Carbon Content in Oregon Tidal Wetland Soils

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Abstract

Tidal wetlands are a powerful carbon sink. They can sequester an order of magnitude more carbon than any other type of wetland system, and emit only negligible amounts of methane compared with freshwater wetlands (Brigham *et al.* 2006, Whiting and Chanton 2001). Soil carbon in tidal wetlands can also affect soil ecology and influence wetland functions such as nutrient processing and foodweb support. We quantified carbon content in the top 30 cm of soil in 17 tidal wetlands in Oregon and tested the hypothesis that there is a difference in the soil carbon content of unrestored, restored, and least-disturbed tidal wetlands. Sampling occurred in three unrestored sites; four restored sites; and ten least-disturbed reference sites. The average concentration of soil organic carbon in reference site soils was 15.7%, 13.5% in restored soils, and 8.6% in unrestored soils. Percent carbon values in unrestored sites were significantly different from the other two groups ($p < 0.001$), but values from reference and restored sites were not significantly different ($p > 0.1$). The similarity between soil carbon in reference and restored sites may support previous work that suggests rapid carbon accumulation after restoration (Craft 2007).

TABLE OF CONTENTS

Carbon Content in Oregon Tidal Wetland Soils

Introduction and Background

Soil organic matter, and thus carbon, can affect hydraulic conductivity, soil biota, and aboveground plant communities in tidal wetlands (Gray 2009, Bezemer 2005). In addition to value for understanding fundamental ecological processes, tidal wetlands have also become notable in the field of carbon sequestration because they are, per unit area, among the most effective carbon sequestering ecosystems (Laffoley and Grimsditch 2009, Chmura *et al.* 2003). Despite the significant ecological role of soil carbon in tidal wetlands and its strong potential as a climate mitigation tool, a large research gap exists in the Pacific Northwest, and in Oregon in particular. This study serves two primary functions: it initiates a database for tidal wetland soil characteristics in the Pacific Northwest, and examines differences in soil carbon under three land management scenarios.

Of all estuarine ecosystems, high marsh and swamp are two of the most highly impacted in Oregon. Because most of these tidal wetlands in Oregon are managed, we investigate differences in soil carbon content between three management types: sites that have been actively or recently grazed and diked, sites that have undergone hydrologic restoration, and least-disturbed reference sites, which are referred to here as unrestored, restored, and reference, respectively.

In Oregon, nearly 70% of historic tidal wetlands have been converted to agricultural uses (Good 2000, Christy 2004). Losses of scrub-shrub and forested tidal wetlands (*i.e.* tidal swamps) have been much higher, as documented in basin-scale studies (Brophy 2005a, Graves *et al.* 1995). Diking, ditching, draining, and livestock grazing are common land management practices in tidal wetlands, and can result in a comprehensive change in aboveground plant communities (Roman *et al.* 1984). This process frequently results in subsidence of the soil surface due to oxidation of organic matter and direct compaction by livestock (Frenkel and Morlan 1991, Callaway 2001). A conceptual model of a tidal wetland ecosystem is illustrated below in Figure 1 (Roegner *et al.* 2008). The model shows how tidal wetland sediment characteristics relate to ecosystem structures such as vegetation type and tidal channel formation, which in turn are closely related to ecosystem processes and functions. Awareness of the critical ecological functions provided by tidal wetlands led to the state of Oregon adopting estuarine restoration and conservation as policy in land use planning Goal 16. Since the establishment of Goal 16 in 1977, tidal wetland restoration has made a significant contribution to Oregon's restoration economy (Good 2000).

Soil organic matter is a particularly significant component of soil ecology (Kennedy and Smith 1995). It has been positively correlated with hydraulic conductivity; as when

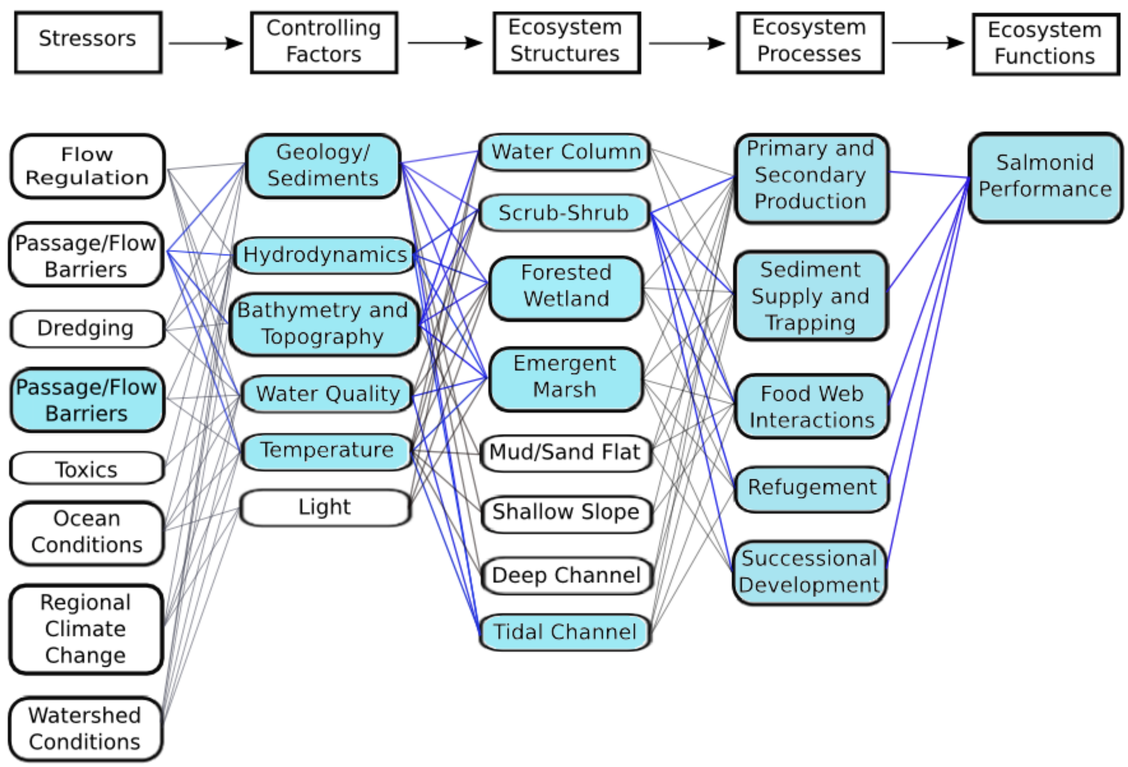

***Figure 1**. Tidal wetland ecosystem conceptual model (Roegner* et al*. 2008).*

higher organic matter results in a soil with low bulk density (extremely low in some tidal wetland cases), which reflects the porosity of the soil matrix (Craft *et al.* 1988). This porosity allows water to pass through the soil profile much more freely than in soils with low organic matter (Mitchell 1993, Judson and Odum 1990). In brackish, tidally influenced soils, this subsurface flow can distribute marine-derived nutrients and salts throughout the site (Judson and Odum 1990). The control exerted by organic matter on soil biota and hydrology can influence surrounding plant communities and the higher trophic levels that rely on them (Hines *et al.* 2006, Oliver *et al.* 2009, Bezemer *et al.* 2005). For example, in their analysis of Californian coastal wetlands, Kwak and Zedler (1996) describe the role of organic matter as the foundation of the marsh food web, which extends through trophic orders to fishes and birds. Because of these important characteristics, soil organic matter, salinity, and pH have been listed as high priority monitoring parameters for tidal wetland restoration projects (Zedler 2001, Simenstad *et al.* 1991).

Because soil is a stable, long term surface reservoir for carbon, it has drawn global attention as a strategic element of greenhouse gas mitigation. Within the scope of soil carbon storage, wetlands stand out. Freshwater wetlands can act as both sinks and sources of greenhouse gases. Large stores of carbon-sequestering organic matter are developed over long periods of time (*e.g.* peat bogs), yet methane is also produced as a byproduct of biotic respiration. In saline tidal wetlands, organic matter can be rapidly buried by tidal sediments, and saline water favors sulfate reduction, reducing methane production to negligible amounts (Whiting and Chanton 2001, King *et al.* 2007). High levels of soil carbon in tidal wetlands have recently brought these systems to the forefront of the global discussion of carbon sequestration and ecosystem-based climate change mitigation (Laffoley and Grimsditch 2009, Crooks *et al.* 2009, Crooks *et al.* 2011). Research has also shown that tidal wetlands with higher soil carbon content may be more resilient to sea level rise (Cahoon *et al.* 2006, Cahoon *et al.* 2004, Craft 2007, Nyman *et al.* 2006, Morris *et al.* 2002).

Lastly, tidal wetland soils research in the US has been concentrated in the Gulf and Atlantic Coasts, where topography, bathymetry, vegetation, and land management practices drive estuarine dynamics and ecological communities that are very different from those of the West Coast. This research is motivated in part by the lack of data that represents the Pacific Northwest where estuarine processes are driven by uniquely regional conditions such as the input of sediment from upland forest management (Pakenham 2009, Hickey and Banas 2003). At the time of writing, two studies of tidal wetland soil carbon have been conducted in the Pacific Northwest. In his 1996 paper, Ronald Thom (Pacific Northwest National Laboratory) presents percent carbon data collected from two sites in Washington and Oregon (and accretion data from six sites). Soil organic matter data may have been collected as part of several regional accretion studies, though it is not presented in respective literature (*e.g.* Johnson and Diefenderfer 2009). Here, we build on data collected by Laura Brophy (Green Point Consulting) in a series of monitoring studies conducted on the Oregon Coast (*e.g*. Brophy 2005b, 2009, 2010) to test the hypothesis that soil carbon content differs in unrestored, restored, and reference tidal wetland soils.

Methods

Sampling Design

Eight estuaries from the Columbia River estuary in northern Oregon to the Coquille estuary in southern Oregon (Figure 2) were included in this study. A total of 75 samples were collected from 17 sites in the estuaries illustrated in Figure 2. We focused sampling in forested tidal wetland (i.e., tidal swamp) and high marsh wetland habitat classes because, as opposed to low marsh, these classes have typically been impacted by human activities in our area. Sampling occurred in three recently grazed sites; four sites that had been previously diked, drained and grazed but have undergone hydrologic restoration; and ten least-disturbed reference sites. These groups are referred to here as unrestored, restored, and reference, respectively. To test the hypothesis that soil carbon content in reference sites differs from that in restored and unrestored sites, we distributed the sampling effort between reference, restored and unrestored sites. Twenty five samples were taken from ten reference sites, 25 from four restored sites, and 25 from two unrestored sites (Table 1). A table of detailed site histories and characteristics is provided in the Appendix.

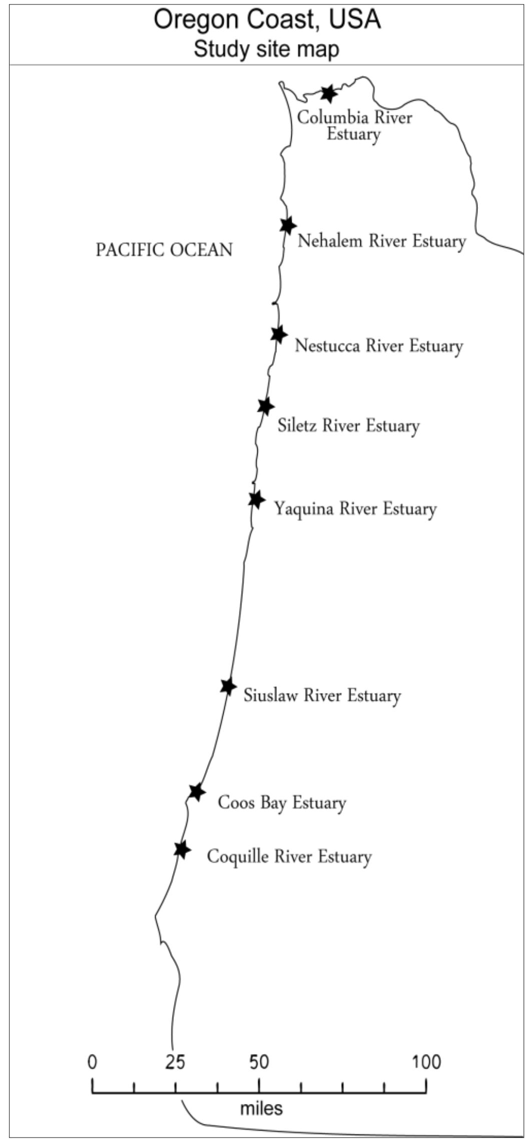

***Figure 2**. Study sites*

Study sites included tidal swamp, high marsh, low marsh, and transitional zones. To leverage study results and provide detailed data on site history, vegetation and hydrology, we selected sites that had previously been monitored for other purposes. Those details are provided in earlier reports (Brophy 2009, 2005b, 2004, 2002). Among the sites were several restoration-reference site pairs with similar historic habitat class and landscape setting (Appendix).

***Table 1**. Study sites and estuaries*

REFERENCE		DISTURBED			
Reference (10)	***n***	**Restored** (4)	***n***	**Unrestored** (3)	***n***
Bandon Marsh (*Coquille R.*)	4	Millport South (*Siletz R.*)	8	S65 (*Siuslaw R.*)	3
Blind Slough (*Columbia R.*)	2	Nestucca East (*Nestucca R.*)	5	Ni-les'tun (*Coquille R.*)	14
Coal Creek (*Nehalem R.*)	2	S59 (*Siuslaw R.*)	3	Waite Ranch (*Siuslaw R.*)	8
Cox Island (*Siuslaw R.*)	2	Y27 (*Yaquina R.*)	9		
Duncan Island (*Siuslaw R.*)	2				
Hidden Marsh (*Coos R.*)	2				
Millport North (*Siletz R.*)	5				
S63 (*Siuslaw R.*)	2				
Y13A (*Yaquina R.*)	2				
Y28 (*Yaquina R.*)	2				

Samples were collected along pre-existing 100m transects which had been distributed in study sites within major elevation strata (Brophy 2002). Because of the strong relationships between tidal marsh plant communities, elevation, hydrology, and topography, we assumed that soil characteristics would also be affected by these conditions, and this transect placement would therefore be appropriate for soil sampling. Previously-established transect markers (PVC posts) aided in transect location. GPS units were used to validate locations or locate transects in the field when necessary.

Samples were collected from the rooting zone (soil surface to 30 centimeters depth), using a Dutch auger following a standard agricultural soil sampling method (Gardner and Hart 1995). When the sample extended into a horizon that clearly lacked any roots (*e.g.* a gleyed clay horizon with no evidence of root growth), that portion of the sample was excluded. Each soil sample was composed of multiple auger cores which were systematically distributed along each transect. Auger cores were then bulked into a single sample per transect for delivery to the laboratory. Each bulked sample was placed in a plastic zip-lock bag and stored at 2°C until processing in the lab. Sample date varied by location; month of sampling ranged from July to January, and samples were collected from 2006 through 2011. We make the assumption that, given the accuracy and resolution of our sampling technique, soil carbon remains relatively stable through the study period despite the potential for seasonal shifts in carbon metabolism by soil biota and vegetation (Neubauer *et al*. 2005).

Laboratory Methods

Laboratory analysis was conducted at Oregon State University's Central Analytical Laboratory. Samples were dried, homogenized, and a subsample was extracted for analysis. Before homogenization, large roots were removed from samples by hand, introducing potential for bias in the data. Electrical conductivity and pH were measured using an electrical conductivity meter and a reference electrode with a pH meter, respectively. Lastly, percent organic matter was measured using Loss on Ignition (LOI) (Nelson and Sommers 1996, Craft *et al.* 1991). Samples were burned in a kiln at approximately 450°C for eight hours.

Data Analysis

Percent soil carbon was calculated from percent organic matter values yielded by LOI using a conversion specific to high organic soils (0.68 x %OM) presented in Kasozi *et al.* (2009). Soil salinity was calculated from electrical conductivity values using a constant multiplier of 0.64, modeled after an online conversion utility (Chapman 2006). For our range of conductivity values (62.4 to 0.22), this constant introduced an average error of 4% compared with the conversion utility. We used one way analysis of variance (ANOVA) to determine whether the percent of soil carbon differed among reference, restored, or unrestored tidal wetland sites. To identify which of the categories in the ANOVA drove the identified difference, we applied the post-hoc Scheffé procedure. We determined that a p value of 0.05 was appropriate for this study. All analyses were performed using SPSS (PSAW Statistics 18, Release Version 18.0.0).

In order to test the ANOVA procedure for sensitivity to a violation of its independence assumption, a multilevel analysis was conducted parallel to the ANOVA described above (Dr. John Light, Oregon Research Institute, personal communication). Spatial autocorrelation is a violation of the independence assumption inherent to ANOVA and may be associated with this dataset due to the proximity of sample transects to each other in each sampling site (Ramsey and Schafer 2002). Multilevel analysis is a method of comparing means which, by utilizing a model with nested sample units, allows for correlation and does not assume independence (Snijders 2003).

Potential Sampling Bias

Site conditions and differences in plant structure can affect soil sampling results. In our study sites, cespitose (clump-forming) grasses or other dense vegetation often occurred adjacent to areas of exposed soil at sampling sites. These conditions presented potential for sampling bias due to the relative amount of effort it takes to collect a sample in dense vegetation compared with bare ground. In light of this, an effort was made to distribute samples representatively in these conditions. Also, soils associated with certain vegetation types occasionally yielded smaller samples. For example, when drilling the auger into well-established stands of slough sedge (*Carex obnupta*), which has thick and dense root systems, some soil can be pushed out from the sample as roots are cut with the auger blades. Lastly, when sampling in extremely porous soil (as inside a cespitose grass) the high porosity generally led to a smaller sample size. In any case, if the auger was less than 2/3 full, the sample was repeated. Otherwise, no effort was made to correct for these circumstances, to maintain a consistent protocol. Since samples with higher bulk density or fewer large roots had the potential to yield more actual mass, these soils could be overrepresented in the bulked sample.

Results and Discussion

All data are presented in Table 6 below.

Soil Carbon

One-way ANOVA results showed significant differences in average concentration of soil organic carbon among the three groups ($F(2,72) = 19.18$, $p < 0.001$). Reference sites showed the highest percent carbon ($M = 15.69$, S.E. = 0.887), restored sites somewhat less ($M = 13.52$, S.E. = .794), and unrestored sites showed the least soil carbon ($M = 8.57$, S.E. = 0.814) (Table 2, Figure 3). Post-hoc Scheffé tests showed that unrestored sites differed significantly from each of the other two groups ($p < 0.001$), but the difference between reference and restored groups was not statistically significant ($p > 0.1$) (Table 3, Figure 3).

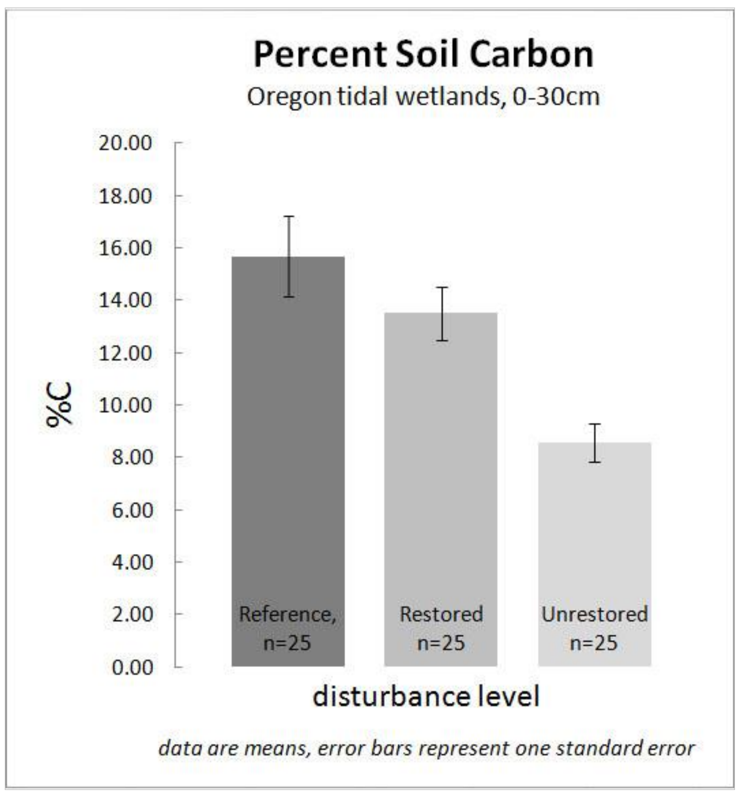

***Figure 3**. Percent soil carbon across site disturbance levels*

Table 2. *Soil characteristics by site condition with one-way ANOVA results at p=0.05**

		% carbon			Salinity		
Site type	**n**	**Mean**	**Significance**	**Std error**	**Mean**	**Significance**	**Std error**
Reference	25	15.69	a	0.89	12.32	ab	1.55
Restored	25	13.52	a	0.79	5.98	b	1.11
Unrestored	25	8.57	b	0.81	4.05	c	0.81

*Means having a common letter in the significance column are not significantly different at the 5% level of significance (*p*=0.05).

Table 3*. Scheffé means comparison of percent carbon across three site disturbance levels*

(I) DISTURBANCE	(J) DISTURBANCE	Mean Difference (I-J)	Std. Error	Significance	95% Confidence Interval Lower	95% Confidence Interval Upper
reference	restored	2.17	1.178	0.19	-0.77	5.12
	unrestored	7.12*	1.178	0.00	4.17	10.06
restored	reference	-2.17	1.178	0.19	-5.12	0.77
	unrestored	4.94*	1.178	0.00	2.00	7.89
unrestored	reference	-7.12*	1.178	0.00	-10.06	-4.17
	restored	-4.94*	1.178	0.00	-7.89	-2.00

*The mean difference is significant at the 0.05 level.

These results were generally validated by the multilevel analysis. In both soil carbon and salinity analyses, comparisons that were significant in the ANOVA were also significant in the multilevel analysis, although *p*-values were at times an order of magnitude higher in the multilevel analysis. Since the multilevel analysis partitions the error between more model parameters, and therefore is likely to reduce the significance of the "treatment" parameter (in this case, disturbance level), a more conservative *p*-value is a predictable response.

The lower carbon content at unrestored sites compared to reference sites strongly suggests that drainage and agricultural use of these former tidal wetlands caused loss of stored soil carbon. Worldwide, wetland drainage is usually associated with large releases of carbon dioxide to the atmosphere, a phenomenon of global importance in the face of rising atmospheric carbon and resultant climate change (Armentano 1980). Frenkel and Morlan (1991) measured 35cm of subsidence at a diked tidal wetland in the Salmon River estuary of Oregon. At South Slough National Estuarine Research Reserve, the pre-restoration soil surface elevation at the diked, drained Kunz Marsh site was about 1m lower than the adjacent reference site (Cornu and Sadro, 2002). In both cases, the authors attributed the subsidence at the diked, drained sites to oxidation of soil organic matter, loss of buoyancy, and compaction by livestock and farm machinery. This subsidence rate rivals those regularly called out in climate change discussions such as that of Indonesia's coastal peat swamps (5cm per year) (Page *et al.* 2002; Dr. Heather Tallis, Natural Capital Project, personal communication).

Although we saw a significant difference in mean soil carbon between unrestored and reference sites, the sample number was small and further studies are warranted. The higher mean soil carbon in restored sites (compared to unrestored sites) may be due to initially high levels of organic matter (before diking and draining), or to accretion of organic matter since restoration.

Three sample values in the dataset are notable. Transect 1 in the Bandon Marsh reference site yielded 7.9% C, a value that was among the lowest in the data set and one that challenges the trend we found of higher C content in reference sites and lower C content in disturbed sites. Much of this site is a relatively young tidal marsh, accreted within the last 150 years, and a 2005 plant community study suggests the site may still be undergoing rapid accretion (Witter *et al.* 2003, Brophy 2005b). Recent and rapid accretion at this site may relate to the changes in sediment regime after human settlement that have been described in the Coquille watershed (Benner 1992). Accelerated sedimentation in the lower Coquille estuary could relate to the low carbon content at the Bandon Marsh reference site, as could the site's landscape setting in the relatively high-energy environment of the lower estuary where larger particles with generally lower carbon content would likely accumulate.

Two other contradictions to the trend of lower C content in disturbed sites were particularly high carbon content in two historically disturbed sites: Transect 4 (T4) at Waite Ranch, an unrestored site (20.4% C), and Transect P3 at S59, a restored site (23.1% C). The Waite Ranch site also showed the highest within-site variability (6.9 to 20.4% C, n=8). In both cases, these observations may relate to the site's historic vegetation class, geomorphology and elevation range. Both sites were historically tidal swamps. The historic vegetation class of the Waite Ranch site was Pacific crabapple swamp, currently a rare ecosystem on the Oregon coast with few remaining examples. Analysis of soil carbon content at a freshwater (diked) crabapple swamp on Oregon's south coast showed unusually high organic matter (25.0% C) (Brophy 2005b). The historic vegetation class of site S59 was Sitka spruce swamp. Studies of soil carbon at least-disturbed willow and Sitka spruce tidal swamps on Oregon's outer coast have shown high organic matter content (12.7 to 26.2% C) (Brophy 2009), so there is a high likelihood that S59 and the

Waite Ranch had very high soil organic matter content prior to diking and conversion to agriculture, which may have been preserved in low, wet parts of the sites.

Soils high in organic matter are likely to undergo substantial elevation subsidence after diking and drainage (Frenkel and Morlan 1991, Callaway 2001). Based on nearby reference sites, we estimate that the lower portions of Waite Ranch have subsided over 1.5m, and S59 is estimated to have subsided up to 1 meter. The resulting low elevations remain saturated much of the year (Brophy 2011), likely conserving organic matter that would have been oxidized under drier conditions. By contrast, higher parts of the site such as the natural levee (e.g. Waite Ranch T7, which had only 8.5% C) have subsided considerably less, probably due to their geomorphic setting. Alluvial deposition processes on natural levees create higher elevations and coarser soil textures, with corresponding better drainage and lower soil organic matter content.

Salinity

Our analysis showed that salinity differed significantly among reference, restored, or unrestored tidal wetland sites ($F(2, 72) = 16.60$, $p<0.001$) (Figure 4, Table 2). Reference sites were most saline ($M = 11.45$, S.E. = 1.56), restored sites showed more moderate salinity ($M = 8.64$, S.E. = 1.02), and unrestored sites showed much less salinity ($M = 2.26$, S.E. = 0.74). The post-hoc Scheffé tests showed statistically significant differences between soil salinity in unrestored sites and each of the other two groups ($p<0.001$), but no statistically significant difference between salinity in reference and restored sites (p>0.2) (Figure 4, Table 5).

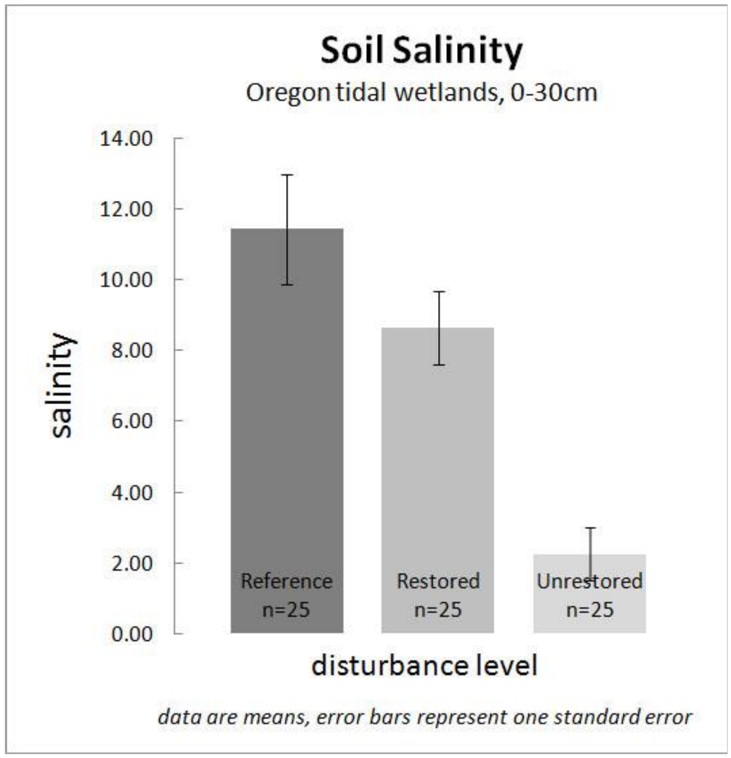

***Figure 4**. Soil salinity across site disturbance levels*

***Table 5**. Scheffé means comparison of salinity across three site disturbance levels*

(I) DISTURBANCE	(J) DISTURBANCE	Mean Difference (I-J)	Std. Error	Significance	95% Confidence Interval Lower Bound	Upper Bound
reference	restored	2.80	1.636	0.24	-1.29	6.89
	unrestored	9.19*	1.636	0.00	5.10	13.28
restored	reference	-2.80	1.636	0.24	-6.89	1.29
	unrestored	6.39*	1.636	0.00	2.30	10.48
unrestored	reference	-9.19*	1.636	0.00	-13.28	-5.10
	restored	-6.39*	1.636	0.00	-10.48	-2.30

*The mean difference is significant at the 0.05 level.

Table 6. Soil characteristics by site.

Site	Number of Samples (n)	Disturbance level (Reference = 1, Restored = 2, Unrestored = 3)	Sampling Date	%OM	%C*	Salinity
Bandon Marsh	4	1	7/22/2010	17.59	11.96	14.7
Blind Slough	2	1	8/28/2007	24.58	16.71	0.48
Coal Creek	2	1	8/30/2007	21.57	14.66	8.64
Cox Island	2	1	8/6/2010	23.68	16.1	14.53
Duncan Island	2	1	8/6/2010	19.21	13.06	11.39
Hidden Marsh	2	1	7/17/2008	26.84	18.25	27.62
Millport North	5	1	9/22/2010	26.51	18.03	7.69
S63	2	1	8/14/2007	27.75	18.87	11.71
Y13A	2	1	12/28/2010	19.67	13.38	9.79
Y28	2	1	11/7/2010	23.11	16.12	12.8
Millport South	8	2	9/21/2010	22.27	15.14	14.86
Nestucca East	5	2	1/19/2010	20.5	13.94	3.56
Y27	9	2	12/28/2010	15.56	10.58	5.11
S59	3	2	8/18/2006	25.42	17.28	11.24
S65	3	3	8/18/2006	12.56	8.54	0.94
Waite Ranch	8	3	8/7/2010, 9/22/10	18.45	12.55	0.21
Ni-les'tun	14	3	7/22/2010	9.28	6.31	3.7

**%C calculated using (0.68 x %OM) following Kasozi* et al. *2009.*

Conclusions and Future Research

Our data suggest that restoration of impacted sites could effectively recover the carbon storage role of tidal wetlands, as long as changes in bulk density don't negate that pattern. These results support previous findings in Craft's study (2007b) of created *Spartina* marshes.

As a rough guide, the decomposition rate of upland soil organic matter is understood to double as soil temperature increases by 10°C (Davidson and Janssens 2006). This rule of thumb illustrates the potential that carbon sequestration efforts may be offset by increased carbon dioxide and methane releases from warming soils in the future. In their review of the Intergovernmental Panel on Climate Change Fourth Assessment Report climate models, Mote and Salathé describe a projected increase of 3°C in the Pacific Northwest by 2080, suggesting a 30% increase in soil organic matter decomposition rates (Mote and Salathé 2009). However, environmental constraints (*e.g*. flooding and soil structure) complicate this projection, and the fact that the rule of thumb describes upland soils can not be overlooked. Wetland soil respiration under projected climate change regimes, particularly in brackish or tidal wetlands, is a rich area for future study.

The methods presented here provide preliminary data on carbon content in Oregon tidal wetland soils but cannot quantify carbon stocks without supplemental information on bulk density that would allow carbon stock estimation. In addition, accretion data would enable carbon sequestration rates to be estimated. Accretion rates have been calculated in some Oregon estuaries (*e.g.* Pakenham 2009, Thom 1992) and provide additional value to collecting supplemental data on bulk density. Because samples in this study were collected along established vegetation monitoring transects, future research into soil bulk density for these sites could be conducted in association with other monitoring activities. Finally, the relatively small amount of field effort necessary for the data collection method presented here could complement rapid assessment protocols (*e.g.* Adamus 2010), if more detailed information on soil carbon is of interest in such assessments.

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Appendix

Study Site Characteristics

Alternating colors indicate paired site groups. "X" indicates the attribute is not applicable to the site.

Estuary	Site name and number*	Number of transects sampled	Site category (Unrestored, Restored or Reference)	Impact type	Impact began	Year of restoration (approx)	Restoration activities	Pair ID	Historic vegetation type
Coquille	Bandon Marsh	4	Ref	X	X	X	X	1	marsh and open water
Coquille	Ni-les'tun	14	Unrest	Diked, ditched, drained, grazed	> 100 years ago	X	X	1	high marsh
Siuslaw	Cox Island (S11)	2	Ref	X	X	X	X	2	high marsh, swamp on E portion
Siuslaw	S59	3	Rest	Diked, ditched, drained, grazed	before 1939	2001	1996 dike breach and tide gate failure, two dike breaches in 2001	2	swamp
Siuslaw	S63	2	Ref	X	X	X	Diked but breached; never ditched	3	swamp
Siuslaw	S65	3	Unrest	Diked, ditched, drained, grazed	before 1939	2007	Breached dike, filled ditches, planted with tidal swamp species.	3	swamp
Siuslaw	Duncan Island (S30)	2	Ref	X	X	X	X	4	high marsh
Siuslaw	Waite Ranch (S26)	8	Unrest	Diked, ditched, drained, grazed	before 1909	active	none	4	swamp

Estuary	Site name and number*	Number of transects sampled	Site category (Unrestored, Restored or Reference)	Impact type	Impact began	Year of restoration (approx)	Restoration activities	Pair ID	Historic vegetation type
Siletz	Millport North	5	Ref	X	X	X	X	5	high marsh
Siletz	Millport South	8	Rest	Diked, dammed, partially ditched, drained, grazed	1929	2003	Removed outer and one inner dike, filled borrow ditch, connected historic sloughs, LWD	5	high marsh
Yaquina	Y13A	2	Ref	X	X	X	X	6	marsh
Yaquina	Y27	9	Rest	Diked, ditched, drained, grazed	1930s and 1940s	2002	Dikes breached in 2001, channels excavated, large woody debris placed, seeded, ditches filled	6	swamp and high marsh
Yaquina	Y28	2	Ref	X	X	X	X	6	swamp
Nestucca	Nestucca East (Little Nestucca)	5	Rest	Diked, ditched (berms on some ditches), drained, grazed	before 1939	2007	Created channels, connected channels, built levees to protect highway, added large woody debris		marsh
Nehalem	Coal Creek	2	Ref	X	X	X	X		swamp
Columbia	Blind Slough	2	Ref	X	X	X	X		swamp
Coos	Hidden Marsh	2	Ref	X	X	X	X		marsh

*site numbers refer to whole-estuary studies (Brophy 1999, 2005).