Biogeosciences Discuss., 10, 19155–19188, 2013
www.biogeosciences-discuss.net/10/19155/2013/
doi:10.5194/bgd-10-19155-2013

Biogeosciences
Discussions
Open Access

Carbon accumulation rates in salt marsh sediments suggest high carbon storage capacity

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Received: 31 October 2013 – Accepted: 15 November 2013 – Published: 6 December 2013

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Published by Copernicus Publications on behalf of the European Geosciences Union.

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Abstract

Studies on carbon stock in salt marsh sediments are increasing. However, uncertainties exist in estimating global carbon storage in these vulnerable coastal habitats, thus hindering the assessment of their importance. Combining direct data and indirect estimation, this study compiled studies involving 158 sites across the southern and Northern Hemispheres, and estimated the global average carbon accumulation rate (CAR) at 242.2 g C m^{-2} yr^{-1} in saltmarsh sediments. Based on region-specific CAR and estimates of salt marsh area in various geographic regions between 40° S to 78.3° N, total CAR in global salt marsh sediments is ∼10.1 Tg C yr^{-1}. The data indicate that while the capacity for carbon sequestration by salt marsh sediments ranked the first amongst coastal wetland and forested terrestrial ecosystems, their carbon budget was the smallest due to their limited and declining global areal extent. However, there may be uncertainties for our global estimate owing to limited and patchy data availability. CAR of salt marsh sediments changes with latitude, tidal range, halophyte genera and elevation, with considerable variation among different biogeographic regions.

1 Introduction

Salt marshes are intertidal vegetated wetland ecosystems, dominant on protected shorelines and on the edge of estuaries in a range of climatic conditions, from subarctic to tropical, while most extensive in temperate latitudes (Mitsch et al., 1994; Butler and Weis, 2009; Laffoley and Grimsditch, 2009). The combination of characteristic vegetation, geomorphology and habitat conditions of salt marshes provide essential ecosystem goods and services, including biogeochemical cycling and transportation of nutrients, habitat or food for coastal biota, shield and protecting coastal areas from storms and floods, water filtration, recreation and cultural benefits. However, salt marshes also critically suffer from losses due to dredging, filling, draining, construction and are particularly threatened by sea level rise as a result of “coastal squeeze” (Doody, 2004; Craft et al., 2008; Polunin, 2008; Gedan et al., 2009; Koch et al., 2009).

Salt marshes appear to be highly efficient in carbon burial, but studies on global carbon accumulation of salt marshes lag behind other coastal ecosystems. Firstly, data on salt marsh extent and carbon stock are patchy. A reliable estimate of global saltmarsh extent is lacking, and large areas of saltmarsh have never been mapped. Existing studies of carbon stock on salt marshes tend to focus on specific sites and lack a broader global perspective (Callaway et al., 2012). Chmura et al. (2003) examined global carbon sequestration of salt marshes, but their study only covered a latitudinal range from 22.4° S to 55.5° N. Secondly, carbon sequestration by mangroves and seagrasses has been analyzed with specific hypotheses in mind, such as the existence of clear latitudinal gradients (McLeod et al., 2011), while such an approach has rarely been attempted for salt marshes. The lack of a global view of carbon accumulation and storage in salt marshes contributes to this deficiency. Considerable studies have investigated carbon accumulation of salt marshes in different sites, including elevation gradients from low to mid or high marsh (Callaway et al., 1996, 2012; Connor et al., 2001; Elsey-Quirk et al., 2011; Adams et al., 2012; Schuerch et al., 2012), but these studies focused on carbon density, organic matter and sediment accretion and no direct estimates have been reached concerning carbon accumulation capacity. Finally, how sediment carbon accumulation may respond to tidal range and species occurrence has been studied individually in specific sites and for various genera of salt marshes (Rothman and Bouchard, 2007; Zhou et al., 2007; Mahaney et al., 2008), but a global consideration of pattern is still lacking. Even though salt marshes have been intensively investigated for more than fifty years, the global capacity for carbon sequestration by salt marshes is yet to be assessed. A global analysis will provide an opportunity to identify the role of these hotspots in climate change impact in terms of carbon storage and to inform future global conservation efforts.

Carbon sinks in salt marshes generally consist of aboveground biomass, belowground biomass and soils. Globally, it is recognized that soils contain the largest quantity of carbon in a range of ecosystems and two thirds of carbon is in the form of organic matter (Batjes, 1996). Likewise, the largest carbon stock of salt marshes is soil organic carbon (Murray et al., 2011), which is influenced by the carbon accumulation rate (CAR). Estimating global salt marsh CAR is significant to understanding carbon sequestration by salt marsh sediments.

CAR is calculated as the product of sediment accretion rate (SAR) and average carbon density of the soil (Connor et al., 2001; Ford et al., 2012). To date, studies on CAR have been restricted in geographic extent, whereas comprehensive data are available on SAR and soil carbon density in salt mash ecosystems. Combining data of the two parameters will establish a global CAR inventory of salt marshes.

This paper aims to refine the global CAR inventory of salt marshes, on the basis of published studies on specific regions, and to explore regional differences (including latitudinal and biogeographic differences) in CAR, as well as the nexus of CAR with tidal range, latitude and halophyte genera. Then the relationship between CAR and elevation change from low marsh to high marsh will be addressed. Finally, CAR and carbon budget of salt marsh sediments are compared with those of other coastal wetland and forested terrestrial ecosystems.

2 Method

2.1 Data sources and collation

We searched for relevant studies using the databases Science Citation Index Expanded, Conference Proceedings Citation Index-Science and Book Citation Index-Science within ISI Web of Science (Thomson Reuters), using the Boolean search statement: Topic = (salt* marsh* or saltmarsh) AND (carbon* or sediment* or soil). This search generated 4939 studies, including 174 reviews, 414 proceeding papers and 56 book chapters, and the rest were journal articles.

Data were then selected, abiding by the following principles:

(a) Some studies recorded CAR by sequestered CO_2. The values were considered as CAR, because salt marshes produce negligible methane (Connor et al., 2001; Callaway et al., 2012).

(b) As far as studies regarding accumulation rate of organic matter were concerned, the conversion factor of soil carbon was adopted as 0.55 of soil organic matter (Lovelock et al., 2010).

(c) As for studies only reporting soil carbon density, related research was searched in the same regions with respect to vertical SAR, which may involve a variety of markers (Ouyang et al., 2013), including long-term ^{137}Cs, ^{210}Pb markers and short-term marker horizons. Then CAR was obtained by multiplying SAR and soil carbon density. As SAR could be variable over small spatial scales, CAR estimation is expectedly influenced by data availability. Despite the absence of method description in 9 % of the studies, most (64 %) employed radionuclide (i.e. ^{137}Cs, ^{210}Pb markers) to measure SAR, while another 27 % of studies used marker horizons. CAR derived from different methods for SAR measurement may generate biases in comparison of CAR.

(d) According to the current classification of salt marshes (Mold, 1974; Chmura et al., 2003), the 158 sites were geographically divided into eight groups (Fig. 1), namely: tropical W. Atlantic, N. Europe, Mediterranean, NE Pacific, NW Atlantic, Arctic, Australasia and Sino-Japan. Also, there is phytobiogeographic division based on the dominant halophyte genera at the 158 sites, namely *Puccinellia*, *Distichlis*, *Spartina*, *Phragmites*, *Juncus* and *Halimione* (*Atriplex*).

Following the above rules, we examined individual studies to confirm the validity of the data. Studies were excluded if they were based on model simulation. This process filtered the studies down to 50, including 37 studies that SAR and soil carbon density data were used to calculate CAR, while the remaining 13 studies directly reported CAR. In addition, among the 50 studies, 47 were based on sediment samples of short cores (< 1 m), whereas only 3 studies sampled using deeper cores. Overall, the studies covered a latitudinal range from 40° S to 78.3° N (Table 1).

A considerable amount of literature has reported the area of salt marshes by specific sites and regions (Dijkema, 1987; O'Callaghan, 1990; Shi-lun and Ji-yu, 1995; Hanson and Calkins, 1996; Saint-Laurent, 1996; Lawrence et al., 2012), while reports of estimates of the global area are scarce. In this study, data of published studies were compiled and to provide an estimate of the present global extent of salt marshes. The global total C stock in salt marshes was then estimated by multiplying region-specific CAR and the respective regional areal extent of salt marshes.

2.2 Data analysis

Analyses were conducted using SPSS 21.0.0.0 (SPSS Inc., Chicago, IL, USA) and R version 3.0.2 (R Core Team, 2013). Deviations are reported as the standard error (SE). For statistical comparisons, data were tested for normality with the Kolmogorov–Smirnov test and for homogeneity of variance with the Levene's test ($\alpha = 0.05$). When homogeneity of variance between groups was violated, data were transformed ($\ln(x)$, $1/x$, or $x^{1/2}$) to satisfy the assumption. Boxplots were used to describe latitudinal distribution of CAR data. Paired-sample t test was used to compare the paired CAR from marshes with different elevations at the same site. One-way analysis of variance (ANOVA) was applied to compare more than two means and Tukey's test was used as post-hoc pairwise test where there was a significant treatment effect.

Stepwise multiple regression was used to determine which of the independent variables, viz. tidal range, latitude (a proxy of temperature) and halophyte genera, accounted for most of the variation in CAR. The six major genera were included as a categorical variable with five levels, while *Elymus* and *Sarcocornia* were excluded owing to few available data. Each level has two values, namely 0 and 1. The categorical variable, serving as a qualitative variable, was included as a block with the default

"Enter" method, whereas tidal range and latitude were included as another block with the default "Stepwise" method in the multiple regression model.

3 Results and discussion

3.1 Regional difference in carbon accumulation rate

In order to assess the regional difference in carbon sequestration by salt marshes, soil CAR was calculated for the eight salt marsh groups (Table 3), for the six dominant halophyte genera (Table 4), and for latitudinal intervals of 10° from 28.4° N to 78.5° N. Region-specific CAR and area were combined to produce a global CAR of salt marshes. Globally, mean CAR in salt marshes sediment is 242.2 ± 25.9 $\mathrm{g\,C\,m^{-2}\,yr^{-1}}$ (Table 5).

In contrast to existing studies, our results showed both differences and common features. Firstly, the average CAR of our study was higher than those from earlier reports, averaged 151 $\mathrm{g\,C\,m^{-2}\,yr^{-1}}$ (Chmura et al., 2003; Duarte et al., 2005). Our estimate has revised the former estimates upward by roughly 60 %. The underpinning source of the difference may relate to the fact that the earlier reports (1) have smaller latitudinal ranges (from 22.4° S to 55.5° N); (2) suffer from the lack of data from significant regions, including the Asia-Pacific, Arctic and Australasia; (3) used a simplistic method for upscaling CAR from individual sites to the global coverage.

The highest average accretion rate of soil carbon, i.e. 477.1 $\mathrm{g\,C\,m^{-2}\,yr^{-1}}$, was recorded from the Mediterranean, with vegetation dominated by *Spartina* spp. The largest carbon stock was stunningly in accordance with data of soil carbon stores in seagrass ecosystems, which was also found in Mediterranean meadows dominated by *Posidonia oceanica* (Fourqurean et al., 2012). However, the average CAR of salt marsh soils in the Arctic is an order of magnitude lower (34.9 $\mathrm{g\,C\,m^{-2}\,yr^{-1}}$) than those of all other regions (128.5 to 477.1 $\mathrm{g\,C\,m^{-2}\,yr^{-1}}$). Furthermore, as shown in Table 3, among the six halophyte genera, *Halimione* demonstrated the highest capacity for soil carbon accumulation, with average CAR at 486.9 $\mathrm{g\,C\,m^{-2}\,yr^{-1}}$, while average CAR of *Puccinellia* (34.4 $\mathrm{g\,C\,m^{-2}\,yr^{-1}}$) ranked the lowest. Significant differences in CAR exist among genera (ANOVA, $P < 0.001$), basically due to the significantly lower average CAR of *Puccinellia* than those of other genera (Tukey's test, $P < 0.001$). As *Puccinellia* is distributed in the coldest Arctic, in contrast to others growing in temperate or tropical regions in our studying sites, the difference may be attributed to the interregional difference in temperature. Lastly, there is significant latitudinal variation of CAR in saltmarsh sediments (ANOVA, $P < 0.001$) (Fig. 2).

For exploring the drivers of CAR variation, the nexus of CAR with tidal range, latitude and the dominant halophyte genera was analyzed using multiple linear regressions. Latitude accounted for most of the variation (51.7 %) in CAR ($P < 0.01$). Similarly, tidal range and halophyte genera represented 29.3 % and 18.2 % of the variation in CAR ($P < 0.01$).

These results suggest that carbon sequestration by salt marsh sediments is affected by multiple biogeochemical and biotic factors. Tidal range determines belowground carbon dynamics (root production, carbon burial) through influencing sediment aeration and porewater flow, also affecting sediment and organic matter import/export dynamics. Soil CAR for saltmarshes was shown positively related to belowground biomass productivity and negatively related to organic matter decomposition (Elsey-Quirk et al., 2011; McLeod et al., 2011; Gonzalez-Alcaraz et al., 2012), which are the predominant biotic processes for carbon accumulation. Both processes are affected by tidal range. For a given inundation depth, biomass productivity should be greatest in low tidal range environment (Schuerch et al., 2012). Where biomass productivity may be low (e.g. some Mediterranean marshes), retention of organic matter is usually high in these micro-tidal environments (Ibañez et al., 2000). Thus CAR could be higher in micro-tidal marshes. Further, tidal range may result in differences in the frequency of tidal flooding (Chmura et al., 2011), which alters the mode and rate of organic matter decomposition (Gonzalez-Alcaraz et al., 2012) and export (Saintilan et al., 2013), thereby influencing CAR. Marsh vegetation influences carbon accumulation through litter input. A number of studies have revealed that different species of halophyte inhabiting salt marshes contributed different quality and quantities of litter to salt marsh sediments (Zhou et al., 2007; Mahaney et al., 2008). Soil microbe mediated decomposition also changes with litter species (Rothman and Bouchard, 2007). These factors combined would result in variation in the quality (e.g. stoichiometry and form of essential elements) as well as quantity (e.g. different production and turnover rates) of organic matter in salt marsh sediments.

As latitude is a proxy of temperature, this study suggests that CAR changes markedly with temperature. This result is in contrast to earlier reports suggesting that average annual temperature explains only 5 % of CAR variability, and the relationship between temperature and CAR was limited (Chmura et al., 2003). Generally, this study suggests CAR of salt marsh sediments peaks at mid-latitudinal range 48.5 ~ 58.5 °N, and decreases towards the poles and the equator. This pattern corresponds with the general latitudinal pattern of salt marsh development.

3.2 Variation of CAR with marsh elevation

Data from a wide range of sites, with regard to marsh elevation, i.e. from low, mid to high marsh, were analyzed to evaluate how CAR varies with salt marsh elevation. Soil CAR presents a clear declining trend from low marsh to mid or high marsh across all locations, while transition from mid to high marsh can result in opposite changes (Fig. 3). Significant heterogeneity (paired-sample t test, $P < 0.05$) exists between CARs of low and mid or high marsh (Table 6), with CAR being highest in the low marsh irrespective of location.

The variation of CAR with respect to elevation could be explained by its determining variables. CAR is decided by three parameters, i.e. SAR, dry bulk density of the soil (DBD) and its organic carbon content, which is positively related to loss on ignition (LOI). Connor et al. (2001) reported that low marsh sediments were characterized by higher soil bulk densities and lower LOI. According to Chmura and Hung (2004), SAR decreases with distance from the nearest creek, i.e. low marsh have higher SAR than high marsh, probably due to shorter inundation time and thus sediment input. Moreover, Oenema and Delaune (1988) developed a function describing the relationship between SAR and the distance of marsh from the major creeks, and further showed that SAR of low marsh is higher than that of high marsh. As provided above, CAR can be expressed as the following equation.

$$\mathrm{CAR} = \mathrm{SAR} \cdot \mathrm{DBD} \cdot \mathrm{C}\,\%$$

In the above equation, CAR is promoted by high SAR and DBD in the low marsh, while the lower carbon content pushes values the opposite direction. High marsh sediments, however, are likely to have a higher carbon content (Connor et al., 2001; Zhou et al., 2007). The pattern of low marsh having higher CARs suggests that this increase in carbon content is more than offset by the decrease in SAR and DBD while going landward. In our collated literature, CAR of mid marsh was lower than high marsh in general. The reason for this lack of a clear-cut pattern from low to high marsh is unclear but differences in tidal inundation duration and flow dynamics between the mid and high marsh elevations are expected to be smaller than those between low and mid elevations.

3.3 Global CAR in salt marsh sediments compared with other ecosystems

Our global estimate of salt marsh carbon stocks was based on the mean value of the 158 sites so that the high CAR of the Mediterranean did not unduly affect the global figure. The product of our mean regional CAR and the area of salt marshes for the reported regions estimates the global CAR of salt marsh sediments to be about 10.1 $\mathrm{Tg\,C\,yr^{-1}}$(Table 7).

Our estimate of global sediment CAR in salt marshes (10.1 ± 1.1 $\mathrm{Tg\,C\,yr^{-1}}$) is lower than both its neighbouring coastal mangrove and seagrass ecosystems (31.1 ± 5.48 to 82.8 ± 22.8 $\mathrm{Tg\,C\,yr^{-1}}$), and the upland terrestrial forest ecosystems (53 ± 10.4 to 78.5 ± 9.88 $\mathrm{Tg\,C\,yr^{-1}}$). As far as sediment CAR is concerned, salt marsh ranks the first highest (Fig. 4) but the overall accumulation rate is reduced because of the limited areal extent of this habitat. The high capacity of carbon sequestration in salt marsh sediments is attributed to oxygen-depleted conditions reducing mineralisation rate, continual sediment deposition, and the combined high primary production but low export rates which facilitate accumulation of organic matter (Hussein et al., 2004; Loomis and Craft, 2010; Callaway et al., 2012; Keller et al., 2012).

Our data demonstrate that salt marshes are significant habitats for carbon accumulation in the biosphere, acting as important but previously neglected carbon sequesters. The remarkable combination of their high capacity for carbon-sequestration but low carbon stock in salt marshes could reflect the past management approach to these habitats, which has resulted in significantly reduced areal extent. The "coastal squeeze" phenomenon affects salt marshes most significantly and, if not managed timely, will continue to erode the importance of salt marshes as potential carbon storage. Despite their high capacity of carbon accumulation, when compared with terrestrial forests, carbon buried in salt marshes, as part of "blue carbon", can be stable over longer time scales (millennia) (Duarte et al., 2005; McLeod et al., 2011) and decompose at lower rate (Reddy and DeLaune, 2004), while most forest carbon stocks are eventually released to atmosphere during forest fires (Fourqurean et al., 2012).

However, this global estimate of CAR in salt marshes needs to be interpreted with caution since the estimate is limited by the quality and quantity of available data. Firstly, the reported global area of salt marshes is far from complete and has not covered all habitats of saltmarsh halophytes. Secondly, there are some compromises made when making extrapolations from a limited data base. For example, CAR of the Mediterranean was estimated from the more humid south European countries, which may overestimate the regional value encompassing also marshes of the arid north African regions, i.e. Tunisia and Morocco, even though these regions belong to the Mediterranean. Accordingly, further studies will be needed to refine CAR of this study when more data are available from a more comprehensive coverage of halophyte habitats in the future.

4 Conclusions

With sediment CAR averaged at $242.2 \pm 25.9\,\mathrm{g\,C\,m^{-2}\,yr^{-1}}$, our global estimate indicates that salt marshes rank among the most effective ecosystems in carbon sequestration. The highest CAR was in the Mediterranean, whereas the lowest CAR was in the Arctic. Regarding the six major halophyte genera, *Halimione*-dominated marshes have the highest CAR, whereas the CAR of *Puccinellia*-dominated habitats have the lowest. Owing to the comparatively small areal extent of salt marshes, global carbon buried in salt marshes is approximately $10.1\,\mathrm{Tg\,C\,yr^{-1}}$, which is far lower than those of other coastal ecosystems and terrestrial forest ecosystems.

Our analysis suggests that the CAR of salt marshes changes with latitude, tidal range, halophyte genera and habitat elevation. It is indicated that CAR of salt marshes varied significantly at latitude intervals of 10° from 28.4° N to 78.5° N. These factors drive CAR variation through physical and biotic control on belowground biomass productivity, microbial decomposition and litter input. Furthermore, it is clear that the CAR of low marsh was higher than mid or high marsh, whereas the capacity of carbon sequestration in mid marsh was generally lower than that of high marsh. Further field studies and experiments are needed to investigate the underlying forces driving carbon sequestration with respect to marsh elevation.

The findings of this study confirm salt marshes as significant coastal hotspots in sequestering carbon. However, with an annual loss rate of 1 % to 2 % between 1980 and 2000 (Duarte et al., 2008), and with loss continuing, just like the mangroves (Kristensen et al., 2008), this trend seriously compromises the capacity of salt marshes for carbon storage unless proper management and rehabilitation is implemented. There are significant data gaps in salt marsh CARs. Further research on CAR of salt marshes in South America and South Asia as well as inclusion of the full range of salt marsh halophytes is strongly recommended.

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Table 1. The distribution and CAR of salt marshes from the literature.

Site	Latitude (°)	Longitude (°)	CAR ($g\,C\,m^{-2}\,yr^{-1}$)[a]	Dominant halophyte species/genera[b]	SAR ($cm\,yr^{-1}$)	Method for SAR estimation[c]	Tidal range[d]
Tropical W. Atlantic	**N**	**W**					
Aransas, Texas	28.4	96.8	178.0	*Spartina alterniflora*	0.45	R	micro-tidal
Fina la-Terre, Louisiana	29	91	136.0	nd	0.50	M	micro-tidal
Fina la-Terre, Louisiana	29	91	18.0	nd	0.10	M	micro-tidal
San Bernard, Texas	29.1	95.6	203.0	*Spartina alterniflora*	0.62	R	micro-tidal
Old Oyster Bayou, Louisiana	29.3	91.1	84.0	nd	0.44	nd	micro-tidal
Bayou Chitigue, Louisiana	29.3	90.6	516.0	nd	3.23	nd	micro-tidal
Rockefeller Refuge, Louisiana	29.5	92.7	309.0	nd	1.10	M	micro-tidal
Rockefeller Refuge, Louisiana	29.5	92.7	27.0	nd	0.08	M	micro-tidal
Lafourche Parish, Louisiana	29.5	90.3	186.0	nd	0.98	M	micro-tidal
Cameron Parish, Louisiana	29.5	93.2	41.0	nd	0.41	nd	micro-tidal
Cameron Parish, Louisiana	29.5	93.2	115.0	nd	1.15	nd	micro-tidal
Barataria Basin, Louisiana	29.5	90	185.0	nd	1.42	R	micro-tidal
Barataria Basin, Louisiana	29.5	90	71.0	nd	0.59	R	micro-tidal
Barataria Basin, Louisiana	29.5	90	93.0	nd	0.78	R	micro-tidal
Unit 1, Marsh Island Refuge, Louisiana	29.5	91.9	318.0	nd	0.29	R	micro-tidal
Unit 1, Marsh Island Refuge, Louisiana	29.5	91.9	763.0	nd	0.70	R	micro-tidal
Three Bayous, Louisiana	29.6	90.1	116.0	nd	0.83	nd	micro-tidal
Unit15, Rockefeller Wildlife Refuge, Louisiana	29.6	92.7	349.0	nd	0.29	R	micro-tidal
Unit15, Rockefeller Wildlife Refuge, Louisiana	29.6	92.7	657.0	nd	0.55	R	micro-tidal
Rockefeller Wildlife Refuge unit 14, Louisiana	29.7	92.7	337.0	nd	0.29	R	micro-tidal
Rockefeller Wildlife Refuge unit 14, Louisiana	29.7	92.7	448.0	nd	0.48	R	micro-tidal
McFaddin National Wildlife Refuge, Texas	29.7	94.1	95.0	nd	0.79	R	micro-tidal
Sabine National Wildlife Refuge Unit 3, Louisiana	29.9	93.5	1713.0	nd	0.90	R	micro-tidal
St. Bernard Parish, Louisiana	30	89.9	140.0	*Spartina patens*	0.50	R	micro-tidal
Sabine National Wildlife Refuge Unit 3, Louisiana	29.9	93.5	714.0	nd	0.59	R	micro-tidal
Biloxi Bay, Mississippi	30.4	88.9	153.0	*Spartina alerniflora*	0.57	R	micro-tidal
Ogeechee River, Georgia Coast	31.3	81.7	28.2	*Spartina alterniflora*	0.24	R	meso-tidal
Altamaha River, Georgia Coast	31.4	81.4	22.4	*Spartina alterniflora*	0.22	R	meso-tidal
Satilla River, Georgia Coast	31.9	81.2	25.9	*Spartina alterniflora*	0.18	R	meso-tidal
N. Europe	**N**	**E**					
St. Annaland, Netherlands	51.5	4.1	277.0	*Spartina anglica*	0.68	R	micro-tidal
St. Annaland, Netherlands	51.5	4.1	139.0	*Halimone portulacoides*	0.34	R	micro-tidal
Rattekaai, Netherlands	51.5	4.1	400	*Spartina anglica*	1.41	R	micro-tidal
Scheldt, Netherlands	51.5	4.1	587.0	*Spartina anglica*	2.02	R	micro-tidal
Scheldt, Netherlands	51.5	4.1	650.0	*Spartina anglica*	3.25	R	micro-tidal
Dengie Marsh, UK	51.7	0.9	187.0	*Halimione portulacoides*	0.46	R	micro-tidal
Dengie Marsh, UK	51.7	0.9	139.0	*Halimione portulacoides*	0.34	R	micro-tidal
Dengie Marsh, UK	51.7	0.9	159.0	*Halimione portulacoides*	0.39	R	micro-tidal
Dengie Marsh, UK	51.7	0.9	110.0	*Halimione portulacoides*	0.27	R	micro-tidal

Table 1. Continued.

Site	Latitude (°)	Longitude (°)	CAR ($g\,C\,m^{-2}\,yr^{-1}$)[a]	Dominant halophyte species/genera[b]	SAR ($cm\,yr^{-1}$)	Method for SAR estimation[c]	Tidal range[d]
Stiflkey Marsh, UK	52.9	0.9	175.6	*Spartina anglica*	0.39	R	meso-tidal
Stiflkey Marsh, UK	52.9	0.9	167.3	*Armeria maritima*	0.27	R	meso-tidal
Hut marsh, UK	53	0.7	165.0	nd	0.61	M	meso-tidal
Hut marsh, UK	53	0.7	77.0	nd	0.28	M	meso-tidal
the peninsula Skallingen, the Wadden Sea, Denmark	55.5	8.3	1085.0	*Halimione portulacoides*	0.19	R	micro-tidal
The German Wadden Sea, the North Sea, Germany	54.8	8.3	1386.0	*Juncus, Atriplex, Spartina*	0.21	R	micro-tidal
sample 1	54.8	8.3	726.0	*Juncus gerardi*	0.11	R	micro-tidal
sample 2	54.8	8.3	1846.0	*Atriplex portulacoides*	0.28	R	micro-tidal
sample 3	54.8	8.3	1650.0	*Spartina anglica*	0.25	R	micro-tidal
Oder River, Poland	54.3	14.6	203.1	*Phragmites communis*	0.71	R	micro-tidal
Oder River, Poland	54.3	14.6	147.2	*Phragmites communis*	0.46	R	micro-tidal
Vistula River, Poland	54.3	18.9	524.2	*Phragmites communis*	1.9	R	micro-tidal
Vistula River, Poland	54.3	18.9	349.3	*Phragmites communis*	0.82	R	micro-tidal
	N	**W**					
The Blackwater estuary, UK	52	0.7	185.7	nd	1.41	R	meso-tidal
sample 1	52	0.7	230.0	*Atriplex portuacoides*	1.75	R	meso-tidal
sample 2	52	0.7	120.0	*Salicornia* spp.	0.91	R	meso-tidal
The Humber Estuary, England	53.7	0.1	31.0	*Spartina*	1.4	R	macro-tidal
Mediterranean	**N**	**E**					
Rhome Delta, France	43.3	4.6	161.0	*Juncus maritimus*	0.22	M	micro-tidal
European Atlantic basin, Iberian Peninsula	37.2	6.9	1071.0	*Spartina maritima*	2.2	M	micro-tidal
The Palmones River estuary, Spain	36.2	5.4	550.0	*S. perennis alpini*	nd	nd	micro-tidal
	N	**W**					
Marina del Carmolí,Spain	37.7	0.9	260.0	*Phragmites australis*	2.68	R	micro-tidal
Pancas, the Tagus estuary, Portugal	38.8	8.9	330.0	*Spartina maritima*	1.0	nd	micro-tidal
Corroios, the Tagus estuary, Portugal	38.8	8.9	750.0	*Spartina maritima*	1.0	nd	micro-tidal
The Mondego estuary, Portugal	40.1	8.6	218.0	*Spartina maritima*	0.7	nd	micro-tidal
NE Pacific	**N**	**W**					
Tijuana Slough California	32.5	117.1	343.0	*Spartina foliosa*	1.91	M	micro-tidal
Tijuana Slough California	32.5	117.1	43.0	nd	0.25	M	micro-tidal
Brookhurst, the Huntington Beach, California	33.6	117.9	34.0	*Sarcocornia acifica*	0.1	M	micro-tidal
Talbert, the Huntington Beach, California	33.6	117.9	23.0	nd	0.1	M	micro-tidal
Alviso, San Francisco Bay, California	37.5	122	385.0	nd	4.28	nd	micro-tidal
Bird Island, San Francisco Bay, California	37.6	122.2	54.0	nd	0.39	nd	micro-tidal
Whale's Tail, San Francisco Bay, California	37.8	122.3	146.7	*Spartina foliosa*	0.77	R	micro-tidal
China Camp, San Francisco Bay, California	38	122.5	141.9	*Spartina foliosa*	0.63	R	micro-tidal
Petaluma River, San Francisco Bay, California	38.2	122.6	87.7	*Spartina foliosa*	0.34	R	micro-tidal
Coon Island, San Francisco Bay, California	38.2	122.3	187.5	*Spartina foliosa*	0.68	R	micro-tidal
Rush Ranch, San Francisco Bay, California	38.2	122	105.0	nd	0.35	R	micro-tidal
Browns Island, California	38	121.9	155.6	nd	0.45	R	micro-tidal

Table 1. Continued.

Site	Latitude (°)	Longitude (°)	CAR ($\mathrm{g\,C\,m^{-2}\,yr^{-1}}$)[a]	Dominant halophyte species/genera[b]	SAR ($\mathrm{cm\,yr^{-1}}$)	Method for SAR estimation[c]	Tidal range[d]
NW Atlantic	**N**	**W**					
Cedar Island National Wildlife Refuge, North Carolina	35	76.4	70.0	nd	0.32	nd	micro-tidal
Oregon Inlet, North Carolina	35.9	75.6	59.0	*Spartina alterniflora*	0.27	R	micro-tidal
Oregon Inlet, North Carolina	35.9	75.6	21.0	*Spartina alterniflora*	0.09	R	micro-tidal
Jacob's Creek, North Carolina	35.3	76.8	146.0	nd	0.36	R	micro-tidal
Jacob's Creek, North Carolina	35.3	76.8	107.0	nd	0.24	R	micro-tidal
MC4, Chesapeake Bay, Maryland	38.3	75.9	308.0	nd	0.77	R	micro-tidal
MCL8, Chesapeake Bay, Maryland	38.3	75.9	213.0	nd	0.79	R	micro-tidal
MCL15, Chesapeake Bay, Maryland	38.3	75.9	340.0	nd	0.77	R	micro-tidal
SA4, Little Assawoman Bay, Delaware	38.4	75.1	159.0	*Spartina alterniflora*	0.25	R	micro-tidal
J1, Little Assawoman Bay, Delaware	38.4	75.1	119.0	*Juncus roemerianus*	0.19	R	micro-tidal
Sybil 1, Connecticut	41.2	72.6	136.0	*Spartina alterniflora*	0.25	R	micro-tidal
Hoadley 1, Connecticut	41.2	72	154.0	*Spartina alterniflora*	0.42	R	micro-tidal
Hoadley 2, Connecticut	41.2	72	169.0	*Spartina patens*	0.42	R	micro-tidal
Hoadley 3, Connecticut	41.2	72	114.0	nd	0.33	R	micro-tidal
East River 1, Connecticut	41.2	72.7	134.0	*Spartina patens*	0.45	R	micro-tidal
East River 2, Connecticut	41.2	72.7	204.0	*Spartina alterniflora*	0.34	R	micro-tidal
The Long Island Sound, Connecticut	41.2	72.7	162.8	nd	0.37	R	micro-tidal
The Long Island Sound, Connecticut	41.2	72.7	80.8	nd	0.37	R	micro-tidal
Sluice 1, Connecticut	41.2	72.7	99.0	*Distichlis spicata*	0.38	R	micro-tidal
Sluice Core 2, Connecticut	41.2	72.7	85.0	*Distichlis spicata*	0.19	R	micro-tidal
Leetes 1, Connecticut	41.2	72.7	153.0	*Distichlis spicata*	0.39	R	micro-tidal
Leetes 2, Connecticut	41.2	72.7	93.0	*Distichlis spicata*	0.31	R	micro-tidal
Sybil 2, Connecticut	41.2	72.6	72.0	*Phragmites australis*	0.25	R	micro-tidal
Sybil 3, Connecticut	41.2	72.6	116.0	*Phragmites australis*	0.25	R	micro-tidal
Brandford River 1, Connecticut	41.2	72.6	182.0	*Spartina alterniflora*	0.63	R	micro-tidal
Brandford River 2, Connecticut	41.2	72.6	182.0	*Spartina alterniflora*	0.70	R	micro-tidal
Farm River, Connecticut	41.2	72.9	70.0	*Spartina patens*	0.28	R	meso-tidal
Bloom's Point, Little Narragansett Bay, Connecticut	41.3	71.9	62.0	*Spartina patens*	0.17	M	micro-tidal
Headquaters, New England	41.3	71.9	186.5	*Spartina patens*	0.22	R	micro-tidal
Davis, New England	41.3	71.8	199.0	*Spartina alterniflora*	0.18	M	micro-tidal
Bloom's Point, New England	41.3	71.9	181.0	*Spartina patens*	0.22	M	micro-tidal
Rhode Island	41.4	71.3	165.0	nd	0.29	R	micro-tidal
Inlet 1, Nauset Bay, Mass., New England	41.5	70	105.0	*Spartina alterniflora*	0.38	R	micro-tidal
The Great Sippewissett Marsh, Mass., New England	41.6	70	88.8	*Spartina alterniflora*	nd	nd	micro-tidal
Nauset Bay, Mass., New England	41.5	70	155.0	*Spartina alterniflora*	0.38	R	micro-tidal
The Sprague River Marsh, Maine	43.8	69.8	40.0	*Spartina alterniflora*	0.07	R	meso-tidal

Table 1. Continued.

Site	Latitude (°)	Longitude (°)	CAR ($g\,C\,m^{-2}\,yr^{-1}$)[a]	Dominant halophyte species/genera[b]	SAR ($cm\,yr^{-1}$)	Method for SAR estimation[c]	Tidal range[d]
Cobscook Bay, Gulf of Maine, Nova Scotia	44.9	67.1	30.8	nd	0.28	M	macro-tidal
Dipper a, Dipper Harbour, Bay of Fundy, New Brunswick	45.1	66.4	85.0	*Spartina patens*	0.18	M	macro-tidal
Dipper d, Dipper Harbour, Bay of Fundy, New Brunswick	45.1	66.4	63.0	*Spartina patens*	0.19	M	macro-tidal
Little Lepreau, Bay of Fundy, New Brunswick	45.1	66.5	80.0	*Spartina patens*	0.14	M	macro-tidal
Chance Harbour, New Brunswick	45.1	66.3	72.0	*Spartina patens*	0.19	M	macro-tidal
Chance Harbour, Bay of Fundy, New Brunswick	45.1	66.3	72.0	*Spartina patens*	0.19	M	macro-tidal
DH SA 3, Dipper Harbour, Bay of Fundy, New Brunswick	45.1	66.4	187.0	*Spartina alterniflora*	0.54	M	macro-tidal
DH SA 2, Dipper Harbour, Bay of Fundy, New Brunswick	45.1	66.4	182.0	*Spartina alterniflora*	0.54	M	macro-tidal
DH SA 1, Dipper Harbour, Bay of Fundy, New Brunswick	45.1	66.4	195.0	*Spartina alterniflora*	0.54	M	macro-tidal
DH Sp 3, Dipper Harbour, Bay of Fundy, New Brunswick	45.1	66.4	85.0	*Spartina patens*	0.18	M	macro-tidal
DH Sp 2, Dipper Harbour, Bay of Fundy, New Brunswick	45.1	66.4	64.0	*Spartina patens*	0.18	M	macro-tidal
DH Sp 1, Dipper Harbour, Bay of Fundy, New Brunswick	45.1	66.4	77.0	*Spartina patens*	0.18	M	macro-tidal
Bocabec River, Bay of Fundy, New Brunswick	45.1	67	456.0	nd	1.34	M	meso-tidal
Bocabec River, Bay of Fundy, New Brunswick	45.1	67	113.0	nd	0.25	M	meso-tidal
Dipper Harbour, Bay of Fundy, New Brunswick	45.1	66.4	445.0	*Spartina patens*	1.48	M	macro-tidal
Dipper Harbour, Bay of Fundy, New Brunswick	45.1	66.4	156.6	*Spartina patens*	0.47	M	macro-tidal
Dipper Harbour, Bay of Fundy, New Brunswick	45.1	66.4	94.0	*Spartina patens*	0.28	M	macro-tidal
Dipper Harbour, Bay of Fundy, New Brunswick	45.1	66.4	85.0	*Spartina patens*	0.18	M	macro-tidal
Dipper Harbour, Bay of Fundy, New Brunswick	45.1	66.4	60.0	*Spartina patens*	0.18	M	macro-tidal
Little Lepreau, Bay of Fundy, New Brunswick	45.1	66.4	89.0	*Spartina patens*	0.15	M	macro-tidal
Eastport, Bay of Fundy, New Brunswick	45.1	64.9	107.2	*Spartina patens*	0.1	R	macro-tidal
Cape Enrage, Bay of Fundy, New Brunswick	45.6	64.8	582.0	nd	3.23	M	macro-tidal
Cape Enrage, Bay of Fundy, New Brunswick	45.6	64.8	186.0	nd	0.81	M	macro-tidal
Lorneville, Bay of Fundy, New Brunswick	45.2	66.2	277.0	nd	0.99	M	macro-tidal
Lorneville, Bay of Fundy, New Brunswick	45.2	66.2	330.0	nd	1.00	M	macro-tidal
St. Martins, Bay of Fundy, New Brunswick	45.3	65.5	265.0	nd	0.98	M	macro-tidal
St. Martins, Bay of Fundy, New Brunswick	45.3	65.5	928.0	nd	3.87	M	macro-tidal
Wood Point, Bay of Fundy, New Brunswick	45.8	64.4	264.0	*Spartina patens*	1.02	M	macro-tidal
Wood Point, Bay of Fundy, New Brunswick	45.8	64.4	253.0	*Spartina patens*	1.01	M	macro-tidal
Kouchigouguacis Lagoon, Gulf of St. Lawrence, New Brunswick	46.7	64.9	102.0	nd	0.33	R	micro-tidal
Bay St-Louis, New Brunswick	46.8	64.9	93.0	nd	0.29	R	micro-tidal
Kouchibouguacis Lagoon, Gulf of St. Lawrence, New Brunswick	46.8	64.9	272.6	nd	0.29	R	micro-tidal
Escuminac, Gulf of St. Lawrence, New Brunswick	47.1	64.9	121.3	*Elymus arenarius*	0.23	R	micro-tidal
Tabusintac Bay, Gulf of St. Lawrence, New Brunswick	47.4	65	66.0	nd	0.20	R	micro-tidal
Malpeque Bay, Gulf of St. Lawrence, New Brunswick	46.5	63.7	71.0	nd	0.24	R	meso-tidal
Rustico, Prince Edward Island, Gulf of St. Lawrence, New Brunswick	46.5	63.6	130.3	*Spartina patens*	0.38	R	meso-tidal

Table 1. Continued.

Site	Latitude (°)	Longitude (°)	CAR (g C m^{-2} yr^{-1})[a]	Dominant halophyte species/genera[b]	SAR (cm yr^{-1})	Method for SAR estimation[c]	Tidal range[d]
Brackley Bay Gulf Of St. Lawrence, New Brunswick	46.4	63.2	89.0	nd	0.25	R	micro-tidal
Pubnico Harbour, Gulf of Maine, Nova Scotia	43.6	65.3	113.0	nd	0.28	R	meso-tidal
Cheboque Harbour, Gulf of Maine, Nova Scotia	43.8	66.4	75.0	nd	0.17	R	meso-tidal
Little River Harbour, Gulf of Maine, Nova Scotia	43.7	66.1	304.0	nd	0.39	R	meso-tidal
Yarmouth, Nova Scotia	43.8	66.1	146.3	*Spartina patens*	0.28	R	meso-tidal
Cole Harbour, Nova Scotia	44.7	63.4	161.0	nd	0.38	R	micro-tidal
Lawrence town Lake, Nova Scotia	44.7	63.4	60.0	nd	0.25	R	micro-tidal
Chezzetcook Inlet, Nova Scotia	44.7	63.4	106.0	nd	0.28	R	micro-tidal
Halifax, Nova Scotia	44.7	63.5	179.7	*Spartina patens*		R	micro-tidal
Rustico Bay, Prince Edward Island	46.4	63.2	125.0	*Spartina patens*	0.37	R	micro-tidal
Arctic	**N**	**W**					
Flakkerhuk, Disko, West Greenland	69.7	52	30.0	*Puccinellia phryganodes*	0.17	R	micro-tidal
Storfjord, Svalvard, Norway	77.5	19.8	33.7	*Puccinellia phryganodes*	0.21	R	micro-tidal
Malangen, Svalvard, Norway	69.3	24.7	7.0	*Puccinellia phryganodes*	0.13	R	micro-tidal
Van Mijen Fjod, Svalvard, Norway	78.3	14.6	34.2	*Puccinellia phryganodes*	0.25	R	micro-tidal
Hornsund, Svalvard, Norway	77.5	14	70.5	*Puccinellia phryganodes*	0.59	R	micro-tidal
Hornsund, Svalvard, Norway	77.5	14	34.2	*Puccinellia phryganodes*	0.25	R	micro-tidal
Australasia	**S**	**E**					
Australia	10 ~ 40	110 ~ 155	274.8	nd	nd	nd	micro-tidal to macro-tidal
Sino-Japan	**N**	**E**					
China	18 ~ 41	110 ~ 135	223.6	nd	nd	nd	micro-tidal to macro-tidal

[a, b, c] Cammen (1975); McCaffrey and Thomson (1980); Howes et al. (1985); Oenema and Delaune (1988); Cahoon and Turner (1989); Cranford et al. (1989); Patrick and Delaune (1990); Kearney and Stevenson (1991); Craft et al. (1993); French and Spencer (1993); Cahoon (1994); Cahoon et al. (1996); Callaway et al. (1996, 1997); Roman et al. (1997); Bryant and Chabreck (1998); Glud et al. (1998); Markewich (1998); Orson et al. (1998); Anisfeld et al. (1999); Hensel et al. (1999); Weinstein and Kreeger (2000); Connor et al. (2001); Haslett et al. (2001); Chmura et al. (2003); Chmura and Hung (2004); Jensen et al. (2006); Abu Hena et al. (2007); Goodman et al. (2007); Simas and Ferreira (2007); Andrews et al. (2008); Xiaonan et al. (2008); Howe et al. (2009); Palomo and Niell (2009); Loomis and Craft (2010); Sousa et al. (2010a, 2010b); Andersen et al. (2011); Chmura et al. (2011); Elsey-Quirk et al. (2011); Adams et al. (2012); Callaway et al. (2012); Gonzalez-Alcaraz et al. (2012); Keller et al. (2012); Lawrence et al. (2012); Schuerch et al. (2012); Burden et al. (2013); Curado et al. (2013); Saintilan et al. (2013); M and R represent marker horizons and radionuclide, respectively; nd represents no data were specified in the reference.

[d] micro-tidal (tidal range = 0 ~ 2 m), meso-tidal (tidal range = 2 ~ 4 m), macro-tidal (tidal range > 4 m). Tidal range is classified into the three types based on tidal range data from references cited in “a”, and from website .

Table 2. Reported area of salt marshes.

Region	Area (km^2)	Ref.
Australia	13 765	Lawrence et al. (2012)
China	5734	Shi-lun and Ji-yu (1995)
America	19 265	Field et al. (1991)
Europe and Scandinavia	2302	Dijkema (1987); Saint-Laurent (1996)
Canada	328	Hanson and Calkins (1996); Wetland International Inventory
Tunisia	59	Wetland International Inventory
Morocco	34	Wetland International Inventory
South Africa	170	O'Callaghan (1990)
Total	41 657	

Table 3. Comparison of CAR in salt marsh geographic groups. Australasia and Sino-Japan are excluded from the variance analysis. There is a significant difference in the mean CAR value among the six groups for which sufficient data are available for comparison (ANOVA, $P = 0.002$).

Groups	Number of sites	Soil CAR, $\mathrm{g\,C\,m^{-2}\,yr^{-1}}$ (Mean ± SE)
Tropical W. Atlantic	29	277.3 ± 64.6
N. Europe	20	337.2 ± 78.9
Mediterranean	7	477.1 ± 126.1
NE Pacific	12	128.5 ± 33.8
NW Atlantic	82	158.9 ± 14.4
Arctic	6	34.9 ± 8.3
Australasia	1	274.8
Sino-Japan	1	223.6

Table 4. Comparison of CAR among halophyte genera. Post-hoc pairwise test (Tukey test) ANOVA was run to test which genera are different from the others. Since soil CAR of *Distichlis* and *Juncus* did not conform to normality, they were excluded from the ANOVA. There is a significant difference in CAR among the other four groups (ANOVA, $P < 0.001$). Groups sharing the same superscript are not significantly different from each other ($P > 0.05$).

Genera	df.	Soil CAR, g C m^{-2} yr^{-1} (Mean ± SE)
Distichlis	3	107.5 ± 15.4
Halimione	7	486.9 ± 225.7^{a}
Juncus	2	335.3 ± 195.7
Spartina	64	208.5 ± 31.5^{a}
Phragmites	6	238.8 ± 59.1^{a}
Puccinellia	6	34.4 ± 7.0^{b}

^{a} and ^{b} are the superscripts used to distinguish groups with significantly different CARs.

Table 5. Estimation of global CAR via specific soil CAR for different regions. America was divided into three sub-groups as per the division of saltmarsh groups in Fig. 1. Area of saltmarsh in these sub-groups was estimated from Coultas and Hsieh (1997). Soil CAR of Europe and Scandinavia was calculated by combining all the CAR data of N. Europe and the Mediterranean. CAR of Tunisia and Morocco adopted that of the Mediterranean group as both belong to the Mediterranean region. There is no available CAR data of South Africa, and thus CAR of *Spartina* as estimated in Table 4 was approximated to represent CAR of this region. Since the saltmarsh area of South Africa is very small, this approximation has little influence on the estimation of total CAR in global saltmarsh sediments.

Region		Soil CAR, $g\,C\,m^{-2}\,yr^{-1}$ (mean ± SE)	Area (km^2)	Soil CAR, $Tg\,C\,yr^{-1}$ (mean ± SE)
Australia		274.8	13 765	3.78
China		223.6	5734	1.28
America	Tropic W. Atlantic region	277.3 ± 64.6	8596	2.38 ± 0.55
	NW Atlantic region	158.9 ± 14.4	2685	0.43 ± 0.04
	NE Pacific region	128.5 ± 33.8	7984	1.03 ± 0.27
Europe and Scandinavia		458.5 ± 84.9	2302	1.06 ± 0.19
Canada[a]		158.9 ± 14.4	328	0.05 ± 0.01
Tunisia[a]		477.1 ± 126.1	59	0.03 ± 0.01
Morocco		477.1 ± 126.1	34	0.02 ± 0.004
South Africa		208.5 ± 31.5	170	0.04 ± 0.01
Total		242.2 ± 25.9	41 657	10.1 ± 1.1

[a] CAR of arid salt marshes may differ from other Mediterranean sites, e.g. Spanish marshes, due to different climatic and biogeographic conditions.

Table 6. Comparison of CAR from low to mid or high marsh. For the total 28 saltmarsh sites, paired-sample *t* test (two-tailed) was employed to compare the paired CARs between low marsh and mid or high marsh at the same sites. There was significant difference in carbon accumulation capacity between all the pairs, i.e. mid and high marsh ($P = 0.029$), low and high marsh ($P < 0.001$) as well as low and mid marsh ($P = 0.005$). Generally, as indicated by significance of the *t* values, CAR of the low marsh was higher than those of the mid or high marsh, while values of the mid marsh was lower than those of the high marsh.

CAR	SE Mean	*t*	df.	Sig.
Mid marsh VS. High marsh	13.25	−2.47	12	0.029
Low marsh VS. High marsh	10.81	6.83	16	< 0.001
Low marsh VS. Mid marsh	19.66	4.08	7	0.005

Table 7. Comparison of carbon accumulation in sediments and soils of salt marshes and other ecosystems.

Ecosystems	Soil CAR, $\mathrm{g\,C\,m^{-2}\,yr^{-1}}$ (mean ± SE)	Global area, $\mathrm{km^2}$	Soil CAR, $\mathrm{Tg\,C\,yr^{-1}}$ (mean ± SE)	Ref.
Coastal ecosystems				
Saltmarshes	242.2 ± 25.9	41 657	10.1 ± 1.1	This study
Mangroves	226 ± 39	137 760 to 152 361	31.1 ± 5.4 to 34.4 ± 5.9	Giri et al. (2011); Chmura et al. (2003); Bird et al. (2007); Lovelock et al. (2010); Sanders et al. (2010); Spalding et al. (2010)
Seagrasses	138 ± 38	300 000 to 600 000	41.4 ± 11.4 to 82.8 ± 22.8	Duarte et al. (2005); Kennedy et al. (2010); Fourqurean et al. (2012)
Terrestrial forest ecosystems				
Temperate	5.1 ± 1.0	10 400 000	53 ± 10.4	Schlesinger and Bernhardt (2013)
Boreal	4.6 ± 2.1	13 700 000	63 ± 28.8	Zehetner (2010)
Tropical	4.0 ± 0.5	19 622 846	78.5 ± 9.8	Asner et al. (2009); Schlesinger and Bernhardt (2013)

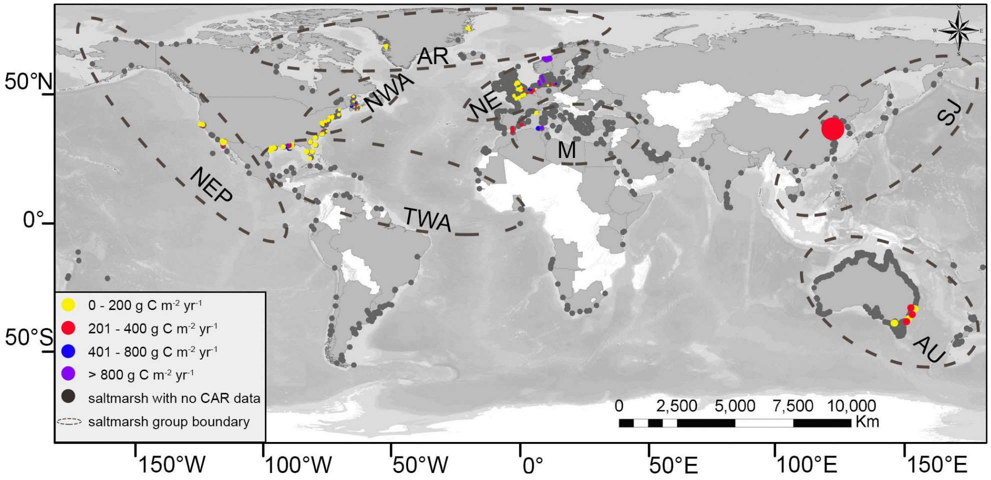

Fig. 1. Groupings and CAR of global salt marsh ecosystems. The eight groups span latitudes from 40° S to 78.3° N, colonizing the coasts and estuaries of the Pacific, Atlantic, Indian and Arctic Oceans. The background graph indicating sites of salt marshes is based on Mold (1974) and Murray et al. (2011). While significant salt marsh occurrences are present in South America, insufficient data is available for inclusion in this analysis since there are no pertinent references. Colour dots are used to account for CAR levels of individual sites that were indicated in Table 1 from 50 studies, whereas dull colour dots represent sites without CAR data. There are not substantial data for the Sino-Japan region, as such a big circle is used to represent the average CAR of this region. Only locations with published data allowing calculation of CAR are represented for clarity. NEP – NE Pacific; TWA – Tropical W. Atlantic; NWA – NW Atlantic; AR – Arctic; NE – N Europe; M – Mediterranean; SJ – Sino-Japan; AU – Australasia.

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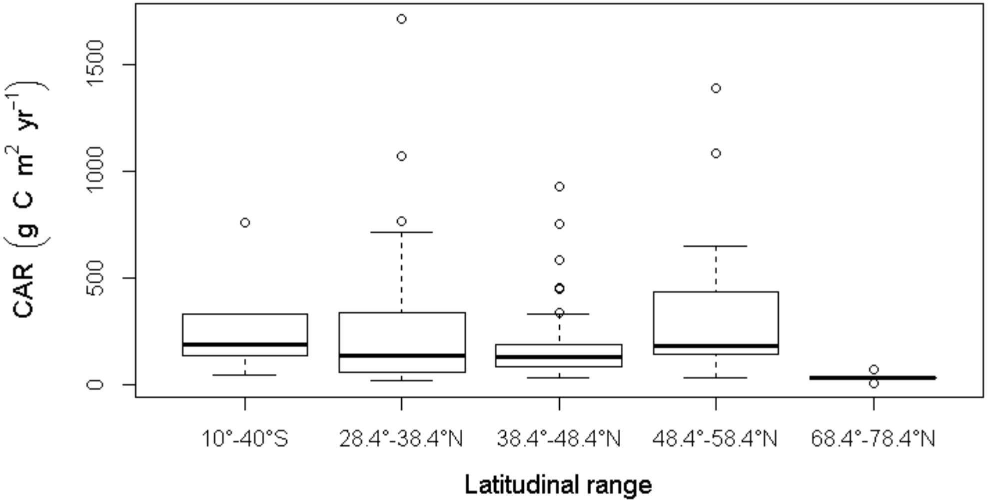

Fig. 2. Latitudinal pattern of CAR for global saltmarshes. The box-whisker plots of CAR reflect a clear pattern at latitudinal range 10–40° S, 28.4–38.4° N, 38.4–48.4° N, 48.4–58.4° N, 68.4–78.4° N, with the highest value in the 48.4–58.4° N (mean CAR = 337.2 $\mathrm{g\,C\,m^{-2}\,yr^{-1}}$), while the lowest value occurs at high latitudinal 68.4–78.4° N (mean CAR = 34.9 $\mathrm{g\,C\,m^{-2}\,yr^{-1}}$). No data is available for the 58.4–68.4° N range and is not presented in the plot. The bottom, middle and top of each box indicates the 25th, 50th (median) and 75th percentiles, respectively. Around 95 % of the data are expected to lie between whiskers. The scattered points above the whiskers are outliers and the upper points are extreme outliers.

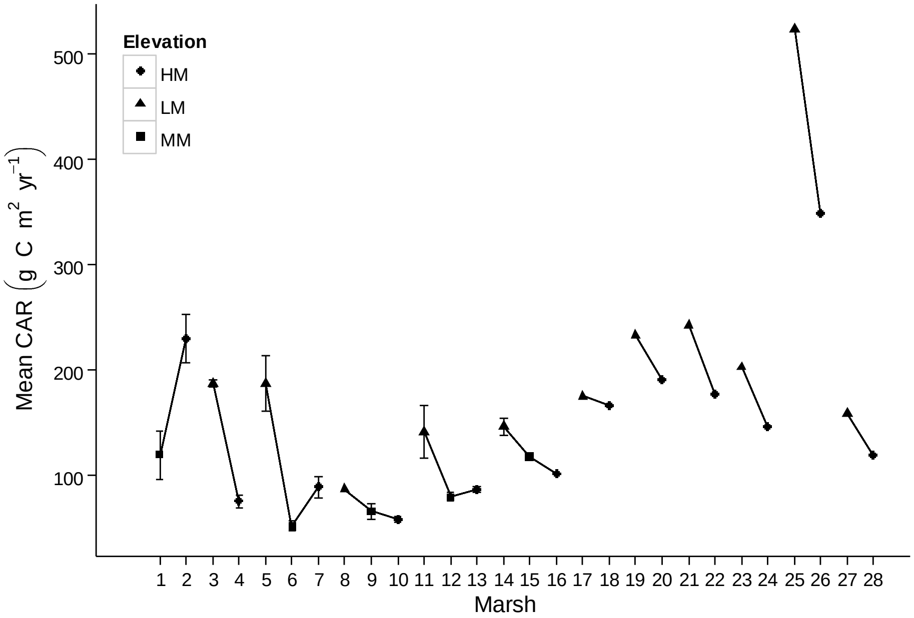

Fig. 3. CAR of salt marshes in relation to habitat elevation from low marsh to mid or high marsh. The marshes, connected by a line, come from the same sites. 1 and 2 – the Blackwater estuary, UK; 3 and 4 – the Bay of Fundy, New Brunswick, Canada; 5, 6 and 7 – Coon Island, San Francisco Bay, California, USA; 8, 9 and 10 – Petaluma River, San Francisco Bay, California, USA; 11, 12 and 13 – China Camp, San Francisco Bay, California, USA; 14, 15 and 16 – Whale's Tail, San Francisco Bay, California, USA; 17 and 18 – Stiffkey Marsh, UK; 19 and 20 – Dengie Marsh, UK; 21 and 22 – St. Annaland, Netherlands; 23 and 24 – Oder River, Poland; 25 and 26 – Vistula River, Poland; 27 and 28 – Little Assawoman Bay, USA.

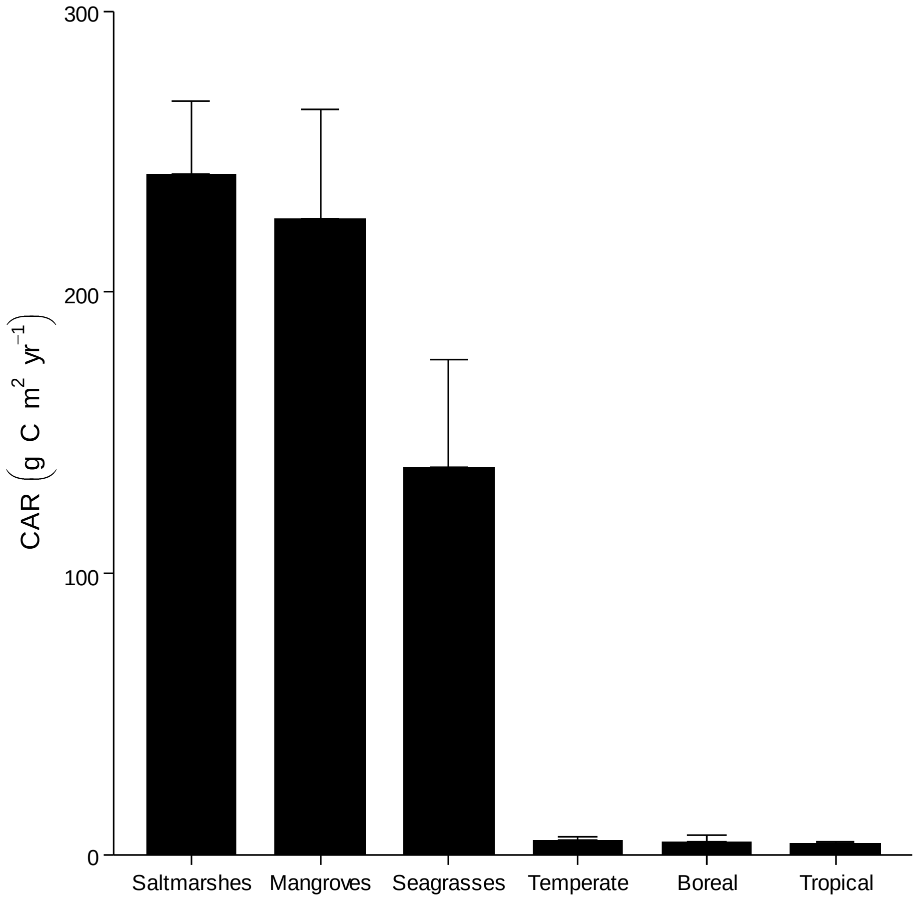

Fig. 4. Average CAR (±SE) in sediments and soils of major coastal ecosystems and terrestrial forest ecosystems.