condition. SDT is conservatively set to zero for project sites drained more than 20 years prior to the project start date. Soils drained for more than 20 years are considered by the Methodology to have lost all the organic matter that is likely to be lost. The Methodology provides equations and instructions for calculating these values if the project plans to include avoided losses of organic matter in the baseline condition.

Geographic boundaries must be clearly defined by the project proponent at the beginning of the project. Information required to define this boundary may include: name of the project area, unique identifier for each parcel of land, maps of the project area, geographical coordinates of the project area, and proof of land rights. In addition, project proponents may define any explicit strata within the project boundaries as well as changes in project area over time due to sea level rise. The purpose of stratification of the project area is to achieve optimal accuracy of net GHG emission reductions and removals and the Methodology discusses the general requirements to define strata. Areas of strata must sum the total project area and must be identified with spatial data, such as maps or GIS imagery that are ground-truthed and less than 10 years old, unless it can be demonstrated that the maps are still accurate.

Strata may be defined based on similarities such as soil type and depth, water table depth, vegetation composition, salinity, land type, or expected changes in these characteristics over the life of the project. For example, tidal salt marshes could be subdivided into strata based on the various habitat types when all stratum areas are known. Strata are determined by the project proponent and verified by an accredited validation/verification body. The baseline scenario, including stratification, must be reevaluated every 10 years during the crediting period. Stratification in the project scenario must be reviewed at each monitoring event prior to verification and revised if necessary.

The carbon pool boundaries in the Methodology include soil organic carbon, biomass (above and below ground), and tree harvesting for the production of wood products. For tidal marshes, the only major carbon pools are typically soil organic carbon and biomass. Biomass includes above and below ground vegetative matter for trees, non-tree vegetation (shrubs), and herbaceous vegetation (herbs).

Greenhouse gases relevant to the Methodology include CO_2, CH_4, and N_2O. CO_2 must be estimated for both the baseline scenario and the project scenario. For the baseline scenario, the Methodology allows for CH_4 and N_2O to be conservatively set to zero rather than measuring the gases or using default values to estimate these emissions. This means that if emissions in the baseline scenario are not accounted for, credit for reducing them in the project scenario cannot be claimed, thereby reducing the amount of carbon offsets generated. For many projects, emissions of these gases will be lower in the project scenario compared to the baseline due to enhanced tidal exchange anticipated from restoration activities. However, CH_4 must be estimated in the project scenario and N_2O must be accounted for in project scenario strata where the water level is lowered by project activities. Various approaches may be used to quantify these three GHG emissions and are provided in detail in the Methodology.

5.2.3 Baseline Scenario

The baseline scenario of a tidal marsh restoration project must be identified that represents the most likely course of action and development of the existing wetland over time, in the absence of the project. The baseline scenario must consist of a degraded tidal marsh that is not expected to re-establish wetland ecological conditions in the absence of the project.

The Methodology uses the Clean Development Mechanism (CDM) *Combined tool to identify the baseline scenario and demonstrate additionality for A/R project activities* (CDM Combined Tool), developed by the United Nations Framework Convention on Climate Change (UNFCCC), to compare continuations of pre-project land uses in various alternative scenarios. The CDM Combined Tool provides a general framework and step-wise approach to simultaneously determine additionality (discussed in the following section) and identify the most plausible baseline scenario. Since the CDM Combined Tool is specific to afforestation and reforestation (A/R) projects, the Methodology provides changes to some definitions, phrases, and words to incorporate tidal marsh projects into the tool. The CDM Combined Tool is used to identify and select a baseline scenario by application of five steps:

- Step 0 – Preliminary screening based on the start date of the project
- Step 1 – Identification of alternative scenarios
- Step 2 – Barrier analysis
- Step 3 – Investment analysis
- Step 4 – Common practice analysis

The application of these steps is discussed in detail in the Results section.

The project proponent must, for the duration of the project, reassess the baseline scenario every 10 years to account for predicted changes in land use and land management practices, hydrologic changes due to existing constraints, expected vegetation succession patterns, and climate variables such as sea level rise. Baseline scenarios must be changed to reflect any impacts to marsh habitat from these factors.

5.2.4 Additionality

Determining additionality refers to demonstrating that a project produces GHG emission reductions beyond those that would have occurred otherwise, under business-as-usual practices (Emmett-Mattox et al., 2010). As long as the applicability conditions discussed above are met, all new tidal wetland restoration in the U.S. that is not otherwise required by law, regulation, statutes, legal rulings, or other regulatory frameworks is considered automatically additional by the VCS. The rationale for automatic additionality is that the need for restoration in the U.S. is so much greater than the nation's ability to fund it, and it is occurring at very low levels compared to restoration goals, that the addition of carbon finance to the funding mix may catalyze new restoration and improve the quantity and quality of restoration (Emmer et al., 2015). For tidal marsh restoration projects outside the United States, proponents must use the CDM Combined Tool to determine if the project is additional as well as to select a baseline scenario.

5.2.5 Quantification of GHG Emission Reductions and Removals

Projects must account for emissions of the greenhouse gases CO_2, CH_4, and N_2O. Emissions may be negative (removal of GHG from the atmosphere) or positive (release of GHG to the atmosphere). A project needs to have net negative emissions (a positive emission reduction) in order to produce carbon credits. This is achieved by having lower total emissions in the project scenario compared to the baseline scenario. There are two major ways a tidal marsh restoration project can result in net negative emissions: 1) avoid or reduce the release of GHG from that of the baseline scenario (e.g., decreasing oxidation of soil organic carbon by returning saturated soil conditions); and 2) increase the uptake of CO_2 in the project scenario by increasing carbon storage in the soil and biomass carbon pools. GHG emissions and removals are quantified in carbon accounting methodologies as carbon dioxide equivalents (CO_2e) based on the global warming potential (GWP) of each gas as compared to CO_2. Changes in organic carbon storage in biomass and soil are converted from mass of carbon to mass of carbon dioxide using the ratio of molecular weights of 44/12 (CO_2/C). The Methodology provides detailed procedures for estimating GHG emissions and removals from biomass, soil, and fossil fuel-use for both the baseline and project scenarios.

To determine whether net emission reductions will be positive for a restoration project, and therefore be eligible to generate carbon credits, emissions must be estimated ex-ante at the beginning of the project for both the baseline and project scenarios. In order to project the future GHG emissions in baseline and project scenarios, the project proponent must apply the VCS module *VMD0019 Methods to Project Future Conditions* for each stratum over the crediting period. The module provides a stepwise approach to assist the project proponent with estimating future values of a wide range of variables that affect GHG pools and emissions. The module is relevant to multiple VCS projects such as cattle grazing and agricultural operations and is not specific only to tidal wetland restoration. For tidal marsh restoration projects similar to Ballona, where no additional land uses occur within the project boundaries, the variables to be projected in the module include changes in soil and biomass carbon pools as well as any fossil fuel use.

The stepwise approach of the module essentially involves defining the parameters of each variable in each scenario (baseline & project), completing an analysis of historical trends of that variable in the project region, defining drivers and constraints influencing the variable, and projecting future values. Historical trends for variables can include site specific data obtained prior to degradation of the marsh or data from reference sites. Reference sites should represent similar habitat and functions as that of the future condition of the project site. The projected values are then used in the calculation of future GHG emissions and reductions in equations provided by the Methodology. For this case study, projected values for changes in carbon pools and fossil fuel use are determined from site-specific data, default values, and data from reference sites. The VCS module requires data to consist of a time series with no more than five years between projected values. Projecting values in five-year time periods is beyond the scope of this case study and instead, results for the initial crediting period are presented for the time periods 2020 to 2030 and 2030 to 2050 based on available habitat area projections for Ballona (ESA PWA, 2012).

The net GHG emission reductions and removals (NER), measured in metric tons of carbon dioxide equivalents (mt CO_2e), are calculated by subtracting the net GHG emissions in the with-project scenario (WPS) and the net emissions due to leakage (LK) from the net GHG emissions in the baseline scenario (BSL). A fire reduction premium is also added to the calculation when fire management is involved.

$$NER = GHG_{BSL} - GHG_{WPS} + FRP - GHG_{LK}$$

Where:

NER	Net CO_2e emission reductions from the project activity; mt CO_2e
GHG_{BSL}	Net CO_2e emissions in the baseline scenario; mt CO_2e
GHG_{WPS}	Net CO_2e emissions in the project scenario; mt CO_2e

FRP Fire Reduction Premium (net CO_2e emission reductions from organic soil combustion due to fire management); mt CO_2e

GHG_{LK} Net CO_2e emissions due to leakage; mt CO_2e

It is important to remember when presenting these calculations in the equation above that net emission reductions and removals (NER) are equivalent to negative emissions (GHG). When emissions are summed and result in a negative value, that value corresponds to a positive net emission reduction or removal (e.g., – GHG = + NER).

The Methodology provides numerous equations, a variety of tools, and varying levels of direction to estimate emissions and reductions for all components of the equation above. These equations and tools are utilized and described using the Ballona Project as a case study in the Results section below. Various options in data sources are available for projects to account for emissions, these include default values, published values, modeling, proxies, and field collected data. These sources are further defined in the Methodology. When a project is delineated into strata, calculations must be made for each individual stratum, which are then added together for an overall net result. A project can always assume an emission is zero when that would be a conservative assumption (least possible carbon credit). As discussed in the next section, during the project crediting period, periodic field monitoring of emissions and carbon pools must be performed to determine the observed project scenario emission reductions.

Sea level rise over the course of the project may lead to submergence of strata within the project boundaries. The consequences of this submergence include: 1) loss of aboveground biomass to oxidation and 2) depending upon the geomorphic setting, soil carbon stocks may be held intact or be eroded and transported out of the project area. Therefore, projects must account for emissions due to a rise in sea level over time. Project proponents must quantify and justify: 1) the point in time when submergence and erosion begins, 2) the amount of carbon that erodes upon submergence, and 3) the oxidation rate of eroded soil organic matter. For the most conservative calculation, the oxidation constant would be 0 for the baseline and 1 for the project scenario.

The project proponent is required by the Methodology to estimate the level of uncertainty associated with the calculation of emissions and carbon stock changes in the baseline and project scenarios. The allowable uncertainty is 20 percent of NER at a 90 percent confidence level or 30 percent of NER at a 95 percent confidence level. Where this precision level is met, no deduction is necessary for uncertainty. If exceeded, a deduction equal to the amount that the uncertainty exceeds the allowable level must be applied. Where uncertainty is not known, it must be demonstrated that the values used are conservative. When conservative values are used, provided they are based on verifiable literature sources or expert judgement, uncertainty is assumed to be zero. Project proponents must use the guidance provided in Section 2.2 and Annex 2A.1 of the IPCC 2006 good practice guidance when using data established from expert judgement.

The next step in the Methodology is to calculate the amount of carbon credits (1 credit = 1 mt CO_2e) that are generated by the project, referred to as Verified Carbon Units (VCU) by the VCS. The number of VCUs issued to a project will not depend on the initial NER estimates provided for the project at validation, but on the results and verification of field monitoring performed at regular intervals by the project proponent. The project proponent must also calculate the number of buffer credits required to be withheld due to an assessment of project risk. The VCS provides a tool (*VCS AFOLU Non-Permanence Risk Tool*) which presents a procedure for assessing the risk of reversal of carbon stocks (unintended loss). These buffer credits are held by the VCS in a buffer account. During the crediting period and upon each verification event of the project, buffer credits may be recovered by the project based on an outcome of a risk assessment that is more favorable than the previous one. After the crediting period, any buffer credits that have not been recovered will expire. The calculation of VCUs and buffer credits is presented in the Results.

The last section of the Results presents a hypothetical high carbon sequestration restoration alternative of the Ballona Project to demonstrate the potential of increasing the total carbon sequestration of a wetland restoration project. Habitat proportions are adjusted to increase the amount of habitats with higher carbon sequestration rates. These results are compared to the results of the proposed restoration alternative.

5.2.6 Monitoring

Following the initial project verification, the VCS Standard requires monitoring and verification of carbon stocks and emissions from carbon pools at least every five years. VCUs are only issued following each monitoring/verification event since the previous monitoring/verification event, so if a project proponent chooses to monitor every five years, the VCS will issue VCUs at the end of each five-year period, following verification. Project proponents can choose to monitor more frequently, but the costs of more frequent monitoring must be considered.

The Methodology requires project proponents to develop a monitoring plan to reliably quantify carbon stocks and GHG emissions in the project scenario during the crediting period. Approved methodologies for the collection and analysis of data are provided in the Methodology and associated tools and modules. The monitoring plan must contain at least the following information:

- Description of each monitoring task to be undertaken, and the technical requirements therein,
- Parameters to be measured,
- Data to be collected and data collection techniques,
- Frequency of monitoring,
- Quality assurance and quality control (QA/QC) procedures,
- Data archiving procedures, and
- Roles, responsibilities and capacity of monitoring team and managemet.

The Methodology also sets requirements for sample size, utilization of horizon markers, determination of soil bulk density and organic matter, and options for determining methane and/or nitrous oxide emissions. Development of a monitoring plan for the Ballona Project case study is beyond the scope of this study.

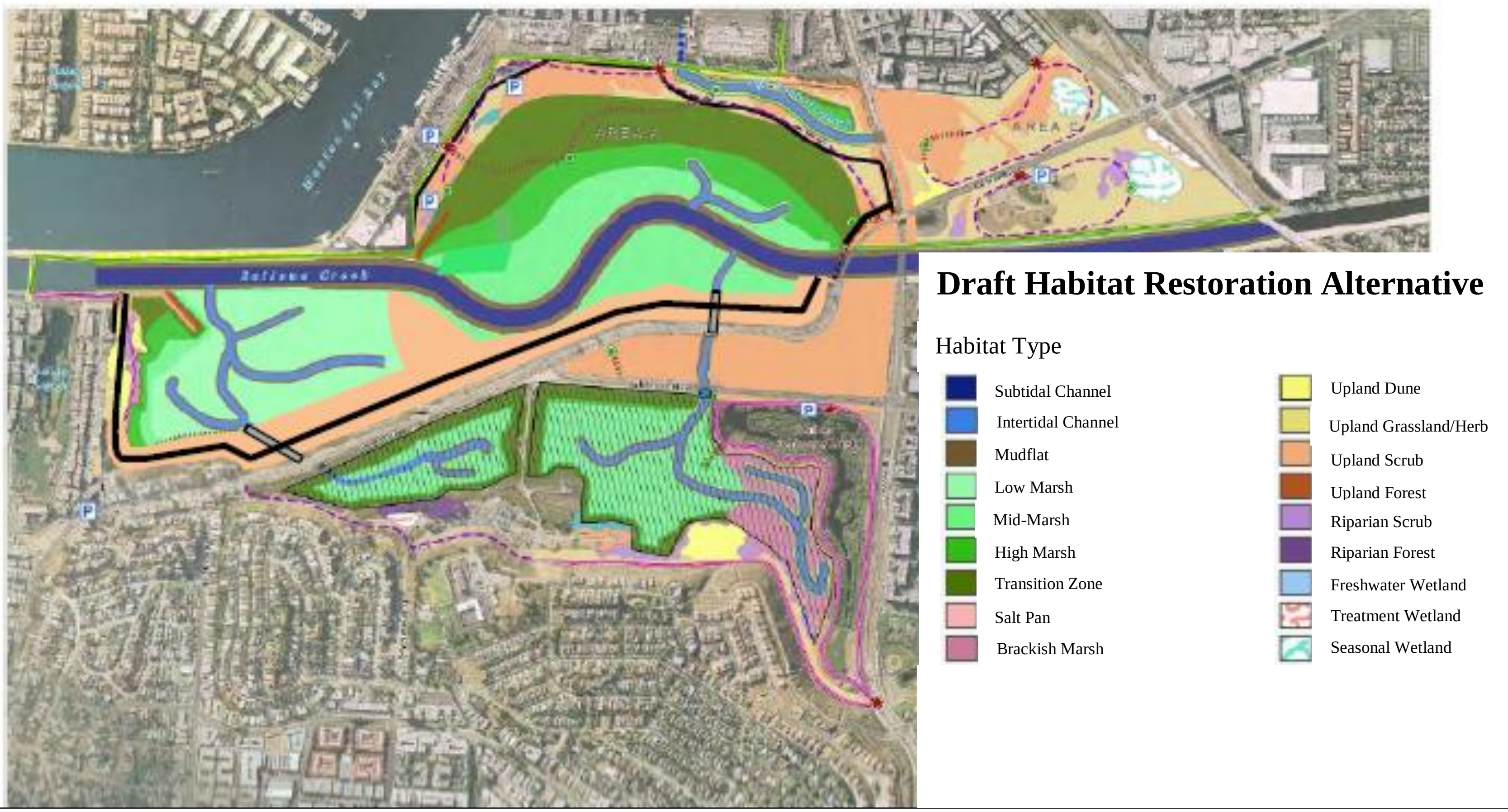
To estimate the required sample size for a project, the Methodology directs users to another CDM tool titled *Calculation of the Number of Sample Plots for Measurements within A/R CDM Project Activities*. This tool is designed specifically for A/R projects and only mentions its application for estimation of biomass stocks, but apparently can be applied to soil carbon samples as well. The tool calculates sample size based on the coefficient of variation of the parameter being measured. If no estimate of this coefficient is available, an estimate from the literature can be used. For instance, the largest coefficient of variation in the studies reviewed by Chmura et al. (2003) for carbon sequestration rates was 0.7 and most were below 0.5 (Emmer et al., 2015). Values in this range require sample sizes of approximately 10-20 samples per stratum. For a project area like Ballona that is divided into 10 or more strata to achieve optimal accuracy of net GHG emission reductions and removals, the number of samples required to be collected and analyzed in a laboratory can be very large (>100).

5.2.7 Case Study Site: Ballona Wetlands Restoration Project

The pre-settlement Ballona Wetlands ecosystem was approximately 2000 acres and included a variety of habitats (Grossinger et al., 2011). Approximately 600 acres remain within the historical wetland footprint, entirely surrounded by the extensively developed metropolitan area of Los Angeles. The Ballona Project occurs generally within the boundaries of the Ballona Wetlands Ecological Reserve. The Ballona Wetlands is divided into three primary areas, each with distinct characteristics and history, known as Areas A, B, and C (Figure 5-1). In 2004, the State of California took title to the Ballona Wetlands and the California Department of Fish & Wildlife (CDFW) designated the majority (577 acres) of the project area as a State Ecological Reserve (PWA et al., 2006). The U.S. EPA has calculated that the area encompassed by the reserve is approximately 626 acres, of which an estimated 85 acres are roads, levees, parking lots and other structures, and the remaining acres are open water, wetlands, and uplands within Areas A, B, and C (EPA, 2012). Area A lies north of Ballona Creek, west of Lincoln Blvd, east of Marina del Rey, and south of Fiji Way and currently comprises approximately 139 acres. Area B is approximately 338 acres and lies south of Ballona Creek, west of Lincoln Blvd, and is buttressed by the Playa Del Rey Bluffs to the south. Finally, Area C is approximately 65 acres and lies north of Ballona Creek, east of Lincoln Blvd, southwest of the Marina Freeway (SR 90), and is bifurcated by Culver Blvd. A portion of the site is in unincorporated Los Angeles County and the rest is in the City of Los Angeles.

Following the acquisition of the Ballona Wetlands by the State of California in 2004, several agencies began working with stakeholders and scientists to develop a plan to restore the wetlands. Five preliminary alternatives for the Ballona Wetlands Restoration Plan were initially developed in 2008, encompassing a range of options for restoring habitat within each of the project areas (PWA et al., 2008). The alternatives ranged from enhancing existing habitat with minimal grading (Alternative 1) to realignment of the Ballona Creek channel with extensive site alteration (Alternative 5). In a Preferred Alternatives Memorandum dated January 15, 2010, the Ballona Wetlands Project Management Team presented revisions and refinements to Alternatives 4 and 5 as the two preferred restoration alternatives (PWA et al., 2010). In 2012, the Project Management Team determined that Alternative 4 would no longer be pursued due to infrastructure constraints. A summary of plan refinements to Alternative 5 was presented and renamed as the Proposed Alternative (ESA PWA, 2012). The Proposed Alternative of the Ballona Project is presented as the project scenario in this case study (Figure 5-2). Table 5-1 shows the areas of the existing wetland habitats, the areas of the Proposed Alternative, and the projected habitat areas for the Proposed Alternative with sea level rise for the years 2030, 2050, and 2100.

Figure 5-2 – Proposed Draft Ballona Wetlands Restoration Alternative



Adapted from ESA PWA, 2012. Preferred Alternative Memorandum

Table 5-1 – Ballona Habitat Areas – Existing, Restored, and Projected for Sea Level Rise

Habitat Type	Baseline (Existing Condition)	2020 Post-Restoration Area (acres)	2030 Area (acres)	2050 Area (acres)	2100 Area (acres)
Low Marsh	9	49	61	52	32
Mid-Marsh	18	103	99	91	111
High Marsh	41	34	30	28	21
Seasonal Wetland Area A	11	0	0	0	0
Seasonal Wetland Area B	74	0	0	0	0
Seasonal Wetland Area C	1	4	4	3	3
Salt Pan	22	20	19	19	14
Brackish Marsh	3	13	13	12	13
Mudflats	15	40	47	82	146
Transition Zone	0	51	55	62	15
Upland	283	171	157	134	118
Total	**477**	**485**	**485**	**483**	**473**

ESA PWA, 2012

5.3 RESULTS

The following sections of Results describe the application of the Methodology using the Ballona Project as a case study. Various data sources are used to provide information regarding the Ballona Project including soil sampling and analyses described in previous chapters of this study and reference data from studies of similar habitats. Soil carbon accumulation of the habitat strata are presented in the previous chapter of this study as an average rate for each habitat with a range of low and high values. Therefore, the calculations of net emission reductions and VCUs in this section are also presented as averages with low and high range values.

5.3.1 Applicability Conditions

The initial component of the Methodology is to determine if the Ballona Project is an activity eligible to produce carbon credits. First, as required by the Methodology, the existing Ballona Wetlands is a degraded tidal marsh and would remain degraded in the absence of the project (Johnston et al., 2015). Second, the following Ballona Project goals and objectives correspond to the required definition of tidal wetland restoration activities outlined in the Methodology and include:

- Restore and create fully tidal wetland habitat,
- Increase tidal flow into the site,
- Improve tidal connectivity within the site by enlarging channels and culverts, and creating new channel networks,
- Include distributary channels in the bluff deltas for coarse sediment distribution where feasible,
- Improve water quality of urban runoff entering the wetlands.

The Ballona Project does not include or support any land uses or activities that will cause leakage by causing additional GHG emissions outside the project area or by displacing land use activities to other areas. In addition, the restoration activities of the Ballona Project are not otherwise required by law, regulation, statutes, legal rulings, or other regulatory frameworks. The BWER is a protected State Ecological Reserve and no burning of organic soils will occur in the Ballona Project, no nitrogen fertilizers are proposed in the project area, and no commercial activities occur in the project area.

The Ballona Project's degraded condition, goals, objectives, and proposed activities are applicable with the conditions set forth in the Methodology and is therefore deemed eligible to generate carbon credits in the VCS program.

5.3.2 Project Boundaries

5.3.2.1 Temporal Boundaries

Temporal boundaries of the Ballona Project pertain to the project start date, crediting period, the longevity of the project, and the soil organic carbon depletion time (SDT). At the time of this study the Ballona Project is still in the planning phases with a draft Environmental Impact Report (EIR) expected in 2017. Estimates of future habitat areas within the Ballona Project due to sea level rise projections are presented by ESA PWA (2012). Habitat area estimates are provided for a post-restoration condition with an unspecified date and for the years 2030, 2050, and 2100 based on projected sea level rise. Because each crediting period is set at 30 years based on VCS rules set out in the VCS Standard, a Ballona Project start date of 2020 is used for this study with an initial 30-year crediting period ending in 2050 and an 80-year project longevity ending in 2100. These assumptions allow for the estimation of greenhouse gas reductions and removals based on the corresponding habitat estimates provided by ESA PWA (2012).

ESA PWA (2012) provides projections of habitat areas for the Ballona Project immediately following restoration (i.e., 2020 start date) and for the years 2030, 2050, and 2100, based on sea level rise calculations. Although the Methodology requires projects to provide emission calculations in five-year increments, based on the habitat data available for the Ballona Project from ESA PWA (2012), the calculations of net GHG emission reductions are presented for the 10-year time period of 2020 (t_1) to 2030 (t_2) and from 2030 to 2050 (t_3), for an initial crediting period of 30 years. Net GHG emission reductions are also presented for the time period 2050 (t_3) to 2100 (t_4). Although some changes in vegetation cover have occurred since the 2007 habitat survey (CDFG, 2007; Johnston et al., 2015), no major vegetation-disturbing activities have occurred at Ballona and the habitat acreages are assumed to currently be the same as the 2007 measured acreages.

Soil emissions have not been measured in the Ballona Wetlands. However, the Methodology does not allow projects to claim emission reductions (e.g., avoided losses) for soils that have been drained for more than 20 years. Draining of the Ballona Wetlands for land use changes began in the mid-1800s and culminated with the construction of the Ballona Channel in the 1930s. Therefore, the Ballona Project cannot claim any reduction of soil emissions through avoided losses and the SDT is set to zero for these soils, SDT = 0

For wetland projects drained within less than 20 years of the project start date or projects with organic soils (peat), emission reductions may be accounted for in projects including rewetting of drained soils.

5.3.2.2 Geographic Boundaries

The geographic boundaries of the Ballona Project are shown in Figure 5-1. The project boundaries are established by surrounding infrastructure and development and will not change due to sea level rise, inland migration, or erosion. However, project strata (habitat areas) are subject to changing areas within the project boundaries due to the projected rise in sea level (ESA PWA, 2012). The Methodology allows for the stratification of the project area into spatially explicit strata that are sufficiently homogenous in order to simplify project accounting procedures. The Ballona Project area is stratified based on the habitat types presented in the 2007 CDFG habitat survey and ESA PWA (2012) habitats and include:

- Mudflats
- Low marsh
- Mid-marsh
- High marsh
- Salt pan
- Seasonal wetland Area A
- Seasonal wetland Area B
- Seasonal wetland Area C
- Brackish marsh
- Subtidal
- Transition zone
- Upland
- Freshwater/Riparian

These strata are the basis for GHG emission reductions and removals calculations in subsequent sections and are summed to produce net emission reductions and removals estimates.

5.3.2.3 Carbon Pools

The carbon pools relevant to the Ballona Project are soil organic carbon and biomass. Litter and dead wood are not included as carbon pools in the Methodology for tidal marsh projects and no wood products are produced, or will be produced, from the project area.

5.3.2.4 Greenhouse Gases

Relevant GHGs for tidal marsh restoration projects are CO_2, CH_4, and N_2O. CO_2 emission removals are estimated for the Ballona Project in both baseline and project scenarios. As explained in Section 5.2.2, CH_4 and N_2O emissions are conservatively set to zero in the baseline scenario and CH_4 is addressed for the project scenario. N_2O is also set to zero in the project scenario because the Methodology allows for this if water levels will not be lowered as a result of project activities.

5.3.3 Baseline Scenario

The CDM *Combined tool to identify the baseline scenario and demonstrate additionality for A/R project activities* (CDM Combined Tool) is demonstrated in the following paragraphs for the proposed Ballona Project applying the tool's five-step approach. Additionality is discussed in the following section.

Step 0 – Preliminary screening based on the start date of the project

This first step of the CDM Combined Tool requires projects to have a starting date after December 31, 1999, and for the sale of carbon offsets to have been seriously considered in the decision to proceed with the project. However, Section 6.1 of the Methodology directs tidal marsh restoration project proponents to disregard Step 0, which is specific to CDM A/R projects.

Step 1 – Identification of alternative scenarios

Through a series of sub-steps this step serves to identify alternative land use scenarios to the proposed project that could represent the baseline scenario.

Sub-step 1a – Identify credible alternative land use scenarios to the proposed project

The identified land use scenarios must at least include:

- *Continuation of the pre-project land use.* Because the Ballona Wetlands Ecological Reserve (BWER) is protected by the state, in the absence of a state-approved restoration project it is unlikely that any other land use would be approved that would further develop or degrade the area.
- *Restoration of the land within the project boundary performed without being registered as a carbon offset project.* Although the Ballona Project could have included carbon funding in its planning phase, it was developed without the initial intent to pursue a carbon offset registry and would likely proceed even without being registered as an offset project.
- *If applicable, restoration of at least part of the land within the project boundary from:*

- *Legal requirements; or*
- *Improvements to ecological conditions within the project boundaries based on observed activities occurring outside the project area.*

There are no known existing legal requirements that would lead to restoration of any part of the project area. In addition, no improvements to ecological conditions within the project area are anticipated in the absence of the project scenario (Johnston et al., 2015).

Sub-step 1a has identified two alternative land use scenarios other than the project scenario:

Alternative 1 – Continuation of the existing Ballona Wetlands condition; and

Alternative 2 – Project scenario without a carbon offset component.

Sub-step 1b – Consistency of credible alternative land use scenarios with enforced mandatory applicable laws and regulations

This sub-step requires the demonstration that all alternative land use scenarios identified in Sub-step 1a are in compliance with all mandatory applicable legal and regulatory requirements. The Ballona Project proponents are currently developing the draft EIR which will address all legal requirements associated with the proposed restoration project. For the purposes of this exercise it is assumed that the existing Ballona Wetlands (Alternative 1) and the proposed Ballona Project without a carbon offset component (Alternative 2) are both in compliance with all applicable laws and regulations.

Step 2 – Barrier analysis

This step is intended to identify any barriers to implementation of an alternative land use scenario and determine which, if any, of the alternatives would be prevented by these barriers.

Sub-step 2a – Identification of barriers that would prevent the implementation of at least one alternative

The CDM Combined Tool presents barriers that could prevent realization of an alternative land use scenario including: investment barriers; institutional barriers (governmental policies or laws); technological barriers; local tradition such as laws, customs, market conditions; ecological conditions such as degraded soils, catastrophic events, or unfavorable biological conditions; social conditions; and/or land rights issues.

Potential barriers to the Ballona Project may include land rights challenges by Native American groups and lawsuits from interest groups with alternate visions for the Ballona Wetlands Ecological Reserve (BWER). No barriers related to ecological or biological conditions are anticipated.

Sub-step 2b – Elimination of land use scenarios that are prevented by the identified barriers

The draft EIR is expected to address any potential issues and challenges associated with the Ballona Project, but for the purposes of this exercise it is assumed that no barriers will ultimately prevent implementation of the restoration project as proposed (Alternative 2). In addition, no barriers are anticipated that would prevent the continuation of the existing Ballona Wetlands condition (Alternative 1). Tidal marsh restoration projects that do identify preventative barriers are required to substantiate and document that all barriers are valid and conclusive as described in the CDM tool.

Sub-step 2c – Determination of baseline scenario (if allowed by the barrier analysis)

The CDM Combined Tool provides a decision tree to complete this sub-step and begins with the following question: *Is restoration without being registered as a carbon offset project included in the list of alternative land use scenarios that are not prevented by a barrier?*

- If yes, then: *Does the list contain only one land use scenario?*

    - If yes, then the restoration project is not additional (for projects outside U.S. only, see Section 5.3.4 Additionality below).
    - If no, then continue with Step 3: Investment Analysis.
- If no, then: *Does the list contain only one land use scenario?*
    - If yes, then the remaining land use is the baseline scenario. Continue with Step 4: Common Practice Test.
    - If no, then through qualitative analysis, assess the removals by sinks for each scenario and select one of the following options:
        - Option 1: Baseline scenario is the land use scenario that allows for the highest baseline GHG removals by sink. Continue with Step 4.
        - Option 2: Continue with Step 3: Investment Analysis.

For the Ballona Project, the answer to the first question: *Is restoration without being registered as a carbon offset project included in the list of alternative land use scenarios that are not prevented by a barrier?* is “yes”. Funding from the sale of offsets was not considered in the initial planning phases. Therefore, the next question in the decision tree is: *Does the list contain only one land use scenario?*, to which the answer is “no”, Alternative 1 – Continuation of the existing Ballona Wetlands condition, is also still on the list. Therefore, the decision tree directs the analysis to Step 3: Investment Analysis.

For project areas that may have other alternative land uses, and are not constrained by a protected status such as an Ecological Reserve, an analysis of GHG removals for all alternative project scenarios would be necessary. Sub-step 2c then requires that the baseline scenario be the most conservative alternative having the lowest net emissions (lowest GHG emissions and highest GHG removals), thereby conservatively lowering the net GHG removals that may be claimed by the project scenario.

Step 3 – Investment analysis

The purpose of this step is to determine which of the remaining alternative land use scenarios is the most economically or financially attractive. It is not immediately clear how a publicly funded project such as the Ballona Project fits into this investment analysis step. Wetlands provide valuable economic benefits to a region including, but not limited to: tourism, public open space, flood control, clean water, and nurseries for fisheries; however, neither of the alternative scenarios for the Ballona Project generates direct financial income. The investment analysis seems to be directed toward alternative A/R land use scenarios on private lands that are agricultural or commercial in nature.

Step 3 includes several sub-steps designed to provide a comparison of financial benefits between alternatives through one of three options: 1) Simple cost analysis, 2) Investment comparison analysis, or 3) Benchmark analysis. For project activities that generate no direct financial benefits, such as the Ballona Project, the simple cost analysis of Option 1 appears appropriate. For project areas subject to income generating alternatives, the CDM tool provides detailed instructions for conducting financial comparisons between alternatives.

Applying the simple cost analysis option (Option 1) to the Ballona Project requires documenting the incomes and costs associated with each of the alternative land use scenarios. As stated, neither of the alternatives is anticipated to produce direct financial income from the land use. However, both alternatives do have associated costs, although substantially different. Continuation of the existing Ballona Wetlands condition (Alternative 1) will have costs associated with continuing maintenance and CDFW enforcement of the Ballona Wetlands

Ecological Reserve. While most of the reserve is closed to the public, CDFW is responsible for enforcement on the property and, in association with local law enforcement, conducts periodic efforts to clear the area of homeless camps and debris. The overall costs of these maintenance and enforcement efforts have not been identified in this study.

For the Ballona Project scenario without a carbon offset component (Alternative 2), estimated costs for the final design of the Ballona Project are also unknown at this time, but are anticipated to amount to several million dollars, plus the cost of continuing maintenance and enforcement that are currently needed. According to the CDM Combined Tool, if neither alternative scenario generates direct financial benefits, the alternative that allows for the highest baseline GHG removals shall be selected as the baseline scenario. If this baseline scenario is the proposed project (Alternative 2), then the tool deems it not additional, and therefore ineligible to generate offsets. However, the CDM tool was developed for simultaneously determining additionality and baseline scenarios for A/R projects while the VCS directs proponents to disregard additionality requirements for tidal restoration projects within the U.S. Since the Ballona Project is a tidal marsh restoration project within the U.S., it is automatically deemed to be additional by VCS and Alternative 2 is not ineligible. Therefore, since Alternative 2 and the Project Scenario are the same project, Alternative 1 is the only remaining alternative to be logically selected as the baseline scenario.

Step 4 – Common practice analysis

The final step is one designed to complement the demonstration of additionality of the project by determining if the proposed project is an activity similar to other activities in the geographical area. In other words, have other tidal restoration projects been conducted in the geographical area in which essential distinctions between the project and similar activities cannot be made. This step is not applicable to the Ballona Project, or other tidal marsh restoration projects in the U.S., because its focus is in determining additionality, and all tidal restoration projects in the U.S. are automatically additional.

The results of the baseline scenario analysis demonstrate that *Alternative 1 – Continuation of the existing Ballona Wetlands condition* is the most plausible baseline scenario in which establishment of ecological conditions is not expected to occur in the absence of the project. This baseline scenario must be reassessed every 10 years to account for changes in land use and land management practices, such as sea level rise or change in ownership.

It is anticipated that many tidal marsh restoration projects, similar to Ballona, will occur on the existing degraded footprint of the historical marsh and will not support any alternative land uses at the time. In these cases, project proponents would benefit if the Methodology greatly simplified this step and allowed the existing marsh condition to be chosen as the baseline condition early in the process.

5.3.4 Additionality

Since the Ballona Project occurs in the U.S. and meets all applicability requirements of the Methodology, it is deemed to be additional.

5.3.5 Quantification of GHG Emission Reductions and Removals

The net GHG emission reductions and removals (NER) between the Ballona Project baseline scenario (BSL) and the with-project scenario (WPS) are calculated by subtracting the net GHG emissions in the project scenario and the net emissions due to leakage (LK) from the net GHG emissions in the baseline scenario. The central equation of the Methodology to calculate NER is:

$$NER = GHG_{BSL} - GHG_{WPS} + FRP - GHG_{LK}$$

A fire reduction premium (FRP) for organic soil combustion is added to the calculation when fire management is involved, but is not relevant to the Ballona Project.

The Methodology provides a series of equations and tools for a project proponent to use in the estimation of baseline (GHG_{BSL}) and project (GHG_{WPS}) emissions as well as leakage (GHG_{LK}). Each of these components of the Methodology is presented and discussed in the following sections.

Projected values for biomass and soil carbon sequestration are estimated primarily from existing reference studies and from Ballona soil data presented in previous chapters of this study. These values are presented and discussed in the following sections where applicable. Many assumptions, estimates, and/or default factors are required to complete the Methodology process for the Ballona Project where information was not available. Where assumptions and estimates are made, the rationale is discussed. An effort is made to use conservative values that would favor more GHG reductions in the baseline scenario and fewer reductions in the project scenario in order to provide conservative GHG reduction estimates. Where components of the Methodology are not applicable to the Ballona Project, they are referenced and briefly discussed.

The calculations of net GHG emission reductions for the Ballona Project from 2020 (t_1) to 2030 (t_2) and from 2030 to 2050 (t_3), for an initial crediting period of 30 years, are presented below using the strata defined previously. Calculations of net emission reductions are presented for an extended project time period from 2050 (t_3) to 2100 (t_4) in a subsequent section.

Emissions are calculated differently for biomass and for soil over the project period ($t_1 - t_4$). Biomass is calculated as the difference in biomass stocks between two years (e.g., $t_2 - t_1$) while soil emissions (sequestration) are calculated as a cumulative process (per year) throughout the entire time period. While the baseline scenario habitats are assumed to remain unchanged from t_1 through t_4, the project scenario habitat areas change over time due to sea level rise. Therefore, baseline biomass emissions are zero from t_1 to t_4 while baseline soil sequesters carbon throughout the entire period. Project scenario biomass at time t_1 is assigned the existing habitat areas to reflect the existing vegetation that will be lost due to clearing the project area for construction. This is a more conservative estimate than using the post-restoration habitat areas for t_1 biomass because the existing wetland contains more acres of vegetated habitat than the post-restoration revegetated habitats and results in more vegetation loss over time, increasing the amount of project scenario emissions.

However, for the project soil calculations, t_1 is set as the post-restoration habitat areas to reflect the increase in tidal inundation immediately following grading of the project area. While project biomass is the difference between stocks at two time periods (e.g., $t_2 - t_1$), project soil emissions are calculated over a time period using one set of habitat areas. Habitat areas for the project soil calculations are conservatively used for the earlier time in a time period. For instance, for the time period from 2020 to 2030 (t_1-t_2) the habitat areas for 2020 are used for the entire 10-year period. This is a more conservative estimation (leading to less carbon sequestration) because the wetland at later times, t_2 in this case, has higher carbon sequestration rates due to increasing areas of low marsh, mid-marsh, high marsh and mudflat habitat over time due to sea level rise. This is the reason that project habitat areas are different for 2020 biomass and 2020 soil strata in Table 5-4 and Table 5-5, respectively.

5.3.5.1 Baseline Scenario Emissions – GHG_{BSL}

The baseline scenario is defined as the continuation of the existing Ballona Wetlands condition (CDFG, 2007). ESA PWA (2012) provides estimates of future habitat area in Ballona due to sea level rise for the project scenario, but not for the baseline scenario. Due to the presence of the tide gate regulating tidal flow from the Ballona Channel, it is assumed for this case study that sea level rise will not cause a rise in tidal elevation within the regulated tidal marsh of the existing wetland. In addition, although Johnston et al. (2015) showed that the Ballona Wetlands are experiencing slowly deteriorating conditions across most of the areas hydrologically disconnected from tidal influence, for the purposes of this study the existing habitat (CDFG, 2007) is assumed to remain unchanged throughout the baseline scenario.

Emissions in the baseline scenario are attributed to carbon stock changes in biomass carbon pools and soil processes. Emissions from fossil fuel use in the project area are not relevant in the baseline scenario of the Ballona Project because negligible on-site fossil fuel combustion is anticipated during the baseline scenario. The Methodology also allows for any fossil fuel use in the baseline scenario to be conservatively excluded.

Because the baseline scenario would only occur in the absence of the project, it is not possible to confirm these estimates through monitoring. Therefore, the baseline emission estimates must be validated at the beginning of the project registration and the baseline scenario must be reevaluated every 10 years to account for predicted changes in land use and land management practices, hydrologic changes due to existing constraints, expected vegetation succession patterns, and climate variables such as sea level rise. Baseline scenarios must be changed to reflect any impacts to marsh habitat from these factors.

Emissions in the baseline scenario are estimated in metric tons of carbon dioxide equivalents (mt CO_2e) by the following equation:

$$GHG_{BSL} = GHG_{BSL\text{-}biomass} + GHG_{BSL\text{-}soil},$$

Where;

GHG_{BSL} = Net CO_2e emissions in the baseline scenario between two estimation years, e.g., t_1 and $t_{2;}$ mt CO_2e

$GHG_{BSL\text{-}biomass}$ = [(44/12) x $\Delta C_{BSL\text{-}biomass}$] emissions from change in biomass in the baseline scenario summed over all strata between two estimation years (t), e.g., t_1 and $t_{2;}$ mt CO_2e, (44/12 = ratio of molecular weights of CO_2/C).

$GHG_{BSL\text{-}soil}$ = soil GHG emissions during the baseline scenario summed over all strata between two estimation years, e.g., t_1 and t_2; mt CO_2e

5.3.5.1.1 Baseline Biomass Emissions – $GHG_{BSL\text{-}biomass}$

Net change in the biomass carbon pool in the baseline scenario is estimated as the change in the biomass of trees and shrubs (tree/shrub) and herbaceous (herb) vegetation for each strata between two estimation years as follows:

$$GHG_{BSL\text{-}biomass} = [(44/12) \times \Delta C_{BSL\text{-}biomass}]$$

$$\Delta C_{BSL\text{-}biomass} = \Delta C_{BSL\text{-}tree/shrub} + \Delta C_{BSL\text{-}herb}; \text{ mt C}$$

The net carbon stock change in biomass vegetation is estimated using baseline scenario vegetated habitat areas (strata) shown in Table 5-2 and equations provided in the Methodology. Only baseline habitats that are proposed to be altered by the Ballona Project, and would contribute to changes in the biomass pool, are shown in Table 5-2. Vegetated habitats that are not proposed to be impacted due to the Ballona Project include 26 acres of freshwater/riparian habitats and one acre of upland woodland. The table also does not include transition zone because this habitat does not exist in the baseline scenario. Non-vegetated habitats including subtidal, mudflat, and salt pan are also not included.

The net carbon stock change in trees and shrubs in the baseline scenario is estimated by:

$$\Delta C_{BSL\text{-}tree/shrub} = (12/44) \times (\Delta C_{TREE\_BSL} + \Delta C_{SHRUB\_BSL}); \text{mt C}$$

To calculate ΔC_{TREE_BSL} and ΔC_{SHRUB_BSL} in the equation above, the Methodology directs users to apply CDM *AR-Tool 14 – Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities* (CDM Tool 14). The equations provided in CDM Tool 14 for ΔC_{TREE_BSL} and ΔC_{SHRUB_BSL} present changes in biomass as metric tons of CO_2 equivalents, rather than as metric tons of carbon presented in equations in the Methodology. Therefore, a conversion factor of 12/44, representing the molecular weight ratio of C/CO_2e, is needed in the equation above to convert mt CO_2e to mt C to maintain consistency in the results for $\Delta C_{BSL\text{-}biomass}$ as mt C.

The net carbon stock change in herbaceous vegetation in the baseline scenario is estimated in subsequent paragraphs using the equation:

$$\Delta C_{BSL\text{-}herb} = (C_{BSL\text{-}herb,\, t2} - C_{BSL\text{-}herb,\, t1}); \text{mt C}$$

Table 5-2 – Baseline Scenario Biomass Strata for Vegetated Habitats

Habitat Type	Area (acres)[1]
Low Marsh	9
Mid-Marsh	18
High Marsh	41
Seasonal Wetland Area A	11
Seasonal Wetland Area B	74
Seasonal Wetland Area C	1
Brackish Marsh	3
Upland Coastal Scrub	94
Upland Grassland/Herbaceous/Dunes	188
Total	**439**

1 = CDFG (2007)

Baseline Tree Emissions

CDM Tool 14 provides various techniques with equations to estimate carbon stocks in trees in the baseline condition including a biomass expansion factor technique, an allometric equation technique, and a baseline default technique. The equations require specific information about the tree species within the project area such as stem volume, wood density, biomass expansion factors, root/shoot ratios, functions to convert tree dimensions to biomass, biomass content in regional forests, and crown cover. Much of this tree-specific information is not readily available to a project proponent and would likely require considerable time and effort performing direct field measurements and/or literature reviews. The tool does not provide default values or data sources to assist with these calculations.

The acreage of trees (woodland) on the existing Ballona Wetlands is relatively small. Existing woodland habitats include three acres of riparian woodland and one acre of upland woodland both dominated by non-native eucalyptus species (CDFG, 2007). Because the total existing acreage of woodland is relatively small (four out of 453 acres of vegetated habitat) and habitat areas are anticipated to remain unchanged throughout both the baseline and project scenarios, the carbon stock change in tree biomass at Ballona is considered negligible:

$$\Delta C_{TREE\_BSL} = 0 \ CO_2e.$$

Baseline Shrub Emissions

Carbon stock in shrub biomass is estimated by the CDM Tool 14 for each shrub stratum delineated on the basis of shrub crown cover, which presumably means that project areas with a shrub cover of 50% would be grouped together as one stratum, and areas with cover of 100% would be grouped together as another stratum, etc. The Ballona Wetlands Ecological Reserve Comprehensive 5-year Monitoring Report (Johnston et al., 2015) surveyed and combined all shrub habitats at Ballona and reported an average shrub cover of approximately 70%, consisting of both native and non-native species. Therefore, without additional delineation of shrub habitats available, one shrub stratum representing 70% cover is used for the Ballona baseline shrub biomass estimation in the CDM Tool 14 equation:

$$C_{SHRUB\_BSL} = C_{SHRUB\_t2} - C_{SHRUB\_t1}\text{; and}$$

$$C_{SHRUB\_t} = (44/12) \text{ x } CF_s \text{ x } (1+R_s) \text{ x } A_{SHRUB} \text{ x } B_{SHRUB} \text{ x } CC_{SHRUB}$$

Where:

C_{SHRUB_t} = Carbon stock in shrub biomass at time t; mt CO_2e

44/12 = ratio of CO_2e to C

CF_s = Carbon fraction of shrub biomass (IPCC default value provided as 0.47); mt C/mt biomass

R_s = Root-shoot ratio for shrubs;

A_{SHRUB} = Area of shrub biomass in stratum; acre

B_{SHRUB} = Shrub biomass per area in stratum assuming 100% cover; mt biomass/acre

CC_{SHRUB} = Crown cover fraction of shrubs in stratum.

The CDFG 2007 survey shows a total existing shrub area at Ballona of 94 acres (Table 5-2) consisting of coastal scrub. As stated, the riparian scrub habitat is not included in these calculations because that habitat is not being altered by the proposed Ballona Project. Gray and Schlesinger (1981) found that biomass in coastal sage scrub habitat in southern California averaged approximately 1418 g/m^2 or 5.7 metric tons per acre. Gray and Schlesinger reported relative cover for shrub species but did not report the total shrub cover in their study plot, therefore, 5.7 metric tons per acre is assumed to represent the biomass for habitat with 100%

shrub cover. Mokany et al. (2006) collected data on root/shoot ratios for a variety of terrestrial biomes and reported average root/shoot ratios of 1.84 for all shrubland and 1.06 for temperate arid shrubland. To complete the shrub biomass calculation, a root/shoot ratio of 1, average scrub cover of 70% (Johnston et al., 2015), and a biomass of 5.7 metric tons/acre (Gray and Schlesinger, 1981) are applied to all 94 acres of shrub habitat in the Ballona Wetlands baseline scenario.

The shrub biomass at the start of the baseline period t_1 (2020) is represented by:

$$C_{SHRUB\_t1} = (44/12\ CO_2/C) \times (0.47\ mt\ C/mt\ biomass) \times (1+1) \times (94\ ac) \times (5.7\ mt\ biomass/ac) \times 0.7 = 1{,}293\ mt\ CO_2e$$

Because this study assumes that the baseline strata remain unchanged throughout the baseline scenario, shrub biomass estimates for the years 2030 (t_2) and 2050 (t_3) are assumed equal to C_{SHRUB_t1}:

$$C_{SHRUB\_t1} = C_{SHRUB\_t2} = C_{SHRUB\_t3} = 1{,}293\ mt\ CO_2e$$

And the net change in shrub biomass in the baseline scenario from t_1 to t_3 is zero.

$\Delta C_{SHRUB\_BSL} = C_{SHRUB\_t3} - C_{SHRUB\_t1} = 0\ mt\ CO_2e$, and for the baseline scenario from t_1 to t_3:

$\Delta C_{BSL\text{-}tree/shrub} = (12/44) \times (\Delta C_{TREE\_BSL} + \Delta C_{SHRUB\_BSL})$; mt C

$\Delta C_{BSL\text{-}tree/shrub} = (12/44) \times (0\ mt\ CO_2e + 0\ mt\ CO_2e) = 0\ mt\ C$

Baseline Herb Emissions

The net carbon stock change in herbaceous vegetation in the baseline scenario is calculated using the equation provided in the Methodology:

$$\Delta C_{BSL\text{-}herb} = (C_{BSL\text{-}herb,\ t2} - C_{BSL\text{-}herb,\ t1}),$$

Where:

$\Delta C_{BSL\text{-}herb}$ Net carbon stock change in herbaceous vegetation carbon pools in the baseline scenario in all strata between two estimation years, e.g., t_1 to t_2; mt C

$C_{BSL\text{-}herb,\ t}$ Carbon stock in herbaceous vegetation in the baseline scenario for all strata at time t; mt C

The majority of habitat area of the existing Ballona Wetlands is dominated by herbaceous vegetation. Habitats dominated by *Salicornia pacifica* (pickleweed), a perennial herb, include low marsh, mid-marsh, high marsh, and seasonal wetland Area B. Habitat dominated by native and non-native grasses and herbs include brackish marsh, seasonal wetland Areas A and C, and upland grassland/herbaceous/dune habitats (CDFG, 2007; Johnston et al., 2015). Mahall and Park (1976) measured aboveground biomass of *S. pacifica*-dominated marshes in the San Francisco Estuary at 553-958 g/m^2 and Zedler (1980) measured aboveground biomass in a *S. pacifica*-dominated marsh in Tijuana Estuary at 412-1,046 g/m^2. An average of the upper and lower values of these ranges gives a biomass estimate of approximately 740 g/m^2 for *S. pacifica*-dominated marshes. If the carbon fraction of 0.47 applied to shrubs is applied for herbs, an estimated value of 348 g C/m^2 results. As an alternative to these values, the Methodology provides a default factor of 300 g C/m^2 of aboveground biomass that can be applied to carbon stock for all herbaceous vegetation. For simplicity, the default factor of 300 g C/m^2 is applied to all herbaceous habitats. Existing habitat areas are assumed to remain unchanged throughout the baseline scenario with herbaceous habitat totaling 345 acres (Table 5-2).

Therefore, the herbaceous biomass stock at time t_1 (year 2020) is:

$$C_{BSL\text{-}herb,\ t1} = A_{HERB} \times B_{HERB} = 345 \text{ ac} \times 300 \text{ g C/m}^2 \times 0.004 = 414 \text{ mt C}$$

Where:

A_{HERB} = Area of shrub biomass in stratum; acre

B_{HERB} = Shrub biomass per area in stratum; g C/m^2

0.004 = Conversion factor (m^2 to acre and g to mt).

Since sea level rise is assumed to not change the areas of habitat in the baseline scenario over time, and assuming that the vegetated areas remain unchanged, the herbaceous biomass stock at time t_2 (year 2030) and t_3 (year 2050) are also estimated as 414 mt C;

$$C_{BSL\text{-}herb,\ t1} = C_{BSL\text{-}herb,\ t2} = C_{BSL\text{-}herb,\ t3} = 414 \text{ mt C}$$

The change in herbaceous biomass during the baseline scenario from t_1 to t_3 is:

$$\Delta C_{BSL\text{-}herb} = C_{BSL\text{-}herb,\ t3} - C_{BSL\text{-}herb,\ t1} = 0 \text{ mt C}$$

<u>Total Baseline Scenario Biomass Emissions</u>

The total change in biomass in the baseline scenario from t_1 to t_3 is therefore:

$$\Delta C_{BSL\text{-}biomass} = \Delta C_{BSL\text{-}tree/shrub} + \Delta C_{BSL\text{-}herb} = 0 + 0 = 0 \text{ mt C},$$

The net emissions from biomass carbon pools in the baseline scenario as carbon dioxide equivalents from t_1 to t_3 are:

$$GHG_{BSL\text{-}biomass} = [(44/12) \text{ x } \Delta C_{BSL\text{-}biomass}] = 0 \text{ mt } CO_2e$$

5.3.5.1.2 Baseline Soil Emissions – $GHG_{BSL\text{-}soil}$

The net GHG emissions from soil in the baseline scenario are estimated and summed for each soil stratum as:

$$GHG_{BSL\text{-}soil} = A \text{ x } (GHG_{BSL\text{-}soil\text{-}CO2} - Deduction_{alloch} + GHG_{BSL\text{-}soil\text{-}CH4} + GHG_{BSL\text{-}soil\text{-}N2O})$$

Where:

$GHG_{BSL\text{-}soil}$	GHG emissions from the SOC pool of strata in the baseline scenario in year t; mt CO_2e/yr
A_t	Area of stratum in year t
$GHG_{BSL\text{-}soil\text{-}CO2}$	CO_2 emissions from the SOC pool of strata in the baseline scenario in year t; mt CO_2e/yr/area
$Deduction_{alloch}$	Deduction of CO_2 emissions from the SOC pool to account for the percentage of the carbon stock that is derived from allochthonous soil organic carbon; mt CO_2e/yr/area
$GHG_{BSL\text{-}soil\text{-}CH4}$	CH_4 emissions from the SOC pool of strata in the baseline scenario in year t; mt CO_2e/yr/area
$GHG_{BSL\text{-}soil\text{-}N2O}$	N_2O emissions from the SOC pool of strata in the baseline scenario in year t; mt CO_2e/yr/area

The Ballona habitats and areas described by CDFG (2007) represent the strata for the soil emission calculations. Habitats with areas as measured in 2007 are shown in Table 5-3 and are assumed to remain unchanged throughout the baseline scenario. Transition zone habitat is not included in the table because it does not exist in the baseline scenario. As for biomass strata in Table 5-2, freshwater/riparian habitats are not included in the soil strata because these habitats are unchanged from the baseline scenario to the project scenario through the year 2100 (ESA PWA, 2012). Therefore, no contributions in net change in emissions are expected from these habitats and they are excluded from the calculations. Subtidal habitat is also not included in the table because its area is only changed slightly by the Ballona Project and this study focuses on tidal marsh habitat.

Table 5-3 – Baseline Scenario Soil Strata

Habitat Type	Area (acres)[1]
Low Marsh	9
Mid-Marsh	18
High Marsh	41
Seasonal Wetland Area A	11
Seasonal Wetland Area B	74
Seasonal Wetland Area C	1
Salt Pan	22
Brackish Marsh	3
Mudflats	15
Upland	283
Total	**477**

1 = CDFG (2007)

Carbon Dioxide Soil Emissions – $GHG_{BSL\text{-}soil\text{-}CO2}$

The first source of soil emissions to be addressed in the baseline scenario is carbon dioxide, $GHG_{BSL\text{-}soil\text{-}CO2}$. Emissions of carbon dioxide from soil may occur due to the oxidation (decomposition) of soil organic matter in a drained tidal wetland. In mineral soils, like those at Ballona, the rate of soil organic matter oxidation tends to be most rapid immediately following the drainage of the wetland and eventually becomes very slow (Emmer et al., 2015). The Methodology does not allow credit for reducing organic matter oxidation in projects that have been drained for more than 20 years. Most of the historical marsh habitat of the Ballona Wetlands has been drained since at least the early 1930s when the Ballona Channel was installed. Due to the extended period since these soils have been inundated, the drained habitats of the existing Ballona Wetlands are considered by the Methodology to contribute negligible CO_2 emissions from organic matter oxidation.

Carbon sequestration in tidal marsh soils is counted as negative soil emissions, or emission reductions, by the Methodology. To estimate carbon sequestration for the baseline scenario, the project proponent can collect field samples of the existing habitats, use peer-reviewed published values, or the default value of 1.46 mt C/ha/yr provided in the Methodology. The default value cannot be used if published data are available. Carbon sequestration rates are estimated for habitats of the Ballona Wetlands in the previous chapter of this study for the baseline strata shown in Table 5-3. Rates are presented as an average value for each habitat type (e.g., low, mid-, high marsh) along with a range of estimated low and high values. Due to the muted tidal influence in the existing wetland, when applicable, rates for habitats are selected as the low range value for those habitats. Therefore, the carbon sequestration rates for existing habitats (i.e., baseline scenario) are generally lower than rates for the same habitats of the project scenario.

The carbon sequestration rates are multiplied by the area of each habitat of the baseline scenario and converted from mt C/yr to mt CO_2e/yr. These calculations are presented in Table D-1 of Appendix D. The results show that the CO_2 emission removal rate of the existing Ballona Wetlands for the baseline scenario is 165 mt CO_2e/yr (or negative emissions of –165 mt CO_2e/yr) and, because habitat areas are considered stable over the baseline scenario, the emission reduction rate remains stable throughout the baseline scenario.

$$GHG_{BSL\text{-}soil\text{-}CO2} = -165 \text{ mt } CO_2\text{e/yr}$$

Emission reductions therefore total 1,650 mt CO_2e for the 10-year period between 2020 (t_1) and 2030 (t_2), 3,300 mt CO_2e for the 20-year period between 2030 (t_2) and 2050 (t_3), totaling 4,950 mt CO_2e over the entire 30-year baseline crediting period.

The Methodology requires project proponents to estimate a deduction to carbon sequestration calculations to account for allochthonous carbon ($Deduct_{alloch}$) unless it can be demonstrated that the allochthonous carbon would have been returned to the atmosphere in the absence of the project. The purpose of this deduction, although not well-defined in the Methodology, is presumably because it is expected that the majority of allochthonous organic matter deposited in the marsh soil surface will be oxidized before it is buried and because any recalcitrant carbon would not be oxidized even in the absence of the project. It is generally understood that wetlands accumulate and bury allochthonous carbon in sediment deposited on the soil surface (Mitra et al., 2005). This process would presumably sequester some of the allochthonous carbon, in addition to any recalcitrant organic matter, that would otherwise be lost to oxidation in the absence of the project. However, the proportion of allochthonous carbon contained in the Ballona soils was not measured in this study. The Methodology allows for the deduction to be conservatively set at zero in the baseline scenario ($Deduction_{alloch}$ = 0 mt CO_2e). An allochthonous carbon deduction is discussed further in the project scenario sections.

Methane Soil Emissions – $GHG_{BSL\text{-}soil\text{-}CH4}$

Methane soil emissions were not measured in the Ballona Wetlands in this study. Keller et al. (2012) conducted field experiments and found that CH_4 flux in a southern California salt marsh was negligible and consistent with previous work suggesting that at soil salinities above 18 ppt, CH_4 flux is low due to competitive suppression by sulfate reducing microbial activities (Connor et al., 2001; Bartlett & Harriss, 1993; Callaway et al., 2012). Measurements of salinity in tidal marsh habitat of the Ballona Wetlands showed soil salinities above 18 ppt at all sampling locations (Johnston et al., 2011). In addition, the Methodology allows for CH_4 emissions to be conservatively set to zero in the baseline scenario:

$$GHG_{BSL\text{-}soil\text{-}CH4} = 0 \text{ mt } CO_2e$$

Nitrous Oxide Soil Emissions – $GHG_{BSL\text{-}soil\text{-}N2O}$

Nitrous oxide soil emissions were not measured in the Ballona Wetlands in this study. Based on a review of existing studies of nitrous oxide fluxes, Murray et al. (2015) found that estuarine environments are sites of a small positive nitrous oxide flux but are currently a small source of this gas. Future changes in climate along with anthropogenic nitrogen loading are expected to increase N_2O emissions from some estuaries (Murray et al., 2015). Like methane emissions, the Methodology allows emissions of nitrous oxide to be conservatively excluded in the baseline scenario:

$$GHG_{BSL\text{-}soil\text{-}N2O} = 0 \text{ mt } CO_2e$$

Total Baseline Soil Emissions – $GHG_{BSL\text{-}soil}$

The GHG baseline equation for soil emissions:

$$GHG_{BSL\text{-}soil} = A \text{ x } (GHG_{BSL\text{-}soil\text{-}CO2} – Deduction_{alloch} + GHG_{BSL\text{-}soil\text{-}CH4} + GHG_{BSL\text{-}soil\text{-}N2O})$$

For total baseline soil emissions from all strata at Ballona becomes;

$$GHG_{BSL\text{-}soil} = A \text{ x } (GHG_{BSL\text{-}soil\text{-}CO2}), \text{ or}$$

$$GHG_{BSL\text{-}soil} = –165 \text{ mt } CO_2e/yr$$

Total emissions from soil are estimated at –4,950 mt CO_2e during the baseline scenario 30-year period from 2020 to 2050 (Table D-1).

5.3.5.1.3 Total Estimated Baseline GHG Emissions

Combining the estimated emissions for biomass and soil for the Ballona baseline scenario crediting period using the equation:

$$GHG_{BSL} = GHG_{BSL\text{-}biomass} + GHG_{BSL\text{-}soil}\text{, results in,}$$

$$GHG_{BSL} = 0 + (–1{,}650) = –1{,}650 \text{ mt } CO_2e\text{, for years 2020 to 2030}$$

$$GHG_{BSL} = 0 + (–3{,}300) = –3{,}300 \text{ mt } CO_2e\text{, for years 2030 to 2050, and}$$

$$GHG_{BSL} = 0 + (–4{,}950) = –4{,}950 \text{ mt } CO_2e\text{, total for years 2020 to 2050}$$

5.3.5.2 Project Scenario Emissions – GHG_{WPS}

The project scenario in this case study is represented by the Proposed Alternative of the Ballona Project as described by ESA PWA (2012)(Figure 5-2). Emissions in the project scenario are attributed to carbon stock changes in biomass carbon pools, soil processes, and fossil fuel combustion. Emissions are estimated ex ante for the project scenario in order to determine whether the project will produce a net positive NER, as required to generate VCUs. Following project validation, field monitoring and verification of actual emission reductions in the project scenario must be completed at least every five years and before a project will be issued the VCUs for that monitoring period.

Emissions associated with prescribed burning within the project area, if any, would also be included in these calculations, but are not applicable to the Ballona Project.

Emissions in the project scenario are estimated as:

$$GHG_{WPS} = GHG_{WPS\text{-}biomass} + GHG_{WPS\text{-}soil} + GHG_{WPS\text{-}fuel}$$

Where;

GHG_{WPS} = Net CO_2e emissions in the project scenario for all strata between two estimation years, e.g., t_1 and $t_{2;}$ mt CO_2e

$GHG_{WPS\text{-}biomass}$ = [(44/12) x $\Delta C_{WPS\text{-}biomass}$] Emissions from change in biomass in the project scenario summed over all strata between two estimation years, e.g., t_1 and t_2; mt CO_2e

$GHG_{WPS\text{-}soil}$ = Soil GHG emissions during the project scenario summed over all strata between two estimation years, e.g., t_1 and t_2; mt CO_2e

$GHG_{WPS\text{-}fuel}$ = CO_2e emissions from fossil fuel use in the project scenario between two estimation years, e.g., t_1 and t_2; mt CO_2e

5.3.5.2.1 Project Biomass Emissions – $GHG_{WPS\text{-}biomass}$

As in the baseline scenario, net carbon stock change in the biomass carbon pool in the project scenario is estimated as the change in the biomass of trees and shrubs (tree/shrub) and herbaceous (herb) vegetation:

$$\Delta C_{WPS\text{-}biomass} = \Delta C_{WPS\text{-}tree/shrub} + \Delta C_{WPS\text{-}herb}; \text{ mt C}$$

The net carbon stock change in biomass vegetation is estimated using project scenario vegetated habitat areas (strata) shown in Table 5-4 and equations provided in the Methodology. As in the baseline biomass calculations, only habitats that are proposed to be altered by the Ballona Project from the baseline condition (i.e., those that would contribute to changes in the biomass pool) are shown in Table 5-4. Vegetated habitats that are not proposed to be impacted due to the Ballona Project include freshwater/riparian habitats and upland woodland. The table includes transition zone because this habitat does exist in the project scenario. Non-vegetated habitats including subtidal, mudflat, and salt pan are also not included.

The net carbon stock change in trees and shrubs in the project scenario are estimated by:

$$\Delta C_{WPS\text{-}tree/shrub} = (12/44) \text{ x } (\Delta C_{TREE\_PROJ} + \Delta C_{SHRUB\_PROJ}); \text{ mt C}$$

The CDM Tool 14 is used again to estimate ΔC_{TREE_PROJ} and ΔC_{SHRUB_PROJ}, both given as mt CO_2e, for the project scenario.

The net carbon stock change in herbaceous vegetation in the project scenario is estimated using the equation:

$$\Delta C_{WPS\text{-}herb} = (C_{WPS\text{-}herb,\ t2} - C_{WPS\text{-}herb,\ t1});\ \text{mt C}$$

Table 5-4 – Project Scenario Biomass Strata for Vegetated Habitats

Habitat Type	**Area (acres) 2020[1]**	**Area (acres) 2030[2]**	**Area (acres) 2050[2]**
Low Marsh	9	61	52
Mid-Marsh	18	99	91
High Marsh	41	30	28
Seasonal Wetland Area A	11	0	0
Seasonal Wetland Area B	74	0	0
Seasonal Wetland Area C	1	4	3
Brackish Marsh	3	13	12
Upland Coastal Scrub	94	52[3]	44[4]
Upland Grassland/Herbaceous/Dunes	188	104[5]	89[6]
Transition Zone	0	55	62
Total	**439**	**418**	**381**

1 = CDFG (2007) – Existing habitat areas conservatively used as project start
2 = ESA PWA (2012)
3 = Same % of 2030 coastal scrub habitat as in existing condition: 157 acres upland habitat x 33% coastal scrub
4 = Same % of 2050 coastal scrub habitat as in existing condition: 134 acres upland habitat x 33% coastal scrub
5 = Same % of 2030 grassland/herb/dunes as in existing condition: 157 acres upland habitat x 66.2% grassland/herb/dunes
6 = Same % of 2050 grassland/herb/dunes as in existing condition: 134 acres upland habitat x 66.2% grassland/herb/dunes

Project Tree Emissions

The three acres of riparian woodland in the existing wetland condition is not proposed to be impacted by project construction and is proposed to remain at three acres over the course of the project through the year 2100 (ESA PWA, 2012). A Ballona Project revegetation plan was not available at the time of this study and upland woodland habitat is assumed to remain at one acre throughout the project scenario. Since the total existing acreage of woodland is relatively small, four out of 543 acres, and is assumed to remain unchanged in future project habitat projections, the carbon stock change in tree biomass during the project scenario is considered negligible;

$$\Delta C_{TREE\_PROJ} = 0\ CO_2e.$$

<u>Project Shrub Emissions</u>

Like the baseline scenario, carbon stock in shrub biomass in the project scenario is estimated by the CDM Tool 14 for each shrub stratum. Because a revegetation plan for the project scenario was not available at the time of this study, like the baseline scenario, one shrub stratum representing 70% cover is also used for the project shrub biomass estimation using the same equation as in the baseline scenario:

$$C_{SHRUB\_t} = (44/12) \times CF_s \times (1+R_s) \times A_{SHRUB} \times B_{SHRUB} \times CC_{SHRUB};\ mt\ CO_2e$$

The acreage of upland habitat in the project scenario changes from 283 acres in the existing condition (t_1), to 157 acres in the project year 2030 (t_2), and 134 acres in project year 2050 (t_3). Since a revegetation plan was not available, ESA PWA (2012) did not define how much of the upland habitat will be comprised of coastal scrub in future years. Therefore, the same percentage of coastal scrub habitat in the total upland habitat in the existing condition (33%, or 94/283 acres) is assumed for upland habitat in the year 2030 (157 acres x 0.33 = 52 acres) and year 2050 (134 acres x 0.33 = 44 acres). Therefore, the total acreage of shrub habitat in the project scenario (coastal scrub) totals 94 acres in 2020, 52 acres in 2030, and 44 acres in 2050 (Table 5-4).

Applying the same values as in the baseline scenario for average shrub cover of 70% (Johnston et al., 2015), shrub biomass of 5.7 metric ton/acre (Gray and Schlesinger, 1981), and a root/shoot ratio of 1 for all shrub habitat in the project scenario for the years 2020 (t_1), 2030 (t_2), and 2050 (t_3) results in:

C_{SHRUB_t1} = (44/12 CO_2/C) x (0.47 mt C/mt biomass) x (1+1) x (94 ac) x (5.7 mt biomass/ac) x 0.7 = 1,293 mt CO_2e

C_{SHRUB_t2} = (44/12 CO_2/C) x (0.47 mt C/mt biomass) x (1+1) x (52 ac) x (5.7 mt biomass/ac) x 0.7 = 715 mt CO_2e

C_{SHRUB_t3} = (44/12 CO_2/C) x (0.47 mt C/mt biomass) x (1+1) x (44 ac) x (5.7 mt biomass/ac) x 0.7 = 605 mt CO_2e

This results in a net emission of GHG from shrub biomass changes in the project scenario between years 2020 and 2050 of:

$$\Delta C_{SHRUB\_PROJ} = (C_{SHRUB,\,t1} - C_{SHRUB,\,t3}) = 1{,}293 - 605 = 688 \text{ mt } CO_2e$$

The positive value for shrub biomass is a loss of 688 mt CO_2e and means that as the acreage of shrub habitat is reduced over time, the carbon in the shrub biomass is oxidized back to the atmosphere. Most of the loss occurs by the year 2030 due to the reduction in coastal scrub habitat following restoration construction.

Project Herb Emissions

The net carbon stock change in herbaceous vegetation in the project scenario between the years t_1 and t_2 and between years t_2 and t_3 is calculated using the equation provided in the Methodology and defined in the baseline scenario calculations:

$$\Delta C_{WPS\text{-}herb} = (C_{WPS\text{-}herb,\ t1} - C_{WPS\text{-}herb,\ t2})$$

As in the baseline scenario, the majority of habitat area of the restored Ballona Wetlands is dominated by herbaceous vegetation including *S. pacifica* (low marsh, mid-marsh, high marsh, transition zone, and seasonal wetland Area B) and native and non-native grasses and herbs (brackish marsh, seasonal wetland Areas A and C, and upland grassland/herbaceous/dunes). Transition zone habitat occurs only in the project scenario. The same default factor of 300 g C/m^2 used in the baseline scenario is applied to all herbaceous biomass in the project scenario.

Table 5-4 presents the project scenario herbaceous habitat areas by year which total 345 acres in 2020, 366 acres in 2030, and 337 acres in 2050. The acreage of herbaceous vegetation initially increases from 2020 to 2030 following restoration activities, then decreases by 2050 due primarily to sea level rise converting vegetated habitat to mudflat.

Therefore, the herbaceous biomass stock during the project scenario is:

$$C_{WPS\text{-}herb,\ t1} = 345 \text{ ac x } 300 \text{ g C/m}^2 \text{ x } 0.004 = 414 \text{ mt C in the year 2020}$$

$$C_{WPS\text{-}herb,\ t2} = 366 \text{ ac x } 300 \text{ g C/m}^2 \text{ x } 0.004 = 439 \text{ mt C in the year 2030, and}$$

$$C_{WPS\text{-}herb,\ t3} = 337 \text{ ac x } 300 \text{ g C/m}^2 \text{ x } 0.004 = 404 \text{ mt C in the year 2050}$$

Where 0.004 is a conversion factor (m^2 to acre and g to mt).

And the total change in herbaceous biomass during the project scenario crediting period (t_1 to t_3) is:

$$\Delta C_{WPS\text{-}herb} = C_{WPS\text{-}herb,\ t1} - C_{WPS\text{-}herb,\ t3} = 414 - 404 = 10 \text{ mt C,}$$

Converting C to CO_2e becomes:

$$\Delta C_{WPS\text{-}herb} = (44/12) \text{ x } 10 \text{ mt C} = 37 \text{ mt } CO_2\text{e}$$

Total Project Scenario Biomass Emissions

The final estimate of greenhouse gas emissions due to biomass changes in the project scenario between years t_1 and t_3 is:

$$\Delta C_{WPS\text{-}biomass} = \Delta C_{WPS\text{-}tree/shrub} + \Delta C_{WPS\text{-}herb}$$

$$\Delta C_{WPS\text{-}biomass} = (0 + 688) + 37 = 725 \text{ mt } CO_2e$$

The positive value means that 725 metric tons of CO_2e emissions are lost to the atmosphere from biomass changes between the project scenario time period t_1 to t_3, and:

$$GHG_{WPS\text{-}biomass} = 725 \text{ mt } CO_2e$$

5.3.5.2.2 Project Soil Emissions – $GHG_{WPS\text{-}soil}$

The net GHG emissions from soil in the project scenario are estimated for each soil strata at time t with the same equation as defined in the baseline calculations:

$$GHG_{WPS\text{-}soil} = A \text{ x } (GHG_{WPS\text{-}soil\text{-}CO2} – Deduct_{alloch} + GHG_{WPS\text{-}soil\text{-}CH4} + GHG_{WPS\text{-}soil\text{-}N2O})$$

The same habitat strata used in the baseline scenario represents the strata for the soil emission calculations in the project scenario, with the addition of transition zone habitat to the project scenario strata. Table 5-5 shows the estimated habitat (strata) acreages for the project scenario for the years 2020 (t_1), 2030 (t_2), and 2050 (t_3).

Table 5-5 – Project Scenario Soil Strata

Habitat Type	2020 Post-Restoration Area (acres)[1]	2030 Area (acres)[1]	2050 Area (acres)[1]
Low Marsh	49	61	52
Mid-Marsh	103	99	91
High Marsh	34	30	28
Seasonal Wetland Area A	0	0	0
Seasonal Wetland Area B	0	0	0
Seasonal Wetland Area C	4	4	3
Salt Pan	20	19	19
Brackish Marsh	13	13	12
Mudflats	40	47	82
Transition Zone	51	55	62
Upland	171	157	134
Total	**485**	**485**	**483**

1 = ESA PWA (2012)

Carbon Dioxide Soil Emissions - $GHG_{WPS\text{-}soil\text{-}CO2}$

The first source of soil emissions in the project scenario is carbon dioxide; $GHG_{WPS\text{-}soil\text{-}CO2}$. As described for the baseline scenario, due to the extended period since these soils have been inundated by tides, the drained habitats of the existing Ballona Wetlands are considered to have negligible CO_2 emissions from the soil.

To calculate soil CO_2 emission reductions (sequestration), the project proponent can collect field samples, use peer-reviewed published values, or the default value of 1.46 mt C/ha/yr provided in the Methodology. Carbon sequestration rates estimated for restored Ballona habitats in the previous chapter of this study are used for the project scenario strata shown in Table 5-5. Rates are presented as an average value for each habitat type (e.g., low, mid-, high marsh) along with a range of low and high values. Therefore, the GHG emission reductions and removals calculations for the project scenario are presented as average, low range and high range values.

The carbon sequestration rates are multiplied by the area of each habitat of the project scenario and converted from mt C/yr to mt CO_2e/yr. These calculations are presented in Table D-2 of Appendix D. The results show that the CO_2 emission reduction rate for the project scenario averages 407 and 430 mt CO_2e/yr for the time periods 2020 to 2030 and 2030 to 2050, respectively. Estimated low and high emission reduction rates ranged from 251 to 758 and 260 to 819 mt CO_2e/yr, also respectively.

Table D-2 shows the calculations of the CO_2e emission reductions for each stratum (habitat type) in the project scenario for the years 2020 to 2030 and 2030 to 2050. Unlike project strata used to calculate biomass, the soil strata acreages for the year 2020 are the post-restoration acreages and represent the project scenario acreages for the time period 2020 to 2030. This is because sea level rise will gradually change the habitat acreages from 2020 to 2030 and using the post-restoration habitat acreages is more conservative than using the 2030 acreages for the 2020 to 2030 time period. The post-restoration wetland has less acreage of habitats with the highest carbon sequestration rates (low marsh and mudflat) than in the year 2030 and therefore results in less (more conservative) overall sequestration in the project scenario than the 2030 habitat acreages would provide. Similarly, the 20-year period 2030-2050 is represented by the 2030 habitat acreages because they contribute less overall sequestration than the 2050 habitat acreages. This provides a conservative estimate of carbon emission reductions over each time period.

The Methodology requires project proponents to estimate a deduction to carbon sequestration calculations to account for allochthonous carbon ($Deduct_{alloch}$) unless it can be demonstrated that the allochthonous carbon would have been returned to the atmosphere in the absence of the project. Because the amount of allochthonous carbon was not measured in the

Ballona soils, a standard deduction for allochthonous carbon, provided by the Methodology, is applied to the calculations of annual carbon emission reductions in this section.

The Methodology provides a generalized estimate for deductions of allochthonous carbon based on the relationship: $y = 174.2\ x^{-1.185}$ (Emmer et al., 2015), where y is the percent allochthonous carbon in the soil and x is the %C at the soil surface. Surface soils are used because allochthonous carbon is deposited at the surface (Emmer et al., 2015). The Methodology does not define a depth for "surface soils". The best representation of marsh surface soil carbon content in this study can be estimated by averaging the samples from the 0-2 centimeter soil depth of all low marsh cores. Low marsh habitat in the existing Ballona has an average surface soil %C of approximately 10%, resulting in an allochthonous carbon deduction of approximately 11%, using the relationship from Emmer et al. (2015) above. Therefore, a reduction of 11% in annual CO_2e emission reductions for allochthonous carbon is included in the calculations for Ballona Project tidal habitats shown in Table D-2. Table D-2 presents the annual CO_2e emission reduction (mt CO_2e/yr) for each habitat strata by multiplying the carbon sequestration rates determined in a previous chapter of this study by the area of each habitat in the project scenario (ESA PWA, 2012) and deducting 11% for the allochthonous carbon content.

During the project scenario time period 2020-2030 (t_1 to t_2) the average CO_2 emission reduction estimate is 4,075 mt CO_2e, with low range and high range estimates of 2,509 and 7,577 mt CO_2e, respectively. During the project scenario time period 2030-2050 (t_2 to t_3) the average CO_2 emission reduction estimate is 8,602 mt CO_2e, with low range and high range estimates of 5,202 and 16,371 mt CO_2e, respectively. For the entire project scenario crediting period the total average emission reduction for soil CO_2 is 12,677 mt CO_2e with 7,711 and 23,948 mt CO_2e as low and high estimates, respectively (Table D-2). Emission reductions are the same as negative emissions:

$$GHG_{WPS\text{-}soil\text{-}CO2} = -12{,}677 \text{ mt } CO_2e \text{ (average); } -7{,}711 \text{ mt } CO_2e \text{ (low range); and } -23{,}948 \text{ mt } CO_2e \text{ (high range).}$$

The negative emission values represent soil carbon sequestration.

Methane Soil Emissions - $GHG_{WPS\text{-}soil\text{-}CH4}$

Methane soil emissions were not measured in the Ballona Wetlands in this study. As in the baseline scenario, because soil salinities in the habitats of Ballona were found to be above 18 ppt at all sampling locations (Johnston et al., 2011), emission of methane in the project scenario of the Ballona Wetlands is considered zero:

$$GHG_{WPS\text{-}soil\text{-}CH4} = 0 \text{ mt } CO_2e$$

Nitrous Oxide Soil Emissions - $GHG_{WPS\text{-}soil\text{-}N2O}$

Nitrous oxide soil emissions were not measured in the Ballona Wetlands in this study. Nitrous oxide emissions only need to be accounted for in the VCS Methodology in cases where the water table is lowered. For projects in which the water table is being lowered in the project scenario the Methodology provides default factors to estimate N_2O emissions for various wetland systems. The default factor for a tidal marsh system is determined from the equation:

$$GHG_{WPS\text{-}soil\text{-}N2O} = 0.000487 \text{ mt } N_2O\text{/ha/yr x } N_2O\text{-GWP}$$

Where N_2O-GWP is the global warming potential of nitrous oxide. The IPCC Fourth Assessment Report on Climate Change (2007) provides a GWP of 298 for N_2O over a 100-year time horizon while the second Methodology assessment report (DNV GL, November 6, 2015) provides a GWP of 310 from an unspecified IPCC source.

The water table is not anticipated to be lowered due to the Ballona Project, therefore, nitrous oxide emissions for the Ballona project scenario can be reported as zero:

$$GHG_{WPS\text{-}soil\text{-}N2O} = 0 \text{ mt } CO_2e$$

Total Project Scenario Soil Emissions

The total GHG soil emissions from all strata for the project scenario crediting period from 2020 to 2050 are therefore:

$GHG_{WPS\text{-}soil}$= A x ($GHG_{WPS\text{-}soil\text{-}CO2}$ – $Deduct_{alloch}$ + $GHG_{WPS\text{-}soil\text{-}CH4}$ + $GHG_{WPS\text{-}soil\text{-}N2O}$)

$GHG_{WPS\text{-}soil}$ = A x ($GHG_{WPS\text{-}soil\text{-}CO2}$ – $Deduct_{alloch}$)

$GHG_{WPS\text{-}soil}$ = –12,677 mt CO_2e (average)

–7,711 mt CO_2e (low range), and

–23,948 mt CO_2e (high range).

5.3.5.2.3 Project Fossil Fuel Emissions – $GHG_{WPS\text{-}fuel}$

Emissions from the use of construction vehicles and mechanical equipment in restoration projects can be estimated in the Methodology by applying CDM Tool – *Estimation of GHG emissions related to fossil fuel combustion in A/R CDM project activities*. The tool is designed for afforestation and reforestation project activities, but may be used for the purposes of the VCS tidal marsh restoration Methodology.

The CDM Tool provides equations to estimate fossil fuel combustion from sources of construction vehicles and equipment. However, to utilize the equations requires specific project information including, but not limited to, vehicle types, load capacities, energy consumption of vehicle types, emission factors, number of vehicles, hours of vehicle use, and fuel types combusted. Construction information for the Ballona Project was not available at the time of this study, although relevant information is anticipated in the draft EIR when available. Calculating accurate greenhouse gas emissions from the construction of the Ballona Project cannot be completed without project specific information and is beyond the scope of this study.

For the purposes of this study, the GHG emissions associated with construction of the Ballona Project are estimated using construction emissions estimates from a similar tidal marsh restoration project, the San Elijo Lagoon Restoration Project. The San Elijo Lagoon is a southern California coastal tidal marsh similar to the Ballona Wetlands and located approximately 95 miles southeast of Ballona. The San Elijo Project consists of 960 acres of tidal marsh and upland habitat similar in composition to Ballona's approximately 550 acres of habitat. Like the Ballona Project, the preferred alternative of the San Elijo Restoration (Alternative 1B) was designed to create a more connected system of habitat types through modifications to channels and habitat areas with creation of secondary channels to increase tidal inundation, resulting in an increase in open water/tidal channels, tidal marsh, mudflat, and transitional habitat compared to existing conditions (SELRP Final EIR/EIS, 2016).

However, the San Elijo Project includes extensive dredging of a large central tidal basin to improve lagoon hydraulics, hydrologic connectivity, and sediment supply. The Ballona Project does not include an equivalent large dredging component. The San Elijo Project EIR estimates emissions for construction equipment including pumping large quantities of dredge material to re-use areas of the project, a component also not included in the Ballona Project. If the emissions associated with dredging and pumping dredge material are removed from the estimate, the total emissions for construction equipment, mobilization, demobilization, and site preparation total approximately 3,700 mt CO_2e over the course of 36-months of active construction. Even though the San Elijo Project area is larger than the Ballona Project area, if a 3-year time frame and similar construction emissions are conservatively assumed for the Ballona Project, the total construction fossil fuel emissions estimate is:

$$GHG_{WPS\text{-}fuel} = 3{,}700 \text{ mt } CO_2e$$

If the Ballona Project construction is completed in less than 36-months, the fossil fuel emission estimate should be revised accordingly.

5.3.5.2.4 Total Estimated Project GHG Emissions

The total emissions for biomass, soil, and fossil fuel use for the Ballona Project scenario from 2020 to 2050 are estimated for the average, low range, and high range carbon sequestration rates using the equation:

$$GHG_{WPS} = GHG_{WPS\text{-}biomass} + GHG_{WPS\text{-}soil} + GHG_{WPS\text{-}fuel}$$

GHG_{WPS} = 725 + (–12,677) + 3,700 = –8,252 mt CO_2e, at the average carbon sequestration rates

GHG_{WPS} = 725 + (–7,711) + 3,700 = –3,286 mt CO_2e, at the low range carbon sequestration rates

GHG_{WPS} = 725 + (–23,948) + 3,700 = –19,523 mt CO_2e, at high range carbon sequestration rates

Even with the loss of biomass over the project scenario (725 mt CO_2e) and the construction fossil fuel emissions (3,700 mt CO_2e), the project scenario results in emission reductions over the 30-year crediting period.

5.3.5.3 Leakage - GHG_{LK}

The Ballona Project as described by ESA PWA (2012) does not include or support any activities that will cause leakage by causing additional GHG emissions outside the project area or by displacing land use activities to other areas. For projects that continue the pre-project land use and that meet the applicability conditions of the Methodology, activity-shifting leakage, market leakage, and ecological leakage may be assumed to be zero;

$$GHG_{LK} = 0 \text{ mt } CO_2e.$$

5.3.5.4 Net GHG Emission Reductions and Removals - NER

Net emission reductions are calculated for both the baseline and project scenarios for the first 30-year crediting period (2020-2050) and for the following 50-year period (2050-2100) based on habitat area projections provided by ESA PWA (2012).

NER – 2020 to 2050

The total net GHG emission reductions and removals associated with the Ballona Project for the 30-year time period from 2020 to 2050 are:

$$NER = GHG_{BSL} – GHG_{WPS} – GHG_{LK}$$

Where the baseline scenario GHG emissions from t_1 to t_3 are:

$$GHG_{BSL} = –4{,}950 \text{ mt } CO_2e$$

And the project scenario GHG emissions from t_1 to t_3 are:

GHG_{WPS} = –8,252 mt CO_2e (average), –3,286 mt CO_2e (low range) and –19,523 mt CO_2e (high range).

And GHG emissions from leakage are:

$$GHG_{LK} = 0 \text{ mt } CO_2e$$

Results in the following NER values over a 30-year time period:

NER = –4,950 – (–8,252) – 0 = 3,302 mt CO_2e, average carbon sequestration rates

NER = –4,950 – (–3,286) – 0 = –1,664 mt CO_2e, low range carbon sequestration rates

NER = –4,950 – (–19,523) – 0 = 14,573 mt CO_2e, high range carbon sequestration rates

The NER value of 3,302 mt CO_2e for estimated average carbon sequestration rates is a total reduction in emissions over the crediting period due to the project. This means that over the 30-year crediting period of the Ballona Project, after accounting for baseline net emission removals of 4,950 mt CO_2e from 2020 to 2050, the project would still reduce total emissions by 3,302 mt CO_2e at average carbon sequestration rates. Based on the range of carbon sequestration rates presented in this chapter to account for uncertainties, it is estimated that net emission reductions from the project could be as high as 14,573 mt CO_2e but could result in a negative NER of –1,664 mt CO_2e at the low range estimate, representing net positive GHG emissions from the project.

<u>NER – 2050 to 2100</u>

To determine the project's NER for a time period beyond the first 30-year crediting period, the calculations presented above are performed for the time period from 2050 (t_3) to 2100 (t_4) using habitat acreage projections for the year 2100 provided in ESA PWA (2012). ESA PWA (2012) does not provide habitat acreage projections beyond the year 2100. The calculations of NER for both baseline and project scenarios for years 2050 (t_3) and 2100 (t_4) are provided in Appendix D and are summarized in Table D-5. For the 50-year period between 2050 and 2100 the NER is calculated as:

NER = 13,457 mt CO_2e for average carbon sequestration rates

NER = 4,502 mt CO_2e, for low range carbon sequestration rates, and

$$NER = 33{,}748 \text{ mt } CO_2e\text{, for high range carbon sequestration rates}$$

NER – 2050 to 2100

The total net emission reductions (NER_T) for the 80-year project period between 2020 (t_1) and 2100 (t_4) can be shown by adding the NER values for the 2020-2050 and 2050-2100 periods:

$$NER(_T) = NER(t_1\text{-}t_3) + NER(t_3\text{-}t_4)$$

$$NER(_T) = 3{,}302 + 13{,}457 = 16{,}759 \text{ mt } CO_2e \text{ for average carbon sequestration rates}$$

$$NER(_T) = –1{,}664 + 4{,}502 = 2{,}838 \text{ mt } CO_2e \text{ for low range carbon sequestration rates}$$

$$NER(_T) = 14{,}573 + 33{,}748 = 48{,}321 \text{ mt } CO_2e \text{ for high range carbon sequestration rates}$$

Similarly, the same NER results can be presented by adding total GHG emissions by source. For the project scenario:

$$GHG_{WPS} = GHG_{WPS\text{-}biomass} + GHG_{WPS\text{-}soil} + GHG_{WPS\text{-}fuel}$$

$GHG_{WPS} = 1{,}073 + (–34{,}732) + 3{,}700 = –29{,}959$ mt CO_2e, at the average carbon sequestration rates

$GHG_{WPS} = 1{,}073 + (–20{,}811) + 3{,}700 = –16{,}038$ mt CO_2e, at the low range carbon sequestration rates

$GHG_{WPS} = 1{,}073 + (–66{,}294) + 3{,}700 = –61{,}521$ mt CO_2e, at high range carbon sequestration rates

For the baseline scenario:

$$GHG_{BSL} = GHG_{BSL\text{-}biomass} + GHG_{BSL\text{-}soil}, + GHG_{WPS\text{-}fuel}$$

$GHG_{BSL} = 0 + (–13{,}200) + 0 = –13{,}200$ mt CO_2e, total for years 2020 to 2050

NER is calculated as:

$$NER = GHG_{BSL} - GHG_{WPS} - GHG_{LK}$$

NER = –13,200 – (–29,959) – 0 = 16,759 mt CO_2e for average carbon sequestration rates

NER = –13,200 – (–16,038) – 0 = 2,838 mt CO_2e for low carbon sequestration rates

NER = –13,200 – (–61,521) – 0 = 48,321 mt CO_2e for high carbon sequestration rates

These results show that over the 80-year project period calculated from 2020 (t1) to 2100 (t_4) the NER($_T$) is estimated at 16,759 mt CO_2e with a range of 2,838 mt CO_2e at the low end to a high value of 48,321 mt CO_2e.

The Methodology requires that the NER value be corrected for uncertainty by estimating the total uncertainty in the calculation of emissions in baseline and project scenarios. However, the methodology allows proponents to assume zero uncertainty if conservative estimates have been used in the carbon stock change calculations. For the purposes of this case study, uncertainty is assumed to be zero. In addition, the NER calculations are presented as a range of values to account for uncertainties in carbon sequestration rates and changes in soil carbon pools. Therefore, no deductions from the NER values calculated in this case study are applied due to uncertainties.

5.3.5.5 Calculation of Verified Carbon Units (VCU)

In order to calculate the total number of verified carbon units (VCUs) that may be issued for the Ballona Project, the number of buffer credits which must be deposited in a buffer account is calculated. These non-tradable buffer credits are deposited in a buffer account to cover the non-permanence risk associated with restoration projects. The number of buffer credits is based on the net change in carbon stocks between two estimation years.

$$VCU = NER – Buffer$$

Where;

VCU = Number of Verified Carbon Units

NER = Total net GHG emission reductions from the project activity between two estimation years

Buffer = NER x Buffer%; Number of buffer credits to be contributed to a buffer account, where,

Buffer% = Percentage of buffer credits to be contributed to buffer account

The percentage of buffer credits to be contributed to the buffer account must be determined by applying the latest version of the *VCS AFOLU Non-Permanence Risk Tool* (Risk Tool). Risk factors are assessed over a period of 100 years and are classified into three categories: internal risks, external risks, and natural risks. Each category presents a series of scored risk factors to be assessed by the project proponent. Where a risk factor applies to the project, the score of that factor is added to the overall risk rating score. The list of risk factors can be reviewed in the Risk Tool. Assessing the Ballona Project risk factors presented in the Risk Tool resulted in the following scores:

1) Internal Risk Score -2
2) External Risk Score 3
3) Natural Risk Score 0
4) Total Risk Score 1

The total risk score, 1 in this case study, is then converted to a percent (1%) and becomes the value for Buffer%. However, per VCS rules, the minimum risk rating cannot be lower than 10. The Buffer% value for the Ballona Project is therefore 10%.

The total buffer credits for the 30-year period from t_1 to t_3 (where 1 mt CO_2e = 1 credit) is calculated as:

Buffer = 3,302 credits x 10% = 330 credits for average carbon sequestration rates,

Buffer = 0 credits for the low range carbon sequestration rates because emission reductions are negative, and

Buffer = 14,573 credits x 10% = 1,457 credits for high range carbon sequestration rates.

And the calculation of VCUs for the Ballona Project for the 30-year estimation period from t_1 to t_3 is calculated as:

$$VCU = NER – Buffer$$

VCU = 3,302 – 330 = 2,972 credits for the average value

VCU = 0 credits for the low range, and

VCU = 14,573– 1,457 = 13,116 credits for the high range

These credits represent an average of approximately 99 VCUs, 0 VCUs, and 437 VCUs per year for the average, low, and high range values, respectively, for the 30-year time period from 2020 to 2050.

The total buffer credits for the 80-year estimation period from t_1 to t_4 (where 1 mt CO_2e = 1 credit) is calculated as:

$$Buffer = NER_{(T)} \times Buffer\% =$$

16,759 credits x 10% = 1,676 buffer credits, for average carbon sequestration rates

2,838 credits x 10% = 284 buffer credits for low range carbon sequestration rates

48,321 credits x 10% = 4,832 buffer credits, for high range carbon sequestration rates

And the calculation of VCUs for the Ballona Project for the 80-year estimation period from 2020 (t_1) to 2100 (t_4) is calculated as:

$$VCU = NER_{(T)} – Buffer$$

VCU = 16,759 – 1,676 = 15,083 credits for the average value

VCU = 2,838 – 284 = 2,554 credits for the low range, and

VCU = 48,321 – 4,832 = 43,489 credits for the high range

These credits represent an average of approximately 188 VCUs, 31 VCUs, and 543 VCUs per year for the average, low, and high range values, respectively, for the time period from 2020 to 2100.

If a subsequent risk assessment of a project shows a more favorable outcome for the project proponent than the previous one, buffer credits may be recovered from the buffer account. However, at the end of the crediting period, all buffer credits will expire.

5.3.6 Monitoring

As discussed previously, projects must perform monitoring of all carbon pools at least every five years during the crediting period. VCUs generated during the monitoring period will not be issued by the VCS until the results of the monitoring event have been verified.

Additional monitoring and preparation of a Monitoring Plan are outside the scope of this study. The Methodology provides direction on the requirements of the monitoring plan, data and parameters to be monitored, and a Monitoring Plan template can be found on the VCS website. Ex post estimates of GHG_{WPS} are based on the monitoring results and will update ex ante estimates. Uncertainties related to the quantification of GHG emission reductions and removals should be adjusted as necessary based on monitoring results. The number and boundaries of the strata defined ex ante shall also be changed during the crediting period based on monitoring results.

5.3.7 Hypothetical High Carbon Sequestration Restoration Alternative

The proposed restoration alternative of the Ballona Wetlands Restoration Project, representing the project scenario in this chapter, was designed to balance habitat restoration potential with environmental and engineering considerations (ESA PWA, 2012). Increasing carbon sequestration is not a stated goal of the project. However, if increasing carbon sequestration was a key objective of a restoration project, adjustments in habitat proportions could be made to achieve this goal. This section presents a hypothetical high-carbon sequestration alternative design of the Ballona Project intended to demonstrate the potential to substantially increase carbon sequestration of the wetland. The hypothetical alternative presented here is not based on any analyses of engineering or sea level rise considerations, but is simply intended to demonstrate the effect of adjusting habitat proportions to achieve more carbon sequestration. The hypothetical alternative contains double the areas of low, mid-, and high marsh habitats as in the proposed alternative for each time period (2020, 2030, 2050, and 2100), eliminates transition zone habitat, and reduces the area of upland habitat accordingly to keep total habitat area equal to the proposed alternative. All other habitat areas (seasonal wetland, salt pan, brackish marsh, and mudflats) are kept at the same areas as in the proposed alternative to maintain habitat diversity (Table 5-6).

Table 5-6 - Habitat Areas for Hypothetical Restoration Alternative

Habitat Type	2020 Post-Restoration Area (acres)	2030 Area (acres)	2050 Area (acres)	2100 Area (acres)
Low Marsh	98	122	104	64
Mid-Marsh	206	198	182	191
High Marsh	68	60	56	42
Seasonal Wetland Area A	0	0	0	0
Seasonal Wetland Area B	0	0	0	0
Seasonal Wetland Area C	4	4	3	3
Salt Pan	20	19	19	14
Brackish Marsh	13	13	12	13
Mudflats	40	47	82	146
Transition Zone	0	0	0	0
Upland	36	22	25	0
Total	**485**	**485**	**483**	**473**

Assuming that biomass emissions ($GHG_{biomass}$) and fossil fuel emissions (GHG_{fuel}) are the same as for the proposed alternative, the only difference in net emission reductions between the proposed alternative and the hypothetical alternative are from soil sequestration (GHG_{soil}). Biomass emissions are assumed to be the same between these two alternatives because both have equal loses of vegetated habitat over time, although from different habitat types. Fossil fuel emissions are also assumed to be the same even though changing the restoration design could change the amount of excavation required. The construction emissions for the proposed alternative are approximated using emission estimates from another tidal marsh restoration project and could also be applicable to the hypothetical alternative.

Table D-6 in Appendix D presents the calculations of soil carbon sequestration by habitat type for the areas of the hypothetical alternative shown in Table 5-6 over the 80-year project life. Doubling the areas of low, mid-, and high marsh habitats and reducing transition zone and upland habitats results in an increase in average total carbon sequestration of 18,881 mt CO_2e over the 80-year project life, with a range of 9,037 – 41,671 mtCO_2e. With emissions from biomass and fossil fuel being the same between these alternatives, the hypothetical high-carbon sequestration alternative would increase total net emission reductions over the proposed alternative by an average of 18,881 mt CO_2e (range: 9,037 – 41,671 mtCO_2e).

If the hypothetical high-carbon sequestration alternative was implemented instead of the proposed alternative, with 10% buffer credits withheld, an additional net of 16,993 carbon credits (8,133-37,504) would be generated for the project over the years 2020 to 2100. The proposed alternative is estimated to generate 15,083 credits (2,544 – 43,489) and the hypothetical high-carbon alternative is estimated to generate approximately double the amount at 32,076 credits (10,677 – 80,993). This alteration to the designed habitat proportions may not be feasible for a number of reasons, but these calculations demonstrate how the number of carbon credits generated over the project life could potentially be doubled. These credits represent an average of approximately 401 VCU/year, 133 VCU/year, and 1,012 VCU/year for the average, low, and high range values, respectively, for the time period from 2020 to 2100.

5.4 DISCUSSION

Tidal marsh restoration as climate change mitigation is a relatively new approach that many believe shows great promise due to the high carbon sequestration rates and large soil carbon storage capacity associated with tidal marshes. There is very little evidence showing that tidal marsh restoration projects are viable components of carbon offset markets, however, there is now sufficient knowledge available to justify taking actions towards the inclusion of coastal ecosystem carbon pools and their sequestration potential in greenhouse gas accounting (Crooks et al., 2011). Expert assessments of the available knowledge suggest that the economic, ecological, and climate mitigation potential of tidal marsh projects is strong (Emmet-Mattox et al., 2010; Crooks et al., 2010). This study is conducted to inform the issue by presenting the Ballona Wetlands Restoration Project as a case study in the *VCS Methodology for Tidal Wetland and Seagrass Restoration VM0033.* The overall objective of this study is to address the question: *Can California tidal marsh restoration projects produce enough carbon credits to be viable components of a carbon market?* This Discussion will present an evaluation of the overall application of the Methodology process and assess the feasibility of the Ballona Project in a carbon trading market.

5.4.1 Evaluation of VCS Methodology Process

The results of this evaluation are generally consistent with the findings of the two assessment reports (Environmental Services, Inc., 2015; DNV GL, Inc., 2015) that the Methodology provides mostly clear, appropriate and adequate procedures and parameters for calculating emissions. However, their findings did not appear to be based on any case studies or real data applied to the Methodology. This study found that when project data is available, via field measurements, default factors, or reference site data, the procedures to calculate net emission reductions is fairly straightforward. However, in some cases the required project data was not readily available and no default values are provided. Also, application of some of the tools and modules, which are often designed specifically for Afforestation/Reforestation (A/R) projects, is challenging and burdensome.

For instance, to calculate tree and shrub biomass the VCS directs users to a CDM tool produced by the United Nations for A/R projects. The CDM tool consists of multiple procedures and equations that require species-specific data for a variety of biometric parameters that may not be readily available to many project proponents. These biometric parameters include biomass content, biomass expansion factors, stem volumes, wood densities, root-shoot ratios, and allometric equations. These procedures and equations appear intended for A/R projects consisting of large areas dominated by few tree species such as in commercial forestry. Obtaining all the required species-specific data for a variety of tidal marsh species would require extensive field measurements and literature and data searches. Rather than using a United Nations tool designed for large A/R projects, the VCS should provide a module that provides procedures and equations specific to tidal marshes. The process would be greatly simplified for project proponents already burdened by extensive field monitoring requirements if data collection were limited to the area and total crown cover of each biomass stratum and default factors for other biometric parameters were provided by the VCS for common tidal marsh species of shrubs and trees. For example, the default factors provided for herbaceous vegetation biomass (300 g C/m^2) and a carbon fraction for shrubs (0.47 mt C/mt biomass) are helpful.

For project validation and for the baseline scenario the Methodology allows the use of published reference data or a default value to estimate soil carbon sequestration. However, in order to be issued carbon credits project proponents must conduct regular field monitoring throughout the project life. The number of field samples per stratum required by the Methodology for project monitoring may be limiting for many projects, particularly for soil carbon content which requires substantial laboratory analyses to determine bulk density and soil organic carbon content. For calculating carbon sequestration rates the VCS estimate of approximately 10-20 samples required per stratum (Emmer et al., 2015) would likely be onerous to most projects. In the Ballona Project case study, more than 10 strata are identified and would therefore require between 100 to 200 field samples each monitoring period. Perhaps the required number of samples per stratum could be applied to only major strata of a project, such as low, mid-, and high marsh habitats, and require fewer samples for less important strata. The number of samples required per stratum by the Methodology should be reevaluated with undue burden to project proponents in mind.

In addition, other Methodology tools are cumbersome in practice, including VCS Module – *Methods to Project Future Conditions* and the CDM – *Combined Tool to Identify Baseline Scenario and Demonstrate Additionality in A/R CDM Project Activities*. As with the CDM Tool 14, these tools appear to be designed for large A/R projects that include other land uses such as commercial and/or agricultural. The VCS Module to project future conditions is a 30-page document complete with multiple steps designed to estimate future values of a wide range of variables. The module seeks to define project variables in different categories and classes and determine future scenarios, temporal characters, and drivers and agents of each variable to be projected. Utilization of this module for the Ballona Project is found to be cumbersome and unclear. After much evaluation of the module, it is determined, unsurprisingly, that for a tidal marsh restoration project such as Ballona, projections of future variables should be made from the existing or expected future trajectory of the variable. In addition, the Methodology requires users to produce maps of current and plausible future land use changes, maps of current and historical tidal barriers and drainage layouts, and perform quantitative hydrological modeling on current hydrological functioning. For proponents of small tidal restoration projects, these requests seem overly burdensome. The exception is the requirement for mapping sea level rise within the project area, which is highly relevant to estimating strata areas used in the emission calculations. For simplicity, the Methodology could allow proponents of tidal marsh restoration projects to forego engaging with the module and simply state in the text that future projections should use published data from reference sites with similar trajectories expected in the project or baseline scenarios.

Similarly, the CDM Combined Tool process is convoluted and filled with steps not likely to be required in a tidal marsh restoration project, where the baseline scenario is typically the existing degraded marsh. Exceptions would be if there were commercial or agricultural activities occurring within the project area.

Furthermore, the Methodology requires users to calculate the level of uncertainty associated with all emission estimates. Calculating uncertainty for each GHG source or sink for both the baseline and project scenarios would be time consuming and the process confusing and burdensome for many project proponents. The Methodology does allow proponents to assume uncertainty is zero if they can justify that conservative values are being used in emission calculations. This option appears best for many tidal marsh restoration projects and the Methodology could assist these proponents by providing, where possible, default factors or methods accepted as “conservative” by the VCS.

Lastly, the Methodology states that project monitoring is required but is not clear on important specifics. Pages of tables in the Methodology provide basic information on data and parameters required at validation and for monitoring, but give few specifics on frequency. For the biomass parameters ΔC_{TREE_PROJ} and ΔC_{SHRUB_PROJ} the AR-Tool 14 states that field measurements are required every five years since the year of the initial verification. However, no mention appears in the Methodology of monitoring frequency for determining strata areas or soil parameters (e.g., carbon sequestration). The First Assessment Report (Environmental Sciences, Inc., 2015) states that "the methodology element notes appropriately that data and parameters for leakage, proxy areas, and project accounting areas must be measured at a minimum of every 5 years or after a significant event that changes carbon stocks", but this is not clearly identified in the Methodology. Personal communication with authors of the Methodology from Restore America's Estuaries (RAE) and Terracarbon confirmed that monitoring for all carbon stocks must be completed within five years of the project start date and at least every five years following the initial verification. Clarification within the Methodology of monitoring frequency requirements for all parameters is needed.

5.4.2 Feasibility of the Ballona Project in a Carbon Market

This study found that applying the Ballona Wetlands Restoration Project case study to the VCS Methodology resulted in a positive net emissions reduction between the project and baseline scenarios over a 30-year crediting period and over an 80-year project life. However, the question posed in this chapter, *Can California tidal marsh restoration projects produce enough carbon credits to be viable components of a carbon market?*, depends on additional factors, including the number of carbon credits generated by the project and the market value of those credits.

This study estimates that over the initial 30-year crediting period the Ballona Project, accounting for construction emissions and buffer adjustments, will generate carbon credits in the range of 0 to 13,116 with an average estimate of 2,972 (99 credits/year). For the 80-year period a credit range is estimated of 2,554 to 43,489 with an average of 15,083 (188 credits/year). The price of a carbon credit in the California market in early 2017 was approximately $13.50 and had been trading between approximately $12 and $13 for the previous two years. At the price of

$13.50 per credit the Ballona Project would generate approximately $1,337/year, with a range of $0 to $5,902/year, during the initial 30-year crediting period. Over the 80-year life of the project, the project would generate approximately $2,538/year, with a range of $420/year to $7,338/year. This is, of course, assuming that the price of credits remains at $13.50 over the project life. The estimated average values of $1,337/year and $2,538/year are trivial when compared to the costs of registration, monitoring and reporting, let alone the overall restoration planning and construction costs.

The carbon accumulation rates used to calculate carbon credits are based on the soil accretion rates estimated for Ballona in a previous chapter of this study. Because the Ballona Watershed is highly developed and mostly composed of impermeable surfaces, the actual amount of sedimentation delivered to the wetland from watershed erosion may be lower than needed to achieve the estimated average soil accretion rates. Although soil accretion rates for Ballona habitats were not measured and the actual rates are not known, presenting ranges for the estimated number of carbon credits helps to account for the uncertainties in actual rates of carbon accumulation in the restored wetland.

Estimates of carbon accumulation in the existing Ballona Wetlands could be substantially improved by direct measurement of soil accretion in these habitats. Ideally, future investigation of the existing habitats would include measurement of soil accretion using surface elevation tables (SET) along with surface horizon markers such as feldspar. The combination of these techniques would also allow for identification of the contributions to surface elevation changes including sedimentation, soil organic matter accumulation, and subsidence. As additional data becomes available, the estimations made in this chapter could be revised.

The carbon accumulation calculations in this study assume no change in existing habitat areas or carbon accumulation rates over the 80-year baseline scenario period. Johnston et al. (2015), however, determined that Ballona is experiencing slowly deteriorating conditions and increases in non-native vegetation across most of the areas hydrologically disconnected from tidal influence, including seasonal wetland in Area B. Although it's not clear how degrading conditions would affect baseline carbon accumulation, the continuing degradation of existing habitats could result in lower carbon sequestration over the baseline period, which would result in more carbon credit generation for the Ballona Project. In addition, habitat areas for the project soil calculations are conservatively used for the earlier time in a time period. For instance, for the time period from 2020 to 2030 (t_1-t_2) the habitat areas for 2020 are used for the entire 10-year period. This is a more conservative estimation (leading to less carbon sequestration) because the wetland at later times, t_2 in this case, has higher carbon sequestration rates due to increasing areas of low marsh, mid-marsh, high marsh and mudflat habitat over time due to sea level rise. If these calculations were made over shorter time periods, say every five years, the resulting increase in carbon sequestration over the project life could be substantial.

If the actual Ballona Project NER turns out to be closer to the high range values estimated in this study, then the annual value of credits could be closer to approximately $5,900/year (437 credits/year x $13.50/credit) and $7,331/year (543 credits/year x $13.50/year) for the initial 30-year crediting period and the 80-year period, respectively. Even at the high range estimates for carbon credits the dollar amounts generated annually is relatively low. At these carbon prices and for the estimated carbon credits generated, the costs of administration, monitoring, and reporting associated with participating in the carbon market would likely be higher than the payoff. In this respect, the Ballona Project is unlikely to be considered a viable participant in the

California market. However, each project would need to be evaluated individually on a cost/benefit basis by its project proponents.

Other factors should be considered that could potentially change the estimated carbon credits or the future carbon credit value. For instance, the estimation of fossil fuel construction emissions for the restoration of the Ballona Project could potentially be lower than anticipated. This estimate is based on restoration calculations for the larger San Elijo Lagoon project (SELRP Final EIR/EIS, 2016) and the actual emissions to be determined in the Ballona EIR may be lower. Also, efforts could be taken to reduce the emissions from construction activities during restoration. Emission control measures can be implemented during construction activities including reducing engine idling, improving equipment maintenance and driver training, increasing use of biodiesel, improving electricity conservation, coordination of worker commuting to reduce miles traveled, and reduction of trips hauling material to and from the site. Reduction of construction related emissions can be achieved through planning and proper management of equipment and crew by recognizing and implementing opportunities throughout a project (EPA, 2007; EPA, 2009).

In addition, the price of a carbon credit may increase in the future if climate change mitigation policy and carbon markets become widely accepted and universally embraced. The United States Environmental Protection Agency (EPA) released an updated report in 2015 that estimates the real cost of carbon to society. The report estimated the social cost of carbon at $42 per metric ton of CO_2e in the year 2020 and increasing to $69 per metric ton of CO_2e by the year 2050 (EPA, 2015). These values are approximately three and five times higher than current market value, and would generate an estimated $7,896 per year (range: $1,302 to $22,806 per year) and $12,972 per year (range: $2,139 to $37,467 per year), respectively, over an 80-year project period. In addition, carbon market regulators should recognize the other inherent values associated with tidal marsh restoration, including ecological and economic values. Whereas the emission of a metric ton of CO_2e has a social cost, the restoration of ecological functions and services has a social benefit that could also be reflected in the price of a carbon credit generated from a tidal marsh restoration. For example, a tidal marsh restoration project and an industrial carbon capture project may remove equal amounts of carbon from the atmosphere, but the tidal marsh provides additional ecological benefits to society such as improved water quality, flood control, and wildlife habitat. Market reflection of the real cost of carbon is highly unlikely to occur in the current political environment of the final years of the 2010s, but may be substantially more likely in the future.

As demonstrated in Section 5.3.7, efforts could be made during the planning phases of projects to increase carbon sequestration and carbon credit generation. Additionally, a planting plan could include installation of a large number of new trees and additional credits would certainly be generated. Similarly, seagrass beds could be planted in subtidal habitat of the restored Ballona Wetlands to increase carbon accumulation above what the proposed subtidal habitat alone would accumulate. These efforts could even be added after the initial registration of the Ballona Project as allowed by the Methodology. For instance, if the potential to restore the Ballona Creek corridor upstream of the wetlands was included as an additional component to the Ballona Project, the future carbon sequestration from newly installed trees and other riparian vegetation could likely be included in later years. It is important to note, however, the concern among the conservation community that blue carbon projects in a financial market may lead to biodiversity-poor carbon farms focused on carbon storage and not ecological functioning. These concerns could be mitigated by adding requirements to GHG methodologies and protocols that require the support of ecosystem restoration goals of the particular region, as recommended by Emmet-Mattox et al. (2010). In this hypothetical scenario, the additional planting of riparian trees upstream of Ballona could add both carbon credits and ecosystem functions to overall project benefits.

5.4.3 Implications of Results

Future tidal marsh projects may wish to explore carbon funding as a means to finance restoration costs. Restoring tidal marshes in California can be costly due to the volumes of soil required to be excavated, relocated, or hauled off-site from coastal wetland areas previously filled for other land uses. The cost of constructing the Ballona Project is unknown at this time but similar tidal marsh restoration projects in California have been estimated to cost in the tens of millions of dollars. Although not entirely equivalent to the Ballona Project in scope, the San Elijo Lagoon Restoration Project, scheduled to begin in the fall of 2017, is estimated to cost between $60 and $80 million and restoration of the San Dieguito Lagoon, scheduled to begin in 2018, is estimated at $65 million. If proponents of the Ballona Project wished to finance a portion of the project costs through carbon funding, say $10 million for example, the average annual income from carbon funding over an 80-year project life would need to be $125,000/year to cover these costs, not including the regular monitoring and reporting anticipated to be required by carbon markets.

The value of carbon credits generated by the Ballona Project over the 80-year life of the project at a price of $13.50/credit is estimated in this study as $2,538/year, with a range of $420/year to $7,338/year. Even at the highest carbon accumulation rates estimated in this study, the potential carbon funding falls far short to pay for project costs. In order to fund restoration costs of $10 million at average carbon accumulation rates, the Ballona Project would need to be nearly 50 times larger than currently proposed, at equivalent habitat proportions. Approximately 500 acres of habitat are used for the calculations of carbon credits generated from the proposed Ballona Project and a project 50 times larger would be the equivalent of 25,000 acres, or about 40 square miles, of habitat of equal proportions. If habitat areas of the proposed Ballona Project are hypothetically adjusted to increase carbon sequestration as presented in Section 5.3.7, the hypothetical alternative is estimated to generate 401 credits per year (range: 133 – 1,012 credits/year) with an estimated value of $5,414/year, and a range of $1,796/year to $13,622/year at a price of $13.50 in 2017 dollars. This is more than double the estimated carbon credit generation for the Ballona Project of 188 credits per year over the 80-year project life. For this hypothetical alternative to fund restoration costs of $10 million at the average carbon accumulation rates, the Ballona Project would need to be 23 times larger than the existing area. This corresponds to a project area of approximately 11,500 acres, or about 18 square miles. Typical tidal marsh restoration projects in California may be unlikely to produce carbon funding substantial enough to compensate for project costs due to high restoration construction costs and emissions and limited area of tidal marsh available for restoration.

However, other areas of the country have more coastal wetland area and potentially lower costs of construction. Only 3.1% of all U.S. coastal wetland area occurs along the west coast compared to 37.5% and 38.7% along the Gulf of Mexico and the Atlantic coasts, respectively (Dahl & Stedman, 2013). In one example along the west coast of the U.S., Crooks et al. (2014) evaluated several proposed restoration projects within the Snohomish Estuary of the Puget Sound and determined that approximately 4,749 hectares (11,730 acres) of converted and drained wetlands exist with 1,353 hectares (3,342 acres) currently in planning or construction. The additional carbon sequestration from all potential wetland restoration in the Snohomish Estuary is estimated to total 4.4 to 8.8 million metric tons of carbon dioxide equivalents after just 20 years.

Furthermore, an evaluation of the carbon market opportunities for Louisiana's coastal wetlands was performed by Mack et al. (2015) and identified approximately 1.4 million acres of coastal wetlands with potential for restoration or enhancement. Of the restoration techniques evaluated in the study, river diversion to reconnect delta plains to river flow was shown to be the most cost effective. A total of 200,000 acres of land are planned for restoration with river diversion and an additional 300,000 acres have been identified to have potential for river diversion restoration. While the potential carbon credit generation from river diversion projects was determined to be lower than other restoration approaches, the lower construction cost per acre (less than half the cost of hydrologic restoration and one eighth the cost of marsh creation) make these projects more attractive.

This study has demonstrated that calculating net emission reductions for tidal marsh restoration projects can be adequately completed using the VCS Methodology. Several opportunities exist to simplify the Methodology process and procedures and ease the burden on project proponents. However, based on this study's estimates of carbon credit generation and the current carbon credit value, the Ballona Project, as currently proposed, does not appear financially feasible in a carbon market at this time. Opportunities do exist to responsibly maximize the amount of carbon credits generated from the Ballona Project, as discussed above, but potentially not enough to make a substantial financial difference. Projects with significantly larger areas of tidal marsh habitat available for restoration may prove feasible in the current carbon market, but initial feasibility studies similar to this study should be performed to evaluate each project. The future success of tidal marsh restoration as climate change mitigation may depend heavily on a future valuation of carbon credits that represents the real cost of carbon to society.

6 CONCLUSIONS

6.1 Overview of Findings

This study investigates the existing soil carbon of a degraded southern California tidal marsh, estimates the change in soil carbon accumulation that would result from a proposed restoration of that marsh, and evaluates the potential feasibility of the restoration project in a carbon trading market.

The results presented in Chapter 3 show that the existing tidal marsh habitats of the Ballona Wetlands contain soil organic carbon densities ranging from 0.018 to 0.030 g/cm^3. Averaging SOC densities by habitat type resulted in a range of 0.022 to 0.027 g C/cm^3, which is similar to natural tidal marshes around the world. Percent organic carbon is highest in low marsh habitat and decreases with increasing marsh habitat elevation (low > mid > high). However, carbon density is lowest in low marsh habitat and increases with increasing habitat elevation (low < mid < high). Carbon content is highest near the soil surface in all vegetated habitats and decreases rapidly due to decomposition of organic matter near the surface before stabilizing at lower soil depths. Higher levels of carbon at the soil surface of the existing habitats shows that even in its degraded condition the soils of the Ballona Wetlands continue to accumulate organic carbon.

Chapter 4 presents a method to calculate carbon accumulation rates using the soil carbon densities measured in Chapter 3 along with soil accretion rates estimated from data in existing studies of tidal marsh habitat. Carbon accumulation rates estimated for habitats of the proposed Ballona Project are similar to rates reported in other tidal marsh studies. Results showed that the proposed restoration of a 600-acre degraded tidal marsh would increase the amount of carbon the habitats accumulate and store by an estimated 286 metric tons of carbon dioxide equivalents

(CO_2e) per year (range 110 – 680 mt CO_2e/yr). This represents a 270% increase from the carbon accumulation estimated for the existing habitats.

The evaluation presented in Chapter 5 indicates that depending on project area, scope of restoration activities, and market value of a carbon credit (where 1 carbon credit = 1 mt CO_2e), restoring tidal marsh habitat in general could be a viable component in a carbon trading market and climate change mitigation. However, due to its small area, high construction costs and emissions, and the currently low value of a carbon credit (approx. $13.50 in early 2017), the Ballona Project is not by itself financially feasible in a carbon market. The annual funding from carbon credit generation of the Ballona Project is estimated at approximately $2,538 per year (range $420 – $7,338) and is unlikely to even cover the monitoring and reporting costs associated with carbon market participation.

6.2 Implications of Findings

The results of this study support a shift in policy for promoting more responsible management of coastal ecosystems as a means of contributing to climate change mitigation. Past and current policies have led to widespread loss of coastal ecosystem habitat and functions. Chapter 3 of this study highlights that even degraded tidal marshes contain vast amounts of soil carbon that must be protected. It is estimated that each year between 0.15 – 1.02 billion metric tons of carbon dioxide are being released globally due to land-use conversion of coastal ecosystems (Pendleton et al., 2012). All existing coastal ecosystems, even degraded tidal marsh habitat, should be ardently conserved because the loss of these habitats would result in the release of their sequestered carbon stocks as carbon dioxide emissions.

The results of Chapter 4 indicate that the widespread restoration of coastal ecosystems could substantially increase the amount of carbon accumulated and stored in their soils globally.

However, due to the small project area, high construction costs and emissions, and the currently low value of carbon credits, the Ballona Project is not considered practicable for inclusion in a carbon trading market, according to the results of this study. Even the costs of administration, monitoring and reporting for carbon market participation would likely far exceed any income generated from carbon offsets. In order for the Ballona Project to pay for a substantial portion of restoration costs ($10 million) with carbon market funding the Ballona Project would need to be nearly 50 times larger than currently proposed, at equivalent habitat proportions. A demonstration of a hypothetical high soil carbon sequestration restoration alternative presented in this study shows that carbon accumulation of the restored wetland could roughly be doubled, but would still need a project area 23 times larger than the existing area to fund restoration costs of $10 million. Typical tidal marsh restoration projects in California may be unlikely to produce carbon funding substantial enough to compensate for project costs due to high construction costs and emissions and limited areas of tidal marsh available for restoration. The role that tidal marsh restoration plays in global climate mitigation may ultimately depend on the scale of the effort. The scale of effort will in part depend on the availability of coastal habitat that can be enhanced, conserved, or restored, and the extent of coastal habitat in California is limited in many areas.

More opportunity is available in other areas of the country, however, such as the Pacific Northwest, but particularly in coastal Louisiana and the Atlantic Coast. Only 3.1% of all U.S. coastal wetland area occurs along the west coast compared to 37.5% and 38.7% along the Gulf of Mexico and the Atlantic coasts, respectively (Dahl & Stedman, 2013). For example, Crooks et al. (2014) evaluated several proposed restoration projects within the Snohomish Estuary of the Puget Sound and determined that the long-term net GHG removals of these projects would most likely contribute to state and national GHG reduction goals. Additional carbon sequestration from all potential wetland restoration in the Snohomish Estuary is estimated to total 4.4 to 8.8 million metric tons of carbon dioxide equivalents after just 20 years. This is a stark contrast to the additional sequestration of only 5,720 metric tons of CO_2e estimated in Chapter 4 for the Ballona Project over 20 years (286 mt CO_2e/year x 20 years).

In an example along the coast of the Gulf of Mexico, ESA (2016) highlighted the importance of conserving and managing the coastal wetlands of Tampa Bay by estimating that these habitats will remove approximately 74 million metric tons of CO_2 by the year 2100. Additionally, an evaluation of the carbon market opportunities for Louisiana's coastal wetlands identified approximately 1.4 million acres of coastal wetlands with potential for restoration or enhancement and determined that coastal wetland restoration has the potential to offset over 1.8 million metric tons of carbon dioxide emissions per year. The generation of over 1.8 million carbon offsets per year is anticipated to provide millions of dollars each year to support wetland restoration projects in Louisiana (Mack et al., 2015).

Although carbon sequestration rates are generally similar from one region of the U.S. to another, typical tidal marshes of southern California have nowhere near the habitat area needed to financially support a restoration project, with large amounts of costly excavation typically needed for California coastal marshes, solely from carbon finance. Depending on the specifics of a particular restoration project and value of carbon offsets, the carbon funding generated by projects like Ballona may at best hope to cover the costs of monitoring, reporting and management required by carbon markets. Financial and policy incentives and coordination between project proponents could promote restoration opportunities or encourage grouping of projects, thus sharing in the administrative costs.

Project proponents of tidal marsh restoration projects in other regions should not be discouraged by the low carbon credit generation of the Ballona Project. Other regions may contain substantially more tidal marsh area to restore than in California and may be able to engage in alternate methods of restoration that require far less soil excavation such as river diversions that may have substantially lower restoration costs.

6.3 Recommendations for Future Research and Policy

Further research of soil accretion and carbon content in tidal marsh habitats is greatly needed as well as of their relationships to other factors such as suspended sediment supply, organic matter accumulation, and above- and belowground biomass production. Additional studies that measure parameters including soil accretion, carbon density, sediment supply, and biomass production in tidal marshes would help to fill information gaps and provide additional data points to refine the estimates for habitats in this and other studies. As more studies provide data for these parameters in tidal marshes throughout a variety of regions, project proponents will be better able to estimate ranges of values for these parameters in their own tidal marsh projects when sampling and measurement is not feasible for them.

The average soil accretion rates estimated for the restored Ballona habitats may not fully reflect the actual rates. Due to the highly urbanized (more than 80% developed and 35-40% impervious) nature of the Ballona Watershed, it is anticipated that relatively low amounts of sediment may be delivered to the restored wetlands (PWA et al., 2008; EPA, 2012; Liu et al., 2011). Therefore, the true accretion rates of the Ballona habitats may be lower, but potentially still within the ranges of values presented.

Estimates of carbon accumulation in the existing Ballona Wetlands could be substantially improved by direct measurement of soil accretion in these habitats. Ideally, future investigation of the existing habitats would include measurement of soil accretion using surface elevation tables (SET) along with surface horizon markers such as feldspar. The combination of these techniques would also help quantify the contributions to surface elevation changes due to sedimentation, soil organic matter accumulation, and subsidence. As additional data becomes available, the estimations made in this chapter could be revised. More comprehensive studies of the soil dynamics in tidal marsh habitats globally will assist policymakers and scientists with planning and management decisions for restoration and for preventing the loss of coastal ecosystems to anticipated sea level rise.

The procedures presented in this study for calculating carbon accumulation in tidal marsh habitats using existing data from studies of similar habitat is generally considered a reasonable methodology and is recommended as a means to estimate carbon accumulation for proposed restoration projects where site-specific data is not readily available. Although the soil accretion rates (SAR) used for Ballona habitats are estimated based on data from other studies, the resulting carbon sequestration rates for Ballona are very similar to those from other studies of tidal marshes around the world. As the number of studies investigating carbon accumulation in tidal marshes grows, more data will be available to estimate rates in other marshes without site-specific data.

Existing carbon market accounting methodologies provide a basic framework to quantify and verify carbon offsets generated by tidal marsh restoration projects. However, tidal marsh restoration is new to the carbon markets and it is recommended that as further research and restoration projects are implemented, policymakers and stakeholders enact needed modifications to the existing methodology process and revise the many modules and tools to be more user-friendly, clear, and specific to tidal marsh habitat. In addition, the inclusion of more default and reference values specific to tidal marshes would be highly useful for project proponents and could substantially reduce the costs of the monitoring and analyses of carbon stocks that is currently required.

Coastal wetland restoration and conservation needs to be a priority of federal, state, and local policymakers. In spite of a decades-old policy of "no net loss" of wetlands supported by each U.S. administration since 1989, although the intentions of the new (2017) administration are unknown, between 2004 and 2009 wetland area in the coastal watersheds of the U.S. declined by more than 360,000 acres, a 25% increase in the rate of loss from the previous reporting period (Dahl & Stedman, 2013). Even when wetland loss is mitigated due to mandatory regulatory compliance, it is not clear whether wetland mitigation projects are effective at replacing the ecological functions of the lost wetlands (Fennessy et al., 2013; Ambrose et al., 2007). In addition, habitat restoration is time consuming and expensive. Restoration of coastal habitats as a means of climate change mitigation must make sense financially to project proponents. As such, the value of carbon credits needs to reflect the real cost of carbon to society as determined by the U.S. EPA (2015). If carbon credits from coastal habitat restoration not only reflected the real cost of carbon to society, but also the real benefit of wetlands to society, land owners may be more motivated to implement restoration projects. Further motivation could be applied by governments through making available public lands and public funds for project implementation.

6.4 Closing

Warming of our planet's atmosphere and oceans and the subsequent changes to our climate present a profound threat to the health and survival of many of the planet's species, including perhaps our own. The reduction of greenhouse gas emissions needed to slow or mitigate the effects of climate change will require a wide variety of approaches and innovations.

Many approaches focus on technologies as a means of achieving mitigation goals including renewable energy sources, nuclear energy, fuel cells, electric vehicles, enhanced energy efficiency, and industrial carbon capture (IEA, 2015; Princiotta & Loughlin, 2014). Current commercialized technologies are capable of achieving less than half of the reductions in GHGs needed to constrain global warming to approximately 2º C (Princiotta & Loughlin, 2014). Therefore, turning to our natural environment to help address the issue is perhaps not only a logical, but a necessary solution. Many of the earth's ecosystems are highly effective at accumulating and storing carbon in biomass and soil and could be managed to enhance these functions. However, to make a significant contribution to GHG reductions would likely require large scale reversals of the degradation done to our ecosystems. It is important to note the concern among the conservation community that blue carbon projects in a financial market may lead to biodiversity-poor carbon farms focused on carbon storage and not ecological functioning. These concerns could be mitigated if policies were enacted to require projects to support ecosystem restoration goals of the particular region. Centuries of habitat destruction in the name of progress must be reversed and a new mindset must be established to view ecosystem health as the solution, not an impediment, to 21st Century progress.

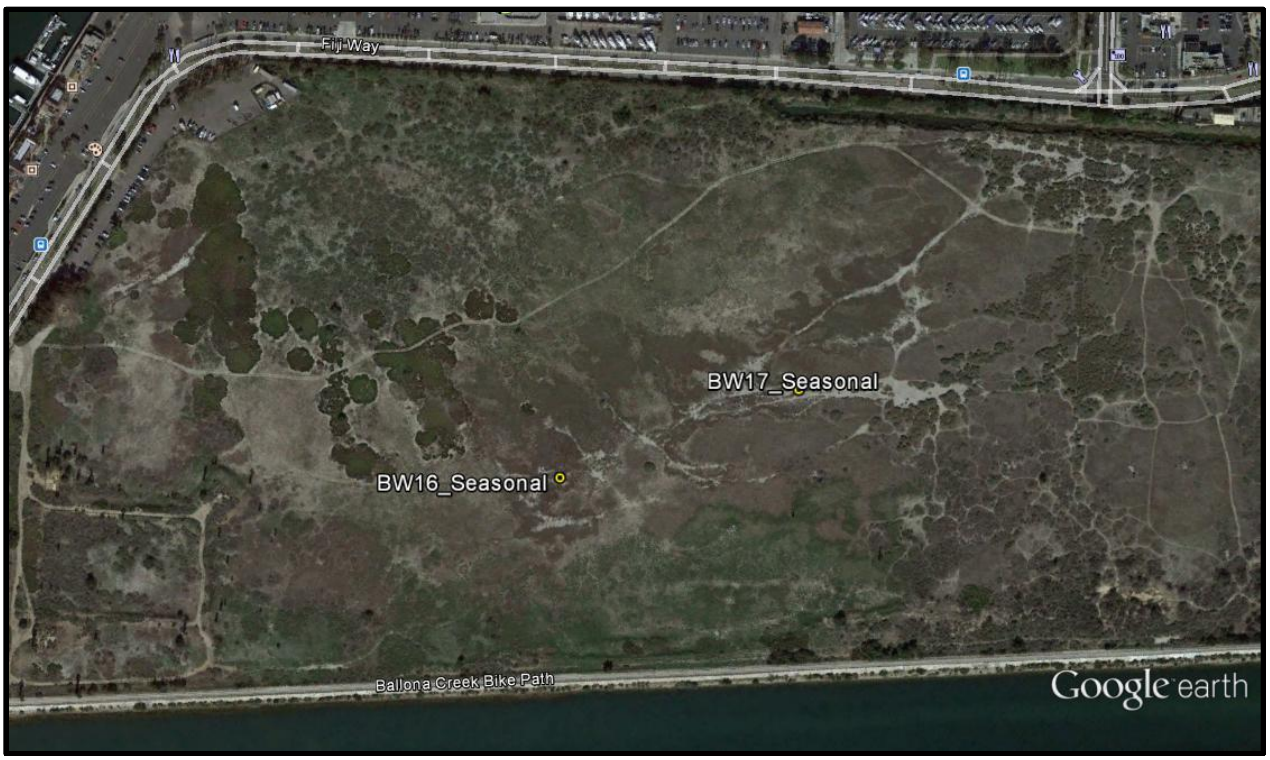
APPENDIX A – Figures of Core Locations by Ballona Wetlands Habitat Area

Below: Core locations in Western Portion of Area B

Below: Core locations in Central Portion of Area B

Below: Core locations in Eastern Portion of Area B

Below: Core locations in Area A



APPENDIX B – Tables of Soil Characteristics of Ballona Cores

Table B-1

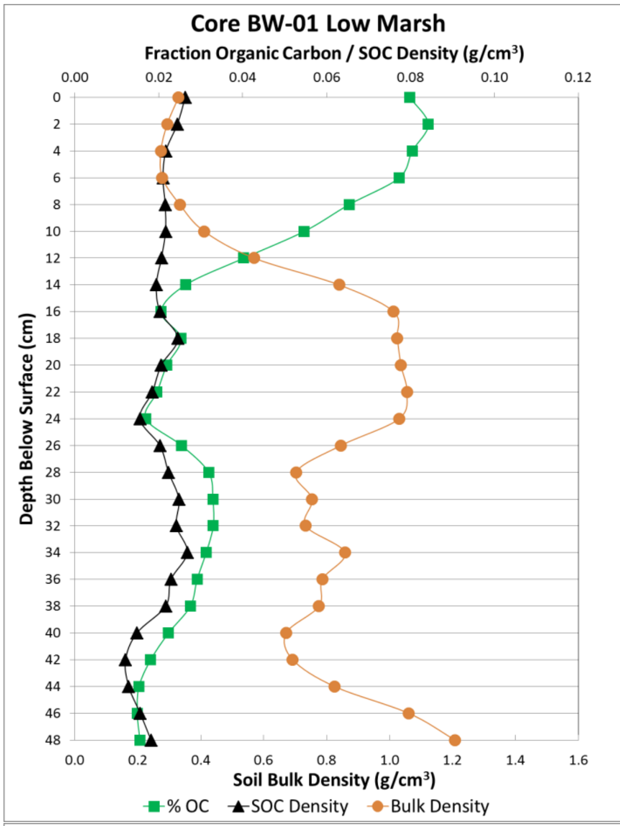
Soil Characteristics of All Soil Cores by Depth

Habitat	Low	Low	Low	Low	Low	Low	Low	Mid	Mid	Mid	Mid	Mid	Mid	Mid	High	High	High	High	Salt Pan	Salt Pan	Salt Pan	Seasonal A	Seasonal A	Seasonal B	Seasonal B
Core ID	BW-01	BW-03	BW-06	BW-07	BW-08	BW-12	BW-21	BW-02	BW-09	BW-10	BW-18	BW-19	BW-22	BW-23	BW-04	BW-05	BW-13	BW-20	BW-11	BW-14	BW-15	BW-16	BW-17	BW-25	BW-26
SOC																									
0to10	0.023	0.024	0.026	0.028	0.028	0.027	0.021	0.026	0.039	0.045	0.036	0.029	0.029	0.025	0.028	0.033	0.034	0.037	0.022	0.027	0.027	0.019	0.025	0.044	0.044
10to20	0.021	0.023	0.023	0.022	0.021	0.021	0.019	0.023	0.028	0.026	0.030	0.021	0.025	0.017	0.024	0.029	0.025	0.032	0.025	0.024	0.027	0.013	0.019	0.036	0.036
20to40	0.022	0.013	0.023	0.019	0.017	0.019	0.028	0.024	0.023	0.020	0.027	0.023	0.021	0.014	0.028	0.026	0.020	0.021	0.021	0.024	0.019	0.014	0.012	0.035	0.033
0to40	0.022	0.018	0.024	0.022	0.020	0.021	0.024	0.024	0.028	0.028	0.030	0.024	0.024	0.018	0.027	0.028	0.024	0.028	0.022	0.025	0.023	0.015	0.017	0.038	0.037
%OC																									
0to10	7.83%	4.21%	3.69%	7.51%	5.29%	7.52%	2.98%	4.17%	3.40%	4.31%	3.43%	5.60%	4.65%	2.01%	2.61%	3.08%	2.84%	3.60%	1.84%	2.41%	2.56%	1.59%	2.07%	4.50%	3.69%
10to20	3.17%	2.80%	3.20%	2.90%	2.96%	3.00%	1.80%	2.52%	3.07%	2.79%	2.67%	2.02%	2.81%	1.47%	2.38%	2.77%	2.27%	2.97%	2.34%	1.82%	2.41%	1.07%	1.38%	3.15%	3.21%
20to40	2.75%	1.87%	2.40%	2.10%	1.78%	2.46%	2.85%	2.39%	2.46%	2.20%	2.69%	1.92%	2.61%	1.10%	3.25%	2.64%	1.79%	2.02%	2.00%	2.05%	1.69%	1.10%	0.95%	3.08%	2.90%
0to40	4.12%	2.69%	2.92%	3.65%	2.95%	3.86%	2.62%	2.95%	2.85%	2.87%	2.87%	2.86%	3.17%	1.42%	2.87%	2.78%	2.17%	2.65%	2.04%	2.08%	2.09%	1.21%	1.34%	3.45%	3.18%
%OM																									
0to10	19.55%	10.52%	9.22%	18.75%	13.20%	18.78%	7.44%	10.41%	8.50%	10.76%	8.58%	13.98%	11.60%	5.03%	6.52%	7.69%	7.09%	9.00%	4.60%	6.01%	6.41%	3.98%	5.18%	11.23%	9.21%
10to20	7.93%	6.99%	8.00%	7.24%	7.40%	7.50%	4.51%	6.30%	7.67%	6.98%	6.67%	5.05%	7.02%	3.68%	5.94%	6.92%	5.68%	7.42%	5.85%	4.54%	6.02%	2.66%	3.45%	7.87%	8.03%
20to40	6.86%	4.66%	5.99%	5.26%	4.46%	6.14%	7.12%	5.96%	6.14%	5.50%	6.72%	4.80%	6.53%	2.76%	8.12%	6.61%	4.47%	5.04%	4.99%	5.11%	4.22%	2.74%	2.38%	7.71%	7.25%
0to40	10.30%	6.71%	7.30%	9.13%	7.38%	9.64%	6.55%	7.37%	7.11%	7.18%	7.17%	7.16%	7.92%	3.55%	7.18%	6.96%	5.43%	6.63%	5.11%	5.19%	5.21%	3.03%	3.35%	8.63%	7.93%
SBD																									
0to10	0.298	0.628	0.784	0.589	0.633	0.434	1.075	0.744	1.159	1.033	1.041	0.599	0.809	1.261	1.103	1.126	1.178	1.038	1.172	1.140	1.054	1.209	1.231	1.013	1.194
10to20	0.788	0.819	0.721	0.773	0.704	0.714	1.170	0.921	0.922	0.927	1.135	1.071	0.869	1.175	1.034	1.034	1.084	1.072	1.072	1.342	1.127	1.210	1.357	1.158	1.123
20to40	0.855	0.723	0.996	0.976	0.969	0.790	1.002	1.021	0.938	0.945	1.019	1.210	0.821	1.313	0.850	0.997	1.115	1.033	1.058	1.195	1.146	1.254	1.264	1.130	1.143
0to40	0.699	0.723	0.874	0.828	0.819	0.682	1.062	0.910	0.989	0.963	1.053	1.023	0.830	1.266	0.959	1.039	1.123	1.044	1.090	1.218	1.118	1.232	1.279	1.108	1.151
% Sand																									
0to10	77.55%	50.81%	37.62%	55.91%	51.81%	65.05%	84.65%	38.36%	24.90%	30.45%	23.00%	45.88%	32.60%	26.71%	11.90%	22.43%	18.75%	20.80%	28.01%	15.97%	22.86%	34.13%	30.67%	22.30%	16.15%
10to20	61.35%	31.62%	26.82%	30.38%	29.41%	35.45%	51.05%	22.10%	31.30%	26.86%	15.80%	22.28%	15.19%	22.70%	12.82%	13.62%	13.89%	12.81%	20.81%	9.97%	25.66%	28.16%	30.29%	13.90%	7.76%
20to40	42.07%	27.87%	19.74%	33.26%	33.51%	26.46%	24.21%	21.56%	28.10%	31.46%	14.10%	9.64%	24.85%	35.30%	14.13%	21.62%	18.61%	14.00%	23.60%	16.17%	18.34%	33.65%	29.49%	20.91%	10.84%
0to40	55.76%	34.54%	25.98%	37.27%	37.06%	38.36%	46.03%	26.03%	28.10%	30.06%	16.75%	21.86%	24.38%	30.00%	13.25%	19.83%	17.46%	15.40%	24.01%	14.57%	21.30%	32.40%	29.99%	19.50%	11.40%

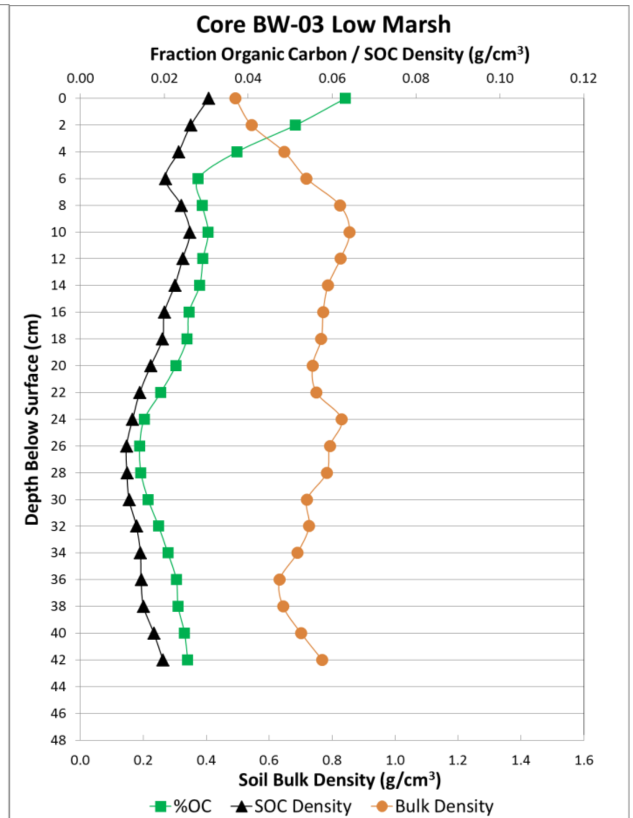
Table B-2
Average Values of All Soil Characteristics Measured by Habitat Type

Habitat	%OC	SBD (g/cm^3)	SOC Density (g/cm^3)	%Sand	%Silt	%Clay	%Water
Low Marsh	3.3	0.813	0.022	39.3	26.5	36.9	63.8
Mid-Marsh	2.7	1.005	0.025	25.3	33.7	41.1	52.1
High Marsh	2.6	1.041	0.027	16.5	33.2	50.8	48.7
Salt Pan	2.1	1.142	0.023	20.0	47.9	33.2	43.7
Seasonal Area A	1.3	1.255	0.016	31.2	51.6	16.2	29.3
Seasonal Area B	3.3	1.129	0.037	15.5	33.5	51.1	32.8

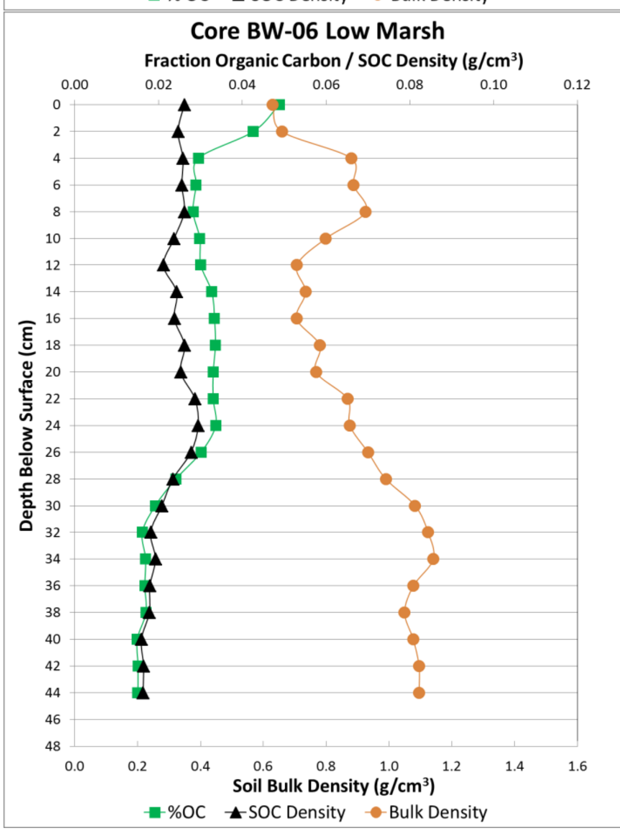
APPENDIX C – Graphs of Soil Characteristics with Depth for Ballona Wetlands Cores



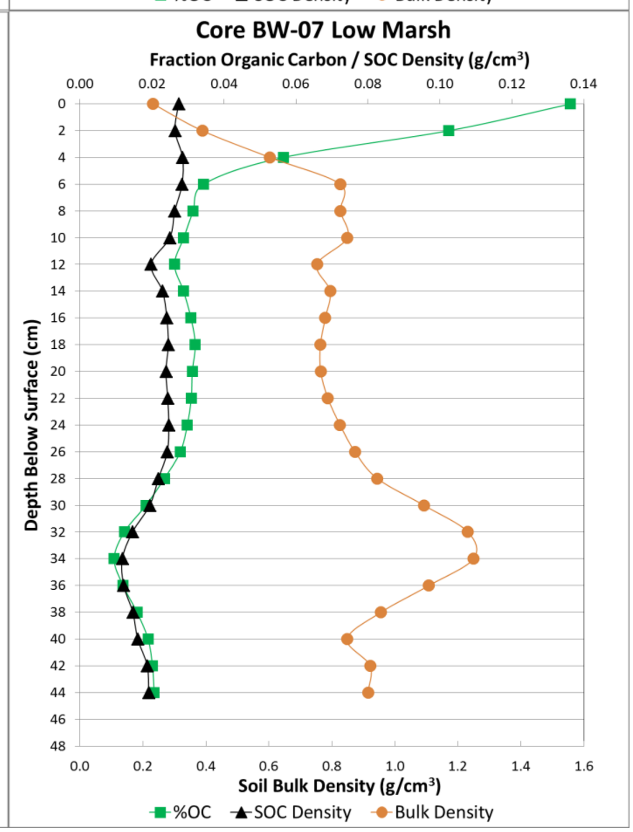
Core BW-01 Low Marsh
Fraction Organic Carbon / SOC Density (g/cm³)
Depth Below Surface (cm)
Soil Bulk Density (g/cm³)
% OC
SOC Density
Bulk Density



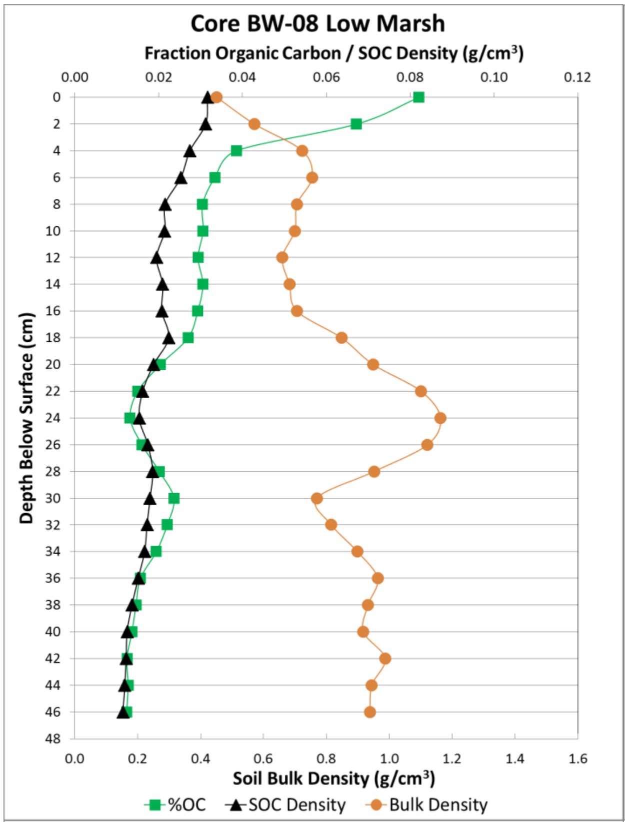
Core BW-03 Low Marsh
Fraction Organic Carbon / SOC Density (g/cm³)
Depth Below Surface (cm)
Soil Bulk Density (g/cm³)
%OC
SOC Density
Bulk Density

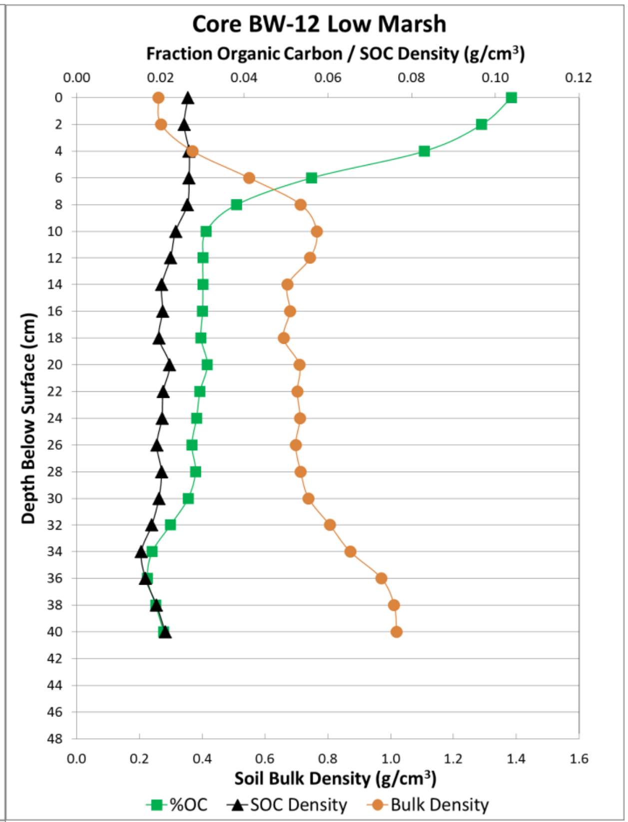


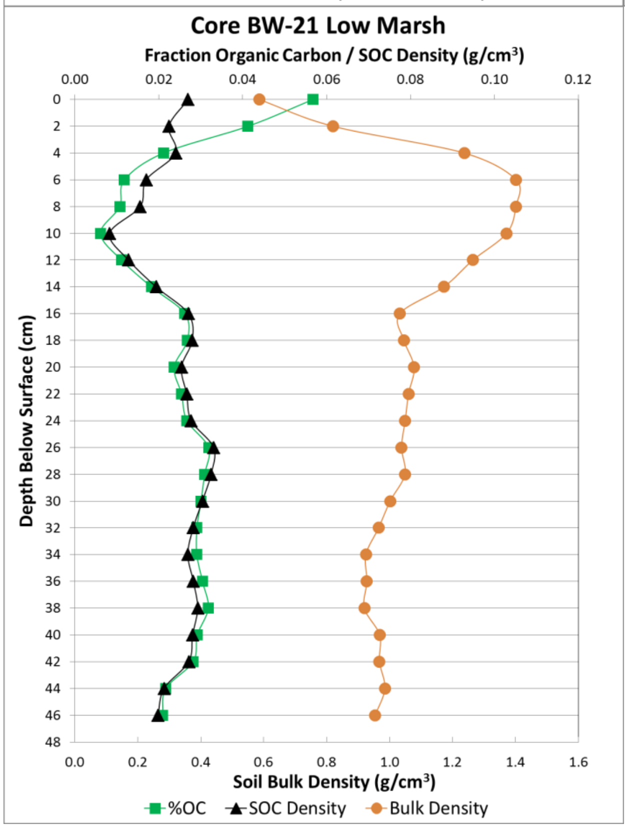
Core BW-06 Low Marsh
Fraction Organic Carbon / SOC Density (g/cm³)
Depth Below Surface (cm)
Soil Bulk Density (g/cm³)
%OC
SOC Density
Bulk Density

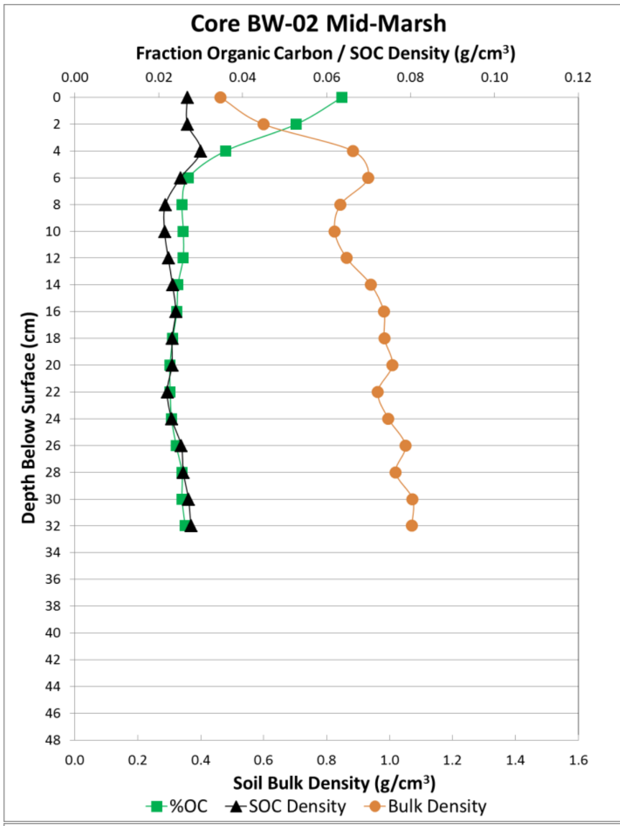


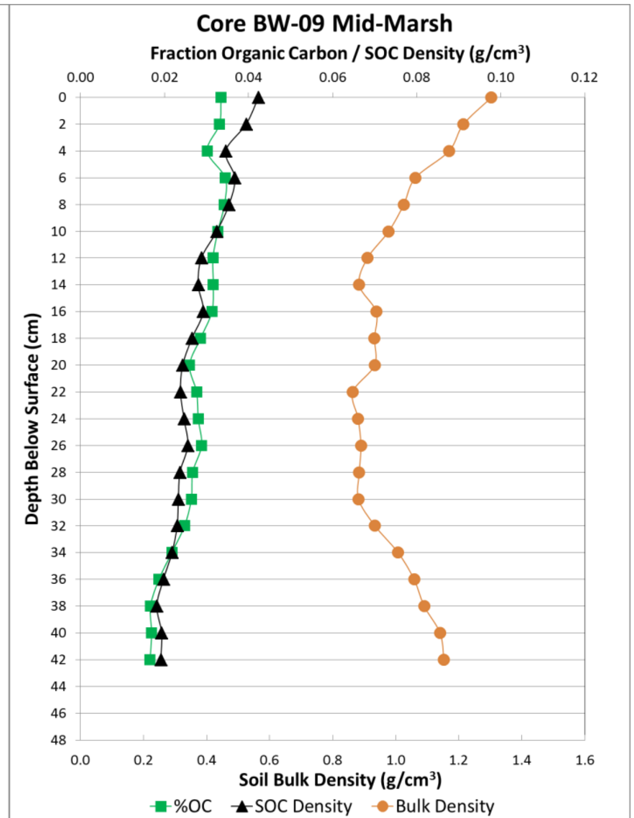
Core BW-07 Low Marsh
Fraction Organic Carbon / SOC Density (g/cm³)
Depth Below Surface (cm)
Soil Bulk Density (g/cm³)
%OC
SOC Density
Bulk Density

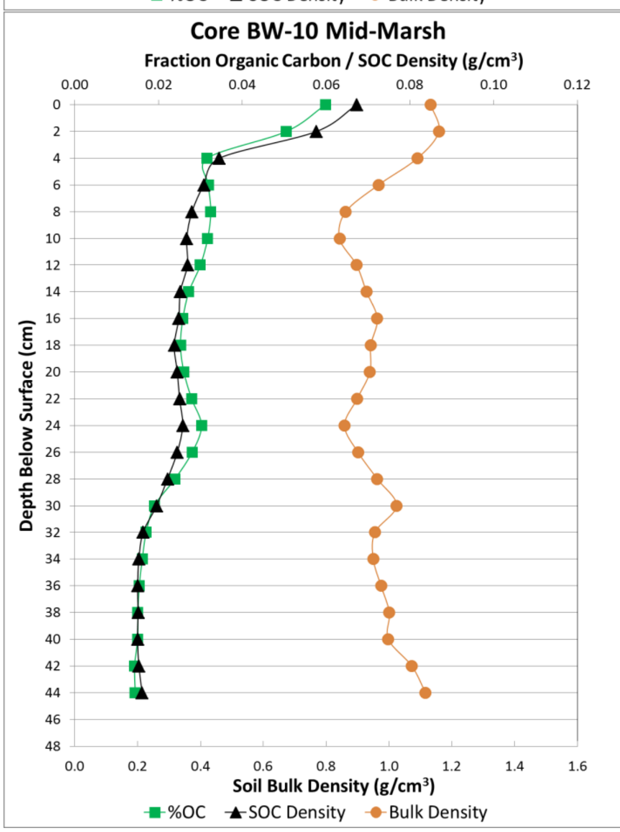

Core BW-08 Low Marsh
Fraction Organic Carbon / SOC Density (g/cm³)
Depth Below Surface (cm)
Soil Bulk Density (g/cm³)
%OC
SOC Density
Bulk Density

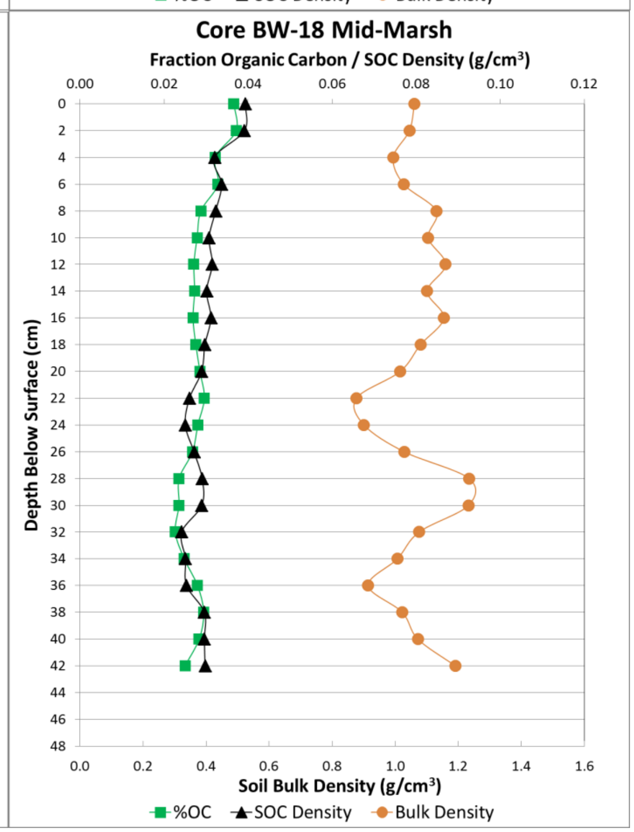

Core BW-12 Low Marsh
Fraction Organic Carbon / SOC Density (g/cm³)
Depth Below Surface (cm)
Soil Bulk Density (g/cm³)
%OC
SOC Density
Bulk Density

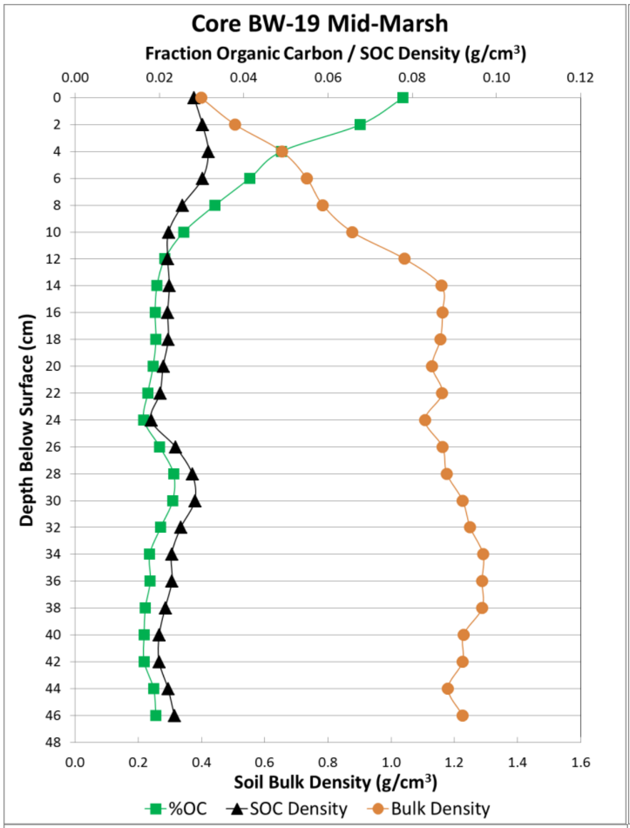

Core BW-21 Low Marsh
Fraction Organic Carbon / SOC Density (g/cm³)
Depth Below Surface (cm)
Soil Bulk Density (g/cm³)
%OC
SOC Density
Bulk Density


Core BW-02 Mid-Marsh
Fraction Organic Carbon / SOC Density (g/cm³)
Depth Below Surface (cm)
Soil Bulk Density (g/cm³)
%OC
SOC Density
Bulk Density

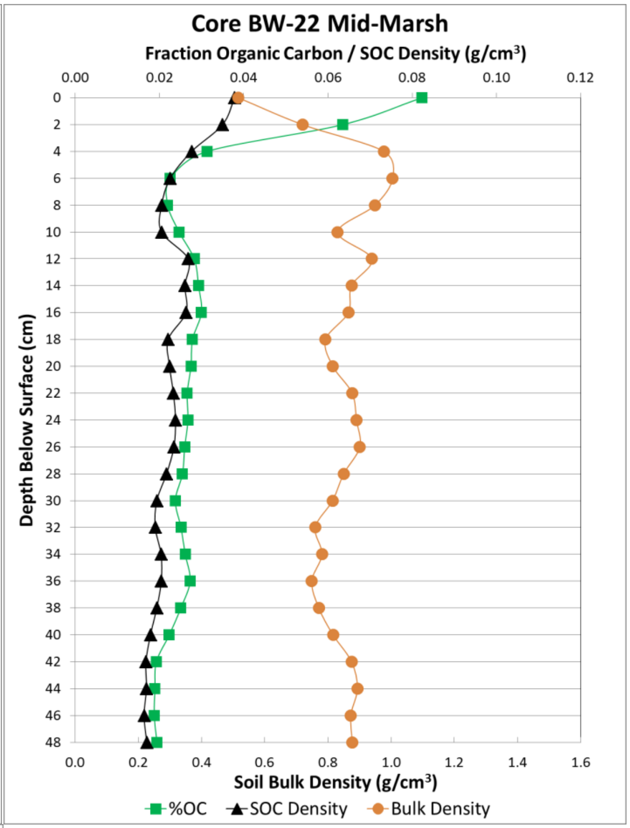

Core BW-09 Mid-Marsh
Fraction Organic Carbon / SOC Density (g/cm³)
Depth Below Surface (cm)
Soil Bulk Density (g/cm³)
%OC
SOC Density
Bulk Density


Core BW-10 Mid-Marsh
Fraction Organic Carbon / SOC Density (g/cm³)
Depth Below Surface (cm)
Soil Bulk Density (g/cm³)
%OC
SOC Density
Bulk Density

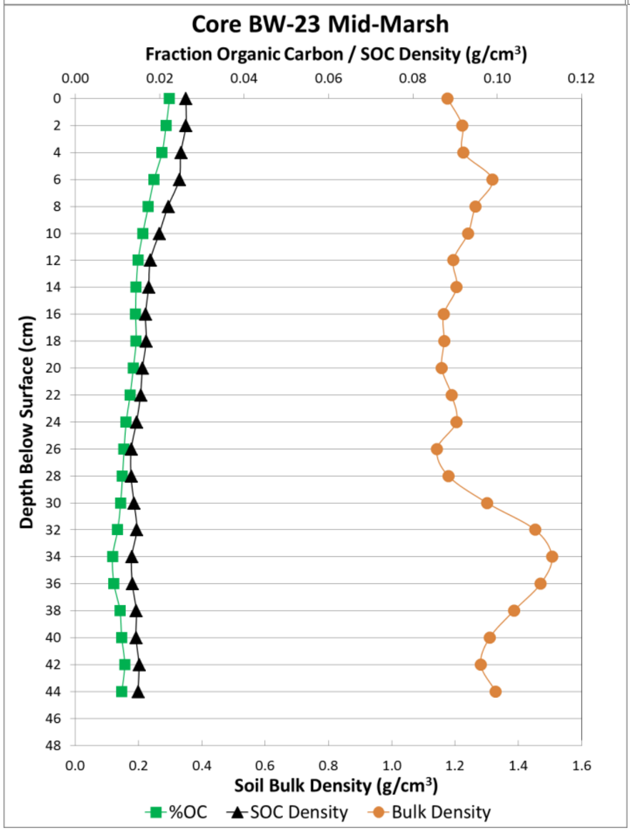

Core BW-18 Mid-Marsh
Fraction Organic Carbon / SOC Density (g/cm³)
Depth Below Surface (cm)
Soil Bulk Density (g/cm³)
%OC
SOC Density
Bulk Density



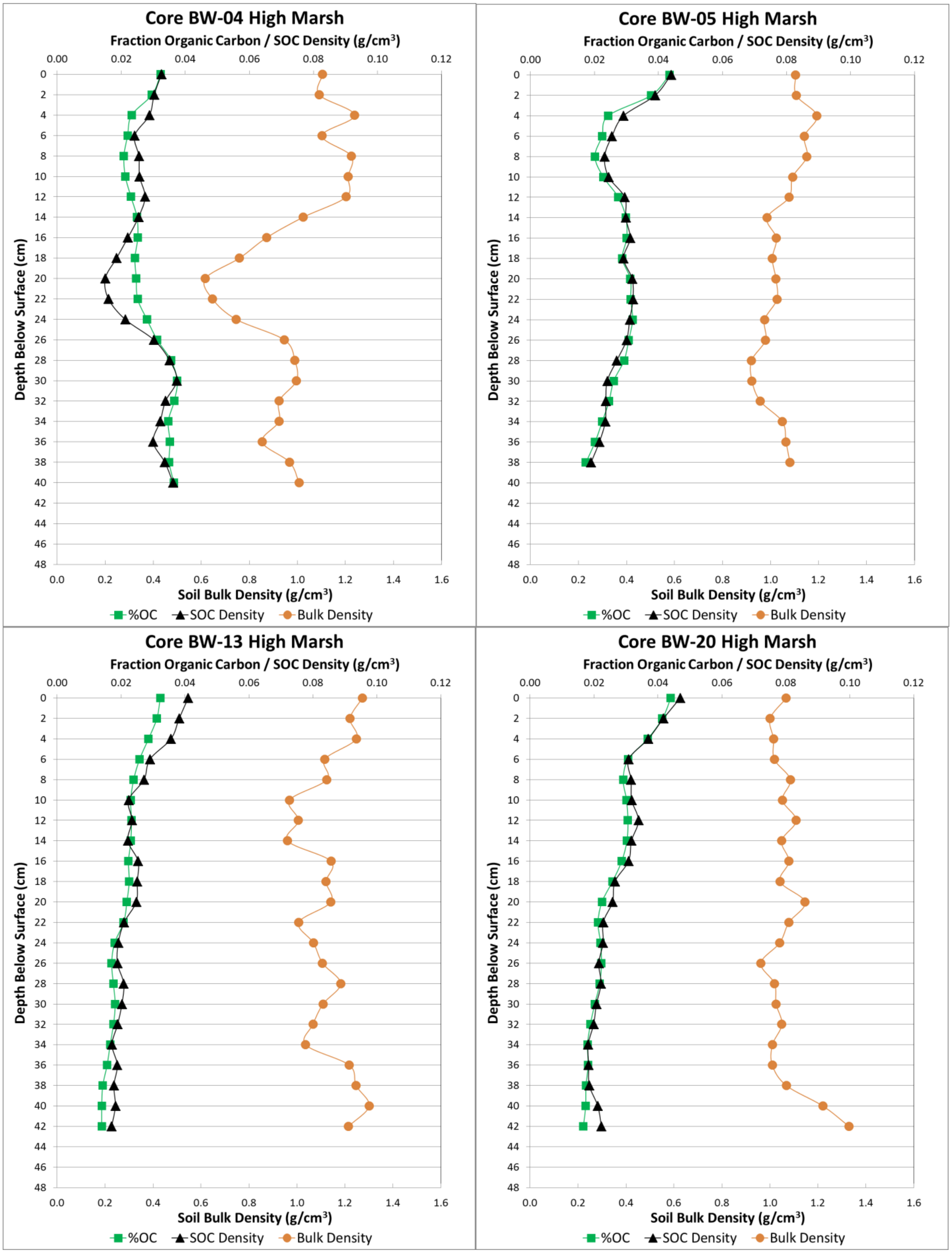
Core BW-19 Mid-Marsh
Fraction Organic Carbon / SOC Density (g/cm³)
Depth Below Surface (cm)
Soil Bulk Density (g/cm³)
%OC
SOC Density
Bulk Density



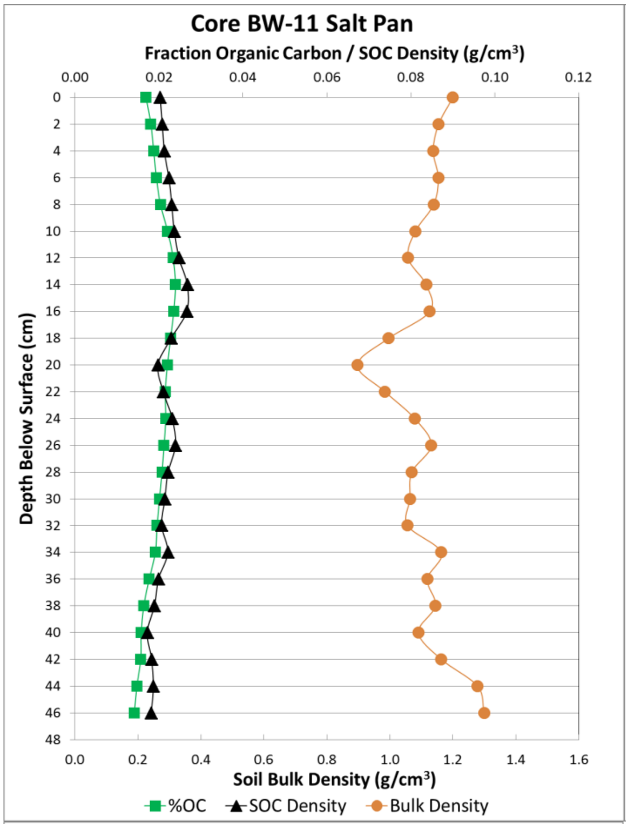
Core BW-22 Mid-Marsh
Fraction Organic Carbon / SOC Density (g/cm³)
Depth Below Surface (cm)
Soil Bulk Density (g/cm³)
%OC
SOC Density
Bulk Density



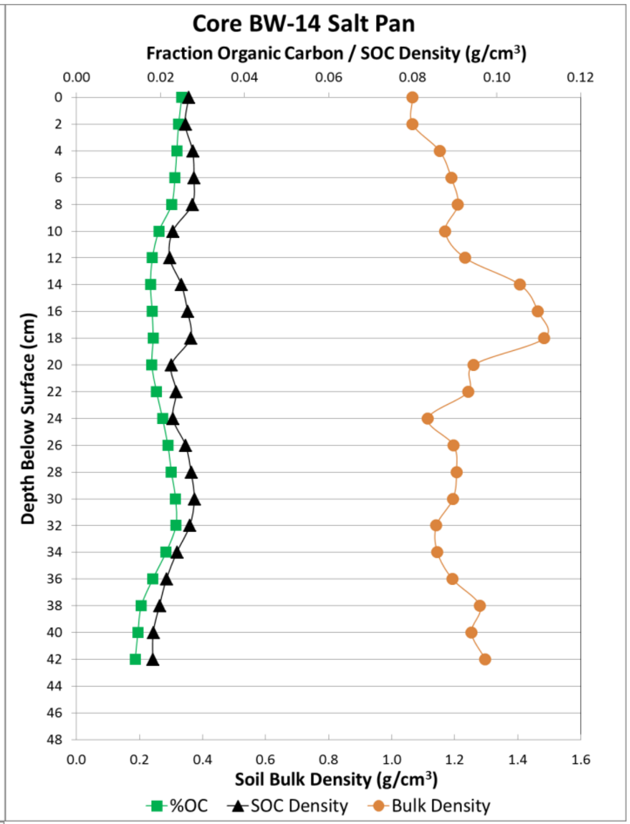
Core BW-23 Mid-Marsh
Fraction Organic Carbon / SOC Density (g/cm³)
Depth Below Surface (cm)
Soil Bulk Density (g/cm³)
%OC
SOC Density
Bulk Density



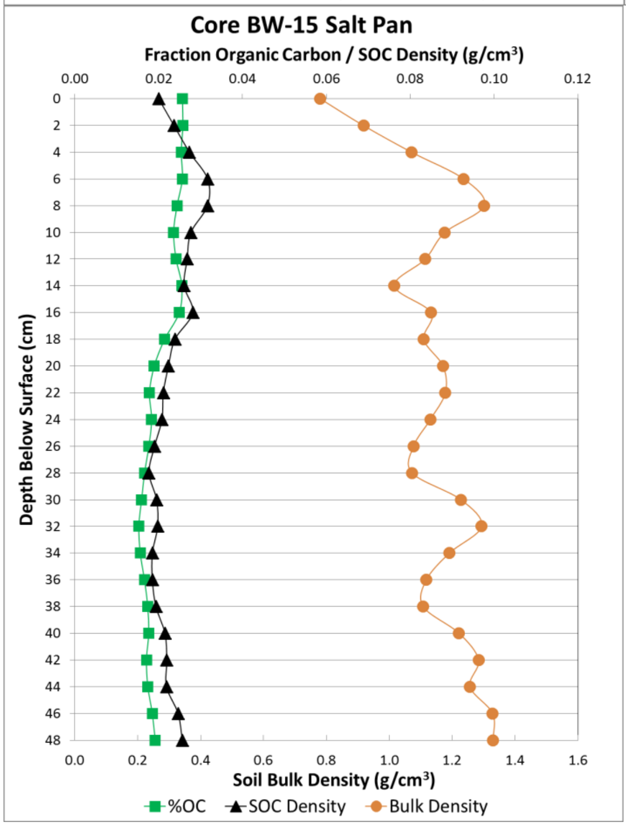
Core BW-04 High Marsh
Fraction Organic Carbon / SOC Density (g/cm³)
Depth Below Surface (cm)
Soil Bulk Density (g/cm³)
%OC
SOC Density
Bulk Density
Core BW-05 High Marsh
Fraction Organic Carbon / SOC Density (g/cm³)
Depth Below Surface (cm)
Soil Bulk Density (g/cm³)
%OC
SOC Density
Bulk Density
Core BW-13 High Marsh
Fraction Organic Carbon / SOC Density (g/cm³)
Depth Below Surface (cm)
Soil Bulk Density (g/cm³)
%OC
SOC Density
Bulk Density
Core BW-20 High Marsh
Fraction Organic Carbon / SOC Density (g/cm³)
Depth Below Surface (cm)
Soil Bulk Density (g/cm³)
%OC
SOC Density
Bulk Density



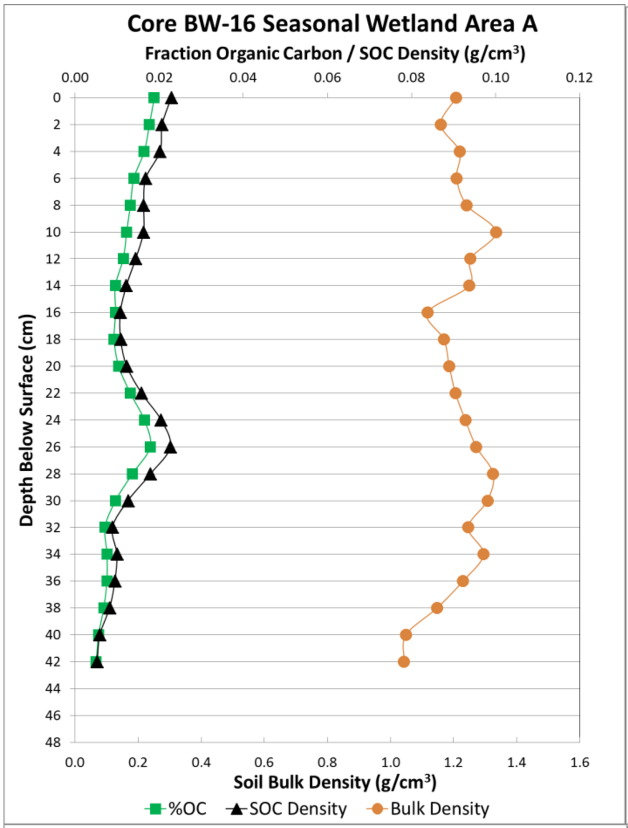
Core BW-11 Salt Pan
Fraction Organic Carbon / SOC Density (g/cm³)
Depth Below Surface (cm)
Soil Bulk Density (g/cm³)
%OC
SOC Density
Bulk Density

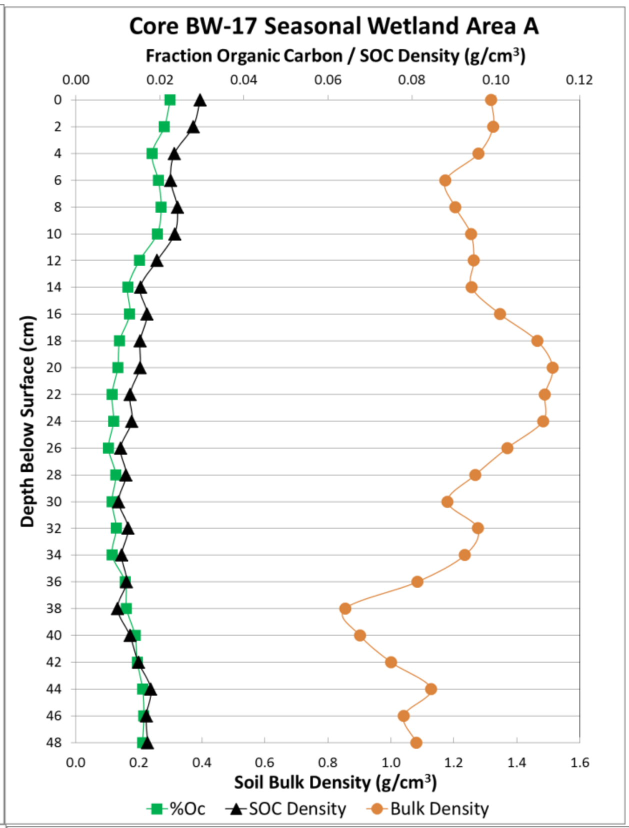


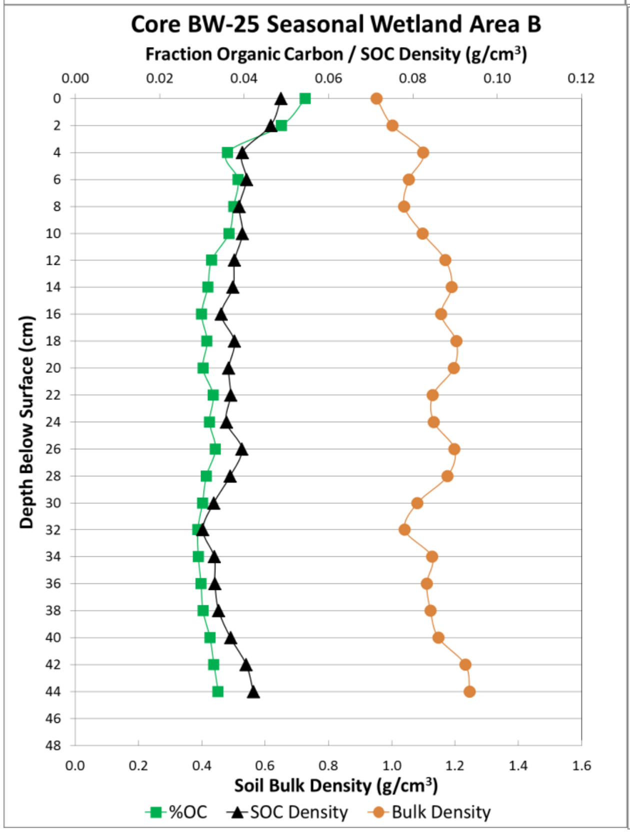
Core BW-14 Salt Pan
Fraction Organic Carbon / SOC Density (g/cm³)
Depth Below Surface (cm)
Soil Bulk Density (g/cm³)
%OC
SOC Density
Bulk Density

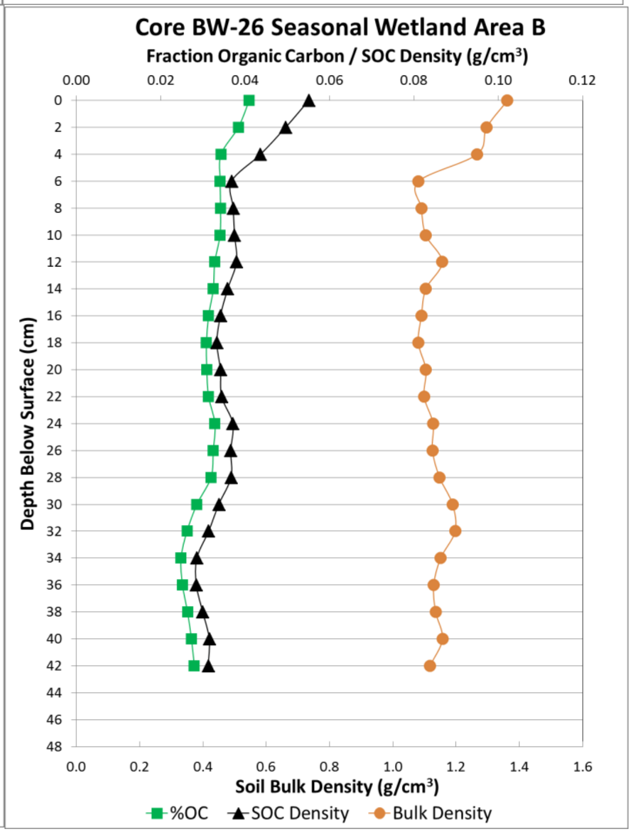


Core BW-15 Salt Pan
Fraction Organic Carbon / SOC Density (g/cm³)
Depth Below Surface (cm)
Soil Bulk Density (g/cm³)
%OC
SOC Density
Bulk Density


Core BW-16 Seasonal Wetland Area A
Fraction Organic Carbon / SOC Density (g/cm³)
Depth Below Surface (cm)
Soil Bulk Density (g/cm³)
%OC
SOC Density
Bulk Density


Core BW-17 Seasonal Wetland Area A
Fraction Organic Carbon / SOC Density (g/cm³)
Depth Below Surface (cm)
Soil Bulk Density (g/cm³)
%OC
SOC Density
Bulk Density


Core BW-25 Seasonal Wetland Area B
Fraction Organic Carbon / SOC Density (g/cm³)
Depth Below Surface (cm)
Soil Bulk Density (g/cm³)
%OC
SOC Density
Bulk Density


Core BW-26 Seasonal Wetland Area B
Fraction Organic Carbon / SOC Density (g/cm³)
Depth Below Surface (cm)
Soil Bulk Density (g/cm³)
%OC
SOC Density
Bulk Density

APPENDIX D – Emission Reductions Calculations

Table D-1
Baseline Soil CO_2e Emission Reductions (2020-2050)

Habitat Type	Carbon Emission Reduction (Sequestration) Rate[a] (g C/m^2*yr)	Area (Acres)[b]	$GHG_{BSL\text{-}soil\text{-}CO2}$ (metric ton CO2e/yr)
Low Marsh	-80	9	-10.7
Mid-Marsh	-28	18	-7.5
High Marsh	-30	41	-18.3
Seasonal Wetland Area A	-16	11	-2.6
Seasonal Wetland Area B	-39	74	-42.8
Seasonal Wetland Area C	-16	1	-0.2
Salt Pan	-9	22	-2.9
Brackish Marsh	-38	3	-1.7
Mudflats	-52	15	-11.6
Transition Zone	0	0	0.0
Upland	-16	283	-67.2
Total		**477**	**-165**
Net Total Reductions (2020-2030)			1,650 mt CO_2e
Net Total Reductions (2030-2050)			3,300 mt CO_2e
Net Total Reductions – Baseline Scenario			**4,950 mt CO_2e**

a: Rates from this study
b: Areas from CDFG (2007)

Table D-2
Project Soil CO_2e Emission Reductions (2020 – 2050)
Including 11% Deduction for Allochthonous Carbon

Habitat Type	Carbon Emission Reduction (Sequestration) Rate (g C/m^2*yr)[1]			2020-2030 Areas (Post-restoration Acreages[2])	2030-2050 Areas (2030 Acreages[2])	2020-2030 Annual CO_2e Emission Reduction (mt CO_2e/yr); including a 11% deduction for allochthonous SOC[3]			2030-2050 Annual CO_2e Emission Reduction (mt CO_2e/yr); including a 11% deduction for allochthonous SOC[3]		
	Average	**Low**	**High**			**Average**	**Low**	**High**	**Average**	**Low**	**High**
Low Marsh	160	80	380	49	61	104	52	246	129	64	306
Mid-Marsh	110	66	198	103	99	150	90	269	144	86	259
High Marsh	72	43	120	34	30	32	19	54	29	17	48
Seasonal Wetland Area A	0	0	0	0	0	0	0	0	0	0	0
Seasonal Wetland Area B	0	0	0	0	0	0	0	0	0	0	0
Seasonal Wetland Area C	16	16	16	4	4	1	1	1	1	1	1
Salt Pan	26	9	44	20	19	7	2	12	7	2	11
Brackish Marsh	38	38	38	13	13	7	7	7	7	7	7
Mudflats	104	52	221	40	47	55	27	117	65	32	137
Transition Zone	16	16	16	51	55	12	12	12	13	13	13
Upland	16	16	16	171	157	41	41	41	37	37	37
Total				**485**	**485**	**407**	**251**	**758**	**430**	**260**	**819**
Emission Reductions (mt CO2e) (2020-2030)						**4,075**	**2,509**	**7,577**			
Emission Reductions (mt CO2e) (2030-2050)									**8,602**	**5,202**	**16,371**
Total Emission Reductions (mt CO2e) (2020-2050)									**12,677**	**7,711**	**23,948**

1: Rates from this study
2: Areas from ESA PWA, 2012
3: Except for non-tidal habitats (Seasonal Wetland; Transition Zone; Upland)

Calculations for period 2050 (t_3) to 2100 (t_4)

The calculation of net greenhouse gas removals for the time period 2050 (t_3) to 2100 (t_4) is shown below for the baseline and project scenarios using the equation:

$$NER = GHG_{BSL} – GHG_{WPS} – GHG_{LK}.$$

Baseline Scenario

Because baseline scenario habitats are assumed to remain unchanged from the existing habitats in year t_1, the baseline biomass and soil strata for year t_4 are the same as those shown in Table 5-2 and Table 5-3, respectively. Therefore, the total change in biomass in the baseline scenario from t_3 to t_4 is:

$$\Delta C_{BSL\text{-}biomass} = \Delta C_{BSL\text{-}tree/shrub} + \Delta C_{BSL\text{-}herb} = 0 + 0 = 0 \text{ mt C},$$

and the net emissions from biomass carbon pools in the baseline scenario from t_3 to t_4 are zero.

$$GHG_{BSL\text{-}biomass} = [(44/12) \text{ x } \Delta C_{BSL\text{-}biomass}] = 0 \text{ mt } CO_2e$$

Where the baseline scenario GHG soil emissions are the same rate for 2050 to 2100 as for the period 2020 to 2050:

$$GHG_{BSL} = –165 \text{ mt } CO_2e\text{/year x 50 years} = –8{,}250 \text{ mt } CO_2e$$

Project Scenario

The projected project scenario biomass and soil strata for the years 2050 and 2100 are provided by PWA ESA (2012) and are shown in Tables D-3 and D-4, respectively.

Table D-3
Project Scenario Biomass Strata for Vegetated Habitats

Habitat Type	Area (acres) 2050[1]	Area (acres) 2100[1]
Low Marsh	52	32
Mid-marsh	91	111
High Marsh	28	21
Seasonal Wetland Area A	0	0
Seasonal Wetland Area B	0	0
Seasonal Wetland Area C	3	3
Brackish Marsh	12	13
Upland Coastal Scrub	44[2]	39[3]
Upland Grassland/Herbaceous/Dunes	89[4]	78[5]
Transition Zone	62	15
Total	**381**	**312**

1 = ESA PWA (2012)
2 = Same percentage of coastal scrub habitat as existing condition: 134 acres upland habitat x 33% coastal scrub
3 = Same percentage of coastal scrub habitat as existing condition: 118 acres upland habitat x 33% coastal scrub
4 = Same percentage of grassland/herb/dunes as existing condition: 134 acres upland habitat x 66.2% grassland/herb/dunes
5 = Same percentage of grassland/herb/dunes as existing condition: 118 acres upland habitat x 66.2% grassland/herb/dunes

Using the same calculations as presented in Section 5.3.5.2.1 for the project scenario (WPS):

C_{SHRUB_t3} = (44/12) x (0.47 mt C/mt biomass) x (1+1) x (44 ac) x (5.7 metric ton biomass/ac) x 0.7 = 605 mt CO_2e

Shrub biomass in the project scenario for year t_4 is:

C_{SHRUB_t4} = (44/12) x (0.47 mt C/mt biomass) x (1+1) x (39 ac) x (5.7 metric ton biomass/ac) x 0.7 = 536 mt CO_2e

The change in shrub biomass between the years t_3 and t_4 is:

$$\Delta C_{SHRUB} = (C_{SHRUB,\ t3} - C_{SHRUB,\ t4}) = 605 - 536 = 69 \text{ mt } CO_2e$$

Section 5.3.5.2.1 also showed herbaceous biomass in the year t_3 as:

$$C_{WPS\text{-}herb,\ t3} = 337 \text{ ac x } 300 \text{ g C/m}^2 \text{ x } 0.004 = 404 \text{ mt C}$$

Where 0.004 is a conversion factor (m^2 to acre and g to mt).

Herbaceous biomass in the project scenario for year t_4 is:

$$C_{WPS\text{-}herb,\ t4} = 273 \text{ ac x } 300 \text{ g C/m}^2 \text{ x } 0.004 = 328 \text{ mt C}$$

And the total emissions from changes in herbaceous biomass during the project scenario period from t_3 to t_4 are:

$$\Delta C_{WPS\text{-}herb} = 404 - 328 = 76 \text{ mt C, and}$$

$$(44/12) \text{ x } 76 \text{ mt C} = 279 \text{ mt } CO_2e$$

The final estimate of greenhouse gas emissions reductions due to biomass in the project scenario for the 50-year period from t_3 to t_4 is:

$$GHG_{WPS\text{-}biomass,\ t3\text{-}t4} = \Delta C_{WPS\text{-}tree/shrub} + \Delta C_{WPS\text{-}herb}$$

$$GHG_{WPS\text{-}biomass,\ t3\text{-}t4} = (0 + 69) + 279 = 348 \text{ mt } CO_2e$$

The positive value means that 348 metric tons of CO_2e are lost to the atmosphere from biomass between the project scenario time period t_3 to t_4.

Table D-4
Project Scenario Soil Strata

Habitat Type	2050 Area (acres)[1]	2100 Area (acres)[1]
Low Marsh	52	32
Mid-marsh	91	111
High Marsh	28	21
Seasonal Wetland Area A	0	0
Seasonal Wetland Area B	0	0
Seasonal Wetland Area C	3	3
Salt Pan	19	14
Brackish Marsh	12	13
Mudflats	82	146
Transition Zone	62	15
Upland	134	118
Total	**483**	**485**

1 = ESA PWA (2012)

Emissions of CH_4 and N_2O are considered zero as discussed in Section 5.3.5.2.2 and soil CO_2e emission reductions with an 11% deduction for allochthonous carbon for years t_3 and t_4 are shown in Table D-5 below.

The total GHG soil emissions for the project scenario crediting period from 2050 to 2100, conservatively using 2050 habitat areas, are therefore:

$GHG_{WPS\text{-}soil} = A \text{ x } (GHG_{WPS\text{-}soil\text{-}CO2} – Deduct_{alloch} + GHG_{WPS\text{-}soil\text{-}CH4} + GHG_{WPS\text{-}soil\text{-}N2O})$

$GHG_{WPS\text{-}soil} = A \text{ x } (GHG_{WPs\text{-}soil\text{-}CO2} – Deduct_{alloch} + 0 + 0)$

$GHG_{WPS\text{-}soil}$ = –22,055 mt CO_2e (average), –13,100 mt CO_2e (low range), and –42,346 mt CO_2e (high range).

And the total project scenario emissions during the period t_3 to t_4 where $GHG_{WPS\text{-}fuel}$ is zero, are:

$$GHG_{WPS} = GHG_{WPS\text{-}biomass} + GHG_{WPS\text{-}soil}$$

GHG_{WPS} = 348 + (–22,055) = –21,707 mt CO_2e, for average carbon sequestration rates

GHG_{WPS} = 348 + (–13,100) = –12,752 mt CO_2e, for low range carbon sequestration rates

GHG_{WPS} = 348 + (–42,346) = –41,998 mt CO_2e, for high range carbon sequestration rates

The net greenhouse gas emission reductions and removals associated with the Ballona Project from time t_3 to t_4 are therefore:

$$NER = GHG_{BSL} – GHG_{WPS} – GHG_{LK}$$

Where the baseline scenario GHG emissions are:

$$GHG_{BSL} = –165 \text{ mt } CO_2\text{e/year x 50 years} = –8,250 \text{ mt } CO_2\text{e}$$

And GHG emissions from leakage are zero:

$$GHG_{LK} = 0 \text{ mt } CO_2\text{e}$$

Results in:

NER = –8,250 – (–21,707) – 0 = 13,457 mt CO_2e for average carbon sequestration rates

NER = –8,250 – (–12,752) – 0 = 4,502 mt CO_2e, for low range carbon sequestration rates

NER = –8,250 – (–41,998) – 0 = 33,748 mt CO_2e, for high range carbon sequestration rates

Table D-5
Project Soil CO_2e Emission Reductions (2050 – 2100)

Habitat Type	Carbon Emission Reduction (Sequestration) Rate (g C/m^2*yr)[1]			2050-2100 Areas (Using 2050 Acreages[2])	2050-2100 Annual CO_2e Emission Reduction (mt CO_2e/yr); including a 11% deduction for allochthonous SOC[3]		
	Average	**Low**	**High**		**Average**	**Low**	**High**
Low Marsh	160	80	380	52	110	55	261
Mid-Marsh	110	66	198	91	132	79	238
High Marsh	72	43	120	28	27	16	44
Seasonal Wetland Area A	0	0	0	0	0	0	0
Seasonal Wetland Area B	0	0	0	0	0	0	0
Seasonal Wetland Area C	16	16	16	3	1	1	1
Salt Pan	26	9	44	19	7	2	11
Brackish Marsh	38	38	38	12	6	6	6
Mudflats	104	52	221	82	113	56	239
Transition Zone	16	16	16	62	15	15	15
Upland	16	16	16	134	32	32	32
Total				**483**	**441**	**262**	**847**
Total Emission Reductions (mt CO2e) (2050-2100)					**22,055**	**13,100**	**42,346**

1: Rates from this study
2: Areas from ESA PWA, 2012
3: Except for non-tidal habitats (Seasonal Wetland; Transition Zone; Upland)

Table D-6
Soil CO_2e Emission Reductions for the Hypothetical High Carbon Sequestration Alternative vs Proposed Alternative (2020-2100)

Habitat Type	Carbon Emission Reduction (Sequestration) Rate (g C/m^2*yr)			2020-2030 Areas (2020 Acreages)	2030-2050 Areas (2030 Acreages)	2050-2100 Areas (2050 Acreages)	2020-2100 Annual CO_2e Emission Reduction (mt CO_2e); including a 11% deduction for allochthonous SOC		
	Average	**Low**	**High**				**Average**	**Low**	**High**
Low Marsh	160	80	380	98	122	104	18214	9107	43258
Mid-Marsh	110	66	198	206	198	182	21965	13179	39536
High Marsh	72	43	120	68	60	56	4450	2658	7417
Seasonal Wetland Area A	0	0	0	0	0	0	0	0	0
Seasonal Wetland Area B	0	0	0	0	0	0	0	0	0
Seasonal Wetland Area C	16	16	16	4	4	3	57	57	57
Salt Pan	26	9	44	20	19	19	525	182	889
Brackish Marsh	38	38	38	13	13	12	497	497	497
Mudflats	104	52	221	40	47	82	7472	3736	15877
Transition Zone	16	16	16	0	0	0	0	0	0
Upland	16	16	16	36	22	25	433	433	433
Total Areas				**485**	**485**	**483**			
Hypothetical Alternative (2020-2100)							53,613	29,848	107,965
Proposed Alternative (2020-2100)							34,732	20,811	66,294
Difference from Proposed Alternative							**18,881**	**9,037**	**41,671**

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