




RESEARCH ARTICLE

Blue carbon benefits from global saltmarsh restoration

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Abstract

Coastal saltmarshes are found globally, yet are 25%–50% reduced compared with their historical cover. Restoration is incentivised by the promise that marshes are efficient storers of ‘blue’ carbon, although the claim lacks substantiation across global contexts. We synthesised data from 431 studies to quantify the benefits of saltmarsh restoration to carbon accumulation and greenhouse gas uptake. The results showed global marshes store approximately 1.41–2.44 Pg carbon. Restored marshes had very low greenhouse gas (GHG) fluxes and rapid carbon accumulation, resulting in a mean net accumulation rate of 64.70 t CO₂e ha⁻¹ year⁻¹. Using this estimate and potential restoration rates, we find saltmarsh regeneration could result in 12.93–207.03 Mt CO₂e accumulation per year, offsetting the equivalent of up to 0.51% global energy-related CO₂ emissions—a substantial amount, considering marshes represent <1% of Earth's surface. Carbon accumulation rates and GHG fluxes varied contextually with temperature, rainfall and dominant vegetation, with the eastern coasts of the USA and Australia particular hotspots for carbon storage. While the study reveals paucity of data for some variables and continents, suggesting need for further research, the potential for saltmarsh restoration to offset carbon emissions is clear. The ability to facilitate natural carbon accumulation by saltmarshes now rests principally on the action of the management-policy community and on financial opportunities for supporting restoration.

KEYWORDS

climate change, coastal wetland, greenhouse gas, marsh creation, organic matter, sequestration

1 | INTRODUCTION

Coastal ecosystems account for 50% of marine sediment carbon burial (Duarte et al., 2005) and offer a promising means for mitigating some of the effects of global carbon emissions. Tidal wetlands, such as mangrove forests and saltmarshes, are particular hotspots for ‘blue’ carbon sequestration. This is due to high carbon

accumulation rates (CAR), coupled to slow degradation of organic matter in water-saturated, low-oxygen sediments (Neubauer & Megonigal, 2021). Saline environments also have much lower emissions of potent greenhouse gases (GHG) such as methane, when compared to freshwater wetlands (Poffenbarger et al., 2011). Overall, carbon sequestration rates per unit area in saltmarshes exceed those of seagrass meadows, terrestrial forests and the open

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ocean (Temmink et al., 2022), with tidal marshes globally accumulating 12.63 Tg C year⁻¹ (Wang et al., 2021). The processes involved in saltmarsh carbon sequestration are outlined in Figure 1. Recent estimates also show saltmarsh soils are a major carbon store, with an average standing stock of 400 Mg C ha⁻¹ (Temmink et al., 2022).

Saltmarshes provide an array of other ecosystem services besides climate regulation, including delivering natural flood defence and water quality enhancement, and supplying habitat for biodiversity, commercial fish species and migratory birds (Adams et al., 2021; de la Barra et al., 2022; Fairchild et al., 2021; Sharps et al., 2017). In the United States, coastal wetlands were valued at US\$23.2 billion year⁻¹ for storm protection services alone (Costanza et al., 2008), and saltmarsh services globally are worth Int\$1.07 trillion year⁻¹ (Davidson et al., 2019, using 2007 'International' \$). Historically, saltmarshes were primarily viewed as valuable for land reclamation to accommodate agriculture and urban sprawl (Bu et al., 2015; Gedan et al., 2009). As a result, global marsh areas decreased by 25%–50% (Crooks et al., 2011; Duarte et al., 2008), although regional losses were often much higher, such as San Francisco Bay, which lost 79% of the historical marsh cover (Valiela et al., 2009). Further marsh losses are anticipated from climate-change processes, including coastal squeeze by sea-level rise (SLR) and increased storminess (Saintilan et al., 2022). Reduction in saltmarsh cover and substantial habitat disturbance undoubtedly have caused, and continue to cause, significant emissions of carbon stored in sediment and plant biomass (Campbell et al., 2022; Lovelock et al., 2017; Macreadie et al., 2013).

Saltmarsh restoration provides an opportunity to replenish the carbon stores which have been lost from marsh degradation. Recent estimates suggest that the equivalent of 2.3%–2.5% of annual global greenhouse gas emissions could be offset through mangrove, seagrass and saltmarsh restoration, collectively (Macreadie et al., 2021). Various methods exist for saltmarsh restoration, here

defined as any positive action or active intervention that aims to restore the habitat (Möller et al., 2021). Managed realignment is predominantly used in northern Europe and involves the breaching of existing flood defences to allow the shoreline to migrate landwards (Garbutt et al., 2006). Regulation of tidal exchange is another approach, which reintroduces flow through structures such as sluices or tide gates (Möller et al., 2021). Other methods of marsh restoration include sediment recharge and vegetation transplantation (e.g. Shiao et al., 2019; Soileau et al., 2018).

The timescale over which a restored marsh will attain functional equivalence to a comparative natural site is largely unknown (Burden et al., 2019). Faunal assemblages have been found to be structurally similar to those on natural sites as quickly as 4 years after saltmarsh creation (Rezek et al., 2017), although a much longer time is required for restored sites to function similarly to natural systems (Callaway, 2005). Carbon storage appears to reach equivalence over longer timescales (Burden et al., 2019; Garbutt & Wolters, 2008). CARs are normally high in the early years after restoration (Mason et al., 2022), due to rapid initial sediment accretion, but accretion then slows over time as bed levels rise (ABPmer, 2021). This was the case at managed realignment sites in the United Kingdom: carbon accumulation, which was 1.04 t C ha⁻¹ year⁻¹ in the first 20 years, slowed to 0.65 t C ha⁻¹ year⁻¹ in later years (Burden et al., 2019). Models resulting from these values suggested approximately 100 years were required for a restored marsh to reach equivalent carbon stock to natural sites (Burden et al., 2019). Early investment in saltmarsh restoration is therefore paramount if the climate-change mitigation potential of marshes is to be reached within the coming decades.

Wetland restoration, alongside effective protection and management, has gained increasing policy focus in recent years, particularly as a contribution to global strategies, such as the Sustainable Development Goals (Macreadie et al., 2021) and the UN's Decade on

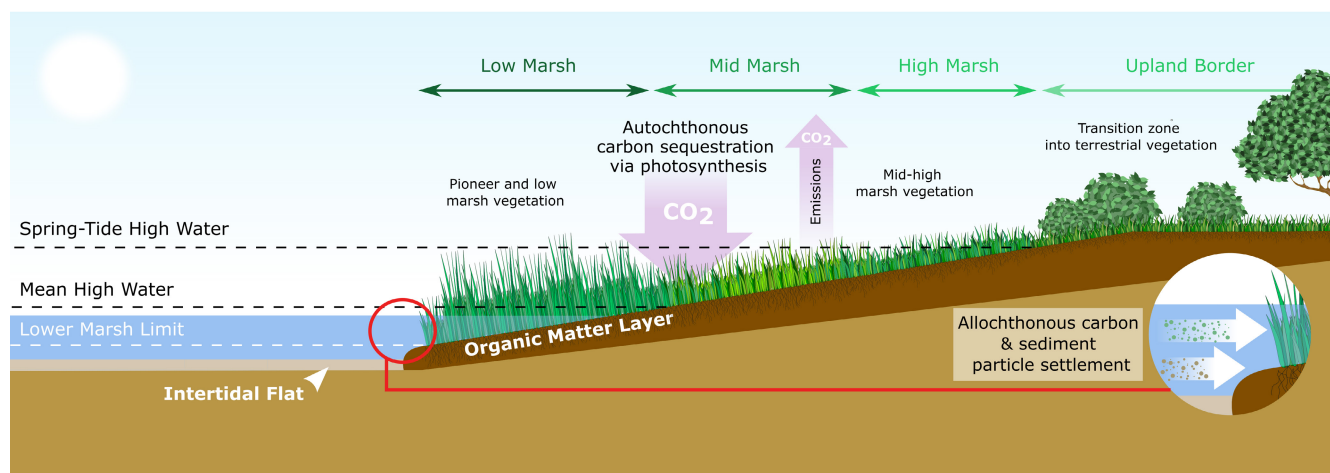


FIGURE 1 Saltmarsh carbon can be generated by the system itself (autochthonous C) or can originate from outside the system (allochthonous C), entering the marsh through passing water and settling out as particulate matter when the vegetation slows down the currents and waves. Carbon sequestration arises from autochthonous processes, such as plant production, and represents the direct removal of CO₂ from the atmosphere, with fixed carbon ultimately stored in the sediment as belowground biomass and dead plant matter. Carbon burial refers to the removal of organic carbon from the active carbon cycle, by accumulating it in the soil at depths below the degradation-active surface layer (Middelburg et al., 1997).

Ecosystem Restoration (2021–2030). Wetland restoration was highlighted in the IPCC Sixth Assessment Report as having the potential to enhance resilience, productivity and sustainability of ecosystems to climate change (IPCC, 2021), and many nations cite blue carbon strategies in their nationally determined contributions to meeting the Paris Agreement (Duarte et al., 2020; Macreadie et al., 2021). However, the definition of restoration success is variable. While some projects incorporate distinct success criteria from early development, many lack clearly defined targets (Wolters et al., 2005). Often natural marshes are used as a reference for the performance of a restored site, for instance contrasting the carbon store of a restored marsh against that of natural sites. Since greenhouse gas fluxes are critical components of calculating the net carbon benefit of saltmarsh habitats, it is imperative to consider fluxes alongside carbon sequestration when quantifying the blue carbon benefit of marsh restoration. Incorporating flux observations is especially important as greenhouse gas flux can be higher at restored than natural sites (e.g. nitrous oxide, Adams et al., 2012). On a global scale, the incorporation of greenhouse gas fluxes into saltmarsh carbon budgets is generally lacking; here we aim to address this knowledge gap.

While several studies of restored marshes have quantified greenhouse gas flux (e.g. Adams et al., 2012; Li & Mitsch, 2016; Li et al., 2021; Wang et al., 2021) or CAR (e.g. Burden et al., 2019; Calvo-Cubero et al., 2014; Yang et al., 2020), few have considered these attributes together. Additionally, there has been no quantitative review reporting both greenhouse gas fluxes and the carbon storage benefit for restored saltmarsh across regional or global scales. CAR can vary substantially between global regions, with temperate (30°–40°) northern hemisphere marshes having an average CAR of $144 \pm 6 \text{ gC m}^{-2} \text{ year}^{-1}$ compared with $88.7 \pm 3.5 \text{ gC m}^{-2} \text{ year}^{-1}$ in the southern hemisphere (Wang et al., 2021). Site-dependent factors, such as vegetation composition, are known to influence carbon accumulation, with species such as *Spartina alterniflora* particularly effective at carbon storing (Unger et al., 2016), and larger-scale processes, such as sea-level rise, also accelerating carbon storage (Rogers et al., 2019). However, a global synthesis of how these contextual drivers influence carbon and greenhouse gas flux is currently lacking. A global prioritisation of saltmarsh restoration is hindered by a limited understanding of where the global hotspots for carbon accumulation are. As such, the regions where saltmarsh restoration would have the greatest benefit for climate regulation remain unknown.

Here we evaluate how carbon stock, carbon accumulation and greenhouse gas fluxes vary between natural and restored saltmarshes, and contrast these across global geographical regions. Using a systematic review and meta-analysis of data from 431 published studies, we test the expectations that newly restored sites will exhibit high CARs and that older restored sites will have fluxes (overall greenhouse gas exchange, including uptake and emissions) comparable to those of natural marshes. We hypothesise that variation in greenhouse gas responses will depend on restoration approach, with tidal re-introduction, for example, resulting in lower emissions than freshwater re-introduction, given lower methane emissions of saline wetlands (Poffenbarger et al., 2011). Finally, we expected

greenhouse gas fluxes to be influenced by environmental context, including geomorphology, vegetation type, climate (temperature and rainfall) and salinity. Our analyses allow us to determine the average annual contribution of restored marshes to global carbon accumulation and to provide the most up to date estimate of global carbon stock buried below coastal salt marshes.

2 | METHODOLOGY

2.1 | Literature search and data extraction

A systematic literature search for data was done on the 21st January 2022, using standard approaches (Pullin & Stewart, 2006; O'Dea et al., 2021) and the search engines *Web of Science* and *Scopus*. No geographical or temporal constraints were applied. The search string was designed to yield studies with data on organic matter content, carbon stock, carbon accumulation and/or greenhouse gas flux (CO_2 , CH_4 or N_2O) in natural and/or restored saltmarsh ecosystems. As such, the search terms consisted of three strings connected with the Boolean operator "AND", as below:

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factor* OR variable* OR condition* OR characteristic* OR driver* OR natural OR restored OR restoration OR creat* OR "managed realignment" OR reintrod* OR re-introd* OR reestab* OR re-estab* OR "managed retreat" OR "regulated tidal exchange" OR RTE*

AND

carbon OR CO2 OR nitrous* OR N2O OR methane OR CH4 OR "greenhouse gas" OR green*house gas OR GHG* OR "greenhouse gases" OR gas* OR flux* OR storage OR sequestration* OR budget* OR sink* OR removal OR accret* OR exchange* OR accumulation OR erosion OR stock* OR burial OR re-created OR "organic matter" OR "organic content"

AND

saltmarsh* OR "salt marsh"
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The search returned 3874 results from *Web of Science* and 29,253 from *Scopus*. Duplicate results were removed, and two additional studies were added (ABPmer, 2021; Mossman et al., 2022: these were not available on online search engines at the time of the literature search) following consultation with the Saltmarsh Code Consortium (<https://www.ceh.ac.uk/our-science/projects/uk-saltmarsh-code>), yielding a final list of 29,182 published studies prior to screening. Publications were screened first by title (3443 retained), then by abstract (930 retained) and finally by full text (431 retained: listed in Supplementary Materials, Table S1). Studies that were

irrelevant to the research questions and which did not include quantitative data were excluded. Review studies and data derived from modelling were also excluded. Data from brackish (salinity=0.5–18ppt) and saline marshes (salinity >18ppt) were included, while studies on terrestrial wetlands, peatland, freshwater marshes, fens, bogs and permafrost marshes were excluded. Studies pertaining to smaller scale biotic processes (e.g. root respiration within salt marsh vegetation) were not included, unless observations were scaled up to the level of whole-marsh areas. Nutrient fluxes were excluded, except when as a gaseous component of greenhouse gasses (e.g. N₂O emissions). Carbon stores in vegetation biomass were not incorporated, apart from as a component of saltmarsh sediment. Data were extracted from text, tables or graphs in the 431 passed papers, using Automeris WebPlotDigitizer Version 4.4 (Rohatgi, 2020). Data were extracted on any organic matter content, carbon stock, carbon sequestration or GHG flux, along with contextual data, such as the average annual air temperature, dominant vegetation, sediment salinity and site geomorphology. In total, 2055 'samples' were extracted from the 431 papers. A 'sample' was defined as a distinct condition (e.g. natural vs. restored) or contextual setting investigated within a study (e.g. different sampling locations) which were reported as separate values. GHG flux was included from studies using a range of methodologies including static (opaque or transparent) chambers and eddy covariance, on a short-term or seasonal basis. Data gaps in the annual rainfall and average annual air temperature data reported by studies were filled in using the geographical coordinates of the study site and the WorldClim climate dataset (Fick & Hijmans, 2017). Geomorphology was initially determined for each site using satellite imagery and classifying locations into four types: estuary, coastal marsh, estuarine lagoon and lagoon (Pye & Blott, 2014). Since for some studies this was not possible (e.g. where specific sampling coordinates were not provided), this classification was further simplified into fluvial, coastal, loch-head and unknown marsh type, for further analysis.

2.2 | Data standardisation

Standardisation of data was required due to considerable variation in approaches and units used by the 431 studies. Meta-data and data concerning environmental context were standardised into common units (e.g. electrical conductivity and salinity into PSU). Marshes were classified into 'natural' or 'restored' based on their description in the original study, with restored marshes defined as those which had experienced active intervention to alter or restore the state of the marsh. Greenhouse gas fluxes were converted into t CO₂e ha⁻¹ year⁻¹ using a 100-year timeframe in accordance with IPCC standard approaches (IPCC, 2014). For studies which gave a carbon (C) stock estimate to <1m, carbon stock observations were extrapolated to 1m for IPCC comparability (IPCC, 2014), assuming a linear distribution of carbon in the top 1m sediment. We expressed the mitigative potential of saltmarshes in units of carbon accumulation (t C ha⁻¹ year⁻¹) and in that term amalgamated data on carbon burial, carbon

accumulation and carbon sequestration (CO₂ uptake by vegetation). The difference between burial and accumulation is that the former infers the carbon is located below the depth of degradation activity, whereas the latter does not (Middelburg et al., 1997). As the depth of degradation activity was rarely reported, we here use the more conservative 'C accumulation' term. Soil organic matter observations (OM) derived from loss on ignition (LOI) were converted to organic carbon content (OC) using the equation:

$$\text{Organic C} = \text{OM} \times 0.52$$

where the 0.52 value was based on the OM/OC conversion factor (1.92) of Ouyang and Lee (2020) for LOI observations. Where bulk density data were also reported, percentage organic carbon content was converted into carbon stock using the following equation:

$$\text{C stock (t C ha}^{-1}\text{)} = \text{depth} \times \text{bulk density} \times \% \text{OC} \times 10000$$

where 'depth' was the core sampling depth and 10,000 was the conversion factor from m to ha. The resulting carbon stock values were then extrapolated to 1m depth as described above.

2.3 | Data analysis

We contrasted natural and restored saltmarshes for variation in 8 response variables: % OC, bulk density, carbon stock, carbon accumulation rate, net CO₂ flux, CO₂ respiration, CH₄ flux and N₂O flux. Pixel maps were produced from natural marsh data for each response variable to identify 'hotspots' including areas with combined high carbon stock and high CARs. Significant differences between natural and restored sites were assessed using non-parametric Mann-Whitney *U*-tests. A generalised linear mixed model (GLMM) tested for differences between natural and restored marshes (included as a binary factor) for each response variable. To account for variation due to the contextual or environmental setting, the GLMM model also incorporated six environmental and geographical predictor variables. These were: continent (categorical; five levels), annual rainfall (continuous), salinity type (categorical; six levels), average annual temperature (continuous), simplified marsh geomorphology (categorical; four levels) and vegetation type (categorical; six levels). We included Study ID as a random effect to account for non-independence of multiple values extracted from the same study. The *performance* package was used to visually inspect global model residuals, test for collinearity among the six predictor variables and ensure that model assumptions were met (Lüdecke et al., 2020). To meet model assumptions, data for carbon stock and net CO₂ flux were rescaled between 0 and 1, with the lowest and highest values in the dataset becoming 0 and 1, then square root transformed (untransformed values are stated in the results of this study). For all other variables, raw data were used. In the GLMM, we identified the predictor variables that best explained variation in each response variable, using a theoretic-based model selection process

(Burnham et al., 2011) and only considering models which included 'natural versus restored' as a predictor. Statistical significance of model fit was assessed using a Chi-squared test between the optimal model and a null model that contained only the random factor (Study ID). The *emmeans* package (Lenth, 2022) was used to (a) extract the estimated difference in marginal means (EMMs) between natural and restored marshes for each response variable and (b) to test for significance.

GLMMs were also used to test for the influence of environmental context, restoration approach (defined in Table S2) and marsh age on the response variables of restored marshes. The same methods and environmental predictors were used as for the first GLMM analysis, except natural versus restored was replaced by restoration approach and site age (time since restoration). Approach to restoration was grouped into the following six categories: artificial structure implementation, freshwater reintroduction, marsh creation (usually sediment addition and vegetation planting, and often fertilisation), sediment alteration, tidal re-introduction (included managed realignment and regulated tidal exchange) and unknown (Table S2). One extremely high and outlying observation (10.4 g cm^{-3}) was removed from the bulk density data set, as its inclusion caused the assumptions of the global GLMM model to be violated. This observation was likely an error value, given it was an order of magnitude larger than the next highest value (1.58 g cm^{-3}). Insufficient data were available to use GLMMs for CO_2 respiration, CH_4 flux and N_2O flux, but their averages are nevertheless reported, and available data shown in figures. All analyses were run using R Version 3.6.3 (R Core Team, 2020), and data are accessible on the repository Dryad (Mason et al., 2023). Statistically significant relationships were inferred where $p < .05$.

Finally, we used recent estimates of saltmarsh cover continentally (Mcowen et al., 2017) and globally (Mcowen et al., 2017; Murray et al., 2022; Worthington et al., 2023) to derive, from our data, an up-to-date estimate of blue carbon stock held by saltmarsh habitats globally, in which we accounted for differences in carbon stocks between geographical regions. We estimated the net carbon accumulation of marshes per continent using CO_2 equivalent values for CARs and accounting for greenhouse gas emissions and uptake. From the net values, we determined the potential global and regional carbon benefit ($\text{t CO}_2\text{e ha}^{-1} \text{ year}^{-1}$) from marsh restoration. Net values were also used to quantify the missed opportunity for carbon accumulation arising each year from reported net saltmarsh losses of $1452.84 (733.1\text{--}2172.07) \text{ km}^2$ between 2000 and 2019 (Campbell et al., 2022).

3 | RESULTS

3.1 | Literature search and data extraction

The past decade saw a rapid increase in the number of relevant studies published, with an average of 29.09 new studies per year in 2012–2022, compared to 3.36 studies per year in 1977–2011

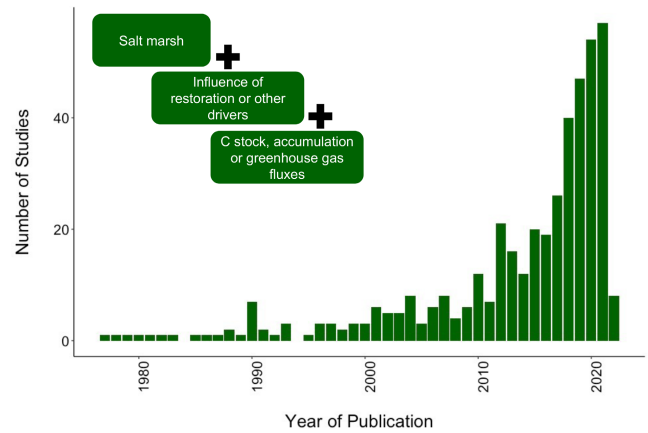


FIGURE 2 Number of relevant studies included in meta-analysis ($n=431$) published per year. Text in boxes describes criteria a paper needed to fulfil to be included in the analysis.

(Figure 2). North American and Asian studies made up 41.5% and 33.6% of the 431 papers included, respectively. There were very few studies from South America and Africa (eight and one studies, respectively; Figure S1). A number of the studies included observations from different conditions and/or contextual settings (e.g. natural vs. restored sites, brackish vs. saline sites), leading to a total of 2055 samples. Far more data were available for natural than restored marshes: out of 2055 samples, 1757 were from natural and 298 were from restored marshes. Out of the 298 samples for restored marshes, most originated from North America (57%) and Europe (35%), with only 18 samples from Asia, 5 from Oceania and 1 from South America. Across the eight response variables that were derived from the extracted data, 3623 individual data points were taken for further analysis.

Based on these studies, three areas of particularly high carbon stock were identified in natural saltmarshes (Figure 3a): one in the North America, one in north-eastern Europe and one on the eastern coast of Australia. Although data on carbon accumulation were more sparsely distributed, reported accumulation rates were highest on the east coasts of Australia, China, the United Kingdom and the USA (Figure 3b).

3.2 | Natural versus restored saltmarshes

Globally, natural and restored marshes varied significantly in %OC, carbon accumulation rate, net CO_2 flux and CO_2 respiration (Table 1; Figure 4). Restored marshes had greater carbon accumulation and net CO_2 uptake (lower net CO_2 flux value), and lower %OC and CO_2 respiration, than natural marshes (Table 1; Figure 4). When separated by continent, significant differences in response variables between natural and restored marshes were predominantly restricted to Europe and North America, likely due to paucity of data for other continents. Carbon stock varied significantly between natural and restored marshes in both Europe and North America, although effects were opposite (Table 1): restored marshes had

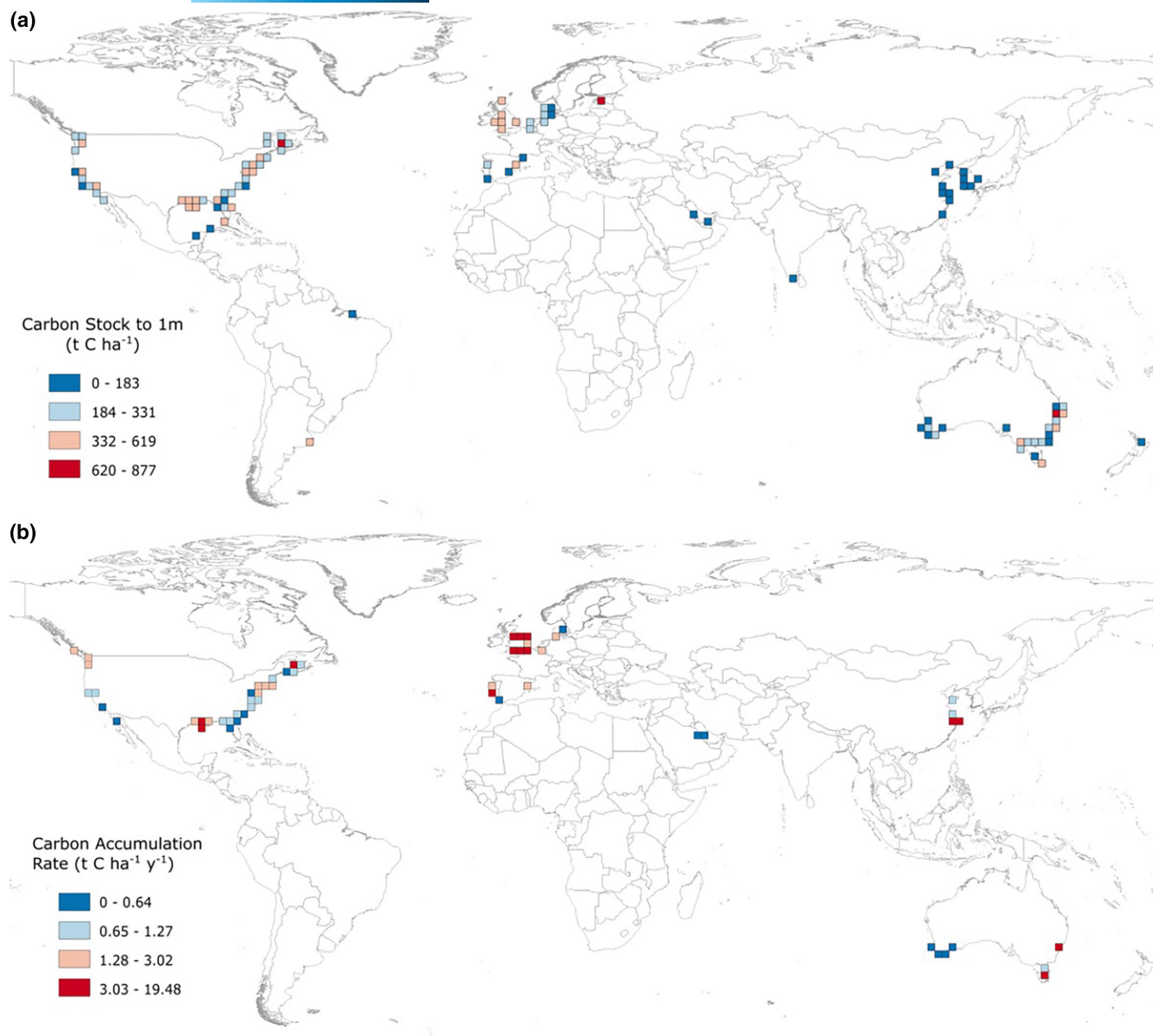


FIGURE 3 Pixel maps of (a) saltmarsh carbon stock to 1 m sediment depth (t C ha^{-1}) and (b) saltmarsh carbon accumulation rate ($\text{t C ha}^{-1} \text{ year}^{-1}$) for global regions. Map lines delineate study areas and do not necessarily depict accepted national boundaries.

greater carbon stock in Europe, but lower stock in North America. Differences between continents were evident even when considering only natural marshes. Organic carbon content was particularly high in the North America (Table 1). Methane emissions of natural and restored marshes in Europe were 25 and 332 times lower than the global average, respectively (Table 1; Figure S2).

Variation in carbon and greenhouse gas variables was explained by a number of bio-environmental contextual variables, besides whether or not the marsh was natural or restored. For all variables other than CH_4 flux and CO_2 respiration, significant optimal models including natural versus restored included at least one other additional contextual variable (Table 2). For example, continent, annual rainfall, sediment salinity, average annual temperature and vegetation type were all significant predictors of organic

carbon stock on a global scale, in addition to whether the marsh was natural or restored ($\chi^2_{18} = 104.22$, $p < .001$). When accounting for these contextual variations between saltmarshes, %OC was an average of $3.25 \pm 0.65\%$ higher in natural marshes compared to restored (pairwise EMM: $p < .001$), with carbon stock following a similar pattern (Table 2). Despite statistically significant optimal models, carbon accumulation, net CO_2 flux and N_2O flux did not significantly differ between natural and restored marshes, suggesting more complex interactions between environmental predictor variables. In short, the statistically optimal models showed that the values of direct parameters of carbon stock (%OC, bulk density and carbon stock) differed between natural and restored marshes, and variation in these three parameters depended on the environmental context.

TABLE 1 Continental and global mean values (\pm SD) of carbon and greenhouse gas fluxes for natural and restored marshes.

	% OC	Bulk density (g cm ⁻³)	C stock (t C ha ⁻¹)	C acc. rate (t C ha ⁻¹ year ⁻¹)	Net CO ₂ flux (t CO ₂ ha ⁻¹ year ⁻¹)	CO ₂ respiration (t CO ₂ ha ⁻¹ year ⁻¹)	CH ₄ flux (t CO ₂ e ha ⁻¹ year ⁻¹)	N ₂ O flux (t CO ₂ e ha ⁻¹ year ⁻¹)
Europe								
Natural	7.00 \pm 7.13 (211)	0.65 \pm 0.32 (122)	342.10 \pm 223.45 (154)	1.87 \pm 1.77 (30)	NA	20.42 \pm 50.88 (11)	0.20 \pm 0.30 (20)	0.06 \pm 1.00 (14)
Restored	4.37 \pm 4.60 (88)	0.88 \pm 0.33 (24)	438.83 \pm 191.97 (22)	5.70 \pm 8.81 (15)	NA	29.08 \pm 35.11 (2)	0.05 \pm 0.08 (4)	0.58 \pm 0.67 (4)
North America								
Natural	11.39 \pm 8.80 (464)	0.39 \pm 0.29 (273)	360.00 \pm 214.16 (295)	1.69 \pm 2.25 (236)	-57.73 \pm 84.26 (47)	30.32 \pm 23.90 (57)	6.67 \pm 25.99 (69)	-0.03 \pm 0.77 (24)
Restored	8.52 \pm 10.41 (99)	0.60 \pm 1.14 (87)	247.23 \pm 169.56 (79)	3.77 \pm 4.53 (63)	-80.10 \pm 48.13 (19)	5.33 \pm 1.46 (6)	23.17 \pm 54.47 (16)	0.19 \pm 0.75 (16)
South America								
Natural	2.37 \pm 1.73 (15)	1.14 \pm 0.18 (4)	156.29 \pm 142.83 (4)	NA	-10.5 (1)	NA	NA	NA
Restored	2.39 (1)	NA	NA	NA	NA	NA	NA	NA
Asia								
Natural	5.14 \pm 8.55 (132)	1.30 \pm 0.35 (106)	90.52 \pm 101.97 (161)	3.82 \pm 6.48 (29)	-14.25 \pm 19.11 (26)	22.26 \pm 26.77 (70)	4.70 \pm 15.14 (106)	0.44 \pm 0.83 (53)
Restored	1.58 \pm 0.60 (4)	1.39 \pm 0.14 (4)	59.45 \pm 49.3 (5)	18.38 \pm 1.56 (2)	-19.04 \pm 22.11 (3)	20.09 \pm 22.10 (8)	15.76 \pm 27.13 (8)	0.77 \pm 1.75 (7)
Africa								
Natural	5.38 \pm 2.64 (6)	NA	NA	NA	NA	NA	NA	NA
Restored	NA	NA	NA	NA	NA	NA	NA	NA
Oceania								
Natural	6.72 \pm 6.82 (78)	0.82 \pm 0.39 (76)	309.94 \pm 304.25 (106)	5.81 \pm 14.70 (17)	3.44 \pm 11.23 (2)	10.31 \pm 19.00 (2)	8.26 \pm 14.30 (3)	0.78 \pm 1.03 (2)
Restored	10.42 \pm 9.25 (3)	1.57 (1)	84.54 \pm 71.15 (3)	0.74 \pm 0.28 (2)	NA	NA	0.19 \pm 0.53 (2)	NA
Global								
Natural	8.86 \pm 8.56 (906)	0.67 \pm 0.46 (581)	287.39 \pm 238.64 (720)	2.13 \pm 4.49 (312)	-41.82 \pm 71.03 (74)	25.23 \pm 28.19 (140)	4.99 \pm 19.00 (198)	0.27 \pm 0.86 (93)
Restored	6.50 \pm 8.37 (195)	0.69 \pm 1.01 (116)	272.81 \pm 193.13 (109)	4.41 \pm 5.91 (82)	-65.51 \pm 52.27 (24)	15.68 \pm 19.70 (16)	16.58 \pm 42.34 (30)	0.39 \pm 1.08 (27)

Note: Including organic carbon (%OC), bulk density, carbon stock (to 1 m depth), carbon accumulation rate, net CO₂ flux, CO₂ respiration, CH₄ flux and N₂O flux. Brackets show numbers of samples (*n*) per mean. Blue values were significantly different between natural and restored sites (Mann-Whitney *U*-test. Significant if *p* < 0.05).

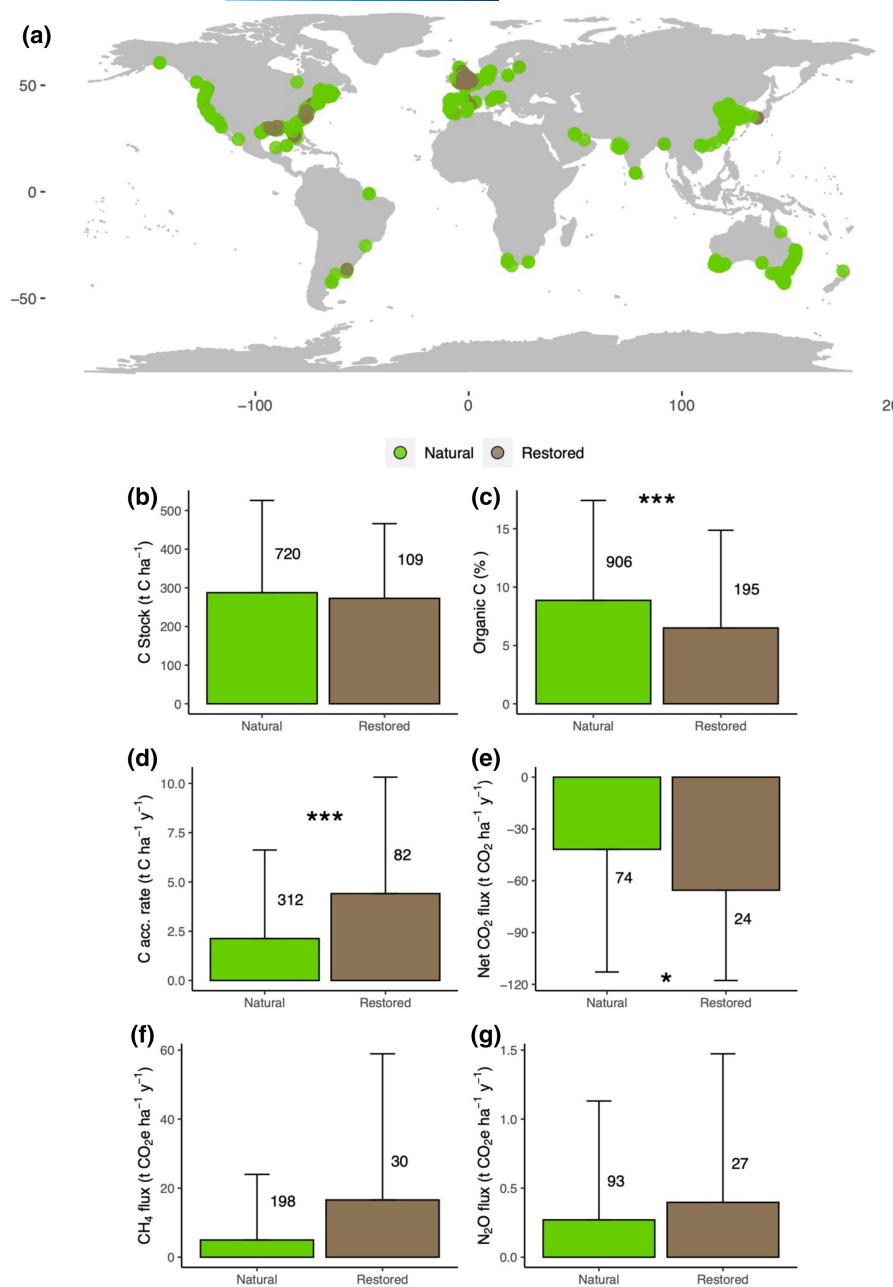


FIGURE 4 (a) Distribution of samples across natural and restored saltmarshes (total $n = 2055$). Global mean values (\pm SD) of (b) carbon stock, (c) organic carbon (%OC), (d) carbon accumulation rate, (e) net CO_2 flux, (f) CH_4 flux and (g) N_2O flux. Numbers above bars indicate number of samples per mean. * denotes $p < .05$ and *** denotes $p < .001$ (Mann-Whitney U-test).

3.3 | Covariation between environmental setting and carbon flux in restored marshes

GLMM models to identify covariations in fluxes between restored marshes could only be fitted to the response variables % OC, bulk density, carbon stock, carbon accumulation and net CO_2 flux, due to a paucity of data for other response variables. Restoration approach explained 28.7% of the variation in %OC of restored marshes (Table 3). %OC was by far the highest in marshes restored via freshwater introduction and lowest where the approach was undefined by the authors of the study (Table 3). Bulk density reduced with marsh age, although the rate of change was very low (Table S3: slope). Bulk density was highest in Asia and Oceania, and low at sites restored by freshwater introduction (Table S3), which was a

restoration approach used only in North America and reported by just two studies (Figure 5). Carbon stock decreased with marsh age and increase in temperature, and peaked in marshes dominated by *Phragmites* spp. plants, which had double the stock of *Spartina* spp. marshes and three times that of *Suaeda* spp. marshes (Table S3). The optimal model for net CO_2 flux included continent and rainfall ($R^2c = 0.626$, $\chi^2 = 11.54$, $p = .009$), but neither restoration approach nor time since restoration. Net CO_2 uptake by restored marshes, as indicated by negative net CO_2 flux values (Table S3), was stimulated by increasing rainfall and was 8 and 19 times greater in North American than Asian and Oceanian restored marshes. CH_4 flux for restored marshes could not be modelled due to paucity of data, although it tended to be greater in marshes restored via freshwater introduction compared to other approaches (Figure 5).

TABLE 2 Contextual drivers of spatial variation in soil physical and chemical variables across all saltmarsh sites, as indicated by GLMM models.

Variable	Natural versus restored pairwise EMIM											
	Best supported model	AICc	R ² c	R ² m	χ ²	Df	p-Value	Difference	SE	Df	T ratio	p-Value
% OC	1 + C + R + Re + S + T + V + (1 SI)	7154.94	0.742	0.145	104.22	18	<.001	3.25	0.653	1035	4.978	<.001
Bulk density (g cm ⁻³)	1 + C + Re + (1 SI)	871.77	0.586	0.258	105.63	6	<.001	-0.346	0.059	688	-5.896	<.001
C stock (t ha ⁻¹)	1 + C + Re + (1 SI)	-1468.92	0.756	0.232	71.99	5	<.001	9.56	7.82	765	2.821	.005
C accumulation (t ha ⁻¹ year ⁻¹)	1 + C + Re + (1 SI)	2219.66	0.719	0.110	37.70	9	<.001	-1.21	0.855	370	-1.420	.156
Net CO ₂ flux (t CO ₂ ha ⁻¹ year ⁻¹)	1 + Re + S + V + (1 SI)	-265.77	0.979	0.076	25.85	9	.002	28.74	28.72	55	0.612	.543
CO ₂ respiration (t CO ₂ ha ⁻¹ year ⁻¹)	1 + Re + (1 SI)	1392.56	0.842	0.001	0.130	1	.719	-2.75	7.46	140	-0.368	.713
CH ₄ flux (t CO ₂ e ha ⁻¹ year ⁻¹)	1 + R + Re + (1 SI)	2057.14	0.479	0.029	4.26	2	.119	-4.56	5.14	215	-0.887	.376
N ₂ O flux (t CO ₂ e ha ⁻¹ year ⁻¹)	1 + Re + T + V + (1 SI)	308.88	0.599	0.215	17.61	6	.007	-0.438	0.25	108	-1.752	.08

Note: Differences (±SE) in pairwise estimated marginalised means (EMMs) are given between natural and restored saltmarshes.

Abbreviations: C, continent; R, annual rainfall (mm); Re, natural or restored; S, salinity (categorical); SI, study ID; T, average annual temperature (°C); V, vegetation type. Carbon stock was to 1 m soil depth.

3.4 | Global blue carbon potential

Using our continental average carbon stock values and the saltmarsh cover values of Mcowen et al. (2017), Campbell et al. (2022) and Worthington et al. (2023), we estimate the current blue carbon stock of global saltmarshes is 1.41–2.44 Pg (Figure 6). This is likely to be a conservative figure, since cover estimates tend to have limited inclusion of high latitude areas (Mcowen et al., 2017; Murray et al., 2022; Worthington et al., 2023). Assuming a saltmarsh net loss of 1452 km² (733–2172 km²) between 2000 and 2019 (Campbell et al., 2022) and using our estimates of net carbon accumulation per unit marsh area, the current annual net carbon accumulation is 0.06 Mt (0.03–1.00 Mt) lower than in 2000. Given many marshes were lost prior to 2000 (Mcowen et al., 2017), the total reduction in carbon accumulation due to marsh loss will be much higher. Our data show that when taking GHG fluxes into account, saltmarshes of all continents provide a net carbon removal benefit, with restored marshes consistently soliciting the greatest gain (Figure 6b). Accounting for greenhouse gas emissions, restored saltmarshes had a net carbon burial rate of -64.70 t CO₂e ha⁻¹ year⁻¹, 45.8% higher than that of natural marshes. Griscom et al. (2017) estimated that 0.2–3.2 million ha saltmarsh could potentially be restored globally, based on data compiled from 76 sources. Using these values alongside our calculated CARs for restored marshes, we estimate that an additional 12.93–207.03 Mt CO₂e could be buried per year through marsh restoration, equating to 0.03–0.51% of global energy-related CO₂ emissions in 2021 (IEA, 2022).

4 | DISCUSSION

4.1 | Global and regional blue carbon benefits

This study offers a firm endorsement of the benefit of saltmarsh restoration to mitigating global greenhouse gas emissions. Restored saltmarshes have very low GHG fluxes and rapid CARs, resulting in an overall net carbon accumulation rate of 64.70 t CO₂e ha⁻¹ year⁻¹. Incorporating greenhouse gas fluxes into global-scale estimates of net carbon accumulation, we show that saltmarsh restoration provides the opportunity for offsetting up to 0.51% of global CO₂ emissions, based on 2021 emission values (IEA, 2022) and considering that up to 3.2 million ha saltmarsh are potentially restorable (Griscom et al., 2017). Half a percent of global emissions is a substantial amount, considering marshes occupy much less than 1% Earth's surface (Costanza et al., 2014). The climate mitigating benefit of marsh restoration will be coupled to other significant socio-ecological gains, including natural flood protection and the provisioning of habitat for threatened wildlife and fisheries species (Barbier et al., 2011), the value of which typically outweighs the cost of restoration 1.3–1.0 (Alvis & Avison, 2021). Our study provides an up-to-date blue carbon estimate of 1.41–2.44 Pg stored in the top 1 m of saltmarsh sediment globally, a higher quantity than recent estimates of 1.35 Pg (Macreadie et al., 2021) and 1.37 Pg (Temmink

TABLE 3 Contextual drivers of spatial variation in the % organic carbon (%OC), bulk density, carbon stock (to 1 m), carbon accumulation rate and net CO₂ flux of restored marshes, as indicated by GLMM models.

Variable	Best supported model	AICc	R ² c	R ² m	χ ²	df	p-Value
% OC	1+RA+(1 SI)	1155.57	0.901	0.287	11.69	5	.039
Bulk density (g cm ⁻³)	1+RA+A+C+(1 SI)	-9.62	0.883	0.631	47.20	9	<.001
C stock (t C ha ⁻¹)	1+A+T+V+(1 SI)	1337.40	0.895	0.360	26.66	6	<.001
C accumulation (t C ha ⁻¹ year ⁻¹)	1+(1 SI)	480.08	0.866	0.000	NA	NA	NA
Net CO ₂ flux (t CO ₂ e ha ⁻¹ year ⁻¹)	1+C+R+(1 SI)	252.97	0.626	0.566	11.54	3	.009

Note: Significant model fit was found for all response variables except for accumulation.

Abbreviations: A, marsh age; C, continent; R, annual rainfall (mm); RA, restoration approach; S, salinity (categorical); SI, study ID; T, average annual temperature (°C); V, vegetation type.

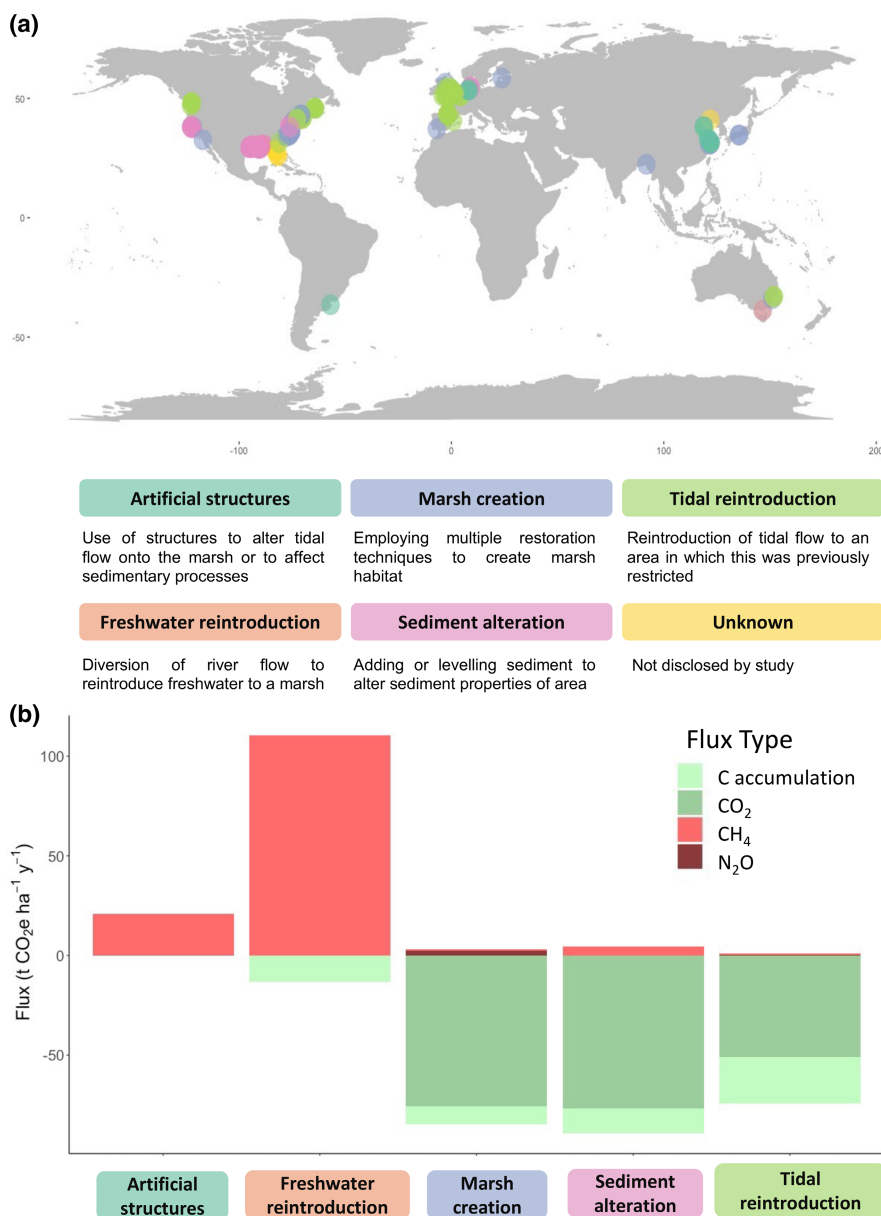


FIGURE 5 (a) Distribution of marsh restoration approaches used by studies (total $n=298$). (b) Means of soil and flux variables per restoration approach, t CO₂e ha⁻¹ year⁻¹. Values above 0 represent emissions (red), values below 0 show uptake (green). Note a lack of carbon accumulation data for artificial structure sites. More detailed descriptions of restoration approach can be found in [Table S2](#).

et al., 2022), but still lower than recent estimates of total carbon stock for mangroves (7.13 Pg) and seagrasses (3.58 Pg) (Lovelock & Reef, 2020). For IPCC comparability (IPCC, 2014), the present study extrapolated original observations of carbon stock to 1 m when

studies had not sampled carbon to this depth. This approach does incur uncertainties to our global stock estimate. A definitive estimate of global carbon stock in saltmarshes would require consistent measurements across the complete soil profile in a greater number

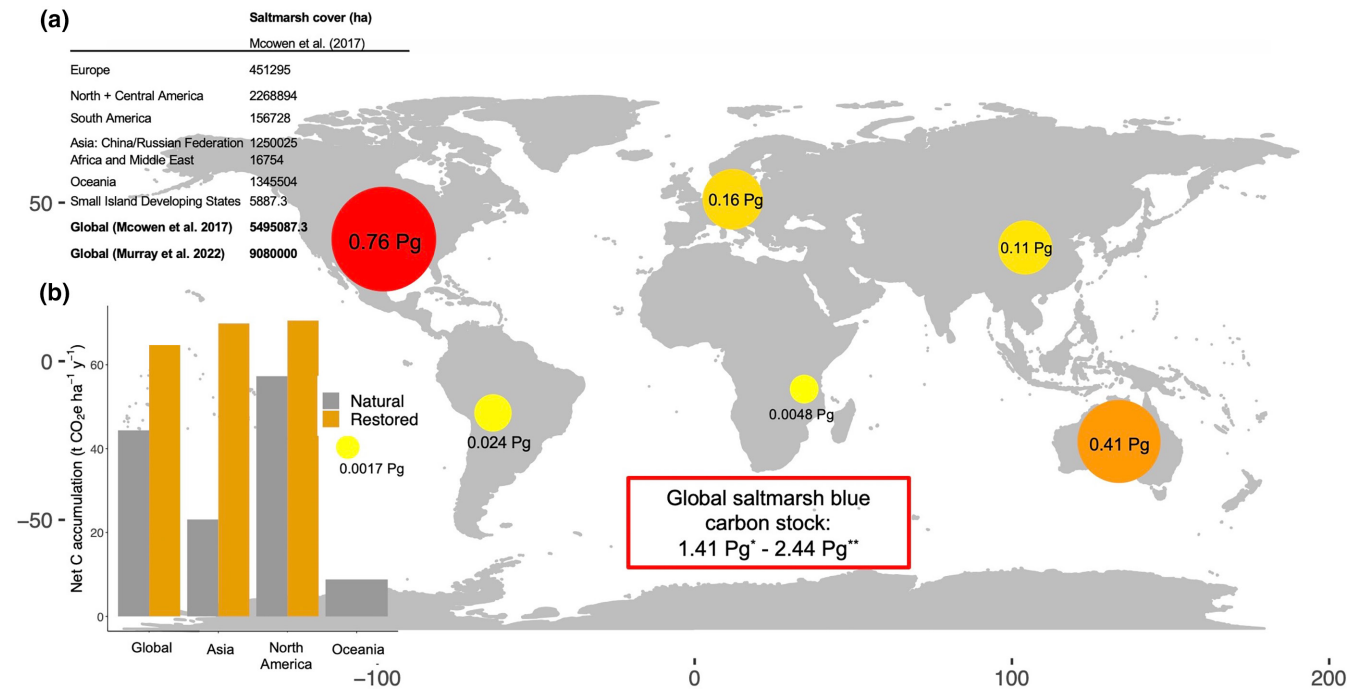


FIGURE 6 Estimated total saltmarsh blue carbon stock per continent to 1 m depth. Estimates were based on the marsh area coverage of Mcowen et al. (2017), Murray et al. (2022) and Worthington et al. (2023) listed in table (a) (units: ha). (b) The average net carbon accumulation rates (accounting for greenhouse gas emissions) for continents where sufficient data were available. For the 'Global saltmarsh blue carbon stock' box, * refers to stock calculated with values from Worthington et al. (2023) and ** for stock calculated from Murray et al. (2022). The value calculated with continental saltmarsh areas from Mcowen et al. (2023) was 1.47 Pg, used to scale up/down to the global area values from Murray et al. (2022) and Worthington et al. (2023).

of studies. Our estimate is based on a substantially higher number of published studies compared with previous studies (e.g. Ouyang & Lee, 2014; Temmink et al., 2022) and used the most recent saltmarsh coverage estimates (Mcowen et al., 2017; Murray et al., 2022; Worthington et al., 2023). The substantial carbon store held by marshes highlights the importance not just of marsh restoration, but of effective policy to protect existing marshes.

Global differences in carbon and GHG fluxes of natural and restored marshes were explained by variation in bio-physical context, with vegetation species composition and rainfall particularly strong drivers of variation in carbon stock and net CO₂ flux. The effect of vegetation type was expected, since plant community shifts are known to alter GHG emissions of saltmarshes (Martin et al., 2018) and plant composition is a reliable predictor of carbon stock (Ford et al., 2019; Smeaton et al., 2022). The eastern coasts of the North America and Australia were particular hotspots for carbon storage, being areas with high carbon stocks and high CARs. Eastern Australia is recognised as an area with strong carbon benefits from saltmarsh restoration (Gulliver et al., 2020; Macreadie et al., 2017). Our study also confirms that the eastern coast of North America is a global hotspot for saltmarsh carbon sequestration. These high carbon stocks may result from previously high rates of relative sea-level rise (RSLR) in the late Holocene, which may have led to surficial carbon densities 1.7–3.7 times higher than those in times, or regions, of stable sea level (Rogers et al., 2019). In addition, US *Spartina alterniflora*-dominated saltmarshes are highly productive and have long been recognised as having higher carbon

stocks than other marsh regions (Cebrian, 2002). Belowground decomposition of *S. alterniflora* is slower compared to other species, with a lignin half-life twice as long (3.6 years) as that of other saltmarsh vegetation (Benner et al., 1987; Unger et al., 2016). These species traits result in high densities of roots in surface sediments and the trapping of substantial quantities of carbon (Tripathee and Schäfer 2015; Redelstein et al., 2018), which causes North American marshes to have higher average organic carbon content and lower sediment bulk density than other continents, as observed here. Prioritising restoration efforts in areas with such naturally high carbon burial rates could offer early climate-mitigatory wins from saltmarsh restoration.

Future climate change may cause losses to some marsh areas, with associated emissions and reduced carbon accumulation in eroded areas. Recent estimates show that 83% of existing coastal marshes across six mid-USA states could be lost with 1.2 m RSLR before 2104 (Warnell et al., 2022). Based on our calculations of net carbon accumulation in North American marshes, this could equate to a loss of annual carbon accumulation up to 17.64 Mt CO₂e year⁻¹. Yet, that rate of sea-level rise may also convert 270,000 ha of forest and forested wetland areas into saltmarsh (Warnell et al., 2022). Areas with greater tidal range and higher suspended sediment supply will be less vulnerable to SLR (Saintilan et al., 2022) and actually experience an increase in carbon storage via greater accommodation space for sediment deposition (Gonneea et al., 2019). In the process of selecting which areas to restore it is evidently prudent to consult spatial projections of future gains and losses to marsh areas arising from SLR.

We found greenhouse gas emissions were a very negligible portion of saltmarsh carbon fluxes, although climatic drivers such as temperature were found to drive small variations in N_2O flux, for example. The CO_2e radiative forcing of N_2O and CH_4 emissions was dwarfed by the net CO_2 uptake, in restored marshes by 4 and 168 times, respectively, and CH_4 and N_2O fluxes did not vary significantly between natural and restored marshes. Clearly, the potential carbon benefit of marsh restoration greatly exceeds any potential warming effect from greenhouse gas emissions. This is in contrast to peatland restoration, where rewetting to improve habitat condition can lead to increased CH_4 emissions due to the anaerobic decomposition of organic material by methanogenic bacteria (Evans et al., 2021). Methane emissions are less substantial in saline environments because the presence of sulphates causes sulphate-reducing bacteria to outcompete methanogens (Bartlett et al., 1987). European marshes had 25 times lower methane flux than the global average. The causes for this are unclear, but we expect differences to be largely attributable to differences in salinity between study sites (Figure S3), with a potential influence of annual temperature and tidal regime (see e.g. Li et al., 2021). Within the extracted data, fresher and brackish sites, without high presence of sulphates to inhibit methanogenesis (Bartlett et al., 1987), were more prevalent in Asia and North America, compared to Europe. Recent reviews of methane fluxes from aquatic ecosystems also show that higher organic matter content can boost methane emissions (Al-Haj & Fulweiler, 2020; Rosentreter et al., 2021), which may have contributed to the higher methane emissions found in the present study from US marshes, for example.

4.2 | Carbon storage via saltmarsh restoration

The result that restored saltmarshes had higher CARs than comparative natural marshes was unsurprising, since many restored sites were sampled in the first 5 years after restoration, when sediment accretion and associated carbon burial is rapid (ABPmer, 2021; Mason et al., 2022). The maintenance of substantial CARs over time in restored marshes indicates the additionality from marsh restoration is enduring (even if all potential areas for restoration became restored), albeit carbon accumulation here does not equate directly to the atmospheric sequestration of CO_2 . Carbon accumulation here comprised observations of carbon burial, carbon accumulation and CO_2 uptake by marsh vegetation. International standards for carbon offsetting from marsh restoration can use CARs and carbon stock changes rather than sequestration as the basis for calculating and issuing tradable carbon credits, as long as deductions for allochthonous carbon (Figure 1) are made when necessary (e.g. VERRA VM0033: VCS Methodology, 2021). To limit the risk of 'double accounting' allochthonous carbon (Williamson & Gattuso, 2022), projects aiming to offset emissions via wetland restoration should aim to distinguish between carbon sequestered by the system itself (autochthonous) and carbon trapped by the marsh from passing water, but originally fixed by another ecosystem (allochthonous, Figure 1) and already

accounted for there. Ultimately, the calculations of carbon benefits from blue carbon ecosystems should incorporate all lateral carbon fluxes, including imports of allochthonous material, as well as the export of autochthonous marsh carbon to other systems, such as the seabed (Sulpis and Middleburg 2023). Marshes are highly dynamic and have spatial and temporal patterns of expansion and erosion (Ladd et al., 2019, 2021). There has been little research into the carbon implications from such dynamics, although the presence of marsh material in other systems further illustrates the offsetting potential of saltmarshes (Zhu et al., 2022).

Restoration approach explained significant amounts of variation in soil organic carbon content (%OC) and bulk density. Soil organic carbon content was highest in marshes restored via freshwater introduction, as were methane emissions, although this was not statistically testable due to insufficient data. The potential of saltmarshes as blue carbon ecosystems relates not only to carbon accumulation, but also to their low methane emissions, as methanogenesis is inhibited at high salinities and methane flux is widely regarded to be negligible above 18 ppt (Needelman et al., 2018; Poffenbarger et al., 2011)—patterns corroborated here through evidence of low mean global methane emissions by natural and restored saltmarsh sites. Salinity will be reduced when freshwater introduction is the mode of restoration, resulting in higher methane fluxes than, for example, when marshes are restored through the reintroduction of tidal flooding. Carbon stock appeared higher in marshes restored via sediment alteration and tidal reintroduction than through methods based on planting, sediment addition and fertilisation (e.g. Li & Mitsch, 2016). In practice, the choice of restoration approach will be constrained by environmental context and may be directed by objectives other than carbon benefits, such as enhancing biodiversity and/or providing natural flood defence (Adams et al., 2021; Barbier et al., 2011).

Bundled socio-ecological gains through ecosystem-service provisioning are generally ensured by marsh restoration (Barbier et al., 2011; Sánchez-Arcilla et al., 2022; Stewart-Sinclair et al., 2020), although the choice of restoration can drive trade-offs between benefits. For instance, while this study showed *Phragmites* reed beds had the highest carbon accumulation of all vegetation communities, the removal of *Phragmites australis* in regions where this is invasive would increase plant and faunal diversity (Findlay et al., 2003; Gratton & Denno, 2005, 2006). Natural flood protection is an important driver of marsh restoration in many global regions and has great potential for co-benefits to carbon and biodiversity (e.g. Barbier et al., 2011; Mossman et al., 2022), but it can also result in trade-offs of other ecosystem services, depending on design (Auerswald et al., 2019; Loon-Steensma and Vellinga 2013). While trade-offs from flood protection projects are relatively well-studied (see e.g. van Loon-Steensma & Vellinga, 2013), insight into trade-offs resulting from projects targeting saltmarsh carbon accumulation is comparatively lacking. The goal and approach of restoration should always be clearly thought through to manage benefit trade-offs. Empirical observations of some marsh ecosystem services are patchily distributed, making it a challenge to deliver holistic trade-off evaluations across all global contexts.

4.3 | Data gaps and areas for further research

While we have confidence in our global estimates and the deduced contribution of marshes to climate regulation, the study did face data scarcity for some geographical regions, environmental contexts and carbon response variables. Our overall estimates of saltmarsh carbon stock, CARs and restoration potentials were based on continental averages, as the spatial cover was insufficiently consistent to go to regional or national levels. In particular, there was spatial paucity in empirical observations of CARs and greenhouse gas fluxes, especially for restored marshes and including otherwise well-studied continents such as Europe. Undoubtedly, boosting the spatial cover of empirical flux observations would give greater confidence in net greenhouse gas budgets and a finer resolution for examining how marsh restoration benefits vary with environmental context. Our statistical models were additive and based on generalised linear distributions. These relatively simple model constructs allowed us to explore the contextual drivers of a wide variety of carbon flux components across natural and restored marsh settings. A more complex modelling approach that considers non-uniform distributions and potential multi-way interactions between different drivers could provide a more detailed understanding into the effects of environmental drivers on carbon flux. Additionally, predictive spatial models might be explored, for example through machine learning techniques, to move from global/continental mean estimates to point level predictions at small spatial scales.

4.4 | Implications for policy and management

Overall, our findings support the assertion of the IPCC Sixth Assessment Report that habitat restoration offers a significant route to mitigating climate change (IPCC, 2021) and meeting Nationally Determined Contributions (NDCs). Many nations already have statutory obligations or stated commitments to restore marshes and the carbon gains from such restoration can be calculated from the data synthesised here. Evidently, the more marsh areas are restored, the less will be the unexplored potential of marshes to contribute further reductions to atmospheric carbon. Marsh restoration is only one of many actionable climate solutions. However, nature-based solutions do offer an effective, short-term opportunity to mitigate global emissions and are, arguably, a critical route for meeting the shorter-term ambitions of the Paris Agreement (Seddon et al., 2020). For example, if the recommended 22,000ha (Dickie et al., 2015) saltmarsh area in the United Kingdom were successfully restored, an additional 0.14MtCyear^{-1} would be accumulated, equating to 0.05% of the UK's 2020 CO_2 emissions (IEA, 2022). While the investment in wetland restoration typically has very positive cost-benefit ratios (Alvis & Avison, 2021), projects do need to have the buy-in from multiple stakeholders, including local communities, the finance sector and environmental managers, before restorable areas can be successfully converted into functional saltmarshes (Figure 7). Much of the policy and science exists, but the roll-out of marsh restoration can stumble on processes associated with practical limitations, such as land availability and the cost of upscaling. Agricultural need for land

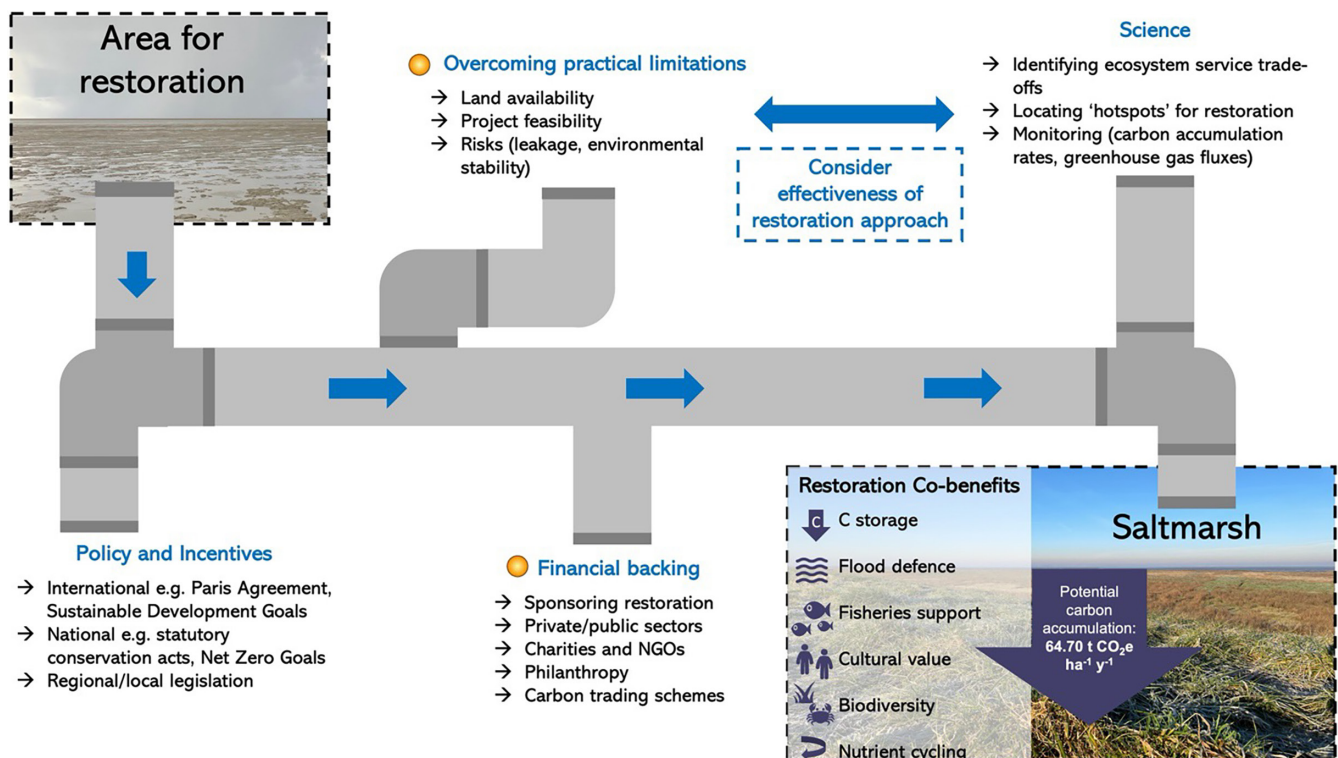


FIGURE 7 Key processes underpinning the transformation of restorable areas into saltmarshes, with multiple societal co-benefits, including carbon storage. Major current challenges which may limit the upscaling of marsh restoration are highlighted in yellow.

was a key driver for historical marsh losses (Mcowen et al., 2017) and may still restrict available areas for restoration, given that there is increasing demand for land for food and housing to meet the needs of a continually growing coastal population (Nicholls et al., 2007). Practical recognition of the bundled benefits associated with marsh restoration (see e.g. Sánchez-Arcilla et al., 2022; Stewart-Sinclair et al., 2020; Figure 7) may become an important factor in overcoming such restoration 'stumbling blocks'. Linking targets for saltmarsh carbon to planning for nature-based flood solutions may provide such an opportunity.

The expense of saltmarsh restoration can be substantial, depending on geographical region and method of restoration, with replanting most expensive (\$89–140,000 ha⁻¹) and hydrological or sediment restoration generally the cheapest (\$24–65,000 ha⁻¹) (Wang et al., 2022). In countries like the United Kingdom, costs may be covered through governmental commitment to flood protection (Carvalho & Spataru, 2023), particularly incorporating nature-based solutions. While high up-front costs and long-term investment can put off private investors in ecological restoration (Wainaina et al., 2020), co-investment to explore a rapidly expanding carbon market offers a promising way to accelerate marsh restoration (Macreadie et al., 2021). Cost-benefit analysis accounting for ecosystem-service gains show the cost of restoration is recovered within 5–30 years, for 20%–40% of projects, respectively, with small-scale projects taking longer to recover expenses and increase in carbon value substantially reducing the timescale (Wang et al., 2022). Currently, only carbon has a significant market to help offset restoration costs and attract investors, but other saltmarsh ecosystem services, such as nutrient-remediation and recreational space, have strong market potentials and unquestionable societal cost benefits (Adams et al., 2021; Lillebø et al., 2010; Wang et al., 2022).

4.5 | Conclusions

Additional data on saltmarsh greenhouse gas fluxes and CARs are required on a global scale for constructing net carbon budgets. While the priority must remain to reduce global greenhouse gas emissions, the potential of saltmarsh restoration to contribute to climate regulation is clear. Our ability to facilitate that natural carbon burial now rests principally on the availability of land to restore, the management of larger-scale processes that threaten marsh area, such as accelerating sea-level rise, and the willingness and action of the management-policy community to connect to multi-sectoral financial opportunities for supporting restoration.

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CONFLICT OF INTEREST STATEMENT

The authors declare no competing financial interests.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in Dryad at <https://doi.org/10.5061/dryad.pc866t1vp>.

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REFERENCES

- ABPmer. (2021). *Blue carbon in managed realignments: An overview with a comparative analysis and valuation of 10 different UK sites*.
- Adams, C. A., Andrews, J. E., & Jickells, T. (2012). Nitrous oxide and methane fluxes vs. carbon, nitrogen and phosphorous burial in new intertidal and saltmarsh sediments. *Science of the Total Environment*, 434, 240–251.
- Adams, J. B., Raw, J. L., Riddin, T., Wasserman, J., & Van Niekerk, L. (2021). Salt marsh restoration for the provision of multiple ecosystem services. *Diversity*, 13(12), 680.
- Al-Haj, A. N., & Fulweiler, R. W. (2020). A synthesis of methane emissions from shallow vegetated coastal ecosystems. *Global Change Biology*, 26(5), 2988–3005.
- Alvis, S., & Avison, Z. (2021). *Levelling up through circular economy jobs*. (pp. 1–16). Green Alliance.
- Auerswald, K., Moyle, P., Seibert, S. P., & Geist, J. (2019). HESS opinions: Socio-economic and ecological trade-offs of flood management-benefits of a transdisciplinary approach. *Hydrology and Earth System Sciences*, 23(2), 1035–1044.
- Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C., & Silliman, B. R. (2011). The value of estuarine and coastal ecosystem services. *Ecological Monographs*, 81(2), 169–193.
- Bartlett, K. B., Bartlett, D. S., Harriss, R. C., & Sebachner, D. I. (1987). Methane emissions along a salt-marsh salinity gradient. *Biogeochemistry*, 4, 183e202.
- Benner, R., Fogel, M. L., Sprague, E. K., & Hodson, R. E. (1987). Depletion of ¹³C in lignin and its implications for stable carbon isotope studies. *Nature*, 329(6141), 708–710.
- Bu, N. S., Qu, J. F., Li, G., Zhao, B., Zhang, R. J., & Fang, C. M. (2015). Reclamation of coastal salt marshes promoted carbon loss from previously-sequestered soil carbon pool. *Ecological Engineering*, 81, 335–339.
- Burden, A., Garbutt, A., & Evans, C. D. (2019). Effect of restoration on saltmarsh carbon accumulation in eastern England. *Biology Letters*, 15(1), 20180773.
- Burnham, K. P., Anderson, D. R., & Huyvaert, K. P. (2011). AIC model selection and multimodel inference in behavioral ecology: Some background, observations, and comparisons. *Behavioral Ecology and Sociobiology*, 65(1), 23–35.
- Callaway, J. C. (2005). The challenge of restoring functioning salt marsh ecosystem. *Journal of Coastal Research*, SI40, 24–36.

- Calvo-Cubero, J., Ibáñez, C., Rovira, A., Sharpe, P. J., & Reyes, E. (2014). Changes in nutrient concentration and carbon accumulation in a Mediterranean restored marsh (Ebro Delta, Spain). *Ecological Engineering*, 71, 278–289.
- Campbell, A. D., Fatoyinbo, L., Goldberg, L., & Lagomasino, D. (2022). Global hotspots of salt marsh change and carbon emissions. *Nature*, 612, 1–6.
- Carvalho, P., & Spataru, C. (2023). Gaps in the governance of floods, droughts, and heatwaves in the United Kingdom. *Frontiers in Earth Science*, 11, 1124166.
- Cebrian, J. (2002). Variability and control of carbon consumption, export, and accumulation in marine communities. *Limnology and Oceanography*, 47(1), 11–22.
- Costanza, R., De Groot, R., Sutton, P., Van der Ploeg, S., Anderson, S. J., Kubiszewski, I., Farber, S. & Turner, R. K. (2014). Changes in the global value of ecosystem services. *Global Environmental Change*, 26, 152–158.
- Costanza, R., Pérez-Maqueo, O., Martínez, M. L., Sutton, P., Anderson, S. J., & Mulder, K. (2008). The value of coastal wetlands for hurricane protection. *Ambio*, 37, 241–248.
- Crooks, S., Herr, D., Tamelander, J., Laffoley, D., & Vandever, J. (2011). *Mitigating climate change through restoration and management of coastal wetlands and near-shore marine ecosystems: Challenges and opportunities*. Environment Department Papers.
- Davidson, N. C., Van Dam, A. A., Finlayson, C. M., & McInnes, R. J. (2019). Worth of wetlands: Revised global monetary values of coastal and inland wetland ecosystem services. *Marine and Freshwater Research*, 70(8), 1189–1194.
- de la Barra, P., Skov, M. W., Lawrence, P. J., Schiaffi, J. I., & Hiddink, J. G. (2022). Tidal water exchange drives fish and crustacean abundances in salt marshes. *Marine Ecology Progress Series*, 694, 61–72.
- Dickie, I., Cryle, P., Anderson, S., Provins, A., Krisht, S., Koshy, A., Doku, A., Maskell, L., Norton, L., Walmsley, S., Scott, C., Fanning, T., Nicol, S., Spurgeon, D., Pywell, R., Bullock, J., Evans, C., Goodwin, A., Jones, L., ... Bealey, B. (2015). *The economic case for investment in natural capital in England final report for the Natural Capital Committee*.
- Duarte, C. M., Agusti, S., Barbier, E., Britten, G. L., Castilla, J. C., Gattuso, J. P., Fulweiler, R. W., Hughes, T. P., Knowlton, N., Lovelock, C. E., & Lotze, H. K. (2020). Rebuilding marine life. *Nature*, 580(7801), 39–51.
- Duarte, C. M., Dennison, W. C., Orth, R. J., & Carruthers, T. J. (2008). The charisma of coastal ecosystems: Addressing the imbalance. *Estuaries and Coasts*, 31(2), 233–238.
- Duarte, C. M., Middelburg, J. J., & Caraco, N. (2005). Major role of marine vegetation on the oceanic carbon cycle. *Biogeosciences*, 2(1), 1–8.
- Evans, C. D., Peacock, M., Baird, A. J., Artz, R. R. E., Burden, A., Callaghan, N., Chapman, P. J., Cooper, H. M., Coyle, M., Craig, E., & Cumming, A. (2021). Overriding water table control on managed peatland greenhouse gas emissions. *Nature*, 593(7860), 548–552.
- Fairchild, T. P., Bennett, W. G., Smith, G., Day, B., Skov, M. W., Möller, I., Beaumont, N., Karunaratna, H., & Griffin, J. N. (2021). Coastal wetlands mitigate storm flooding and associated costs in estuaries. *Environmental Research Letters*, 16(7), 074034.
- Fick, S. E., & Hijmans, R. J. (2017). WorldClim 2: New 1 km spatial resolution climate surfaces for global land areas. *International Journal of Climatology*, 37(12), 4302–4315.
- Findlay, S., Groffman, P., & Dye, S. (2003). Effects of *Phragmites australis* removal on marsh nutrient cycling. *Wetlands Ecology and Management*, 11(3), 157–165.
- Ford, H., Garbutt, A., Duggan-Edwards, M., Pagès, J. F., Harvey, R., Ladd, C., & Skov, M. W. (2019). Large-scale predictions of salt-marsh carbon stock based on simple observations of plant community and soil type. *Biogeosciences*, 16(2), 425–436.
- Garbutt, A., & Wolters, M. (2008). The natural regeneration of salt marsh on formerly reclaimed land. *Applied Vegetation Science*, 11(3), 335–344.
- Garbutt, R. A., Reading, C. J., Wolters, M., Gray, A. J., & Rothery, P. (2006). Monitoring the development of intertidal habitats on former agricultural land after the managed realignment of coastal defences at Tollesbury, Essex, UK. *Marine Pollution Bulletin*, 53(1–4), 155–164.
- Gedan, K. B., Silliman, B. R., & Bertness, M. D. (2009). Centuries of human-driven change in salt marsh ecosystems. *Annual Review of Marine Science*, 1(1), 117–141.
- Gonnessa, M. E., Maio, C. V., Kroeger, K. D., Hawkes, A. D., Mora, J., Sullivan, R., Madsen, S., Buzard, R. M., Cahill, N., & Donnelly, J. P. (2019). Salt marsh ecosystem restructuring enhances elevation resilience and carbon storage during accelerating relative sea-level rise. *Estuarine, Coastal and Shelf Science*, 217, 56–68.
- Gratton, C., & Denno, R. F. (2005). Restoration of arthropod assemblages in a *Spartina* salt marsh following removal of the invasive plant *Phragmites australis*. *Restoration Ecology*, 13(2), 358–372.
- Gratton, C., & Denno, R. F. (2006). Arthropod food web restoration following removal of an invasive wetland plant. *Ecological Applications*, 16(2), 622–631.
- Griscom, B. W., Adams, J., Ellis, P. W., Houghton, R. A., Lomax, G., Miteva, D. A., Schlesinger, W. H., Shoch, D., Siikamäki, J. V., Smith, P., & Woodbury, P. (2017). Natural climate solutions. *Proceedings of the National Academy of Sciences of the United States of America*, 114(44), 11645–11650.
- Gulliver, A., Carnell, P. E., Trevathan-Tackett, S. M., de Paula, D., Costa, M., Masqué, P., & Macreadie, P. I. (2020). Estimating the potential blue carbon gains from tidal marsh rehabilitation: A case study from south eastern Australia. *Frontiers in Marine Science*, 7, 403.
- IEA. (2022). *Global energy review: CO₂ emissions in 2021*. IEA. <https://www.iea.org/reports/global-energy-review-co2-emissions-in-2021-2>
- IPCC. (2014). In T. Hiraiishi, T. Krug, K. Tanabe, N. Srivastava, J. Baasansuren, M. Fukuda, & T. G. Troxler (Eds.), *2013 supplement to the 2006 IPCC guidelines for National Greenhouse Gas Inventories: Wetlands*. IPCC.
- IPCC. (2021). In V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, & B. Zhou (Eds.), *Climate change 2021: The physical science basis. Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change*. Cambridge University Press.
- Ladd, C. J. T., Duggan-Edwards, M., Bouma, T. J., & Skov, M. W. (2019). Sediment supply explains long-term and large-scale patterns in saltmarsh lateral expansion and erosion. *Geophysical Research Letters*, 46, 11178–11187.
- Ladd, C. J. T., Duggan-Edwards, M. F., Pagès, J., & Skov, M. W. (2021). Saltmarsh resilience to periodic shifts in tidal channels. *Frontiers in Marine Science*, 8, 757715.
- Lenth, R. V. (2022). *Emmeans: Estimated marginal means, aka least-squares means*. R package version 1.7.3. <https://CRAN.R-project.org/package=emmeans>
- Li, J., Leng, Z., Wu, Y., Li, G., Ren, G., Wu, G., Jiang, Y., Yuguda, T. K., & Du, D. (2021). The impact of sea embankment reclamation on greenhouse gas GHG fluxes and stocks in invasive *Spartina alterniflora* and native *Phragmites australis* wetland marshes of East China. *Sustainability*, 13(22), 12740.
- Li, X., & Mitsch, W. J. (2016). Methane emissions from created and restored freshwater and brackish marshes in Southwest Florida, USA. *Ecological Engineering*, 91, 529–536.
- Lillebø, A. I., Sousa, A. I., Flindt, M. R., Pereira, M. E., Duarte, A. C., Pardal, M. A., & Caçador, I. (2010). Nutrient cycling in salt marshes: An ecosystem service to reduce eutrophication. In *Eutrophication: Ecological effects, sources, prevention and reversal* (pp. 135–160). Nova Science Publishers, Inc..
- Lovelock, C. E., Fourqurean, J. W., & Morris, J. T. (2017). Modeled CO₂ emissions from coastal wetland transitions to other land uses: Tidal

- marshes, mangrove forests, and seagrass beds. *Frontiers in Marine Science*, 4, 143.
- Lovelock, C. E., & Reef, R. (2020). Variable impacts of climate change on blue carbon. *One Earth*, 3(2), 195–211.
- Lüdecke, D., Makowski, D., Waggoner, P., & Patil, I. (2020). *Performance: Assessment of regression models performance*. R package version 0.4, 5.
- Macreadie, P. I., Costa, M. D., Atwood, T. B., Friess, D. A., Kelleway, J. J., Kennedy, H., Lovelock, C. E., Serrano, O., & Duarte, C. M. (2021). Blue carbon as a natural climate solution. *Nature Reviews Earth & Environment*, 2(12), 826–839.
- Macreadie, P. I., Hughes, A. R., & Kimbro, D. L. (2013). Loss of 'blue carbon' from coastal salt marshes following habitat disturbance. *PLoS One*, 8(7), e69244.
- Macreadie, P. I., Ollivier, Q. R., Kelleway, J. J., Serrano, O., Carnell, P. E., Ewers Lewis, C. J., Atwood, T. B., Sanderman, J., Baldock, J., Connolly, R. M., & Duarte, C. M. (2017). Carbon sequestration by Australian tidal marshes. *Scientific Reports*, 7(1), 1–10.
- Martin, R. M., Wigand, C., Elmstrom, E., Lloret, J., & Valiela, I. (2018). Long-term nutrient addition increases respiration and nitrous oxide emissions in a New England salt marsh. *Ecology and Evolution*, 8(10), 4958–4966.
- Mason, V. G., Burden, A., Epstein, G. E., Jupe, L. L., Wood, K. A., & Skov, M. W. (2023). Data from: Blue carbon benefits from global saltmarsh restoration. *Dryad*. <https://doi.org/10.5061/dryad.pc866t1vp>.
- Mason, V. G., Wood, K. A., Jupe, L. L., Burden, A., & Skov, M. W. (2022). Saltmarsh blue carbon in UK and NW Europe—Evidence synthesis for a UK saltmarsh carbon code. In *Report to the natural environment investment readiness fund* (p. 36). UK Centre for Ecology & Hydrology.
- Mcowen, C. J., Weatherdon, L. V., Van Bochove, J. W., Sullivan, E., Blyth, S., Zockler, C., Stanwell-Smith, D., Kingston, N., Martin, C. S., Spalding, M., & Fletcher, S. (2017). A global map of saltmarshes. *Biodiversity Data Journal*, 5, e11764.
- Middelburg, J. J., Nieuwenhuize, J., Lubberts, R. K., & Van de Plassche, O. (1997). Organic carbon isotope systematics of coastal marshes. *Estuarine, Coastal and Shelf Science*, 45(5), 681–687.
- Möller, I., Spencer, T., Best, M., Austin, W., & Burden, A. (2021). Saltmarsh restoration: An introduction. In R. Hudson, J. Kenworthy, & M. Best (Eds.), *Saltmarsh restoration handbook: UK and Ireland* (pp. 1–16). Environment Agency.
- Mossman, H. L., Pontee, N., Born, K., Hill, C., Lawrence, P. J., Rae, S., Scott, J., Serato, B., Sparkes, R. B., Sullivan, M. J. P., & Dunk, R. M. (2022). Rapid carbon accumulation at a saltmarsh restored by managed realignment exceeded carbon emitted in direct site construction. *PLoS One*, 17(11), e0259033. <https://doi.org/10.1371/journal.pone.0259033>
- Murray, N. J., Worthington, T. A., Bunting, P., Duce, S., Hagger, V., Lovelock, C. E., Lucas, R., Saunders, M. I., Sheaves, M., Spalding, M., Waltham, N. J., & Lyons, M. B. (2022). High-resolution mapping of losses and gains of Earth's tidal wetlands. *Science*, 376(6594), 744–749.
- Needelman, B. A., Emmer, I. M., Emmett-Mattox, S., Crooks, S., Magonigal, J. P., Myers, D., Oreska, M. P., & McGlathery, K. (2018). The science and policy of the verified carbon standard methodology for tidal wetland and seagrass restoration. *Estuaries and Coasts*, 41(8), 2159–2171.
- Neubauer, S. C., & Magonigal, J. P. (2021). Biogeochemistry of wetland carbon preservation and flux. *Wetland Carbon and Environmental Management*, 19, 33–71.
- Nicholls, R. J., Hanson, S., Herweijer, C., Patmore, N., Hallegatte, S., Corfee-Morlot, J., Chateau, J., & Muir-Wood, R. (2007). *Ranking of the world's cities most exposed to coastal flooding today and in the future*. Organisation for Economic Co-Operation and Development (OECD).
- O'Dea, R. E., Lagisz, M., Jennions, M. D., Koricheva, J., Noble, D. W., Parker, T. H., Gurevitch, J., Page, M. J., Stewart, G., Moher, D., & Nakagawa, S. (2021). Preferred reporting items for systematic reviews and meta-analyses in ecology and evolutionary biology: A PRISMA extension. *Biological Reviews*, 96(5), 1695–1722.
- Ouyang, X., & Lee, S. Y. (2014). Updated estimates of carbon accumulation rates in coastal marsh sediments. *Biogeosciences*, 11(18), 5057–5071.
- Ouyang, X., & Lee, S. Y. (2020). Improved estimates on global carbon stock and carbon pools in tidal wetlands. *Nature Communications*, 11(1), 1–7.
- Poffenbarger, H. J., Needelman, B. A., & Magonigal, J. P. (2011). Salinity influence on methane emissions from tidal marshes. *Wetlands*, 31(5), 831–842.
- Pullin, A. S., & Stewart, G. B. (2006). Guidelines for systematic review in conservation and environmental management. *Conservation Biology*, 20(6), 1647–1656.
- Pye, K., & Blott, S. J. (2014). The geomorphology of UK estuaries: The role of geological controls, antecedent conditions and human activities. *Estuarine, Coastal and Shelf Science*, 150, 196–214.
- R Core Team. (2020). *R: A language and environment for statistical computing*. Version 3.6.3. R Foundation for Statistical Computing.
- Redelstein, R., Dinter, T., Hertel, D., & Leuschner, C. (2018). Effects of inundation, nutrient availability and plant species diversity on fine root mass and morphology across a saltmarsh flooding gradient. *Frontiers in Plant Science*, 9, 98.
- Rezek, R. J., Lebreton, B., Sterba-Boatwright, B., & Beseres Pollack, J. (2017). Ecological structure and function in a restored versus natural salt marsh. *PLoS One*, 12(12), e0189871.
- Rogers, K., Kelleway, J. J., Saintilan, N., Magonigal, J. P., Adams, J. B., Holmquist, J. R., Lu, M., Schile-Beers, L., Zawadzki, A., Mazumder, D., & Woodroffe, C. D. (2019). Wetland carbon storage controlled by millennial scale variation in relative sea-level rise. *Nature*, 567(7746), 91–95.
- Rohatgi, A. (2020). *Automeris WebPlotDigitizer Version 4.4*. <https://automeris.io/WebPlotDigitizer>.
- Rosentreter, J. A., Al-Haj, A. N., Fulweiler, R. W., & Williamson, P. (2021). Methane and nitrous oxide emissions complicate coastal blue carbon assessments. *Global Biogeochemical Cycles*, 35(2), e2020GB006858.
- Saintilan, N., Kovalenko, K. E., Guntenspergen, G., Rogers, K., Lynch, J. C., Cahoon, D. R., Lovelock, C. E., Friess, D. A., Ashe, E., Krauss, K. W., & Cormier, N. (2022). Constraints on the adjustment of tidal marshes to accelerating sea level rise. *Science*, 377(6605), 523–527.
- Sánchez-Arcilla, A., Cáceres, I., Le Roux, X., Hinkel, J., Schuerch, M., Nicholls, R. J., del Mar Otero, M., Staneva, J., de Vries, M., Pernice, U., & Briere, C. (2022). Barriers and enablers for upscaling coastal restoration. *Nature-Based Solutions*, 2, 100032.
- Seddon, N., Chausson, A., Berry, P., Giardin, C. A. J., Smith, A., & Turner, B. (2020). Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 375, 20190120.
- Sharps, E., Smart, J., Mason, L. R., Jones, K., Skov, M. W., Garbutt, A., & Hiddink, J. G. (2017). Nest trampling and ground nesting birds: Quantifying temporal and spatial overlap between cattle activity and breeding redshank. *Ecology and Evolution*, 7(16), 6622–6633.
- Shiau, Y. J., Burchell, M. R., Krauss, K. W., Broome, S. W., & Birgand, F. (2019). Carbon storage potential in a recently created brackish marsh in eastern North Carolina, USA. *Ecological Engineering*, 127, 579–588.
- Smeaton, C., Burden, A., Ruranska, P., Ladd, C. J., Garbutt, A., Jones, L., McMahon, L., Miller, L. C., Skov, M. W., & Austin, W. E. (2022). Using citizen science to estimate surficial soil blue carbon stocks in Great British saltmarshes. *Frontiers in Marine Science*, 9, 1461.

- Soileau, J. M., Lyons, E. K., Chung, B., Hoffman, J., & LeMieux, F. (2018). Defining success criteria for *Spartina alterniflora* restoration projects in Southwestern Louisiana. *Southeastern Naturalist*, 17(4), 541–553.
- Stewart-Sinclair, P. J., Purandare, J., Bayraktarov, E., Waltham, N., Reeves, S., Statton, J., Sinclair, E. A., Brown, B. M., Shribman, Z. I., & Lovelock, C. E. (2020). Blue restoration – Building confidence and overcoming barriers. *Frontiers in Marine Science*, 7, 748.
- Sulpis, O., & Middelburg, J. J. (2023). Inorganic blue carbon sequestration. *Nature Sustainability*, 1–2.
- Temmink, R. J., Lamers, L. P., Angelini, C., Bouma, T. J., Fritz, C., van de Koppel, J., Lexmond, R., Rietkerk, M., Silliman, B. R., Joosten, H., & van der Heide, T. (2022). Recovering wetland biogeomorphic feedbacks to restore the world's biotic carbon hotspots. *Science*, 376(6593), eabn1479.
- Tripathee, R., & Schäfer, K. V. R. (2015). Above-and belowground biomass allocation in four dominant salt marsh species of the eastern United States. *Wetlands*, 35(1), 21–30.
- Unger, V., Eelsey-Quirk, T., Sommerfield, C., & Velinsky, D. (2016). Stability of organic carbon accumulating in *Spartina alterniflora*-dominated salt marshes of the mid-Atlantic US. *Estuarine, Coastal and Shelf Science*, 182, 179–189.
- Valiela, I., Kinney, E., Culbertson, J., Peacock, E., Smith, S., & Duarte, C. M. (2009). 4. *Global losses of mangroves and salt marshes by global loss of coastal habitats rates, causes and consequences*.
- van Loon-Steenma, J. M., & Vellinga, P. (2013). Trade-offs between biodiversity and flood protection services of coastal salt marshes. *Current Opinion in Environmental Sustainability*, 5(3–4), 320–326.
- VCS Methodology. (2021). *VM0033 methodology for tidal wetlands and seagrass restoration v2.0*.
- Wainaina, P., Minang, P. A., Gituku, E., & Duguma, L. (2020). Cost-benefit analysis of landscape restoration: A stocktake. *Land*, 9(11), 465.
- Wang, F., Sanders, C. J., Santos, I. R., Tang, J., Schuerch, M., Kirwan, M. L., Kopp, R. E., Zhu, K., Li, X., Yuan, J., & Liu, W. (2021). Global blue carbon accumulation in tidal wetlands increases with climate change. *National Science Review*, 8(9), nwaa296.
- Wang, J. J., Li, X. Z., Lin, S. W., & Ma, Y. X. (2022). Economic evaluation and systematic review of salt marsh restoration projects at a global scale. *Frontiers in Ecology and Evolution*, 10, 865516.
- Warnell, K., Olander, L., & Currin, C. (2022). Sea level rise drives carbon and habitat loss in the US mid-Atlantic coastal zone. *PLOS Climate*, 1(6), e0000044.
- Williamson, P., & Gattuso, J. P. (2022). Carbon removal using coastal blue carbon ecosystems is uncertain and unreliable, with questionable climatic cost-effectiveness. *Frontiers in Climate*, 4, 853666.
- Wolters, M., Garbutt, A., & Bakker, J. P. (2005). Salt-marsh restoration: Evaluating the success of de-embankments in north-West Europe. *Biological Conservation*, 123(2), 249–268.
- Worthington, T. A., Spalding, M., Landis, E., Maxwell, T. L., Navarro, A., Smart, L. S., & Murray, N. J. (2023). The distribution of global tidal marshes from earth observation data. *bioRxiv*, 2023-05.
- Wang, F., Sanders, C. J., Santos, I. R., Tang, J., Schuerch, M., Kirwan, M. L., Kopp, R. E., Zhu, K., Li, X., Yuan, J., & Liu, W. (2020). Enhanced carbon uptake and reduced methane emissions in a newly restored wetland. *Journal of Geophysical Research: Biogeosciences*, 125(1), e2019JG005222.
- Zhu, P., Chen, X., Zhang, Y., Zhang, Q., Wu, X., Zhao, H., Qi, L., Shao, X., & Li, L. (2022). Porewater-derived blue carbon outwelling and greenhouse gas emissions in a subtropical multi-species saltmarsh. *Frontiers in Marine Science*, 9, 884951.
- in eastern Tasmania (pp. 61–74). Papers and Proceedings. Royal Society of Tasmania. <https://doi.org/10.26749/rstpp.153.61>
- Abbott, K. M., Eelsey-Quirk, T., & DeLaune, R. D. (2019). Factors influencing blue carbon accumulation across a 32-year chronosequence of created coastal marshes. *Ecosphere* (Washington, D.C.), 10(8), e02828. <https://doi.org/10.1002/ecs2.2828>
- ABPmer. (2021). *Blue carbon in managed realignments: An overview with a comparative analysis and valuation of 10 different UK sites*.
- Adams, C. A., Andrews, J. E., & Jickells, T. (2012). Nitrous oxide and methane fluxes vs. carbon, nitrogen and phosphorous burial in new intertidal and saltmarsh sediments. *The Science of the Total Environment*, 434, 240–251. <https://doi.org/10.1016/j.scitotenv.2011.11.058>
- Alexander, C. R., Hodgson, J. Y. S., & Brandes, J. A. (2017). Sedimentary processes and products in a mesotidal salt marsh environment: Insights from Groves Creek, Georgia. *Geo-Marine Letters*, 37(4), 345–359. <https://doi.org/10.1007/s00367-017-0499-1>
- Allred, M., Borrelli, J. J., Hoellein, T., Bruesewitz, D., & Zarnoch, C. (2020). Marsh plants enhance coastal marsh resilience by changing sediment oxygen and sulfide concentrations in an urban, eutrophic estuary. *Estuaries and Coasts: Journal of the Estuarine Research Federation*, 43(4), 801–813. <https://doi.org/10.1007/s12237-020-00700-9>
- Allen, J. R., Cornwell, J. C., & Baldwin, A. H. (2021). Contributions of organic and mineral matter to vertical accretion in tidal wetlands across a Chesapeake Bay subestuary. *Journal of Marine Science and Engineering*, 9(7), 751. <https://doi.org/10.3390/jmse9070751>
- Andrews, J. E., Samways, G., Dennis, P. F., & Maher, B. A. (2000). Origin, abundance and storage of organic carbon and Sulphur in the Holocene Humber estuary: Emphasizing human impact on storage changes. *Geological Society Special Publication*, 166(1), 145–170.
- Andrews, J. E., Samways, G., & Shimmield, G. B. (2008). Historical storage budgets of organic carbon, nutrient and contaminant elements in saltmarsh sediments: Biogeochemical context for managed realignment, Humber estuary, UK. *The Science of the Total Environment*, 405(1–3), 1–13. <https://doi.org/10.1016/j.scitotenv.2008.07.044>
- Anisfeld, S. C., & Hill, T. D. (2012). Fertilization effects on elevation change and belowground carbon balance in a Long Island sound tidal marsh. *Estuaries and Coasts*, 35(1), 201–211. <https://doi.org/10.1007/s12237-011-9440-4>
- Anisfeld, S. C., Tobin, M. J., & Benoit, G. (1999). Sedimentation rates in flow-restricted and restored salt marshes in Long Island sound. *Estuaries*, 22(2), 231. <https://doi.org/10.2307/1352980>
- Antler, G., Mills, J. V., Hutchings, A. M., Redeker, K. R., & Turchyn, A. V. (2019). The sedimentary carbon-sulfur-iron interplay—A lesson from east Anglian salt marsh sediments. *Frontiers in Earth Science*, 7, 140. <https://doi.org/10.3389/feart.2019.00140>
- Archer, M. J., Pitchford, J. L., Biber, P., & Underwood, W. (2022). Assessing vegetation, nutrient content and soil dynamics along a coastal elevation gradient in a Mississippi estuary. *Estuaries and Coasts*, 45(5), 1217–1229. <https://doi.org/10.1007/s12237-021-01012-2>
- van Ardenne, L. B., Hughes, J. F., & Chmura, G. L. (2021). Tidal marsh sediment and carbon accretion on a geomorphologically dynamic coastline. *Journal of Geophysical Research Biogeosciences*, 126(11), e2021JG006507. <https://doi.org/10.1029/2021jg006507>
- Arias-Ortiz, A., Oikawa, P. Y., Carlin, J., Masqué, P., Shahan, J., Kanneg, S., ... Baldocchi, D. D. (2021). Tidal and nontidal marsh restoration: A trade-off between carbon sequestration, methane emissions, and soil accretion. *Journal of Geophysical Research Biogeosciences*, 126(12), e2021JG006573. <https://doi.org/10.1029/2021jg006573>
- Arriola, J. M., & Cable, J. E. (2017). Variations in carbon burial and sediment accretion along a tidal creek in a Florida salt marsh. *Limnology and Oceanography*, 62(S1), S15–S28. <https://doi.org/10.1002/lno.10652>
- Bai, J., Wang, J., Yan, D., Gao, H., Xiao, R., Shao, H., & Ding, Q. (2012). Spatial and temporal distributions of soil organic carbon and total nitrogen in two marsh wetlands with different flooding frequencies of the Yellow River delta, China. *Clean: Soil, Air, Water*, 40(10), 1137–1144. <https://doi.org/10.1002/clen.201200059>
- Bang, J. H., & Lee, E. J. (2019). Differences in crab burrowing and halophyte growth by habitat types in a Korean salt marsh. *Ecological Indicators*, 98, 599–607. <https://doi.org/10.1016/j.ecolind.2018.11.029>
- Barry, A., Ooi, S. K., Helton, A. M., Steven, B., Elphick, C. S., & Lawrence, B. A. (2022). Vegetation zonation predicts soil carbon mineralization and microbial communities in southern New England salt marshes. *Estuaries and Coasts*, 45(1), 168–180. <https://doi.org/10.1007/s12237-021-00943-0>

DATA SOURCES

Aalders, J. G., McQuillan, P., & Prahalad, V. N. (2019). *Vegetation communities and edaphic relationships along a typical coastal saltmarsh to woodland gradient*

- Bartholdy, J., Bartholdy, A. T., Kim, D., & Pedersen, J. B. T. (2014). On autochthonous organic production and its implication for the consolidation of temperate salt marshes. *Marine Geology*, 351, 53–57. <https://doi.org/10.1016/j.margeo.2014.03.015>
- Bartlett, K. B., Bartlett, D. S., Harriss, R. C., & Sebach, D. I. (1987). Methane emissions along a salt marsh salinity gradient. *Biogeochemistry*, 4(3), 183–202. <https://doi.org/10.1007/bf02187365>
- Baustian, J. J., & Eugene Turner, R. (2006). Restoration success of backfilling canals in coastal Louisiana marshes. *Restoration Ecology*, 14(4), 636–644. <https://doi.org/10.1111/j.1526-100x.2006.00175.x>
- Baustian, M. M., Stagg, C. L., Perry, C. L., Moss, L. C., Carruthers, T. J. B., & Allison, M. (2017). Relationships between salinity and short-term soil carbon accumulation rates from marsh types across a landscape in the Mississippi river delta. *Wetlands (Wilmington, N.C.)*, 37(2), 313–324. <https://doi.org/10.1007/s13157-016-0871-3>
- Bescansa, P., & Roquero, C. (1990). Characterization and classification of tidal marsh soils and plant communities in North-West Spain. *Catena*, 17(4–5), 347–355. [https://doi.org/10.1016/0341-8162\(90\)90037-e](https://doi.org/10.1016/0341-8162(90)90037-e)
- Blackwell, M. S. A., Yamulki, S., & Bol, R. (2010). Nitrous oxide production and denitrification rates in estuarine intertidal saltmarsh and managed realignment zones. *Estuarine, Coastal and Shelf Science*, 87(4), 591–600. <https://doi.org/10.1016/j.ecss.2010.02.017>
- Boyd, B. M., Sommerfield, C. K., & Eelsey-Quirk, T. (2017). Hydrogeomorphic influences on salt marsh sediment accumulation and accretion in two estuaries of the U.S. Mid-Atlantic coast. *Marine Geology*, 383, 132–145. <https://doi.org/10.1016/j.margeo.2016.11.008>
- Boyd, B. M., & Sommerfield, C. K. (2016). Marsh accretion and sediment accumulation in a managed tidal wetland complex of Delaware Bay. *Ecological Engineering*, 92, 37–46. <https://doi.org/10.1016/j.ecoleng.2016.03.045>
- Brevik, E. C., & Homburg, J. A. (2004). A 5000 year record of carbon sequestration from a coastal lagoon and wetland complex, Southern California, USA. *Catena*, 57(3), 221–232. <https://doi.org/10.1016/j.catena.2003.12.001>
- Brooks, K. L., Mossman, H. L., Chitty, J. L., & Grant, A. (2015). Limited vegetation development on a created salt marsh associated with over-consolidated sediments and lack of topographic heterogeneity. *Estuaries and Coasts*, 38(1), 325–336. <https://doi.org/10.1007/s12237-014-9824-3>
- Brown, C. E., & Rajkaran, A. (2020). Biomass partitioning in an endemic southern African salt marsh species *Salicornia tetegaria* (Chenopodiaceae). *African Journal of Aquatic Science*, 45(1–2), 41–48. <https://doi.org/10.2989/16085914.2019.1687419>
- Brown, L. N., Rosencranz, J. A., Willis, K. S., Ambrose, R. F., & MacDonald, G. M. (2020). Multiple stressors influence salt marsh recovery after a spring fire at mugu lagoon, CA. *Wetlands (Wilmington, N.C.)*, 40(4), 757–769. <https://doi.org/10.1007/s13157-019-01210-6>
- Bryant, J. C., & Chabreck, R. H. (1998). Effects of impoundment on vertical accretion of coastal marsh. *Estuaries*, 21(3), 416. <https://doi.org/10.2307/1352840>
- Bu, N., Qu, J., Li, Z., Li, G., Zhao, H., Zhao, B., ... Fang, C. (2015). Effects of *Spartina alterniflora* invasion on soil respiration in the Yangtze River estuary, China. *PLoS One*, 10(3), e0121571. <https://doi.org/10.1371/journal.pone.0121571>
- Bu, N., Wu, S., Yang, X., Sun, Y., Chen, Z., Ma, X., ... Yan, Z. (2019). *Spartina alterniflora* invasion affects methane emissions in the Yangtze River estuary. *Journal of Soils and Sediments*, 19(2), 579–587. <https://doi.org/10.1007/s11368-018-2073-5>
- Bu, N.-S., Qu, J.-F., Li, G., Zhao, B., Zhang, R.-J., & Fang, C.-M. (2015). Reclamation of coastal salt marshes promoted carbon loss from previously-sequestered soil carbon pool. *Ecological Engineering*, 81, 335–339. <https://doi.org/10.1016/j.ecoleng.2015.04.051>
- Bulmer, R. H., Stephenson, F., Jones, H. F. E., Townsend, M., Hillman, J. R., Schwendenmann, L., & Lundquist, C. J. (2020). Blue carbon stocks and cross-habitat subsidies. *Frontiers in Marine Science*, 7, 380. <https://doi.org/10.3389/fmars.2020.00380>
- Burden, A., Garbutt, A., & Evans, C. D. (2019). Effect of restoration on saltmarsh carbon accumulation in eastern England. *Biology Letters*, 15(1), 20180773. <https://doi.org/10.1098/rsbl.2018.0773>
- Burden, A., Garbutt, R. A., Evans, C. D., Jones, D. L., & Cooper, D. M. (2013). Carbon sequestration and biogeochemical cycling in a saltmarsh subject to coastal managed realignment. *Estuarine, Coastal and Shelf Science*, 120, 12–20. <https://doi.org/10.1016/j.ecss.2013.01.014>
- Butzeck, C., Eschenbach, A., Gröngörft, A., Hansen, K., Nolte, S., & Jensen, K. (2015). Sediment deposition and accretion rates in tidal marshes are highly variable along estuarine salinity and flooding gradients. *Estuaries and Coasts*, 38(2), 434–450. <https://doi.org/10.1007/s12237-014-9848-8>
- Caçador, I., Costa, A. L., & Vale, C. (2004). Carbon storage in Tagus salt marsh sediments. In *Biogeochemical investigations of terrestrial, freshwater, and wetland ecosystems across the globe* (pp. 701–714). Springer.
- Cacho, C. V., Conrad, S. R., Brown, D. R., Riggs, A., Gardner, K., Li, L., ... Sanders, C. J. (2021). Local geomorphological gradients affect sedimentary organic carbon storage: A blue carbon case study from sub-tropical Australia. *Regional Studies in Marine Science*, 45(101840), 101840. <https://doi.org/10.1016/j.rsma.2021.101840>
- Callaway, J. C., Borgnis, E. L., Turner, R. E., & Milan, C. S. (2012). Carbon sequestration and sediment accretion in San Francisco bay tidal wetlands. *Estuaries and Coasts*, 35(5), 1163–1181. <https://doi.org/10.1007/s12237-012-9508-9>
- Calvo-Cubero, J., Ibáñez, C., Rovira, A., Sharpe, P. J., & Reyes, E. (2014). Changes in nutrient concentration and carbon accumulation in a Mediterranean restored marsh (Ebro Delta, Spain). *Ecological Engineering*, 71, 278–289. <https://doi.org/10.1016/j.ecoleng.2014.07.023>
- Cao, L., Zhou, Z., Xu, X., & Shi, F. (2020). Spatial and temporal variations of the greenhouse gas emissions in coastal saline wetlands in southeastern China. *Environmental Science and Pollution Research International*, 27(1), 1118–1130. <https://doi.org/10.1007/s11356-019-06951-9>
- Capocci, M., & Vargas, R. (2022). Diel and seasonal patterns of soil CO₂ efflux in a temperate tidal marsh. *The Science of the Total Environment*, 802(149715), 149715. <https://doi.org/10.1016/j.scitotenv.2021.149715>
- Carnero-Bravo, V., Sanchez-Cabeza, J.-A., Ruiz-Fernández, A. C., Merino-Ibarra, M., Corcho-Alvarado, J. A., Sahli, H., ... Hillaire-Marcel, C. (2018). Sea level rise sedimentary record and organic carbon fluxes in a low-lying tropical coastal ecosystem. *Catena*, 162, 421–430. <https://doi.org/10.1016/j.catena.2017.09.016>
- Cartaxana, P., & Catarino, F. (1997). Allocation of nitrogen and carbon in an estuarine salt marsh in Portugal. *Journal of Coastal Conservation*, 3(1), 27–34. <https://doi.org/10.1007/bf02908176>
- Champlin, L., Velinsky, D., Tucker, K., Sommerfield, C., Laurent, K. S., & Watson, E. (2020). Carbon sequestration rate estimates in Delaware Bay and Barnegat Bay tidal wetlands using interpolation mapping. *Data*, 5(1), 11. <https://doi.org/10.3390/data5010011>
- Chaudhary, D. R., Rathore, A. P., & Jha, B. (2018). Aboveground, belowground biomass and nutrients pool in *Salicornia brachiata* at coastal area of India: Interactive effects of soil characteristics. *Ecological Research*, 33(6), 1207–1218. <https://doi.org/10.1007/s11284-018-1634-9>
- Chen, Q., Guo, B., Zhao, C., & Xing, B. (2018). Characteristics of CH₄ and CO₂ emissions and influence of water and salinity in the Yellow River delta wetland, China. *Environmental Pollution (Barking, Essex: 1987)*, 239, 289–299. <https://doi.org/10.1016/j.envpol.2018.04.043>
- Chen, Q.-F., Ma, J.-J., Liu, J.-H., Zhao, C.-S., & Liu, W. (2013). Characteristics of greenhouse gas emission in the Yellow River Delta wetland. *International Biodeterioration & Biodegradation*, 85, 646–651. <https://doi.org/10.1016/j.ibiod.2013.04.009>
- Chen, S., Torres, R., & Goñi, M. A. (2016). The role of salt marsh structure in the distribution of surface sedimentary organic matter. *Estuaries and Coasts*, 39(1), 108–122. <https://doi.org/10.1007/s12237-015-9957-z>
- Cheng, X., Luo, Y., Chen, J., Lin, G., Chen, J., & Li, B. (2006). Short-term C4 plant *Spartina alterniflora* invasions change the soil carbon in C3 plant-dominated tidal wetlands on a growing estuarine island. *Soil Biology & Biochemistry*, 38(12), 3380–3386. <https://doi.org/10.1016/j.soilbio.2006.05.016>
- Cheng, X., Luo, Y., Xu, Q., Lin, G., Zhang, Q., Chen, J., & Li, B. (2010). Seasonal variation in CH₄ emission and its ¹³C-isotopic signature from *Spartina alterniflora* and *Scirpus mariqueter* soils in an estuarine wetland. *Plant and Soil*, 327(1–2), 85–94. <https://doi.org/10.1007/s11104-009-0033-y>
- Cheng, Y., Zha, Y., Tong, C., Du, D., Chen, L., & Wei, G. (2021). Estimating the gaseous carbon budget of a degraded tidal wetland. *Ecological Engineering*, 160(106147), 106147. <https://doi.org/10.1016/j.ecoleng.2021.106147>
- Chi, Z., Wang, W., Li, H., Wu, H., & Yan, B. (2021). Soil organic matter and salinity as critical factors affecting the bacterial community and function of *Phragmites australis* dominated riparian and coastal wetlands. *The Science of the Total Environment*, 762(143156), 143156. <https://doi.org/10.1016/j.scitotenv.2020.143156>
- Chmura, G. L., Kellman, L., & Guntenspergen, G. R. (2011). The greenhouse gas flux and potential global warming feedbacks of a northern macrotidal and microtidal salt marsh. *Environmental Research Letters*, 6(4), 44016. <https://doi.org/10.1088/1748-9326/6/4/044016>
- Chmura, G. L., Kellman, L., van Ardenne, L., & Guntenspergen, G. R. (2016). Greenhouse gas fluxes from salt marshes exposed to chronic nutrient enrichment. *PLoS One*, 11(2), e0149937. <https://doi.org/10.1371/journal.pone.0149937>

- Choi, Y., & Wang, Y. (2004). Dynamics of carbon sequestration in a coastal wetland using radiocarbon measurements. *Global Biogeochemical Cycles*, 18(4), GB4016. <https://doi.org/10.1029/2004gb002261>
- Choi, Y., Wang, Y., Hsieh, Y.-P., & Robinson, L. (2001). Vegetation succession and carbon sequestration in a coastal wetland in Northwest Florida: Evidence from carbon isotopes. *Global Biogeochemical Cycles*, 15(2), 311–319. <https://doi.org/10.1029/2000gb001308>
- Chu, X., Han, G., Wei, S., Xing, Q., He, W., Sun, B., ... Song, W. (2021). Seasonal not annual precipitation drives 8-year variability of interannual net CO₂ exchange in a salt marsh. *Agricultural and Forest Meteorology*, 308–309(108557), 108557. <https://doi.org/10.1016/j.agrformet.2021.108557>
- Chu, X., Han, G., Xing, Q., Xia, J., Sun, B., Yu, J., & Li, D. (2018). Dual effect of precipitation redistribution on net ecosystem CO₂ exchange of a coastal wetland in the Yellow River Delta. *Agricultural and Forest Meteorology*, 249, 286–296. <https://doi.org/10.1016/j.agrformet.2017.11.002>
- Connor, R. F., Chmura, G. L., & Beecher, C. B. (2001). Carbon accumulation in bay of fundy salt marshes: Implications for restoration of reclaimed marshes. *Global Biogeochemical Cycles*, 15(4), 943–954. <https://doi.org/10.1029/2000gb001346>
- Conrad, S., Brown, D. R., Alvarez, P. G., Bates, B., Ibrahim, N., Reid, A., ... Sanders, C. J. (2019). Does regional development influence sedimentary blue carbon stocks? A case study from three Australian estuaries. *Frontiers in Marine Science*, 5, 518. <https://doi.org/10.3389/fmars.2018.00518>
- Cornell, J. A., Craft, C. B., & Megonigal, J. P. (2007). Ecosystem gas exchange across a created salt marsh chronosequence. *Wetlands*, 27(2), 240–250.
- Correa, R. E., Xiao, K., Conrad, S. R., Wadnerkar, P. D., Wilson, A. M., Sanders, C. J., & Santos, I. R. (2022). Groundwater carbon exports exceed sediment carbon burial in a salt marsh. *Estuaries and Coasts*, 45(6), 1545–1561. <https://doi.org/10.1007/s12237-021-01021-1>
- Craft, C. (2007). Freshwater input structures soil properties, vertical accretion, and nutrient accumulation of Georgia and U.S. tidal marshes. *Limnology and Oceanography*, 52(3), 1220–1230. <https://doi.org/10.4319/lo.2007.52.3.1220>
- Craft, C., Broome, S., & Campbell, C. (2002). Fifteen years of vegetation and soil development after brackish-water marsh creation. *Restoration Ecology*, 10(2), 248–258. <https://doi.org/10.1046/j.1526-100x.2002.01020.x>
- Craft, C., Megonigal, P., Broome, S., Stevenson, J., Freese, R., Cornell, J., ... Sacco, J. (2003). The pace of ecosystem development of constructed *Spartina alterniflora* marshes. *Ecological Applications*, 13(5), 1417–1432. <https://doi.org/10.1890/02-5086>
- Craft, C. B. (2001). Soil organic carbon, nitrogen, and phosphorus as indicators of recovery in restored spartina marshes. *Ecological Restoration*, 19(2), 87–91. <https://doi.org/10.3368/er.19.2.87>
- Craft, C. B., Broome, S. W., & Seneca, E. D. (1988). Nitrogen, phosphorus and organic carbon pools in natural and transplanted marsh soils. *Estuaries*, 11(4), 272. <https://doi.org/10.2307/1352014>
- Craft, C. B., Seneca, E. D., & Broome, S. W. (1991a). Loss on ignition and kjeldahl digestion for estimating organic carbon and total nitrogen in estuarine marsh soils: Calibration with dry combustion. *Estuaries*, 14(2), 175. <https://doi.org/10.2307/1351691>
- Craft, C. B., Seneca, E. D., & Broome, S. W. (1991b). Porewater chemistry of natural and created marsh soils. *Journal of Experimental Marine Biology and Ecology*, 152(2), 187–200. [https://doi.org/10.1016/0022-0981\(91\)90214-h](https://doi.org/10.1016/0022-0981(91)90214-h)
- Craft, C. B., Seneca, E. D., & Broome, S. W. (1993). Vertical accretion in microtidal regularly and irregularly flooded estuarine marshes. *Estuarine, Coastal and Shelf Science*, 37(4), 371–386. <https://doi.org/10.1006/ecss.1993.1062>
- Crozier, C. R., & DeLaune, R. D. (1996). Methane production by soils from different Louisiana marsh vegetation types. *Wetlands (Wilmington, N.C.)*, 16(2), 121–126. <https://doi.org/10.1007/bf03160685>
- Cuellar-Martinez, T., Ruiz-Fernández, A. C., Sanchez-Cabeza, J.-A., Pérez-Bernal, L.-H., & Sandoval-Gil, J. (2019). Relevance of carbon burial and storage in two contrasting blue carbon ecosystems of a north-East Pacific coastal lagoon. *The Science of the Total Environment*, 675, 581–593. <https://doi.org/10.1016/j.scitotenv.2019.03.388>
- Cui, H., Bai, J., Du, S., Wang, J., Kechulak, G. N., Wang, W., ... Jia, J. (2021). Interactive effects of groundwater level and salinity on soil respiration in coastal wetlands of a Chinese delta. *Environmental Pollution (Barking, Essex: 1987)*, 286(117400), 117400. <https://doi.org/10.1016/j.envpol.2021.117400>
- Curado, G., Grewell, B. J., Figueroa, E., & Castillo, J. M. (2014). Effectiveness of the aquatic halophyte *Sarcocornia perennis* spp. *perennis* as a biotool for ecological restoration of salt marshes. *Water, Air, and Soil Pollution*, 225(9), 1–14. <https://doi.org/10.1007/s11270-014-2108-5>
- Curado, G., Rubio-Casal, A. E., Figueroa, E., Grewell, B. J., & Castillo, J. M. (2013). Native plant restoration combats environmental change: Development of carbon and nitrogen sequestration capacity using small cordgrass in European salt marshes. *Environmental Monitoring and Assessment*, 185(10), 8439–8449. <https://doi.org/10.1007/s10661-013-3185-4>
- Cusack, M., Saderne, V., Arias-Ortiz, A., Masqué, P., Krishnakumar, P. K., Rabaoui, L., ... Duarte, C. M. (2018). Organic carbon sequestration and storage in vegetated coastal habitats along the western coast of the Arabian Gulf. *Environmental Research Letters*, 13(7), 74007. <https://doi.org/10.1088/1748-9326/aac899>
- Czaplá, K. M., Anderson, I. C., & Currin, C. A. (2020). The effect of fertilization on biomass and metabolism in North Carolina salt marshes: Modulated by location-specific factors. *Journal of Geophysical Research Biogeosciences*, 125(10), e2019JG005238. <https://doi.org/10.1029/2019jg005238>
- Dausse, A., Garbutt, A., Norman, L., Papadimitriou, S., Jones, L. M., Robins, P. E., & Thomas, D. N. (2012). Biogeochemical functioning of grazed estuarine tidal marshes along a salinity gradient. *Estuarine, Coastal and Shelf Science*, 100, 83–92. <https://doi.org/10.1016/j.ecss.2011.12.037>
- Davis, J. L., Nowicki, B., & Wigand, C. (2004). Denitrification in fringing salt marshes of Narragansett Bay, Rhode Island, USA. *Wetlands*, 4(4), 870–878.
- DeLaune, R. D., Jugsujinda, A., Peterson, G. W., & Patrick, W. H., Jr. (2003). Impact of Mississippi River freshwater reintroduction on enhancing marsh accretionary processes in a Louisiana estuary. *Estuarine, Coastal and Shelf Science*, 58(3), 653–662. [https://doi.org/10.1016/s0272-7714\(03\)00177-x](https://doi.org/10.1016/s0272-7714(03)00177-x)
- DeLaune, R. D., Kongchum, M., White, J. R., & Jugsujinda, A. (2013). Freshwater diversions as an ecosystem management tool for maintaining soil organic matter accretion in coastal marshes. *Catena*, 107, 139–144. <https://doi.org/10.1016/j.catena.2013.02.012>
- DeLaune, R. D., Patrick, W. H., Jr., & Buresh, R. J. (1979). Effect of crude oil on a Louisiana *Spartina alterniflora* salt marsh. *Environmental Pollution*, 20(1), 21–31. [https://doi.org/10.1016/0013-9327\(79\)90050-8](https://doi.org/10.1016/0013-9327(79)90050-8)
- DeLaune, R. D., & Pezeshki, S. R. (2003). The role of soil organic carbon in maintaining surface elevation in rapidly subsiding US Gulf of Mexico coastal marshes. *Water, Air and Soil Pollution: Focus*, 3, 167–179.
- DeLaune, R. D., Reddy, C. N., & Patrick, W. H. (1981). Accumulation of plant nutrients and heavy metals through sedimentation processes and accretion in a Louisiana salt marsh. *Estuaries*, 4(4), 328. <https://doi.org/10.2307/1352157>
- Derby, R. K., Needelman, B. A., Roden, A. A., & Megonigal, J. P. (2022). Vegetation and hydrology stratification as proxies to estimate methane emission from tidal marshes. *Biogeochemistry*, 157(2), 227–243. <https://doi.org/10.1007/s10533-021-00870-z>
- Diefenderfer, H. L., Cullinan, V. I., Borde, A. B., Gunn, C. M., & Thom, R. M. (2018). High-frequency greenhouse gas flux measurement system detects winter storm surge effects on salt marsh. *Global Change Biology*, 24(12), 5961–5971. <https://doi.org/10.1111/gcb.14430>
- Ditě, Z., Šuvadová, R., Eliáš, P., Jr., Piš, V., & Ditě, D. (2019). Salt marsh vegetation on the Croatian coast: Plant communities and ecological characteristics. *Plant Systematics and Evolution*, 305(10), 899–912. <https://doi.org/10.1007/s00606-019-01617-y>
- Dong, H., Qian, L., Yan, J., & Wang, L. (2020). Evaluation of the carbon accumulation capability and carbon storage of different types of wetlands in the Nanhui tidal flat of the Yangtze River estuary. *Environmental Monitoring and Assessment*, 192(9), 585. <https://doi.org/10.1007/s10661-020-08547-0>
- Doroski, A. A., Helton, A. M., & Vadas, T. M. (2019). Denitrification potential and carbon mineralization in restored and unrestored coastal wetland soils across an urban landscape. *Wetlands (Wilmington, N.C.)*, 39(4), 895–906. <https://doi.org/10.1007/s13157-019-01128-z>
- Drexler, J. Z., Woo, I., Fuller, C. C., & Nakai, G. (2019). Carbon accumulation and vertical accretion in a restored versus historic salt marsh in southern Puget Sound, Washington, United States. *Restoration Ecology*, 27(5), 1117–1127. <https://doi.org/10.1111/rec.12941>
- Duan, W. M., Hedrick, D. B., Pye, K., Coleman, H. L., & White, D. C. (1996). A preliminary study of the geochemical and microbiological characteristics of modern sedimentary concretions. *Limnology and Oceanography*, 41(7), 1404–1414. <https://doi.org/10.4319/lo.1996.41.7.1404>
- Duarte, B., Freitas, J., Valentim, J., Medeiros, J. P., Costa, J. L., Silva, H., ... Caçador, I. (2014). Abiotic control modelling of salt marsh sediments respiratory CO₂ fluxes: Application to increasing temperature scenarios. *Ecological Indicators*, 46, 110–118. <https://doi.org/10.1016/j.ecolind.2014.06.018>
- Edwards, K. R., & Proffitt, C. E. (2003). Comparison of wetland structural characteristics between created and natural salt marshes in Southwest

- Louisiana, USA. *Wetlands (Wilmington, N.C.)*, 23(2), 344–356. <https://doi.org/10.1672/0-20>
- Ellison, J., & Beasy, K. (2018). Sediment carbon accumulation in southern latitude saltmarsh communities of Tasmania, Australia. *Biology*, 7(2), 27. <https://doi.org/10.3390/biology7020027>
- Eley-Quirk, T., Seliskar, D. M., Sommerfield, C. K., & Gallagher, J. L. (2011). Salt marsh carbon pool distribution in a mid-Atlantic lagoon, USA: Sea level rise implications. *Wetlands (Wilmington, N.C.)*, 31(1), 87–99. <https://doi.org/10.1007/s13157-010-0139-2>
- Emery, H. E., & Fulweiler, R. W. (2017). Incomplete tidal restoration may lead to persistent high CH₄ emission. *Ecosphere (Washington, D.C.)*, 8(12), e01968. <https://doi.org/10.1002/ecs2.1968>
- Ewers Lewis, C. J., Baldock, J. A., Hawke, B., Gadd, P. S., Zawadzki, A., Heijns, H., ... Macreadie, P. I. (2019). Impacts of land reclamation on tidal marsh 'blue carbon' stocks. *The Science of the Total Environment*, 672, 427–437. <https://doi.org/10.1016/j.scitotenv.2019.03.345>
- Ewers Lewis, C. J., Carnell, P. E., Sanderman, J., Baldock, J. A., & Macreadie, P. I. (2018). Variability and vulnerability of coastal 'blue carbon' stocks: A case study from Southeast Australia. *Ecosystems (New York, N.Y.)*, 21(2), 263–279. <https://doi.org/10.1007/s10021-017-0150-z>
- Ewers Lewis, C. J., Young, M. A., Ierodiakonou, D., Baldock, J. A., Hawke, B., Sanderman, J., ... Macreadie, P. I. (2020). Drivers and modelling of blue carbon stock variability in sediments of southeastern Australia. *Biogeosciences*, 17(7), 2041–2059. <https://doi.org/10.5194/bg-17-2041-2020>
- Fearnley, S. (2008). The soil physical and chemical properties of restored and natural back-barrier salt marsh on isles Dernieres, Louisiana. *Journal of Coastal Research*, 24(1), 84–94. <https://doi.org/10.2112/05-0620.1>
- Feng, H., Zhao, H., Xia, L., Yang, W., Zhao, Y., Jeelani, N., & An, S. (2022). Nitrogen cycling in plant and soil subsystems is driven by changes in soil salinity following coastal embankment in typical coastal saltmarsh ecosystems of eastern China. *Ecological Engineering*, 174(106467), 106467. <https://doi.org/10.1016/j.ecoleng.2021.106467>
- Fennessy, M. S., Ibáñez, C., Calvo-Cubero, J., Sharpe, P., Rovira, A., Callaway, J., & Caiola, N. (2019). Environmental controls on carbon sequestration, sediment accretion, and elevation change in the Ebro River Delta: Implications for wetland restoration. *Estuarine, Coastal and Shelf Science*, 222, 32–42. <https://doi.org/10.1016/j.ecss.2019.03.023>
- Fernández, C., Lara, R. J., & Parodi, E. R. (2021). Influence of microphytobenthos on the sedimentary organic matter composition in two contrasting estuarine microhabitats. *Environmental Monitoring and Assessment*, 193(4), 201. <https://doi.org/10.1007/s10661-021-08888-4>
- Fernández, S., Santín, C., Marquín, J., & Álvarez, M. A. (2010). Saltmarsh soil evolution after land reclamation in Atlantic estuaries (Bay of Biscay, North coast of Spain). *Geomorphology (Amsterdam, Netherlands)*, 114(4), 497–507. <https://doi.org/10.1016/j.geomorph.2009.08.014>
- Ferreira, F. P., Vidal-Torrado, P., Buurman, P., Macías, F., Otero, X. L., & Boluda, R. (2009). Pyrolysis-gas chromatography/mass spectrometry of soil organic matter extracted from a Brazilian mangrove and Spanish salt marshes. *Soil Science Society of America Journal Soil Science Society of America*, 73(3), 841–851. <https://doi.org/10.2136/sssaj2008.0028>
- Ferronato, C., Marinari, S., Francioso, O., Bello, D., Trasar-Cepeda, C., & Antisari, L. V. (2019). Effect of waterlogging on soil biochemical properties and organic matter quality in different salt marsh systems. *Geoderma*, 338, 302–312. <https://doi.org/10.1016/j.geoderma.2018.12.019>
- Firstater, F. N., Narvarte, M., Alvarez, M. F., Fanjul, M. E., & Iribarne, O. O. (2016). Cordgrass canopy elicits weak effects on sediment properties and microphytobenthic abundance in a harsh environment. *Marine Ecology Progress Series*, 550, 101–110. <https://doi.org/10.3354/meps11726>
- Forbrich, I., & Giblin, A. E. (2015). Marsh-atmosphere CO₂ exchange in a New England salt marsh. *Journal of Geophysical Research. Biogeosciences*, 120(9), 1825–1838. <https://doi.org/10.1002/2015jg003044>
- Forbrich, I., Giblin, A. E., & Hopkinson, C. S. (2018). Constraining marsh carbon budgets using long-term C burial and contemporary atmospheric CO₂ fluxes. *Journal of Geophysical Research Biogeosciences*, 123(3), 867–878. <https://doi.org/10.1002/2017jg004336>
- Ford, H., Garbutt, A., Duggan-Edwards, M., Pagès, J. F., Harvey, R., Ladd, C., & Skov, M. W. (2019). Large-scale predictions of salt-marsh carbon stock based on simple observations of plant community and soil type. *Biogeosciences*, 16(2), 425–436. <https://doi.org/10.5194/bg-16-425-2019>
- Ford, H., Garbutt, A., Jones, L., & Jones, D. L. (2012). Methane, carbon dioxide and nitrous oxide fluxes from a temperate salt marsh: Grazing management does not alter global warming potential. *Estuarine, Coastal and Shelf Science*, 113, 182–191. <https://doi.org/10.1016/j.ecss.2012.08.002>
- Gailis, M., Kohfeld, K. E., Pellatt, M. G., & Carlson, D. (2021). Quantifying blue carbon for the largest salt marsh in southern British Columbia: Implications for regional coastal management. *Coastal Engineering Journal*, 63(3), 275–309. <https://doi.org/10.1080/21664250.2021.1894815>
- Gallagher, J. B., Prahald, V., & Aalders, J. (2021). Inorganic and black carbon hotspots constrain blue carbon mitigation services across tropical seagrass and temperate tidal marshes. *Wetlands (Wilmington, N.C.)*, 41(5), 1–13. <https://doi.org/10.1007/s13157-021-01460-3>
- Gao, D., Hou, L., Li, X., Liu, M., Zheng, Y., Yin, G., ... Han, P. (2019). Exotic *Spartina alterniflora* invasion alters soil nitrous oxide emission dynamics in a coastal wetland of China. *Plant and Soil*, 442(1–2), 233–246. <https://doi.org/10.1007/s1104-019-04179-7>
- Gao, J., Bai, F., Yang, Y., Gao, S., Liu, Z., & Li, J. (2012). Influence of *Spartina* colonization on the supply and accumulation of organic carbon in tidal salt marshes of northern Jiangsu province, China. *Journal of Coastal Research*, 280, 486–498. <https://doi.org/10.2112/jcoastres-d-11-00062.1>
- Gao, M., Kong, F., Xi, M., Li, Y., & Li, J. (2017). Effects of environmental conditions and aboveground biomass on CO₂ budget in *Phragmites australis* wetland of Jiaozhou Bay, China. *Chinese Geographical Science*, 27(4), 539–551. <https://doi.org/10.1007/s11769-017-0886-6>
- Gao, Y., Chen, J., Zhang, T., Zhao, B., McNulty, S., Guo, H., ... Zhuang, P. (2021). Lateral detrital C transfer across a *Spartina alterniflora* invaded estuarine wetland. *Ecological Processes*, 10(1), 1–19. <https://doi.org/10.1186/s13717-021-00340-2>
- Ge, B., Jiang, S., Yang, L., Zhang, H., & Tang, B. (2020). Succession of macrofaunal communities and environmental properties along a gradient of smooth cordgrass *Spartina alterniflora* invasion stages. *Marine Environmental Research*, 156(104862), 104862. <https://doi.org/10.1016/j.marenvres.2019.104862>
- George, U. S., & Antoine, A. D. (1982). Denitrification potential of a salt marsh soil: Effect of temperature, pH and substrate concentration. *Soil Biology & Biochemistry*, 14(2), 117–125. [https://doi.org/10.1016/0038-0717\(82\)90054-2](https://doi.org/10.1016/0038-0717(82)90054-2)
- Giani, L., Ditttrich, K., Martsfeld-Hartmann, A., & Peters, G. (1996). Methanogenesis in saltmarsh soils of the North Sea coast of Germany. *European Journal of Soil Science*, 47(2), 175–182. <https://doi.org/10.1111/j.1365-2389.1996.tb01388.x>
- Gispert, M., Kulush, T., Dyachenko, L., Kharytonov, M., Emran, M., Verdager, D., ... Carrasco-Barea, L. (2021). Appraising soil carbon storage potential under perennial and annual *Chenopodiaceae* in salt marsh of NE Spain. *Estuarine, Coastal and Shelf Science*, 252(107240), 107240. <https://doi.org/10.1016/j.ecss.2021.107240>
- Gispert, M., Phang, C., & Carrasco-Barea, L. (2020). The role of soil as a carbon sink in coastal salt-marsh and agropastoral systems at La Pletera, NE Spain. *Catena*, 185(104331), 104331. <https://doi.org/10.1016/j.catena.2019.104331>
- Glooschenko, W. A., & Capobianco, J. A. (1980). Geochemistry of a subarctic salt marsh environment. *Marine Geology*, 37(3–4), 231–240. [https://doi.org/10.1016/0025-3227\(80\)90103-6](https://doi.org/10.1016/0025-3227(80)90103-6)
- Goman, M. F. (2005). Discrimination of estuarine marsh subenvironments (San Francisco bay, California, USA) using a multivariate statistical calibration of abiotic sediment properties. *Journal of Sedimentary Research*, 75(3), 398–408. <https://doi.org/10.2110/jsr.2005.031>
- Gonnee, M. E., Maio, C. V., Kroeger, K. D., Hawkes, A. D., Mora, J., Sullivan, R., ... Donnelly, J. P. (2019). Salt marsh ecosystem restructuring enhances elevation resilience and carbon storage during accelerating relative sea-level rise. *Estuarine, Coastal and Shelf Science*, 217, 56–68. <https://doi.org/10.1016/j.ecss.2018.11.003>
- González-Alcaraz, M. N., Egea, C., Jiménez-Cárceles, F. J., Párraga, I., María-Cervantes, A., Delgado, M. J., & Álvarez-Rogel, J. (2012). Storage of organic carbon, nitrogen and phosphorus in the soil-plant system of *Phragmites australis* stands from a eutrophicated Mediterranean salt marsh. *Geoderma*, 185–186, 61–72. <https://doi.org/10.1016/j.geoderma.2012.03.019>
- Gorham, C., Lavery, P., Kelleway, J. J., Salinas, C., & Serrano, O. (2021). Soil carbon stocks vary across geomorphic settings in Australian temperate tidal marsh ecosystems. *Ecosystems (New York, N.Y.)*, 24(2), 319–334. <https://doi.org/10.1007/s10021-020-00520-9>
- Gorham, C., Lavery, P. S., Kelleway, J. J., Masque, P., & Serrano, O. (2021). Heterogeneous tidal marsh soil organic carbon accumulation among and within temperate estuaries in Australia. *The Science of the Total Environment*, 787(147482), 147482. <https://doi.org/10.1016/j.scitotenv.2021.147482>

- Granville, K. E., Ooi, S. K., Koenig, L. E., Lawrence, B. A., Elphick, C. S., & Helton, A. M. (2021). Seasonal patterns of denitrification and N₂O production in a southern New England salt marsh. *Wetlands (Wilmington, N.C.)*, 41(1), 1–13. <https://doi.org/10.1007/s13157-021-01393-x>
- Graversen, A. E. L., Banta, G. T., Masque, P., & Krause-Jensen, D. (2022). Carbon sequestration is not inhibited by livestock grazing in Danish salt marshes. *Limnology and Oceanography*, 67(52), S19–S35. <https://doi.org/10.1002/lno.12011>
- Grey, A., Cunningham, A., Lee, A., Monteys, X., Coveney, S., McCaul, M. V., ... Kelleher, B. P. (2021). Geochemical mapping of a blue carbon zone: Investigation of the influence of riverine input on tidal affected zones in Bull Island. *Regional Studies in Marine Science*, 45(101834), 101834. <https://doi.org/10.1016/j.rmsa.2021.101834>
- Gu, J., van Ardenne, L. B., & Chmura, G. L. (2020). Invasive Phragmites increases blue carbon stock and soil volume in a St. Lawrence estuary marsh. *Journal of Geophysical Research Biogeosciences*, 125(8), e2019JG005473. <https://doi.org/10.1029/2019jg005473>
- Guan, Y., Bai, J., Wang, J., Wang, W., Wang, X., Zhang, L., ... Liu, X. (2021). Effects of groundwater tables and salinity levels on soil organic carbon and total nitrogen accumulation in coastal wetlands with different plant cover types in a Chinese estuary. *Ecological Indicators*, 121(106969), 106969. <https://doi.org/10.1016/j.ecolind.2020.106969>
- Gulliver, A., Carnell, P. E., Trevathan-Tackett, S. M., de Paula, D., Costa, M., Masqué, P., & Macreadie, P. I. (2020). Estimating the potential blue carbon gains from tidal marsh rehabilitation: A case study from south eastern Australia. *Frontiers in Marine Science*, 7, 403. <https://doi.org/10.3389/fmars.2020.00403>
- Guo, H., Noormets, A., Zhao, B., Chen, J., Sun, G., Gu, Y., ... Chen, J. (2009). Tidal effects on net ecosystem exchange of carbon in an estuarine wetland. *Agricultural and Forest Meteorology*, 149(11), 1820–1828. <https://doi.org/10.1016/j.agrfor.2009.06.010>
- Hansen, K., Butzack, C., Eschenbach, A., Gröngroft, A., Jensen, K., & Pfeiffer, E.-M. (2017). Factors influencing the organic carbon pools in tidal marsh soils of the Elbe estuary (Germany). *Journal of Soils and Sediments*, 17(1), 47–60. <https://doi.org/10.1007/s11368-016-1500-8>
- Hansen, V. D., & Nestlerode, J. A. (2014). Carbon sequestration in wetland soils of the northern Gulf of Mexico coastal region. *Wetlands Ecology and Management*, 22(3), 289–303. <https://doi.org/10.1007/s11273-013-9330-6>
- Harvey, H. R., Fallon, R. D., & Patton, J. S. (1989). Methanogenesis and microbial lipid synthesis in anoxic salt marsh sediments. *Biogeochemistry*, 7(2), 111–129. <https://doi.org/10.1007/bf00004124>
- Harvey, R. J., Garbutt, A., Hawkins, S. J., & Skov, M. W. (2019). No detectable broad-scale effect of livestock grazing on soil blue-carbon stock in salt marshes. *Frontiers in Ecology and Evolution*, 7, 151. <https://doi.org/10.3389/fevo.2019.00151>
- Havens, K. J., Varnell, L. M., & Bradshaw, J. G. (1995). An assessment of ecological conditions in a constructed tidal marsh and two natural reference tidal marshes in coastal Virginia. *Ecological Engineering*, 4(2), 117–141. [https://doi.org/10.1016/0925-8574\(94\)00051-6](https://doi.org/10.1016/0925-8574(94)00051-6)
- Hayes, M. A., Jesse, A., Hawke, B., Baldock, J., Tabet, B., Lockington, D., & Lovelock, C. E. (2017). Dynamics of sediment carbon stocks across intertidal wetland habitats of Moreton Bay, Australia. *Global Change Biology*, 23(10), 4222–4234. <https://doi.org/10.1111/gcb.13722>
- Haywood, B. J., Hayes, M. P., White, J. R., & Cook, R. L. (2020). Potential fate of wetland soil carbon in a deltaic coastal wetland subjected to high relative sea level rise. *The Science of the Total Environment*, 711(135185), 135185. <https://doi.org/10.1016/j.scitotenv.2019.135185>
- He, C., Wang, X., Wang, D., Zhao, Z., Wang, F., Cheng, L., ... Zhang, P. (2021). Impact of *Spartina alterniflora* invasion on soil bacterial community and associated greenhouse gas emission in the Jiuduansha wetland of China. *Applied Soil Ecology: A Section of Agriculture, Ecosystems & Environment*, 168(104168), 104168. <https://doi.org/10.1016/j.apsoil.2021.104168>
- He, C.-Q., Ni, G., Zhi, G.-Y., Liang, X., Du, W., & Lei, Y.-R. (2012). Spatial-temporal distribution characteristics of soil organic matter and total nitrogen in the Jiuduansha wetlands of the Yangtze estuary. 2012 International Conference on Biomedical Engineering and Biotechnology. Presented at the 2012 International Conference on Biomedical Engineering and Biotechnology (iCBEB), Macau, Macao. <https://doi.org/10.1109/icbeb.2012.359>
- He, Y., Widney, S., Ruan, M., Herbert, E., Li, X., & Craft, C. (2016). Accumulation of soil carbon drives denitrification potential and lab-incubated gas production along a chronosequence of salt marsh development. *Estuarine, Coastal and Shelf Science*, 172, 72–80. <https://doi.org/10.1016/j.ecss.2016.02.002>
- He, Y., Zhou, X., Cheng, W., Zhou, L., Zhang, G., Zhou, G., ... Cheng, W. (2019). Linking improvement of soil structure to soil carbon storage following invasion by a C4 plant *Spartina alterniflora*. *Ecosystems (New York, N.Y.)*, 22(4), 859–872. <https://doi.org/10.1007/s10021-018-0308-3>
- Heilman, J. L., Cobos, D. R., Heinsch, F. A., Campbell, C. S., & McInnes, K. J. (1999). Tower-based conditional sampling for measuring ecosystem-scale carbon dioxide exchange in coastal wetlands. *Estuaries*, 22(3), 584. <https://doi.org/10.2307/1353046>
- Heinsch, F. (2004). Carbon dioxide exchange in a high marsh on the Texas Gulf Coast: Effects of freshwater availability. *Agricultural and Forest Meteorology*, 125(1–2), 159–172. <https://doi.org/10.1016/j.agrformet.2004.02.007>
- Hidalgo, F. J., Canepuccia, A. D., Arcusa, J., Fanjul, E., Álvarez, G., & Iribarne, O. O. (2021). Black fire ant mounds modify soil properties and enhanced plant growth in a salt marsh in Argentina. *Estuarine, Coastal and Shelf Science*, 261(107534), 107534. <https://doi.org/10.1016/j.ecss.2021.107534>
- Hikouei, I. S., Christian, J., Kim, S. S., Sutter, L. A., Durham, S. A., Yang, J. J., & Vickery, C. G. (2021). Use of random forest model to identify the relationships among vegetative species, salt marsh soil properties, and interstitial water along the Atlantic coast of Georgia. *Infrastructures*, 6(5), 70. <https://doi.org/10.3390/infrastructures6050070>
- Hill, T. D., & Anisfeld, S. C. (2015). Coastal wetland response to sea level rise in Connecticut and New York. *Estuarine, Coastal and Shelf Science*, 163, 185–193. <https://doi.org/10.1016/j.ecss.2015.06.004>
- Hirota, M., Senga, Y., Seike, Y., Nohara, S., & Kunii, H. (2007). Fluxes of carbon dioxide, methane and nitrous oxide in two contrastive fringing zones of coastal lagoon, Lake Nakaumi, Japan. *Chemosphere*, 68(3), 597–603. <https://doi.org/10.1016/j.chemosphere.2007.01.002>
- Ho, C. L. (1977). Chemical environment of coastal marshes and swamps, Louisiana. *Catena*, 4(4), 369–383. [https://doi.org/10.1016/0341-8162\(77\)90005-4](https://doi.org/10.1016/0341-8162(77)90005-4)
- Holm, G. O., Jr., Perez, B. C., McWhorter, D. E., Krauss, K. W., Johnson, D. J., Rainie, R. C., & Killebrew, C. J. (2016). Ecosystem level methane fluxes from tidal freshwater and brackish marshes of the Mississippi river delta: Implications for coastal wetland carbon projects. *Wetlands (Wilmington, N.C.)*, 36(3), 401–413. <https://doi.org/10.1007/s13157-016-0746-7>
- Howe, A. J., Rodríguez, J. F., & Saco, P. M. (2009). Surface evolution and carbon sequestration in disturbed and undisturbed wetland soils of the Hunter estuary, Southeast Australia. *Estuarine, Coastal and Shelf Science*, 84(1), 75–83. <https://doi.org/10.1016/j.ecss.2009.06.006>
- Hu, M., Peñuelas, J., Sardans, J., Huang, J., Li, D., & Tong, C. (2019). Effects of nitrogen loading on emission of carbon gases from estuarine tidal marshes with varying salinity. *The Science of the Total Environment*, 667, 648–657. <https://doi.org/10.1016/j.scitotenv.2019.02.429>
- Hu, W., Zhang, W., Zhang, L., Tong, C., Sun, Z., Chen, Y., & Zeng, C. (2019). Nitrogen along the hydrological gradient of marsh sediments in a subtropical estuary: Pools, processes, and fluxes. *International Journal of Environmental Research and Public Health*, 16(11), 2043. <https://doi.org/10.3390/ijerph16112043>
- Hu, Y., Li, Y., Wang, L., Tang, Y., Chen, J., Fu, X., ... Wu, J. (2012). Variability of soil organic carbon reservation capability between coastal salt marsh and river-side freshwater wetland in Chongming Dongtan and its microbial mechanism. *Journal of Environmental Sciences (China)*, 24(6), 1053–1063. [https://doi.org/10.1016/s1001-0742\(11\)60877-2](https://doi.org/10.1016/s1001-0742(11)60877-2)
- Huang, J., Luo, M., Liu, Y., Zhang, Y., & Tan, J. (2019). Effects of tidal scenarios on the methane emission dynamics in the subtropical tidal marshes of the Min River estuary in Southeast China. *International Journal of Environmental Research and Public Health*, 16(15), 2790. <https://doi.org/10.3390/ijerph16152790>
- Huang, L., Bai, J., Chen, B., Zhang, K., Huang, C., & Liu, P. (2012). Two-decade wetland cultivation and its effects on soil properties in salt marshes in the Yellow River Delta, China. *Ecological Informatics*, 10, 49–55. <https://doi.org/10.1016/j.ecoinf.2011.11.001>
- Huang, Y., Chen, Z., Tian, B., Zhou, C., Wang, J., Ge, Z., & Tang, J. (2020). Tidal effects on ecosystem CO₂ exchange in a Phragmites salt marsh of an intertidal shoal. *Agricultural and Forest Meteorology*, 292–293(108108), 108108. <https://doi.org/10.1016/j.agrformet.2020.108108>
- Huliz, P., Gonet, S. S., Giani, L., & Markiewicz, M. (2013). Chronosequential alterations in soil organic matter during initial development of coastal salt marsh soils at the southern North Sea. *Zeitschrift Für Geomorphologie Supplementary Issues*, 57(4), 515–529. <https://doi.org/10.1127/0372-8854/2013/0112>
- Huliz, P., Krzeslak, I., & Karasiewicz, M. T. (2012). Characteristics of sedimentary environments in brackish marsh soils in relation to organic matter properties (Puck Lagoon, Northern Poland).

- Hussein, A. H., Rabenhorst, M. C., & Tucker, M. L. (2004). Modeling of carbon sequestration in coastal marsh soils. *Soil Science Society of America Journal*, 68(5), 1786–1795. <https://doi.org/10.2136/sssaj2004.1786>
- Ihm, B.-S., Lee, J.-S., Kim, J.-W., & Kim, J.-H. (2007). Coastal plant and soil relationships along the southwestern coast of South Korea. *Journal of Plant Biology*, 50(3), 331–335. <https://doi.org/10.1007/bf03030663>
- Iram, N., Kavehei, E., Maher, D. T., Bunn, S. E., Rezaei Rashti, M., Farahani, B. S., & Adame, M. F. (2021). Soil greenhouse gas fluxes from tropical coastal wetlands and alternative agricultural land uses. *Biogeosciences*, 18(18), 5085–5096. <https://doi.org/10.5194/bg-18-5085-2021>
- Irvine, I. C., Vivanco, L., Bentley, P. N., & Martiny, J. B. H. (2012). The effect of nitrogen enrichment on c(1)-cycling microorganisms and methane flux in salt marsh sediments. *Frontiers in Microbiology*, 3, 90. <https://doi.org/10.3389/fmicb.2012.00090>
- Ishtiaq, K. S., & Abdul-Aziz, O. I. (2020). Ecological parameter reductions, environmental regimes, and characteristic process diagram of carbon dioxide fluxes in coastal salt marshes. *Scientific Reports*, 10(1), 15732. <https://doi.org/10.1038/s41598-020-72066-8>
- Jacobo, E. J., Rodriguez, A. M., Fariña, C. M., & Paggi, Y. (2015). Tidal suppression negatively affects soil properties and productivity of *Spartina densiflora* salt marsh. *Rangeland Ecology & Management*, 68(3), 276–284. <https://doi.org/10.1016/j.rama.2015.03.005>
- Janousek, C. N., Buffington, K. J., Guntenspergen, G. R., Thorne, K. M., Dugger, B. D., & Takekawa, J. Y. (2017). Inundation, vegetation, and sediment effects on litter decomposition in pacific coast tidal marshes. *Ecosystems (New York, N.Y.)*, 20(7), 1296–1310. <https://doi.org/10.1007/s10021-017-0111-6>
- Jaworski, A. Z., & Tedrow, J. C. F. (1985). Pedologic properties of New Jersey tidal marshes. *Soil Science*, 139(1), 21–29. <https://doi.org/10.1097/00010694-198501000-00004>
- Jiang, Y., Yin, G., Hou, L., Liu, M., Gao, D., Zhang, Z., ... Han, P. (2021). Variations of dissimilatory nitrate reduction processes along reclamation chronosequences in Chongming Island, China. *Soil & Tillage Research*, 206(104815), 104815. <https://doi.org/10.1016/j.still.2020.104815>
- Jiménez-Arias, J. L., Morris, E., Rubio-de-Inglés, M. J., Peralta, G., García-Robledo, E., Corzo, A., & Pappaspyrou, S. (2020). Tidal elevation is the key factor modulating burial rates and composition of organic matter in a coastal wetland with multiple habitats. *The Science of the Total Environment*, 724(138205), 138205. <https://doi.org/10.1016/j.scitotenv.2020.138205>
- Jordan, T. E., Correll, D. L., & Whigham, D. F. (1983). Nutrient flux in the Rhode River: Tidal exchange of nutrients by brackish marshes. *Estuarine, Coastal and Shelf Science*, 17(6), 651–667. [https://doi.org/10.1016/0272-7714\(83\)90032-x](https://doi.org/10.1016/0272-7714(83)90032-x)
- Kaal, J., Martínez Cortizas, A., Mateo, M.-Á., & Serrano, O. (2020). Deciphering organic matter sources and ecological shifts in blue carbon ecosystems based on molecular fingerprinting. *The Science of the Total Environment*, 742(140554), 140554. <https://doi.org/10.1016/j.scitotenv.2020.140554>
- Kadiri, M., Spencer, K. L., Heppell, C. M., & Fletcher, P. (2011). Sediment characteristics of a restored saltmarsh and mudflat in a managed realignment scheme in Southeast England. *Hydrobiologia*, 672(1), 79–89. <https://doi.org/10.1007/s10750-011-0755-8>
- Kathilankal, J. C., Mozdzer, T. J., Fuentes, J. D., D'Odorico, P., McGlathery, K. J., & Ziemann, J. C. (2008). Tidal influences on carbon assimilation by a salt marsh. *Environmental Research Letters*, 3(4), 44010. <https://doi.org/10.1088/1748-9326/3/4/044010>
- Kauffman, J. B., Bernardino, A. F., Ferreira, T. O., Giovannoni, L. R., de O Gomes, L. E., Romero, D. J., ... Ruiz, F. (2018). Carbon stocks of mangroves and salt marshes of the Amazon region, Brazil. *Biology Letters*, 14(9), 20180208. <https://doi.org/10.1098/rsbl.2018.0208>
- Kauffman, J. B., Giovannoni, L., Kelly, J., Dunstan, N., Borde, A., Diefenderfer, H., ... Brophy, L. (2020). Total ecosystem carbon stocks at the marine–terrestrial interface: Blue carbon of the Pacific northwest coast, United States. *Global Change Biology*, 26(10), 5679–5692. <https://doi.org/10.1111/gcb.15248>
- Kavirasan, T., Dahms, H. U., Gokul, M. S., Henciya, S., Muthukumar, K., Shankar, S., & Arthur James, R. (2019). Seasonal species variation of sediment organic carbon stocks in salt marshes of Tuticorin area, Southern India. *Wetlands (Wilmington, N.C.)*, 39(3), 483–494. <https://doi.org/10.1007/s13157-018-1094-6>
- Kelleway, J. J., Saintilan, N., Macreadie, P. I., Baldock, J. A., & Ralph, P. J. (2017). Sediment and carbon deposition vary among vegetation assemblages in a coastal salt marsh. *Biogeosciences*, 14(16), 3763–3779. <https://doi.org/10.5194/bg-14-3763-2017>
- Kelleway, J. J., Saintilan, N., Macreadie, P. I., & Ralph, P. J. (2016). Sedimentary factors are key predictors of carbon storage in SE Australian saltmarshes. *Ecosystems (New York, N.Y.)*, 19(5), 865–880. <https://doi.org/10.1007/s10021-016-9972-3>
- Kelleway, J. J., Saintilan, N., Macreadie, P. I., Skilbeck, C. G., Zawadzki, A., & Ralph, P. J. (2016). Seventy years of continuous encroachment substantially increases 'blue carbon' capacity as mangroves replace intertidal salt marshes. *Global Change Biology*, 22(3), 1097–1109. <https://doi.org/10.1111/gcb.13158>
- Kiehn, W. M., Mendelsohn, I. A., & White, J. R. (2013). Biogeochemical recovery of oligohaline wetland soils experiencing a salinity pulse. *Soil Science Society of America Journal*, 77(6), 2205–2215. <https://doi.org/10.2136/sssaj2013.05.0202>
- Kim, J., Chaudhary, D. R., Lee, J., Byun, C., Ding, W., Kwon, B.-O., ... Kang, H. (2020). Microbial mechanism for enhanced methane emission in deep soil layer of Phragmites-introduced tidal marsh. *Environment International*, 134(105251), 105251. <https://doi.org/10.1016/j.envint.2019.105251>
- Kim, J., Lee, J., Yun, J., Yang, Y., Ding, W., Yuan, J., & Kang, H. (2020). Mechanisms of enhanced methane emission due to introduction of *Spartina anglica* and *Phragmites australis* in a temperate tidal salt marsh. *Ecological Engineering*, 153(105905), 105905. <https://doi.org/10.1016/j.ecoleng.2020.105905>
- King, G. M., & Wiebe, W. J. (1978). Methane release from soils of a Georgia salt marsh. *Geochimica et Cosmochimica Acta*, 42(4), 343–348. [https://doi.org/10.1016/0016-7037\(78\)90264-8](https://doi.org/10.1016/0016-7037(78)90264-8)
- Kumar, M., Boski, T., González-Vila, F. J., Jiménez-Morillo, N. T., & González-Pérez, J. A. (2020). Characteristics of organic matter sources from Guadiana estuary salt marsh sediments (SW Iberian Peninsula). *Continental Shelf Research*, 197(104076), 104076. <https://doi.org/10.1016/j.csr.2020.104076>
- Landi, M., & Angiolini, C. (2015). Soil–plant relationships in Mediterranean salt marshes across dune-cultivated land gradient. *Journal of Coastal Research*, 31(3), 588–594. <https://doi.org/10.2112/jcoastres-d-13-00009.1>
- Langis, R., Zalejko, M., & Zedler, J. B. (1991). Nitrogen assessments in a constructed and a natural salt marsh of San Diego bay. *Ecological Applications*, 1(1), 40–51. <https://doi.org/10.2307/1941846>
- Langston, A. K., Coleman, D. J., Jung, N. W., Shawler, J. L., Smith, A. J., Williams, B. L., ... Kirwan, M. L. (2022). The effect of marsh age on ecosystem function in a rapidly transgressing marsh. *Ecosystems (New York, N.Y.)*, 25(2), 252–264. <https://doi.org/10.1007/s10021-021-00652-6>
- Ledford, T. C., Mortazavi, B., Tatariw, C., Starr, S. F., Smyth, E., Wood, A. G., ... Cherry, J. A. (2021). Ecosystem carbon exchange and nitrogen removal rates in two 33-year-old constructed salt marshes are similar to those in a nearby natural marsh. *Restoration Ecology*, 29(7), e13439. <https://doi.org/10.1111/rec.13439>
- Lee, J., Kim, B., Noh, J., Lee, C., Kwon, I., Kwon, B.-O., ... Khim, J. S. (2021). The first national scale evaluation of organic carbon stocks and sequestration rates of coastal sediments along the West Sea, South Sea, and East Sea of South Korea. *The Science of the Total Environment*, 793(148568), 148568. <https://doi.org/10.1016/j.scitotenv.2021.148568>
- Lee, P. O., Shoemaker, C., & Olson, J. B. (2019). Wetland soil properties and resident bacterial communities are influenced by changes in elevation. *Wetlands (Wilmington, N.C.)*, 39(1), 99–112. <https://doi.org/10.1007/s13157-018-1077-7>
- Leorri, E., Zimmerman, A. R., Mitra, S., Christian, R. R., Fatela, F., & Mallinson, D. J. (2018). Refractory organic matter in coastal salt marshes-effect on C sequestration calculations. *The Science of the Total Environment*, 633, 391–398. <https://doi.org/10.1016/j.scitotenv.2018.03.120>
- Lewis, D. B., Brown, J. A., & Jimenez, K. L. (2014). Effects of flooding and warming on soil organic matter mineralization in *Avicennia germinans* mangrove forests and *Juncus roemerianus* salt marshes. *Estuarine, Coastal and Shelf Science*, 139, 11–19. <https://doi.org/10.1016/j.ecss.2013.12.032>
- Li, H., Dai, S., Ouyang, Z., Xie, X., Guo, H., Gu, C., ... Zhao, B. (2018). Multi-scale temporal variation of methane flux and its controls in a subtropical tidal salt marsh in eastern China. *Biogeochemistry*, 137(1–2), 163–179. <https://doi.org/10.1007/s10533-017-0413-y>
- Li, J., Yang, W., Li, Q., Pu, L., Xu, Y., Zhang, Z., & Liu, L. (2018). Effect of reclamation on soil organic carbon pools in coastal areas of eastern China. *Frontiers of Earth Science*, 12(2), 339–348. <https://doi.org/10.1007/s11707-018-0680-5>
- Li, J., Leng, Z., Wu, Y., Li, G., Ren, G., Wu, G., Jiang, Y., Yuguda, T. K., & Du, D. (2021). The impact of sea embankment reclamation on greenhouse gas GHG fluxes and stocks in invasive *Spartina alterniflora* and native *Phragmites australis* wetland

- marshes of East China. *Sustainability*, 13(22), 12740. <https://doi.org/10.3390/su132212740>
- Li, J., Han, G., Wang, G., Liu, X., Zhang, Q., Chen, Y., ... Li, P. (2022). Imbalanced nitrogen-phosphorus input alters soil organic carbon storage and mineralisation in a salt marsh. *Catena*, 208(105720), 105720. <https://doi.org/10.1016/j.catena.2021.105720>
- Li, X., & Mitsch, W. J. (2016). Methane emissions from created and restored freshwater and brackish marshes in Southwest Florida, USA. *Ecological Engineering*, 91, 529–536. <https://doi.org/10.1016/j.ecoleng.2016.01.001>
- Li, X., Sardans, J., Hou, L., Liu, M., Xu, C., & Peñuelas, J. (2020). Climatic temperature controls the geographical patterns of coastal marshes greenhouse gases emissions over China. *Journal of Hydrology*, 590(125378), 125378. <https://doi.org/10.1016/j.jhydrol.2020.125378>
- Li, Y., Wang, D., Chen, Z., Chen, J., Hu, H., & Wang, R. (2021). Methane emissions during the tide cycle of a Yangtze estuary salt marsh. *Atmosphere*, 12(2), 245. <https://doi.org/10.3390/atmos12020245>
- Li, Y., Wang, D., Chen, Z., Jin, H., Hu, H., Chen, J., & Yang, Z. (2018). Role of *Scirpus mariqueter* on methane emission from an intertidal saltmarsh of Yangtze estuary. *Sustainability*, 10(4), 1139. <https://doi.org/10.3390/su10041139>
- Li, Y.-L., Guo, H.-Q., Ge, Z.-M., Wang, D.-Q., Liu, W.-L., Xie, L.-N., ... Tang, J.-W. (2020). Sea-level rise will reduce net CO₂ uptake in subtropical coastal marshes. *The Science of the Total Environment*, 747(141214), 141214. <https://doi.org/10.1016/j.scitotenv.2020.141214>
- Li, Y.-L., Wang, L., Zhang, W.-Q., Zhang, S.-P., Wang, H.-L., Fu, X.-H., & Le, Y.-Q. (2010). Variability of soil carbon sequestration capability and microbial activity of different types of salt marsh soils at Chongming Dongtan. *Ecological Engineering*, 36(12), 1754–1760. <https://doi.org/10.1016/j.ecoleng.2010.07.029>
- Li, Z., Zhang, Z., Li, M., Wu, H., & Jiang, M. (2020). Molecular fingerprints of soil organic carbon in wetlands covered by native and non-native plants in the Yellow River delta. *Wetlands (Wilmington, N.C.)*, 40(6), 2189–2198. <https://doi.org/10.1007/s13157-020-01340-2>
- Lin, T., Ye, S., Ma, C., Ding, X., Brix, H., Yuan, H., ... Guo, Z. (2013). Sources and preservation of organic matter in soils of the wetlands in the Liaohe (Liao River) Delta, North China. *Marine Pollution Bulletin*, 71(1–2), 276–285. <https://doi.org/10.1016/j.marpolbul.2013.01.036>
- Liu, D., & Chi, Y. (2020). Horizontal and vertical distributions of estuarine soil total organic carbon and total nitrogen under complex land surface characteristics. *Global Ecology and Conservation*, 24, e01268. <https://doi.org/10.1016/j.gecco.2020.e01268>
- Liu, F., Huo, Y., Chai, M., & Shi, F. (2012). Effects of exotic cordgrass *Spartina alterniflora* on soil physical and chemical characteristics in the Haihe river estuary, China. In *2nd International Conference On Remote Sensing, Environment And Transportation Engineering. Presented at the 2012 2nd international conference on remote sensing, environment and transportation engineering (RSETE)*. IEEE. <https://doi.org/10.1109/rsete.2012.6260556>
- Liu, J., Zhou, H., Qin, P., & Zhou, J. (2007). Effects of *Spartina alterniflora* salt marshes on organic carbon acquisition in intertidal zones of Jiangsu Province, China. *Ecological Engineering*, 30(3), 240–249. <https://doi.org/10.1016/j.ecoleng.2007.01.010>
- Liu, J.-E., Deng, D., Zou, C., Han, R., Xin, Y., Shu, Z., & Zhang, L.-M. (2021). *Spartina alterniflora* saltmarsh soil organic carbon properties and sources in coastal wetlands. *Journal of Soils and Sediments*, 21(10), 3342–3351. <https://doi.org/10.1007/s11368-021-02969-0>
- Liu, J.-Q., Wang, W.-Q., Shen, L.-D., Yang, Y.-L., Xu, J.-B., Tian, M.-H., ... Wu, H.-S. (2022). Response of methanotrophic activity and community structure to plant invasion in China's coastal wetlands. *Geoderma*, 407(115569), 115569. <https://doi.org/10.1016/j.geoderma.2021.115569>
- Loomis, M. J., & Craft, C. B. (2010). Carbon sequestration and nutrient (nitrogen, phosphorus) accumulation in river-dominated tidal marshes, Georgia, USA. *Soil Science Society of America Journal*, 74(3), 1028–1036. <https://doi.org/10.2136/sssaj2009.0171>
- Lu, Q., Bai, J., Zhang, G., Zhao, Q., & Wu, J. (2018). Spatial and seasonal distribution of carbon, nitrogen, phosphorus, and sulfur and their ecological stoichiometry in wetland soils along a water and salt gradient in the Yellow River Delta, China. *Physics and Chemistry of the Earth*, 2002(104), 9–17. <https://doi.org/10.1016/j.pce.2018.04.001>
- Luk, S. Y., Todd-Brown, K., Eagle, M., McNichol, A. P., Sanderman, J., Gosselin, K., & Spivak, A. C. (2021). Soil organic carbon development and turnover in natural and disturbed salt marsh environments. *Geophysical Research Letters*, 48(2), e2020GL090287. <https://doi.org/10.1029/2020gl090287>
- Macreadie, P. I., Hughes, A. R., & Kimbro, D. L. (2013). Loss of 'blue carbon' from coastal salt marshes following habitat disturbance. *PLoS One*, 8(7), e69244. <https://doi.org/10.1371/journal.pone.0069244>
- Madrid, E. N., Quigg, A., & Armitage, A. R. (2012). Marsh construction techniques influence net plant carbon capture by emergent and submerged vegetation in a brackish marsh in the northwestern Gulf of Mexico. *Ecological Engineering*, 42, 54–63. <https://doi.org/10.1016/j.ecoleng.2012.02.001>
- Magenheimer, J. F., Moore, T. R., Chmura, G. L., & Daoust, R. J. (1996). Methane and carbon dioxide flux from a macrotidal salt marsh, bay of Fundy, New Brunswick. *Estuaries*, 19(1), 139. <https://doi.org/10.2307/1352658>
- Mao, R., Ye, S.-Y., & Zhang, X.-H. (2018). Soil-aggregate-associated organic carbon along vegetation zones in tidal salt marshes in the Liaohe delta. *Clean: Soil, Air, Water*, 46(4), 1800049. <https://doi.org/10.1002/clean.201800049>
- Mariotti, G., Eelsey-Quirk, T., Bruno, G., & Valentine, K. (2020). Mud-associated organic matter and its direct and indirect role in marsh organic matter accumulation and vertical accretion. *Limnology and Oceanography*, 65(11), 2627–2641. <https://doi.org/10.1002/lno.11475>
- Marsh, A. S., Rasse, D. P., Drake, B. G., & Patrick Magonigal, J. (2005). Effect of elevated CO₂ on carbon pools and fluxes in a brackish marsh. *Estuaries*, 28(5), 694–704. <https://doi.org/10.1007/bf02732908>
- Martin, R. M., Wigand, C., Elmstrom, E., Lloret, J., & Valiela, I. (2018). Long-term nutrient addition increases respiration and nitrous oxide emissions in a New England salt marsh. *Ecology and Evolution*, 8(10), 4958–4966. <https://doi.org/10.1002/ece3.3955>
- Martins, M., de los Santos, C. B., Masqué, P., Carrasco, A. R., Veiga-Pires, C., & Santos, R. (2022). Carbon and nitrogen stocks and burial rates in intertidal vegetated habitats of a mesotidal coastal lagoon. *Ecosystems (New York, N.Y.)*, 25(2), 372–386. <https://doi.org/10.1007/s10021-021-00660-6>
- McClellan, S. A., Eelsey-Quirk, T., Laws, E. A., & DeLaune, R. D. (2021). Root-zone carbon and nitrogen pools across two chronosequences of coastal marshes formed using different restoration techniques: Dredge sediment versus river sediment diversion. *Ecological Engineering*, 169(106326), 106326. <https://doi.org/10.1016/j.ecoleng.2021.106326>
- McTigue, N., Davis, J., Rodriguez, A. B., McKee, B., Atencio, A., & Currin, C. (2019). Sea level rise explains changing carbon accumulation rates in a salt marsh over the past two Millennia. *Journal of Geophysical Research Biogeosciences*, 124(10), 2945–2957. <https://doi.org/10.1029/2019jg005207>
- Middelburg, J. J., Nieuwenhuize, J., Lubberts, R. K., & van de Plassche, O. (1997). Organic carbon isotope systematics of coastal marshes. *Estuarine, Coastal and Shelf Science*, 45(5), 681–687. <https://doi.org/10.1006/ecss.1997.0247>
- Miller, W. D., Neubauer, S. C., & Anderson, I. C. (2001). Effects of sea level induced disturbances on high salt marsh metabolism. *Estuaries*, 24(3), 357. <https://doi.org/10.2307/1353238>
- Morgan, P. A., Burdick, D. M., & Short, F. T. (2009). The functions and values of fringing salt marshes in northern New England, USA. *Estuaries and Coasts*, 32(3), 483–495. <https://doi.org/10.1007/s12237-009-9145-0>
- Morgan, P. A., & Short, F. T. (2002). Using functional trajectories to track constructed salt marsh development in the great bay estuary, Maine/ New Hampshire, U.S.A. *Restoration Ecology*, 10(3), 461–473. <https://doi.org/10.1046/j.1526-100x.2002.01037.x>
- Morris, J. T., & Bradley, P. M. (1999). Effects of nutrient loading on the carbon balance of coastal wetland sediments. *Limnology and Oceanography*, 44(3), 699–702. <https://doi.org/10.4319/lo.1999.44.3.0699>
- Morris, J. T., & Jensen, A. (1998). The carbon balance of grazed and non-grazed *Spartina anglica* saltmarshes at Skallingen, Denmark. *The Journal of Ecology*, 86(2), 229–242. <https://doi.org/10.1046/j.1365-2745.1998.00251.x>
- Morris, J. T., & Whiting, G. J. (1986). Emission of gaseous carbon dioxide from salt-marsh sediments and its relation to other carbon losses. *Estuaries*, 9(1), 9. <https://doi.org/10.2307/1352188>
- Morrissey, E. M., Gillespie, J. L., Morina, J. C., & Franklin, R. B. (2014). Salinity affects microbial activity and soil organic matter content in tidal wetlands. *Global Change Biology*, 20(4), 1351–1362. <https://doi.org/10.1111/gcb.12431>
- Moseman-Valtierra, S., Abdul-Aziz, O. I., Tang, J., Ishtiaq, K. S., Morkeski, K., Mora, J., ... Kroeger, K. D. (2016). Carbon dioxide fluxes reflect plant zonation and belowground biomass in a coastal marsh. *Ecosphere (Washington, D.C.)*, 7(11), e01560. <https://doi.org/10.1002/ecs2.1560>
- Moseman-Valtierra, S., Gonzalez, R., Kroeger, K. D., Tang, J., Chao, W. C., Crusius, J., Bratton, J., Green, A., & Shelton, J. (2011). Short-term nitrogen additions can shift a coastal wetland from a sink to a source of N₂O. *Atmospheric Environment (Oxford, England: 1994)*, 45(26), 4390–4397. <https://doi.org/10.1016/j.atmosenv.2011.05.046>

- Mossman, H. L., Pontee, N., Born, K., Lawrence, P. J., Rae, S., Scott, J., ... Dunk, R. M. (2021). Rapid carbon accumulation at a saltmarsh restored by managed realignment far exceeds carbon emitted in site construction. <https://doi.org/10.1101/2021.10.12.464124>
- Mou, X., Liu, X., Sun, Z., Tong, C., & Lu, X. (2019). Short-term effect of exogenous nitrogen on N₂O fluxes from native and invaded tidal marshes in the min river estuary, China. *Wetlands (Wilmington, N.C.)*, 39(1), 139–148. <https://doi.org/10.1007/s13157-018-1060-3>
- Moy, L. D., & Levin, L. A. (1991). Are *Spartina* marshes a replaceable resource? A functional approach to evaluation of marsh creation efforts. *Estuaries*, 14(1), 1. <https://doi.org/10.2307/1351977>
- Mueller, P., Granse, D., Nolte, S., Weingartner, M., Hoth, S., & Jensen, K. (2020). Unrecognized controls on microbial functioning in blue carbon ecosystems: The role of mineral enzyme stabilization and allochthonous substrate supply. *Ecology and Evolution*, 10(2), 998–1011. <https://doi.org/10.1002/ece3.5962>
- Mueller, P., Ladiges, N., Jack, A., Schmiedl, G., Kutzbach, L., Jensen, K., & Nolte, S. (2019). Assessing the long-term carbon-sequestration potential of the semi-natural salt marshes in the European Wadden Sea. *Ecosphere (Washington, D.C.)*, 10(1), e02556. <https://doi.org/10.1002/ecs2.2556>
- Nedwell, D. B., Embley, T. M., & Purdy, K. J. (2004). Sulphate reduction, methanogenesis and phylogenetics of the sulphate reducing bacterial communities along an estuarine gradient. *Aquatic Microbial Ecology: International Journal*, 37, 209–217. <https://doi.org/10.3354/ame037209>
- Negandhi, K., Edwards, G., Kelleway, J. J., Howard, D., Safari, D., & Saintilan, N. (2019). Blue carbon potential of coastal wetland restoration varies with inundation and rainfall. *Scientific Reports*, 9(1), 4368. <https://doi.org/10.1038/s41598-019-40763-8>
- Netto, S. A., & Lana, P. C. (1997). Influence of *Spartina alterniflora* superficial sediment characteristics of tidal flats in paranaguá bay (South-Eastern Brazil). *Estuarine, Coastal and Shelf Science*, 44(5), 641–648. <https://doi.org/10.1006/ecss.1996.0154>
- Noyce, G. L., & Megonigal, J. P. (2021). Biogeochemical and plant trait mechanisms drive enhanced methane emissions in response to whole-ecosystem warming. *Biogeosciences*, 18(8), 2449–2463. <https://doi.org/10.5194/bg-18-2449-2021>
- Nyman, J. A., Delaune, R. D., & Patrick, W. H., Jr. (1990). Wetland soil formation in the rapidly subsiding Mississippi River deltaic plain: Mineral and organic matter relationships. *Estuarine, Coastal and Shelf Science*, 31(1), 57–69. [https://doi.org/10.1016/0272-7714\(90\)90028-p](https://doi.org/10.1016/0272-7714(90)90028-p)
- Nyman, J. A., DeLaune, R. D., Roberts, H. H., & Patrick, W. H., Jr. (1993). Relationship between vegetation and soil formation in a rapidly submerging coastal marsh. *Marine Ecology Progress Series*, 96, 269–279. <https://doi.org/10.3354/meps096269>
- Nyman, J. A., Walters, R. J., Delaune, R. D., & Patrick, W. H., Jr. (2006). Marsh vertical accretion via vegetative growth. *Estuarine, Coastal and Shelf Science*, 69(3–4), 370–380. <https://doi.org/10.1016/j.ecss.2006.05.041>
- O'Driscoll, N. J., Canário, J., Crowell, N., & Webster, T. (2011). Mercury speciation and distribution in coastal wetlands and tidal mudflats: Relationships with Sulphur speciation and organic carbon. *Water, Air, and Soil Pollution*, 220(1–4), 313–326. <https://doi.org/10.1007/s11270-011-0756-2>
- Oenema, O. (1990). Pyrite accumulation in salt marshes in the eastern Scheldt, Southwest Netherlands. *Biogeochemistry*, 9(1), 75–98. <https://doi.org/10.1007/bf00002718>
- Oenema, O., & DeLaune, R. D. (1988). Accretion rates in salt marshes in the eastern Scheldt, south-West Netherlands. *Estuarine, Coastal and Shelf Science*, 26(4), 379–394. [https://doi.org/10.1016/0272-7714\(88\)90019-4](https://doi.org/10.1016/0272-7714(88)90019-4)
- Olsen, Y. S., Dausse, A., Garbutt, A., Ford, H., Thomas, D. N., & Jones, D. L. (2011). Cattle grazing drives nitrogen and carbon cycling in a temperate salt marsh. *Soil Biology & Biochemistry*, 43(3), 531–541. <https://doi.org/10.1016/j.soilbio.2010.11.018>
- Olsson, L., Ye, S., Yu, X., Wei, M., Krauss, K. W., & Brix, H. (2015). Factors influencing CO₂ and CH₄ emissions from coastal wetlands in the Liaohe Delta, Northeast China. *Biogeosciences*, 12(16), 4965–4977. <https://doi.org/10.5194/bg-12-4965-2015>
- Onaindia, M., Albizu, I., & Amezcaga, I. (2001). Effect of time on the natural regeneration of salt marsh. *Applied Vegetation Science*, 4(2), 247–256. <https://doi.org/10.1111/j.1654-109x.2001.tb00493.x>
- Onorevole, K. M., Thompson, S. P., & Piehler, M. F. (2018). Living shorelines enhance nitrogen removal capacity over time. *Ecological Engineering*, 120, 238–248. <https://doi.org/10.1016/j.ecoleng.2018.05.017>
- Oosterlee, L., Cox, T. J. S., Vandenbruwaene, W., Maris, T., Temmerman, S., & Meire, P. (2018). Tidal marsh restoration design affects feedbacks between inundation and elevation change. *Estuaries and Coasts*, 41(3), 613–625. <https://doi.org/10.1007/s12237-017-0314-2>
- Osgood, D. T., & Zieman, J. C. (1993). Spatial and temporal patterns of substrate physicochemical parameters in different-aged barrier Island marshes. *Estuarine, Coastal and Shelf Science*, 37(4), 421–436. <https://doi.org/10.1006/ecss.1993.1065>
- Owers, C. J., Rogers, K., Mazumder, D., & Woodroffe, C. D. (2020). Temperate coastal wetland near-surface carbon storage: Spatial patterns and variability. *Estuarine, Coastal and Shelf Science*, 235(106584), 106584. <https://doi.org/10.1016/j.ecss.2020.106584>
- Pace, G., Peteet, D., Dunton, M., Wang-Mondaca, C., Ismail, S., Supino, J., & Nichols, J. (2021). Importance of quantifying the full-depth carbon reservoir of Jamaica Bay salt marshes, New York. *City and Environment Interactions*, 12(100073), 100073. <https://doi.org/10.1016/j.cacint.2021.100073>
- Page, H. M., Lastra, M., Rodil, I. F., Briones, M. J. I., & Garrido, J. (2010). Effects of non-native *Spartina patens* on plant and sediment organic matter carbon incorporation into the local invertebrate community. *Biological Invasions*, 12(11), 3825–3838. <https://doi.org/10.1007/s10530-010-9775-y>
- Palacios, M. M., Trevathan-Tackett, S. M., Malerba, M. E., & Macreadie, P. I. (2021). Effects of a nutrient enrichment pulse on blue carbon ecosystems. *Marine Pollution Bulletin*, 165(112024), 112024. <https://doi.org/10.1016/j.marpolbul.2021.112024>
- Persico, E. P., Sharp, S. J., & Angelini, C. (2017). Feral hog disturbance alters carbon dynamics in southeastern US salt marshes. *Marine Ecology Progress Series*, 580, 57–68. <https://doi.org/10.3354/meps12282>
- Pinsonneault, A. J., Neale, P. J., Tzortziou, M., Canuel, E. A., Pondell, C. R., Morrissette, H., ... Megonigal, J. P. (2021). Dissolved organic carbon sorption dynamics in tidal marsh soils. *Limnology and Oceanography*, 66(1), 214–225. <https://doi.org/10.1002/lno.11598>
- Pollmann, T., Böttcher, M. E., & Giani, L. (2021). Young soils of a temperate barrier Island under the impact of formation and resetting by tides and wind. *Catena*, 202(105275), 105275. <https://doi.org/10.1016/j.catena.2021.105275>
- Poppe, K. L., & Rybczyk, J. M. (2021). Tidal marsh restoration enhances sediment accretion and carbon accumulation in the Stillaguamish River estuary, Washington. *PLoS One*, 16(9), e0257244. <https://doi.org/10.1371/journal.pone.0257244>
- Powell, E. B., Krause, J. R., Martin, R. M., & Watson, E. B. (2020). Pond excavation reduces coastal wetland carbon dioxide assimilation. *Journal of Geophysical Research Biogeosciences*, 125(2), e2019JG005187. <https://doi.org/10.1029/2019jg005187>
- Puchkoff, A. L., & Lawrence, B. A. (2022). Experimental sediment addition in salt-marsh management: Plant–soil carbon dynamics in southern New England. *Ecological Engineering*, 175(106495), 106495. <https://doi.org/10.1016/j.ecoleng.2021.106495>
- Qian, L., Yan, J., Hu, Y., Gao, L., Wu, P., & Wang, L. (2019). Spatial distribution patterns of annual soil carbon accumulation and carbon storage in the Jiuduansha wetland of the Yangtze River estuary. *Environmental Monitoring and Assessment*, 191(12), 750. <https://doi.org/10.1007/s10661-019-7914-1>
- Qin, D., Gao, M., Wu, X., Du, X., & Bi, X. (2015). Seasonal changes in soil TN and SOC in a seawall-reclaimed marsh in the Yellow River Delta, China. *Journal of Coastal Conservation*, 19(1), 79–84. <https://doi.org/10.1007/s11852-014-0362-8>
- Qiu, D., Cui, B., Yan, J., Ma, X., Ning, Z., Wang, F., ... Bai, J. (2019). Effect of burrowing crabs on retention and accumulation of soil carbon and nitrogen in an intertidal salt marsh. *Journal of Sea Research*, 154(101808), 101808. <https://doi.org/10.1016/j.jseares.2019.101808>
- Radabaugh, K. R., Moyer, R. P., Chappel, A. R., Powell, C. E., Bociu, I., Clark, B. C., & Smoak, J. M. (2018). Coastal blue carbon assessment of mangroves, salt marshes, and salt barrens in Tampa bay, Florida, USA. *Estuaries and Coasts*, 41(5), 1496–1510. <https://doi.org/10.1007/s12237-017-0362-7>
- Rae, J. E., & Allen, J. R. L. (1993). The significance of organic matter degradation in the interpretation of historical pollution trends in depth profiles of estuarine sediment. *Estuaries*, 16(3), 678. <https://doi.org/10.2307/1352804>
- Rasse, D. P., Peresta, G., & Drake, B. G. (2005). Seventeen years of elevated CO₂ exposure in a Chesapeake Bay wetland: Sustained but contrasting responses of plant growth and CO₂ uptake. *Global Change Biology*, 11(3), 369–377. <https://doi.org/10.1111/j.1365-2486.2005.00913.x>
- Reid, M. C., Tripathi, R., Schäfer, K. V. R., & Jaffé, P. R. (2013). Tidal marsh methane dynamics: Difference in seasonal lags in emissions driven by storage in vegetated versus unvegetated sediments. *Journal of Geophysical Research Biogeosciences*, 118(4), 1802–1813. <https://doi.org/10.1002/2013jg002438>

- Rhew, R. C., Miller, B. R., Bill, M., Goldstein, A. H., & Weiss, R. F. (2002). Environmental and biological controls on methyl halide emissions from southern California coastal salt marshes. *Biogeochemistry*, 60, 141–161.
- Rhew, R. C., Miller, B. R., & Weiss, R. F. (2000). Natural methyl bromide and methyl chloride emissions from coastal salt marshes. *Nature*, 403(6767), 292–295. <https://doi.org/10.1038/35002043>
- Ríos, I., Bouza, P. J., Bortolus, A., & del Alvarez, M. P. (2018). Soil-geomorphology relationships and landscape evolution in a southwestern Atlantic tidal salt marsh in Patagonia, Argentina. *Journal of South American Earth Sciences*, 84, 385–398. <https://doi.org/10.1016/j.jsames.2018.04.015>
- Roughan, B. L., Kellman, L., Smith, E., & Chmura, G. L. (2018). Nitrous oxide emissions could reduce the blue carbon value of marshes on eutrophic estuaries. *Environmental Research Letters*, 13(4), 44034. <https://doi.org/10.1088/1748-9326/aab63c>
- Sammul, M., Kauer, K., & Köster, T. (2012). Biomass accumulation during reed encroachment reduces efficiency of restoration of Baltic coastal grasslands. *Applied Vegetation Science*, 15(2), 219–230. <https://doi.org/10.1111/j.1654-109x.2011.01167.x>
- Santini, C., de la Rosa, J. M., Knicker, H., Otero, X. L., Álvarez, M. Á., & González-Vila, F. J. (2009). Effects of reclamation and regeneration processes on organic matter from estuarine soils and sediments. *Organic Geochemistry*, 40(9), 931–941. <https://doi.org/10.1016/j.orggeochem.2009.06.005>
- Santini, N. S., Lovelock, C. E., Hua, Q., Zawadzki, A., Mazumder, D., Mercer, T. R., ... Vergés, A. (2019). Natural and regenerated saltmarshes exhibit similar soil and belowground organic carbon stocks, root production and soil respiration. *Ecosystems* (New York, N.Y.), 22(8), 1803–1822. <https://doi.org/10.1007/s10021-019-00373-x>
- Santos, R., Duque-Núñez, N., de Los Santos, C. B., Martins, M., Carrasco, A. R., & Veiga-Pires, C. (2019). Superficial sedimentary stocks and sources of carbon and nitrogen in coastal vegetated assemblages along a flow gradient. *Scientific Reports*, 9(1), 610. <https://doi.org/10.1038/s41598-018-37031-6>
- Sapkota, Y., & White, J. R. (2019). Marsh edge erosion and associated carbon dynamics in coastal Louisiana: A proxy for future wetland-dominated coastlines world-wide. *Estuarine, Coastal and Shelf Science*, 226(106289), 106289. <https://doi.org/10.1016/j.ecss.2019.106289>
- Sapkota, Y., & White, J. R. (2021). Long-term fate of rapidly eroding carbon stock soil profiles in coastal wetlands. *The Science of the Total Environment*, 753(141913), 141913. <https://doi.org/10.1016/j.scitotenv.2020.141913>
- Schile, L. M., Kauffman, J. B., Crooks, S., Fourqurean, J. W., Glavan, J., & Magonigal, J. P. (2017). Limits on carbon sequestration in arid blue carbon ecosystems. *Ecological Applications*, 27(3), 859–874. <https://doi.org/10.1002/eap.1489>
- Schulte Ostermann, T., Kleyer, M., Heuner, M., Fuchs, E., Temmerman, S., Schoutens, K., ... Minden, V. (2021). Hydrodynamics affect plant traits in estuarine ecotones with impact on carbon sequestration potentials. *Estuarine, Coastal and Shelf Science*, 259(107464), 107464. <https://doi.org/10.1016/j.ecss.2021.107464>
- Seyfferth, A. L., Bothfeld, F., Vargas, R., Stuckey, J. W., Wang, J., Kearns, K., ... Sparks, D. L. (2020). Spatial and temporal heterogeneity of geochemical controls on carbon cycling in a tidal salt marsh. *Geochimica et Cosmochimica Acta*, 282, 1–18. <https://doi.org/10.1016/j.gca.2020.05.013>
- Shafer, D. J., & Streever, W. J. (2000). A comparison of 28 natural and dredged material salt marshes in Texas with an emphasis on geomorphological variables. *Wetlands Ecology and Management*, 8, 353–366.
- Shafiqul Islam, M., Pervez, A., Aminur Rahman, M., & Habibur Rahman Molla, M. (2021). Eco-engineering of coastal environment through saltmarsh restoration towards climate change impact mitigation and community adaptation in Bangladesh. *Regional Studies in Marine Science*, 46(101880), 101880. <https://doi.org/10.1016/j.rsma.2021.101880>
- Sharp, S. J., & Angelini, C. (2019). The role of landscape composition and disturbance type in mediating salt marsh resilience to feral hog invasion. *Biological Invasions*, 21(9), 2857–2869. <https://doi.org/10.1007/s10530-019-02018-5>
- Sheng, Q., Wang, L., & Wu, J. (2015). Vegetation alters the effects of salinity on greenhouse gas emissions and carbon sequestration in a newly created wetland. *Ecological Engineering*, 84, 542–550. <https://doi.org/10.1016/j.ecoleng.2015.09.047>
- Sheng, Q., Zhao, B., Huang, M., Wang, L., Quan, Z., Fang, C., ... Wu, J. (2014). Greenhouse gas emissions following an invasive plant eradication program. *Ecological Engineering*, 73, 229–237. <https://doi.org/10.1016/j.ecoleng.2014.09.031>
- Shiau, Y.-J., Burchell, M. R., Krauss, K. W., Birgand, F., & Broome, S. W. (2016). Greenhouse gas emissions from a created brackish marsh in eastern North Carolina. *Wetlands (Wilmington, N.C.)*, 36(6), 1009–1024. <https://doi.org/10.1007/s13157-016-0815-y>
- Shiau, Y.-J., Burchell, M. R., Krauss, K. W., Broome, S. W., & Birgand, F. (2019). Carbon storage potential in a recently created brackish marsh in eastern North Carolina, USA. *Ecological Engineering*, 127, 579–588. <https://doi.org/10.1016/j.ecoleng.2018.09.007>
- Simpson, L. T., Osborne, T. Z., Duckett, L. J., & Feller, I. C. (2017). Carbon storages along a climate induced coastal wetland gradient. *Wetlands (Wilmington, N.C.)*, 37(6), 1023–1035. <https://doi.org/10.1007/s13157-017-0937-x>
- Simpson, L. T., Osborne, T. Z., & Feller, I. C. (2019). Wetland soil CO₂ efflux along a latitudinal gradient of spatial and temporal complexity. *Estuaries and Coasts*, 42(1), 45–54. <https://doi.org/10.1007/s12237-018-0442-3>
- Smeaton, C., Barlow, N. L. M., & Austin, W. E. N. (2020). Coring and compaction: Best practice in blue carbon stock and burial estimations. *Geoderma*, 364(114180), 114180. <https://doi.org/10.1016/j.geoderma.2020.114180>
- Smith, A. J., & Kirwan, M. L. (2021). Sea level-driven marsh migration results in rapid net loss of carbon. *Geophysical Research Letters*, 48(13), e2021GL092420. <https://doi.org/10.1029/2021gl092420>
- Song, H., & Liu, X. (2016). Anthropogenic effects on fluxes of ecosystem respiration and methane in the Yellow River estuary, China. *Wetlands (Wilmington, N.C.)*, 36(5), 113–123. <https://doi.org/10.1007/s13157-014-0587-1>
- Soto-Jiménez, M., Páez-Osuna, F., & Ruiz-Fernández, A. (2003). Organic matter and nutrients in an altered subtropical marsh system, Chirichahueto, NW Mexico. *Environmental Geology*, 43(8), 913–921. <https://doi.org/10.1007/s00254-002-0711-z>
- Sousa, A. I., Lillebø, A. I., Pardal, M. A., & Caçador, I. (2010). The influence of *Spartina maritima* on carbon retention capacity in salt marshes from warm-temperate estuaries. *Marine Pollution Bulletin*, 61(4–6), 215–223. <https://doi.org/10.1016/j.marpolbul.2010.02.018>
- Sousa, A. I., Santos, D. B., da Silva, E. F., Sousa, L. P., Cleary, D. F. R., Soares, A. M. V. M., & Lillebø, A. I. (2017). 'Blue carbon' and nutrient stocks of salt marshes at a temperate coastal lagoon (ria de Aveiro, Portugal). *Scientific Reports*, 7(1), 41225. <https://doi.org/10.1038/srep41225>
- Spencer, K. L., Carr, S. J., Diggins, L. M., Tempest, J. A., Morris, M. A., & Harvey, G. L. (2017). The impact of pre-restoration land-use and disturbance on sediment structure, hydrology and the sediment geochemical environment in restored saltmarshes. *The Science of the Total Environment*, 587–588, 47–58. <https://doi.org/10.1016/j.scitotenv.2016.11.032>
- Spohn, M., & Giani, L. (2012). Carbohydrates, carbon and nitrogen in soils of a marine and a brackish marsh as influenced by inundation frequency. *Estuarine, Coastal and Shelf Science*, 107, 89–96. <https://doi.org/10.1016/j.ecss.2012.05.006>
- St. Laurent, K. A., Hribar, D. J., Carlson, A. J., Crawford, C. M., & Siok, D. (2020). Assessing coastal carbon variability in two Delaware tidal marshes. *Journal of Coastal Conservation*, 24(6), 1–16. <https://doi.org/10.1007/s11852-020-00783-3>
- Starr, G., Jarnigan, J. R., Staudhammer, C. L., & Cherry, J. A. (2018). Variation in ecosystem carbon dynamics of saltwater marshes in the northern Gulf of Mexico. *Wetlands Ecology and Management*, 26(4), 581–596. <https://doi.org/10.1007/s11273-018-9593-z>
- Staver, L. W., Stevenson, J. C., Cornwell, J. C., Nidzicko, N. J., Staver, K. W., Owens, M. S., ... Malkin, S. Y. (2020). Tidal marsh restoration at poplar Island: II. Elevation trends, vegetation development, and carbon dynamics. *Wetlands (Wilmington, N.C.)*, 40(6), 1687–1701. <https://doi.org/10.1007/s13157-020-01295-4>
- Steinmuller, H. E., & Chambers, L. G. (2019). Characterization of coastal wetland soil organic matter: Implications for wetland submergence. *The Science of the Total Environment*, 677, 648–659. <https://doi.org/10.1016/j.scitotenv.2019.04.405>
- Steinmuller, H. E., Dittmer, K. M., White, J. R., & Chambers, L. G. (2019). Understanding the fate of soil organic matter in submerging coastal wetland soils: A microcosm approach. *Geoderma*, 337, 1267–1277. <https://doi.org/10.1016/j.geoderma.2018.08.020>
- Steinmuller, H. E., Foster, T. E., Boudreau, P., Hinkle, C. R., & Chambers, L. G. (2020). Characterization of herbaceous encroachment on soil biogeochemical cycling within a coastal marsh. *The Science of the Total Environment*, 738(139532), 139532. <https://doi.org/10.1016/j.scitotenv.2020.139532>
- Steinmuller, H. E., Hayes, M. P., Hurst, N. R., Sapkota, Y., Cook, R. L., White, J. R., ... Chambers, L. G. (2020). Does edge erosion alter coastal wetland soil properties? A Multi-Method Biogeochemical Study. *Catena*, 187(104373), 104373. <https://doi.org/10.1016/j.catena.2019.104373>
- Sun, W., Sun, Z., Mou, X., & Sun, W. (2018). Short-term study on variations of carbon dioxide and methane emissions from intertidal zone of the Yellow River estuary during autumn and winter. *Wetlands (Wilmington, N.C.)*, 38(4), 835–854. <https://doi.org/10.1007/s13157-018-1035-4>

- Sun, Z., Jiang, H., Wang, L., Mou, X., & Sun, W. (2013). Seasonal and spatial variations of methane emissions from coastal marshes in the northern Yellow River estuary, China. *Plant and Soil*, 369(1–2), 317–333. <https://doi.org/10.1007/s11104-012-1564-1>
- Sun, Z., Wang, L., Tian, H., Jiang, H., Mou, X., & Sun, W. (2013). Fluxes of nitrous oxide and methane in different coastal Suaeda salsa marshes of the Yellow River estuary, China. *Chemosphere*, 90(2), 856–865. <https://doi.org/10.1016/j.chemosphere.2012.10.004>
- Taylor, B. W., Paterson, D. M., & Baxter, J. M. (2019). Sediment dynamics of natural and restored *Bolboschoenus maritimus* saltmarsh. *Frontiers in Ecology and Evolution*, 7, 237. <https://doi.org/10.3389/fevo.2019.00237>
- Tempest, J. A., Harvey, G. L., & Spencer, K. L. (2015). Modified sediments and subsurface hydrology in natural and recreated salt marshes and implications for delivery of ecosystem services. *Hydrological Processes*, 29(10), 2346–2357. <https://doi.org/10.1002/hyp.10368>
- Tong, C., Huang, J. F., Hu, Z. Q., & Jin, Y. F. (2013). Diurnal variations of carbon dioxide, methane, and nitrous oxide vertical fluxes in a subtropical estuarine marsh on neap and spring tide days. *Estuaries and Coasts*, 36(3), 633–642. <https://doi.org/10.1007/s12237-013-9596-1>
- Tong, C., She, C. X., Yang, P., Jin, Y. F., & Huang, J. F. (2015). Weak correlation between methane production and abundance of methanogens across three brackish marsh zones in the min river estuary, China. *Estuaries and Coasts*, 38(6), 1872–1884. <https://doi.org/10.1007/s12237-014-9930-2>
- Tong, C., Wang, W.-Q., Huang, J.-F., Gauci, V., Zhang, L.-H., & Zeng, C.-S. (2012). Invasive alien plants increase CH₄ emissions from a subtropical tidal estuarine wetland. *Biogeochemistry*, 111(1–3), 677–693. <https://doi.org/10.1007/s10533-012-9712-5>
- Tong, C., Wang, W.-Q., Zeng, C.-S., & Marrs, R. (2010). Methane (CH₄) emission from a tidal marsh in the Min River estuary, Southeast China. *Journal of environmental science and health. Part a, toxic/hazardous Substances & Environmental Engineering*, 45(4), 506–516. <https://doi.org/10.1080/10934520903542261>
- Tong, C., Huang, J., & Jia, Y. (2015). Small-scale spatial variability of soil methane production potential and porewater characteristics in an estuarine *Phragmites australis* marsh. *Journal of Coastal Research*, 314, 994–1004. <https://doi.org/10.2112/jcoastres-d-14-00121.1>
- Tonti, N. E., Gassmann, M. I., & Pérez, C. F. (2018). First results of energy and mass exchange in a salt marsh on southeastern South America. *Agricultural and Forest Meteorology*, 263, 59–68. <https://doi.org/10.1016/j.agrfor.2018.08.001>
- Twohig, T. M., & Stolt, M. H. (2011). Soils-based rapid assessment for quantifying changes in salt marsh condition as a result of hydrologic alteration. *Wetlands (Wilmington, N.C.)*, 31(5), 955–963. <https://doi.org/10.1007/s13157-011-0210-7>
- Vaccare, J., Meselhe, E., & White, J. R. (2019). The denitrification potential of eroding wetlands in Barataria Bay, LA, USA: Implications for river reconnection. *The Science of the Total Environment*, 686, 529–537. <https://doi.org/10.1016/j.scitotenv.2019.05.475>
- Valentine, K., Bruno, G., Eelsey-Quirk, T., & Mariotti, G. (2021). Brackish marshes erode twice as fast as saline marshes in the Mississippi Delta region. *Earth Surface Processes and Landforms*, 46(9), 1739–1749. <https://doi.org/10.1002/esp.5108>
- Valéry, L., Bouchard, V., & Lefeuvre, J. C. (2004). Impact of the invasive native species *Elymus athericus* on carbon pools in a salt marsh. *Wetlands*, 24(2), 268–276.
- Van Allen, R., Schreiner, K. M., Guntenspergen, G., & Carlin, J. (2021). Changes in organic carbon source and storage with sea level rise-induced transgression in a Chesapeake Bay marsh. *Estuarine, Coastal and Shelf Science*, 261(107550), 107550. <https://doi.org/10.1016/j.ecss.2021.107550>
- van Ardenne, L. B., Jolicoeur, S., Bérubé, D., Burdick, D., & Chmura, G. L. (2018). High resolution carbon stock and soil data for three salt marshes along the northeastern coast of North America. *Data in Brief*, 19, 2438–2441. <https://doi.org/10.1016/j.dib.2018.07.037>
- Van de Broek, M., & Govers, G. (2019). Quantification of organic carbon concentrations and stocks of tidal marsh sediments via mid-infrared spectroscopy. *Geoderma*, 337, 555–564. <https://doi.org/10.1016/j.geoderma.2018.09.051>
- Van de Broek, M., Temmerman, S., Merckx, R., & Govers, G. (2016). Controls on soil organic carbon stocks in tidal marshes along an estuarine salinity gradient. *Biogeochemistry*, 13(24), 6611–6624. <https://doi.org/10.5194/bg-13-6611-2016>
- Van de Broek, M., Vandendriessche, C., Poppelmonde, D., Merckx, R., Temmerman, S., & Govers, G. (2018). Long-term organic carbon sequestration in tidal marsh sediments is dominated by old-aged allochthonous inputs in a macrotidal estuary. *Global Change Biology*, 24(6), 2498–2512. <https://doi.org/10.1111/gcb.14089>
- VanZomeren, C. M., Berkowitz, J. F., Piercy, C. D., & White, J. R. (2018). Restoring a degraded marsh using thin layer sediment placement: Short term effects on soil physical and biogeochemical properties. *Ecological Engineering*, 120, 61–67. <https://doi.org/10.1016/j.ecoleng.2018.05.012>
- Vaughn, D. R., Bianchi, T. S., Shields, M. R., Kenney, W. F., & Osborne, T. Z. (2020). Increased organic carbon burial in northern Florida mangrove-salt marsh transition zones. *Global Biogeochemical Cycles*, 34(5), e2019GB006334. <https://doi.org/10.1029/2019gb006334>
- Vaughn, D. R., Bianchi, T. S., Shields, M. R., Kenney, W. F., & Osborne, T. Z. (2021). Blue carbon soil stock development and estimates within northern Florida wetlands. *Frontiers in Earth Science*, 9, 552721. <https://doi.org/10.3389/feart.2021.552721>
- Vázquez-Lule, A., & Vargas, R. (2021). Biophysical drivers of net ecosystem and methane exchange across phenological phases in a tidal salt marsh. *Agricultural and Forest Meteorology*, 300(108309), 108309. <https://doi.org/10.1016/j.agrfor.2020.108309>
- Velinsky, D. J., Paudel, B., Belton, T. J., & Sommerfield, C. K. (2017). Tidal marsh record of nutrient loadings in Barnegat Bay, New Jersey. *Journal of Coastal Research*, 78, 79–88. <https://doi.org/10.2112/si78-008.1>
- Velinsky, D. J., Paudel, B., Quirk, T., Pehler, M., & Smyth, A. (2017). Salt marsh denitrification provides a significant nitrogen sink in Barnegat Bay, New Jersey. *Journal of Coastal Research*, 78, 70–78. <https://doi.org/10.2112/si78-007.1>
- Vincent, R. E., Burdick, D. M., & Dionne, M. (2013). Ditching and ditch-plugging in New England salt marshes: Effects on hydrology, elevation, and soil characteristics. *Estuaries and Coasts*, 36(3), 610–625. <https://doi.org/10.1007/s12237-012-9583-y>
- Vivanco, L., Irvine, I. C., & Martiny, J. B. H. (2015). Nonlinear responses in salt marsh functioning to increased nitrogen addition. *Ecology*, 96(4), 936–947. <https://doi.org/10.1890/13-1983.1>
- Vizza, C., West, W. E., Jones, S. E., Hart, J. A., & Lamberti, G. A. (2017). Regulators of coastal wetland methane production and responses to simulated global change. *Biogeochemistry*, 14(2), 431–446. <https://doi.org/10.5194/bg-14-431-2017>
- Voltz, B., Denis, L., Duong, G., Santoni, A.-L., Artigas, L. F., Cornille, V., ... Gontharet, S. (2021). A multiproxy study of intertidal surface sediments from two macrotidal estuarine systems (Canche, Authie) in northern France: Insights into environmental processes. *Continental Shelf Research*, 230(104554), 104554. <https://doi.org/10.1016/j.csr.2021.104554>
- Vranken, M., Oenema, O., & Mulder, J. (1990). Effects of tide range alterations on salt marsh sediments in the Eastern Scheldt, S. W. Netherlands. *Hydrobiologia*, 195(1), 13–20. <https://doi.org/10.1007/bf00026810>
- Wan, S., Liu, X., Mou, X., & Zhao, Y. (2020). Comparison of carbon, nitrogen, and sulfur in coastal wetlands dominated by native and invasive plants in the Yancheng national nature reserve, China. *Chinese Geographical Science*, 30(2), 202–216. <https://doi.org/10.1007/s11769-020-1108-1>
- Wang, C., Lai, D. Y. F., Tong, C., Wang, W., Huang, J., & Zeng, C. (2015). Variations in temperature sensitivity (Q10) of CH₄ emission from a subtropical estuarine marsh in Southeast China. *PLoS One*, 10(5), e0125227. <https://doi.org/10.1371/journal.pone.0125227>
- Wang, C., Pei, X., Yue, S., & Wen, Y. (2016). The response of *Spartina alterniflora* biomass to soil factors in Yancheng, Jiangsu province, P.R. China. *Wetlands (Wilmington, N.C.)*, 36(2), 229–235. <https://doi.org/10.1007/s13157-016-0732-0>
- Wang, D., Chen, Z., Wang, J., Xu, S., Yang, H., Chen, H., ... Hu, L. (2007). Summer-time denitrification and nitrous oxide exchange in the intertidal zone of the Yangtze estuary. *Estuarine, Coastal and Shelf Science*, 73(1–2), 43–53. <https://doi.org/10.1016/j.ecss.2006.11.002>
- Wang, D., Chen, Z., Xu, S., Da, L., Bi, C., & Wang, J. (2007). Denitrification in tidal flat sediment, Yangtze estuary. *Science in China Series B: Chemistry*, 50(6), 812–820. <https://doi.org/10.1007/s1426-007-0109-6>
- Wang, D., Huang, W., Liang, R., & Li, F. (2016). Effects of *Spartina alterniflora* invasion on soil quality in coastal wetland of Beibu gulf of South China. *PLoS One*, 11(12), e0168951. <https://doi.org/10.1371/journal.pone.0168951>
- Wang, F., Eagle, M., Kroeger, K. D., Spivak, A. C., & Tang, J. (2021). Plant biomass and rates of carbon dioxide uptake are enhanced by successful restoration of tidal connectivity in salt marshes. *The Science of the Total Environment*, 750(141566), 141566. <https://doi.org/10.1016/j.scitotenv.2020.141566>
- Wang, F., Yan, J., Ma, X., Qiu, D., Xie, T., & Cui, B. (2019). Tidal regime influences the spatial variation in trait-based responses of Suaeda salsa and edaphic conditions. *Ecosphere (Washington, D.C.)*, 10(3), e02642. <https://doi.org/10.1002/ecs2.2642>

- Wang, H. (2016). Determining the spatial variability of wetland soil bulk density, organic matter, and the conversion factor between organic matter and organic carbon across coastal Louisiana, USA. *Journal of Coastal Research*, 33(3), 507. <https://doi.org/10.2112/jcoastres-d-16-00014.1>
- Wang, J., Qin, P., & Sun, S. (2007). The flux of chloroform and tetrachloromethane along an elevational gradient of a coastal salt marsh, East China. *Environmental Pollution (Barking, Essex: 1987)*, 148(1), 10–20. <https://doi.org/10.1016/j.envpol.2006.11.016>
- Wang, J., Sun, S., Qin, P., Wang, J., Zhong, C., & Xin, W. (2009). DMS and CH₄ fluxes along an elevational gradient of a coastal salt marsh, East China: Positive correlations. In *2009 3rd international conference on bioinformatics and biomedical engineering*. Presented at the 2009 3rd International Conference on Bioinformatics and Biomedical Engineering (ICBBE). <https://doi.org/10.1109/icbbe.2009.5162654>
- Wang, J., & Wang, J. (2017). *Spartina alterniflora* alters ecosystem DMS and CH₄ emissions and their relationship along interacting tidal and vegetation gradients within a coastal salt marsh in Eastern China. *Atmospheric Environment (Oxford, England: 1994)*, 167, 346–359. <https://doi.org/10.1016/j.atmosenv.2017.08.041>
- Wang, W., Sardans, J., Wang, C., Asensio, D., Bartrons, M., & Peñuelas, J. (2018). Species-specific impacts of invasive plant success on vertical profiles of soil carbon accumulation and nutrient retention in the minjiang river tidal estuarine wetlands of China. *Soil Systems*, 2(1), 5. <https://doi.org/10.3390/soils2010005>
- Wang, X., Hu, M., Ren, H., Li, J., Tong, C., & Musenze, R. S. (2018). Seasonal variations of nitrous oxide fluxes and soil denitrification rates in subtropical freshwater and brackish tidal marshes of the Min River estuary. *The Science of the Total Environment*, 616–617, 1404–1413. <https://doi.org/10.1016/j.scitotenv.2017.10.175>
- Wang, X.-C., Chen, R. F., & Berry, A. (2003). Sources and preservation of organic matter in Plum Island salt marsh sediments (MA, USA): Long-chain n-alkanes and stable carbon isotope compositions. *Estuarine, Coastal and Shelf Science*, 58(4), 917–928. <https://doi.org/10.1016/j.ecss.2003.07.006>
- Wang, Y., Wang, Z.-L., Feng, X., Guo, C., & Chen, Q. (2014). Long-term effect of agricultural reclamation on soil chemical properties of a coastal saline marsh in Bohai Rim, northern China. *PLoS One*, 9(4), e93727. <https://doi.org/10.1371/journal.pone.0093727>
- Ward, M. A., Hill, T. M., Souza, C., Filipczyk, T., Ricart, A. M., Merolla, S., ... Beheshti, K. M. (2021). Blue carbon stocks and exchanges along the California coast. *Biogeosciences*, 18(16), 4717–4732. <https://doi.org/10.5194/bg-18-4717-2021>
- Watson, E. B. (2004). Changing elevation, accretion, and tidal marsh plant assemblages in a South San Francisco Bay tidal marsh. *Estuaries*, 27(4), 684–698. <https://doi.org/10.1007/bf02907653>
- Wei, S., Han, G., Chu, X., Song, W., He, W., Xia, J., & Wu, H. (2020). Effect of tidal flooding on ecosystem CO₂ and CH₄ fluxes in a salt marsh in the Yellow River Delta. *Estuarine, Coastal and Shelf Science*, 232(106512), 106512. <https://doi.org/10.1016/j.ecss.2019.106512>
- Welti, N., Hayes, M., & Lockington, D. (2017). Seasonal nitrous oxide and methane emissions across a subtropical estuarine salinity gradient. *Biogeochemistry*, 132(1–2), 55–69. <https://doi.org/10.1007/s10533-016-0287-4>
- Weston, N. B., Neubauer, S. C., Velinsky, D. J., & Vile, M. A. (2014). Net ecosystem carbon exchange and the greenhouse gas balance of tidal marshes along an estuarine salinity gradient. *Biogeochemistry*, 120(1–3), 163–189. <https://doi.org/10.1007/s10533-014-9989-7>
- Widdows, J., Brinsley, M. D., Pope, N. D., FJ Staff, Bolam, S. G., & Somerfield, P. J. (2006). Changes in biota and sediment erodability following the placement of fine dredged material on upper intertidal shores of estuaries. *Marine Ecology Progress Series*, 319, 27–41. <https://doi.org/10.3354/meps319027>
- Więski, K., Guo, H., Craft, C. B., & Pennings, S. C. (2010). Ecosystem functions of tidal fresh, brackish, and salt marshes on the Georgia coast. *Estuaries and Coasts*, 33(1), 161–169. <https://doi.org/10.1007/s12237-009-9230-4>
- Wigand, C., Roman, C. T., Davey, E., Stolt, M., Johnson, R., Hanson, A., ... Rafferty, P. (2014). Below the disappearing marshes of an urban estuary: Historic nitrogen trends and soil structure. *Ecological Applications*, 24(4), 633–649. <https://doi.org/10.1890/13-0594.1>
- Wills, S. A., Needelman, B. A., & Weil, R. R. (2008). Carbon distribution in restored and reference marshes at Blackwater National Wildlife Refuge. *Archiv Fur Acker- Und Pflanzenbau Und Bodenkunde*, 54(3), 239–248. <https://doi.org/10.1080/03650340701793587>
- Wilson, B. J., Servais, S., Mazzei, V., Kominoski, J. S., Hu, M., Davis, S. E., ... Troxler, T. G. (2018). Salinity pulses interact with seasonal dry-down to increase ecosystem carbon loss in marshes of the Florida Everglades. *Ecological Applications*, 28(8), 2092–2108. <https://doi.org/10.1002/eap.1798>
- Witte, S., & Gianni, L. (2016). Greenhouse gas emission and balance of marshes at the southern North Sea coast. *Wetlands (Wilmington, N.C.)*, 36(1), 121–132. <https://doi.org/10.1007/s13157-015-0722-7>
- Wollenberg, J. T., Ollerhead, J., & Chmura, G. L. (2018). Rapid carbon accumulation following managed realignment on the bay of Fundy. *PLoS One*, 13(3), e0193930. <https://doi.org/10.1371/journal.pone.0193930>
- Xi, M., Zhang, X., Kong, F., Li, Y., Sui, X., & Wang, X. (2019). CO₂ exchange under different vegetation covers in a coastal wetland of Jiaozhou Bay, China. *Ecological Engineering*, 137, 26–33. <https://doi.org/10.1016/j.ecoleng.2018.12.025>
- Xia, S., Song, Z., Li, Q., Guo, L., Yu, C., Singh, B. P., ... Wang, H. (2021). Distribution, sources, and decomposition of soil organic matter along a salinity gradient in estuarine wetlands characterized by C:N ratio, δ¹³C-δ¹⁵N, and lignin biomarker. *Global Change Biology*, 27(2), 417–434. <https://doi.org/10.1111/gcb.15403>
- Xia, S., Wang, W., Song, Z., Kuzyakov, Y., Guo, L., Van Zwieten, L., ... Wang, H. (2021). *Spartina alterniflora* invasion controls organic carbon stocks in coastal marsh and mangrove soils across tropics and subtropics. *Global Change Biology*, 27(8), 1627–1644. <https://doi.org/10.1111/gcb.15516>
- Xiang, J., Liu, D., Ding, W., Yuan, J., & Lin, Y. (2015). Invasion chronosequence of *Spartina alterniflora* on methane emission and organic carbon sequestration in a coastal salt marsh. *Atmospheric Environment (Oxford, England: 1994)*, 112, 72–80. <https://doi.org/10.1016/j.atmosenv.2015.04.035>
- Xiangzhen, Q., Huiyu, L., Zhenshan, L., Xiang, L., & Haibo, G. (2019). Impacts of age and expansion direction of invasive *Spartina alterniflora* on soil organic carbon dynamics in coastal salt marshes along eastern China. *Estuaries and Coasts*, 42(7), 1858–1867. <https://doi.org/10.1007/s12237-019-00611-4>
- Xie, R., Zhu, Y., Li, J., & Liang, Q. (2019). Changes in sediment nutrients following *Spartina alterniflora* invasion in a subtropical estuarine wetland, China. *Catena*, 180, 16–23. <https://doi.org/10.1016/j.catena.2019.04.016>
- Xie, T., Dou, P., Li, S., Cui, B., Bai, J., Wang, Q., & Ning, Z. (2020). Potential effect of bioturbation by burrowing crabs on sediment parameters in coastal salt marshes. *Wetlands (Wilmington, N.C.)*, 40(6), 2775–2784. <https://doi.org/10.1007/s13157-020-01341-1>
- Xiong, J., Sheng, X., Wang, M., Wu, M., & Shao, X. (2022). Comparative study of methane emission in the reclamation-restored wetlands and natural marshes in the Hangzhou Bay coastal wetland. *Ecological Engineering*, 175(106473), 106473. <https://doi.org/10.1016/j.ecoleng.2021.106473>
- Xu, Y., Zhen, Y., Han, S., & Zhang, H. B. (2018). Spatial distribution characteristics of soil organic matter and nitrogen under natural conditions in Yancheng coastal wetlands. *Applied Ecology & Environmental Research*, 16(5), 6917–6925.
- Xue, L., Jiang, J., Li, X., Yan, Z., Zhang, Q., Ge, Z., ... Craft, C. (2020). Salinity affects topsoil organic carbon concentrations through regulating vegetation structure and productivity. *Journal of Geophysical Research Biogeosciences*, 125(1), e2019JG005217. <https://doi.org/10.1029/2019jg005217>
- Xuehui, Z., Zhongsheng, Z., Zhe, L., Min, L., Haitao, W., & Ming, J. (2021). Impacts of *Spartina alterniflora* invasion on soil carbon contents and stability in the Yellow River Delta, China. *The Science of the Total Environment*, 775(145188), 145188. <https://doi.org/10.1016/j.scitotenv.2021.145188>
- Yamochi, S., Tanaka, T., Otani, Y., & Endo, T. (2017). Effects of light, temperature and ground water level on the CO₂ flux of the sediment in the high water temperature seasons at the artificial north salt marsh of Osaka Nanko bird sanctuary, Japan. *Ecological Engineering*, 98, 330–338. <https://doi.org/10.1016/j.ecoleng.2016.09.012>
- Yan, J., Qian, L., Fu, X., Wu, J., Tsang, Y. F., & Wang, L. (2020). Conversion behaviors of litter-derived organic carbon of two halophytes in soil and their influence on SOC stabilization of wetland in the Yangtze River estuary. *The Science of the Total Environment*, 716(137109), 137109. <https://doi.org/10.1016/j.scitotenv.2020.137109>
- Yan, J., Wang, L., Hu, Y., Tsang, Y. F., Zhang, Y., Wu, J., ... Sun, Y. (2018). Plant litter composition selects different soil microbial structures and in turn drives different litter decomposition pattern and soil carbon sequestration capability. *Geoderma*, 319, 194–203. <https://doi.org/10.1016/j.geoderma.2018.01.009>
- Yang, B., Li, X., Lin, S., Jiang, C., Xue, L., Wang, J., ... Mander, Ü. (2021). Invasive *Spartina alterniflora* changes the Yangtze estuary salt marsh from CH₄ sink to source. *Estuarine, Coastal and Shelf Science*, 252(107258), 107258. <https://doi.org/10.1016/j.ecss.2021.107258>
- Yang, B., Li, X., Lin, S., Xie, Z., Yuan, Y., Espenberg, M., ... Mander, Ü. (2020). Invasive *Spartina alterniflora* can mitigate N₂O emission in coastal salt marshes.

- Ecological Engineering*, 147(105758), 105758. <https://doi.org/10.1016/j.ecoleng.2020.105758>
- Yang, D., Miao, X.-Y., Wang, B., Jiang, R.-P., Wen, T., Liu, M.-S., ... Xu, C. (2020). System-specific complex interactions shape soil organic carbon distribution in coastal salt marshes. *International Journal of Environmental Research and Public Health*, 17(6), 2037. <https://doi.org/10.3390/ijerph17062037>
- Yang, H., Tang, J., Zhang, C., Dai, Y., Zhou, C., Xu, P., ... Chen, X. (2020). Enhanced carbon uptake and reduced methane emissions in a newly restored wetland. *Journal of Geophysical Research Biogeosciences*, 125(1), e2019JG005222. <https://doi.org/10.1029/2019jg005222>
- Yang, J., Paytan, A., Yang, Y., Wei, S., Liu, B., Cui, H., ... Zhao, Y. (2020). Organic carbon and reduced inorganic sulfur accumulation in subtropical salt marsh sediments along a dynamic coast, Yancheng, China. *Journal of Marine Systems: Journal of the European Association of Marine Sciences and Techniques*, 211(103415), 103415. <https://doi.org/10.1016/j.jmarsys.2020.103415>
- Yang, P., Hu, Z., & Shu, Q. (2021). Factors affecting soil organic carbon content between natural and reclaimed sites in rudong coast, Jiangsu province, China. *Journal of Marine Science and Engineering*, 9(12), 1453. <https://doi.org/10.3390/jmse9121453>
- Yang, P., Wang, M. H., Lai, D. Y. F., Chun, K. P., Huang, J. F., Wan, S. A., ... Tong, C. (2019). Methane dynamics in an estuarine brackish *Cyperus malaccensis* marsh: Production and porewater concentration in soils, and net emissions to the atmosphere over five years. *Geoderma*, 337, 132–142. <https://doi.org/10.1016/j.geoderma.2018.09.019>
- Yang, R.-M. (2020). Characterization of the salt marsh soils and visible-near-infrared spectroscopy along a chronosequence of *Spartina alterniflora* invasion in a coastal wetland of eastern China. *Geoderma*, 362(114138), 114138. <https://doi.org/10.1016/j.geoderma.2019.114138>
- Yang, R.-M., & Guo, W.-W. (2018). Exotic *Spartina alterniflora* enhances the soil functions of a coastal ecosystem. *Soil Science Society of America Journal. Soil Science Society of America*, 82(4), 901–909. <https://doi.org/10.2136/sssaj2017.12.0411>
- Yang, W., An, S., Zhao, H., Fang, S., Xia, L., Xiao, Y., ... Cheng, X. (2015). Labile and recalcitrant soil carbon and nitrogen pools in tidal salt marshes of the eastern Chinese coast as affected by short-term C4Plant *Spartina alterniflora* invasion. *Clean: Soil, Air, Water*, 43(6), 872–880. <https://doi.org/10.1002/clen.201300846>
- Yang, W., Li, N., Leng, X., Qiao, Y., Cheng, X., & An, S. (2016). The impact of sea embankment reclamation on soil organic carbon and nitrogen pools in invasive *Spartina alterniflora* and native *Suaeda salsa* salt marshes in eastern China. *Ecological Engineering*, 97, 582–592. <https://doi.org/10.1016/j.ecoleng.2016.10.064>
- Yang, W., Xia, L., Zhu, Z., Jiang, L., Cheng, X., & An, S. (2019). Shift in soil organic carbon and nitrogen pools in different reclaimed lands following intensive coastal reclamation on the coasts of eastern China. *Scientific Reports*, 9(1), 5921. <https://doi.org/10.1038/s41598-019-42048-6>
- Yang, W., Yan, Y., Jiang, F., Leng, X., Cheng, X., & An, S. (2016). Response of the soil microbial community composition and biomass to a short-term *Spartina alterniflora* invasion in a coastal wetland of eastern China. *Plant and Soil*, 408(1–2), 443–456. <https://doi.org/10.1007/s11104-016-2941-y>
- Yang, W., Zhao, H., Chen, X., Yin, S., Cheng, X., & An, S. (2013). Consequences of short-term C4 plant *Spartina alterniflora* invasions for soil organic carbon dynamics in a coastal wetland of eastern China. *Ecological Engineering*, 61, 50–57. <https://doi.org/10.1016/j.ecoleng.2013.09.056>
- Yang, W., Zhao, H., Leng, X., Cheng, X., & An, S. (2017). Soil organic carbon and nitrogen dynamics following *Spartina alterniflora* invasion in a coastal wetland of eastern China. *Catena*, 156, 281–289. <https://doi.org/10.1016/j.catena.2017.03.021>
- Yang, W.-B., Yuan, C.-S., Tong, C., Yang, P., Yang, L., & Huang, B.-Q. (2017). Diurnal variation of CO₂, CH₄, and N₂O emission fluxes continuously monitored in situ in three environmental habitats in a subtropical estuarine wetland. *Marine Pollution Bulletin*, 119(1), 289–298. <https://doi.org/10.1016/j.marpolbul.2017.04.005>
- Yao, Z., Du, S., Liang, C., Zhao, Y., Dini-Andreote, F., Wang, K., & Zhang, D. (2019). Bacterial community assembly in a typical estuarine marsh with multiple environmental gradients. *Applied and Environmental Microbiology*, 85(6), e02602-18. <https://doi.org/10.1128/AEM.02602-18>
- Ye, S., Krauss, K. W., Brix, H., Wei, M., Olsson, L., Yu, X., ... Moss, R. F. (2016). Inter-annual variability of area-scaled gaseous carbon emissions from wetland soils in the Liaohe Delta, China. *PLoS One*, 11(8), e0160612. <https://doi.org/10.1371/journal.pone.0160612>
- Yousefi Lalimi, F., Silvestri, S., D'Alpaos, A., Roner, M., & Marani, M. (2018). The spatial variability of organic matter and decomposition processes at the marsh scale. *Journal of Geophysical Research Biogeosciences*, 123(12), 3713–3727. <https://doi.org/10.1029/2017jg004211>
- Yu, J., Dong, H., Li, Y., Wu, H., Guan, B., Gao, Y., ... Wang, Y. (2014). Spatiotemporal distribution characteristics of soil organic carbon in newborn coastal wetlands of the Yellow River delta estuary. *Clean: Soil, Air Water*, 42(3), 311–318. <https://doi.org/10.1002/clen.201100511>
- Yu, O. T., & Chmura, G. L. (2009). Soil carbon may be maintained under grazing in a St Lawrence estuary tidal marsh. *Environmental Conservation*, 36(4), 312–320. <https://doi.org/10.1017/s0376892910000184>
- Yu, Z., Li, Y., Deng, H., Wang, D., Chen, Z., & Xu, S. (2012). Effect of *Scirpus marqueteeron* nitrous oxide emissions from a subtropical monsoon estuarine wetland. *Journal of Geophysical Research*, 117(G2), 2011JG001850. <https://doi.org/10.1029/2011jg001850>
- Yuan, H.-W., Chen, J.-F., Ye, Y., Lou, Z.-H., Jin, A.-M., Chen, X.-G., ... Loh, P. S. (2017). Sources and distribution of sedimentary organic matter along the Andong salt marsh, Hangzhou Bay. *Journal of Marine Systems: Journal of the European Association of Marine Sciences and Techniques*, 174, 78–88. <https://doi.org/10.1016/j.jmarsys.2017.06.001>
- Yuan, H.-W., Loh, P. S., Lin, S.-Y., Hu, X.-Y., Qian, J., Chen, J.-F., ... Jiang, Z.-P. (2017). Sources, distribution, and decomposition stages of sedimentary organic matter in estuaries and its adjacent areas. *Toxicological and Environmental Chemistry*, 99(9–10), 1346–1357. <https://doi.org/10.1080/02772248.2017.1377715>
- Yuan, J., Ding, W., Liu, D., Kang, H., Freeman, C., Xiang, J., & Lin, Y. (2015). Exotic *Spartina alterniflora* invasion alters ecosystem-atmosphere exchange of CH₄ and N₂O and carbon sequestration in a coastal salt marsh in China. *Global Change Biology*, 21(4), 1567–1580. <https://doi.org/10.1111/gcb.12797>
- Yuan, J., Ding, W., Liu, D., Xiang, J., & Lin, Y. (2014). Methane production potential and methanogenic archaea community dynamics along the *Spartina alterniflora* invasion chronosequence in a coastal salt marsh. *Applied Microbiology and Biotechnology*, 98(4), 1817–1829. <https://doi.org/10.1007/s00253-013-5104-6>
- Yuan, Y., Li, X., Jiang, J., Xue, L., & Craft, C. B. (2020). Distribution of organic carbon storage in different salt-marsh plant communities: A case study at the Yangtze estuary. *Estuarine, Coastal and Shelf Science*, 243(106900), 106900. <https://doi.org/10.1016/j.ecss.2020.106900>
- Zhang, C., Liu, W., Guan, M., Wang, J., Pan, X., Ge, Y., & Chang, J. (2019). Nitrous oxide emission rate in response to plant, soil and microbial properties in marshes impacted by alien *Spartina alterniflora*. *Biologia*, 74(9), 1087–1097. <https://doi.org/10.2478/s11756-019-00267-2>
- Zhang, G., Bai, J., Jia, J., Wang, X., Wang, W., Zhao, Q., & Zhang, S. (2018). Soil organic carbon contents and stocks in coastal salt marshes with *Spartina alterniflora* following an invasion chronosequence in the Yellow River delta, China. *Chinese Geographical Science*, 28(3), 374–385. <https://doi.org/10.1007/s11769-018-0955-5>
- Zhang, G., Bai, J., Xi, M., Zhao, Q., Lu, Q., & Jia, J. (2016). Soil quality assessment of coastal wetlands in the Yellow River Delta of China based on the minimum data set. *Ecological Indicators*, 66, 458–466. <https://doi.org/10.1016/j.ecolind.2016.01.046>
- Zhang, G., Bai, J., Zhao, Q., Jia, J., Wang, W., & Wang, X. (2020). Bacterial succession in salt marsh soils along a short-term invasion chronosequence of *Spartina alterniflora* in the Yellow River estuary, China. *Microbial Ecology*, 79(3), 644–661. <https://doi.org/10.1007/s00248-019-01430-7>
- Zhang, G., Bai, J., Zhao, Q., Jia, J., Wang, X., Wang, W., & Wang, X. (2021). Soil carbon storage and carbon sources under different *Spartina alterniflora* invasion periods in a salt marsh ecosystem. *Catena*, 196(104831), 104831. <https://doi.org/10.1016/j.catena.2020.104831>
- Zhang, P., Yang, Z., & Wu, J. (2021). Livestock grazing promotes ecosystem multifunctionality of a coastal salt marsh. *The Journal of Applied Ecology*, 58(10), 2124–2134. <https://doi.org/10.1111/1365-2664.13957>
- Zhang, S., Wang, L., Hu, J., Zhang, W., Fu, X., Le, Y., & Jin, F. (2011). Organic carbon accumulation capability of two typical tidal wetland soils in Chongming Dongtan, China. *Journal of Environmental Sciences (China)*, 23(1), 87–94. [https://doi.org/10.1016/s1001-0742\(10\)60377-4](https://doi.org/10.1016/s1001-0742(10)60377-4)
- Zhang, Y., Ding, W., Luo, J., & Donnison, A. (2010). Changes in soil organic carbon dynamics in an eastern Chinese coastal wetland following invasion by a C4 plant *Spartina alterniflora*. *Soil Biology & Biochemistry*, 42(10), 1712–1720. <https://doi.org/10.1016/j.soilbio.2010.06.006>
- Zhang, Y., Li, Y., Wang, L., Tang, Y., Chen, J., Hu, Y., ... Le, Y. (2013). Soil microbiological variability under different successional stages of the Chongming Dongtan wetland and its effect on soil organic carbon storage. *Ecological Engineering*, 52, 308–315. <https://doi.org/10.1016/j.ecoleng.2012.10.002>

- Zhao, Q., Bai, J., Gao, Y., Zhao, H., Huang, Y., Zhang, W., ... Chen, G. (2019). Effects of freshwater inputs on soil quality in the Yellow River Delta, China. *Ecological Indicators*, 98, 619–626. <https://doi.org/10.1016/j.ecolind.2018.11.041>
- Zhao, Q., Bai, J., Wang, X., Zhang, W., Huang, Y., Wang, L., & Gao, Y. (2020). Soil organic carbon content and stock in wetlands with different hydrologic conditions in the Yellow River Delta, China. *International Journal of Ecohydrology & Hydrobiology*, 20(4), 537–547. <https://doi.org/10.1016/j.ecohyd.2019.10.008>
- Zhao, Q., Bai, J., Zhang, G., Jia, J., Wang, W., & Wang, X. (2018). Effects of water and salinity regulation measures on soil carbon sequestration in coastal wetlands of the Yellow River Delta. *Geoderma*, 319, 219–229. <https://doi.org/10.1016/j.geoderma.2017.10.058>
- Zhou, C., Zhao, H., Sun, Z., Zhou, L., Fang, C., Xiao, Y., ... An, S. (2015). The invasion of *Spartina alterniflora* Alters carbon dynamics in China's Yancheng natural reserve. *Clean: Soil, Air Water*, 43(2), 159–165. <https://doi.org/10.1002/clean.201300839>
- Zhou, H.-X., Liu, J.-E., Zhou, J., & Qin, P. (2008). Effect of an alien species *Spartina alterniflora* Loisel on biogeochemical processes of intertidal ecosystem in the Jiangsu coastal region, China. *Pedosphere*, 18(1), 77–85. [https://doi.org/10.1016/s1002-0160\(07\)60105-2](https://doi.org/10.1016/s1002-0160(07)60105-2)
- Zhou, J., Wu, Y., Zhang, J., Kang, Q., & Liu, Z. (2006). Carbon and nitrogen composition and stable isotope as potential indicators of source and fate of organic

- matter in the salt marsh of the Changjiang estuary, China. *Chemosphere*, 65(2), 310–317. <https://doi.org/10.1016/j.chemosphere.2006.02.026>
- Zhou, S., & Bi, X. (2020). Seawall effects in a coastal wetland landscape: Spatial changes in soil carbon and nitrogen pools. *Journal of Coastal Conservation*, 24(1), 11. <https://doi.org/10.1007/s11852-019-00718-7>

SUPPORTING INFORMATION

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