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Research Article

# Spatiotemporal Distribution Characteristics of Soil Organic Carbon in Newborn Coastal Wetlands of the Yellow River Delta Estuary

The distribution and seasonal variation of soil organic carbon (SOC) in newborn coastal wetland of the Yellow River Delta (YRD) estuary at eastern China were studied based on monitoring data in 2009 at two transects from the bank of the Yellow River to the seaside. The results showed that SOC contents of 0–60 cm soil layer in transects ranged from 0.46 to 10.15 $\mathrm{g\,kg^{-1}}$ and average values of soil profiles ranged from 2.15 to 5.00 $\mathrm{g\,kg^{-1}}$. The SOC contents tended to increase from the river flood land to the salt beach, which could be accounted for the organic matters including large algae, the bodies and excretion of marine animals due to the feedback of tides. The significant difference of SOC contents at different vegetation communities was observed, while the difference of SOC in soil profiles was not obvious. The SOC contents in 0–30 cm soil layers decreased with plant growth period, while in 40–60 cm soil layers were relatively stable. The mean soil organic carbon density was 3.05 $\mathrm{kg\,C\,m^{-2}}$ in study region, which was much lower than that reported in other ecosystems, and its spatiotemporal variations were consistent with that of SOC content. Further analysis revealed that SOC was positively correlated with total nitrogen and clay contents. Our findings indicated that the newborn coastal wetland in the YRD should be a potential sink of SOC.

**Keywords:** Coastal wetland; Soil organic carbon; Spatiotemporal distribution; Yellow River Delta

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## 1 Introduction

Soil organic carbon (SOC) plays an important role in global carbon cycle and global change, as it is the largest terrestrial carbon pool. It can act as a source or a sink of atmospheric carbon, whereby it can indicate the climate change as a sensible indicator of climate [1]. The world's soils represent a large reservoir of carbon of about 1500 PgC [2–4], and it is as much as two to three times more than in living vegetation [5]. Natural wetlands are significant carbon reservoirs [6]. SOC is not only the important components of wetland soils, but also the ecological factors that greatly influence the productivity of wetland ecosystem [7]. Because SOC dynamics are tightly coupled to the biogeochemical cycles of nitrogen in wetland soils by the processes of decomposition, mineralization, and plant uptake [8], the studies about SOC in wetlands were paid more attention by ecologists and environmental scientists [9–14].

The Yellow River Delta (YRD), which is the youngest natural coastal wetland ecosystems and well protected for the important habitat, breeding, or stopover place for the birds in China, is one of the most intensive land–ocean interaction regions among the large river deltas in the world [15]. The typical characteristics of the YRD are rapid deposit and fast evolution because the sediment load delivered into the sea accounts for 6% of the global rivers sediment load into the sea [16]. Thus the Yellow River is regarded as the largest contributor of fluvial sediment load to the ocean in the world [17]. The net increase of delta shoreline length was ~61.64 km with annual increase of ~1.81 km, and net extension of area was ~309.81 $\mathrm{km^2}$ with rate of ~9.11 $\mathrm{km^2\,year^{-1}}$ in the duration of 1976–2009 [18]. For the past few years, there are many studies which focus on the landscape pattern [5, 19–22], biodiversity conservation [23, 24], ecological restoration [25], and wetland evolution [15, 26] of the YRD. It is the first time to estimate the vegetation carbon storage in YRD using Landsat Thematic Mapper (TM) data in 2002 [27]. Zhang et al. estimated that the carbon sequestration of trees were 222.41 $\mathrm{t\,ha^{-1}}$ and carbon storage by herbaceous matter and soil was 0.50 and 50.34 $\mathrm{t\,ha^{-1}}$ for the YRD region [28]. Unfortunately, only several field results about the nutriment elements biogeochemical cycles in this area have been reported so far [25, 27, 29, 30]. Cui et al. found that soil quality was constantly improved through salinity reduction and soil organic matter accumulation in the restored wetland in the YRD since 2001 and suggested that the contribution of harvesting vegetation to stabilizing nutrient removal rate and the accumulation of soil organic matter in the soil were a remaining issue for future

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**Abbreviations:** **BD**, bulk density; **EC**, electrical conductivity; **SOC**, soil organic carbon; **SOCD**, soil organic carbon density; **TN**, total nitrogen; **YRD**, Yellow River Delta study [25]. Wang et al. found that the SOC and C:N ratio of the soil were significantly increased in the degraded coastal wetlands treated with freshwater in the YRD, indicating that freshwater addition and the concomitant increase in soil moisture content enhances the accumulation of SOC. However, there is a lack of studies on the SOC content in newborn wetland in the YRD. In this study, we present field results of SOC in tidal flat wetlands of the YRD. Our purposes were: (a) to study the contents and distribution of SOC in tidal flat wetlands of the YRD; (b) to illuminate the impacts of soil pH, electrical conductivity (EC), total nitrogen (TN) contents, and clay contents on SOC distribution in a coastal wetland.

## 2 Materials and methods

### 2.1 Study area

The studied region is located in the YRD Natural Reserves, which established in 1992 to preserve the habit for birds and unique coastal wetland ecosystems, at 37°35′–38°12′N, 118°33′–119°20′E between the Bohai gulf and the Laizhou gulf in eastern China (Fig. 1). It is one of the most active regions of land-ocean interaction among the large river deltas in the world. It is estimated that about 1300 ha territory land is formed here annually. A total of 1524 kinds of wild animals including over 200 migratory bird species have been recorded in the region. Among them, 10 species are listed as Class I of national protection wildlife such as red-crowned crane (*Grus japonensis*) and oriental white stork (*Ciconia boyciana*), and 49 species as Class II.

A total of 400 plant species including 116 seed plants are recorded in the reserve covered by natural saline vegetation with 55.1% vegetation coverage [31]. The YRD has clear horizontal distribution vegetation zones of ecosystems with the changes in soil salinity from seaside to inland (Fig. 1). The climate of this region is characterized by a warm temperate continental monsoon climate with a typical rainfall season in June, July, and August. The mean annual temperature is about 12.1°C and the average annual precipitation is 551.6 mm. The frost-free period is about 196 days. The main soil types are Solonchak and Fluvisols (FAO).

### 2.2 Soil sampling and analysis methods

SOC distribution in the YRD was studied in 2009. Two transects were set from the bank of the Yellow River to the seaside in newborn coastal wetland, which formed since 1976 (Fig. 1). Based on vegetation community, ten soil sampling plots were chosen in each transect. The characteristics of sampling plots in study site were shown in Tab. 1. In each plot, three replicates soil samples from six different depths (0–10, 10–20, 20–30, 30–40, 40–50, and 50–60 cm) were collected in May, August, September, and November of 2009, respectively, with a total number of 360 samples collected at each sampling time. The air dried soil samples were kept in sealed plastic bags at 5°C to limit the microorganism activities until the time of the SOC and other soil physical and chemical properties analysis after sieved through a 2 mm coarse stainless steel sieve. Roots as well as other organic matters were removed to homogenize the sample.

SOC and TN were determined by Total Organic Carbon Analyzer (TOC-V$_{\mathrm{CPH}}$, Shimadzu, Japan) and Continuous Flow Analyzer (SKALAR-SAN$^{++}$, Netherlands), respectively. Grain size was measured by laser particle analyzer (Marlvern Mastersizer 2000F). Soil pH and EC values were measured with electricity conduction method (soil/water = 1:5). Cutting ring was used to measure soil bulk density (BD).

Soil organic carbon density (SOCD) was calculated as:

$$\mathrm{SOCD} = \mathrm{SOC} \times \mathrm{BD} \times H \times 0.01 \qquad (1)$$

where SOCD is the soil organic carbon density (kg m$^{-2}$), SOC the soil organic carbon content (g kg$^{-1}$), BD the soil bulk density (g cm$^{-3}$), and $H$ is the soil layer height (cm).

### 2.3 Statistical analysis

One-way analysis of variance analysis (ANOVA) was used to test the difference of SOC contents among the ten sampling plots and the depths (differences considered significant if $p < 0.05$). Pearson correlation coefficients were computed to analyze relationships among SOC, TN, pH values, EC, and clay contents. Analysis and figures were

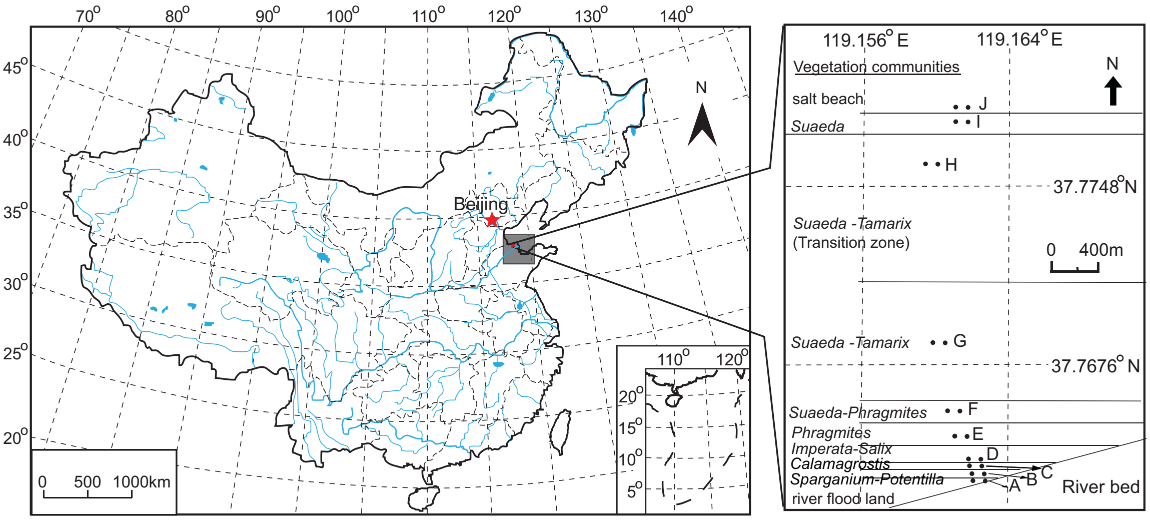

**Figure 1.** The location of study region and sampling sites.

**Table 1.** The characteristics of sampling sites in transects

| Sites | Location | Belts width (m) | Vegetation communities | Soil type |
|---|---|---|---|---|
| A | N37°45′47.7″, E119°09′45.2″ | 15 | None river flood land | Sand and loamy sand |
| B | N37°45′48.3″ E 119°09′45.0″ | 28 | *Sparganium stoloniferum* Buch.-Ham. – *Potentilla supina* Linn. | Sand and loamy sand |
| C | N37°45′49.3″ E119°09′44.6″ | 29 | *Calamagrostis pseudophragmites* (Hall. F.) Koel. | Sand and loamy sand/sandy loam |
| D | N37°45′50.3″ E119°09′43.4″ | 24 | *Imperata cylindrica* (Linn.) Beauv. – *Salix matsudana* Koidz. | Sand and loamy sand/sandy loam |
| E | N37°45′51.5″ E119°09′42.9″ | 72 | *Phragmites communis* Trin. | Sandy loam/silty loam |
| F | N37°45′53.6″ E119°09′42.0″ | 184 | *Suaeda heteroptera* Kitag. – *Phragmites communis* Trin. | Sandy loam/loam |
| G | N37°45′57.0″ E119°09′40.7″ | 1202 | *Suaeda heteroptera* Kitag. – *Tamarix chinensis* Lour. | Sandy loam/silty loam |
| H | N37°46′35.8″ E119°09′36.0″ | 163 | *Suaeda heteroptera* Kitag. – *Tamarix chinensis* Lour. (Transition zone) | Sandy loam/loam |
| I | N37°46′38.9″ E119°09′41.4″ | 68 | *Suaeda heteroptera* Kitag. | Loam/silty loam |
| J | N37°46′41.1″ E119°09′41.3″ | 600 | None (salt beach) | Silty loam |

conducted using SPSS 10.0 statistical package (Lead Technologies, USA) and Origin 8.0 software package (OriginLab, USA), respectively.

## 3 Results

### 3.1 The spatiotemporal distribution characteristics of SOC

The SOC contents of 0–60 cm soil depth for ten types of vegetation communities (sampling sites) varied with soil depth (Fig. 2A). The SOC contents ranged from 0.46 to 10.15 g $kg^{-1}$ in study area, and average values of soil profiles ranged from 2.15 to 5.00 g $kg^{-1}$. As shown in Fig. 2A, the average SOC contents in studied sites tended to increase from the river flood land (A spot) to the salt beach (J spot). The highest mean SOC contents were observed in I and J sites, while the lowest value was found in site A.

In each vertical soil profile, SOC appeared different distribution pattern among different vegetation community. The SOC content change with soil layer in studied sites was not obvious. The highest SOC contents were found in 0–10 cm layer in soil profile of sites A, B, D, F, or J and variations of profile SOC content decreased with depth were observed in sites A, B, and J. There was a small SOC accumulation peak at soil layer of 40–50 cm in sites E and I. There were two SOC peaks of soil layer of 50–60 and 20–30 cm at sites of G and H. Additionally, no significant changes of SOC content at bottom layer (50–60 cm) were found in all study sites. Furthermore, significant difference of SOC contents at different soil depths did not observed ($p \geq 0.05$), while there were significant differences among the soils in different vegetation communities ($p < 0.01$).

The average SOC content in studied sites reduced radically with time in plant growth period (Fig. 2B). The mean SOC contents were about 4.13, 3.96, 3.60, and 3.35 g $kg^{-1}$ in May, August, September, and November, respectively. The mean SOC contents in soil layers of 0–10, 10–20, and 20–30 cm in study sites decreased with plant growth period, while the seasonal variation of those in the subsoil layers of 40–50 and 50–60 cm were not obvious, which was confirmed by one-way ANOVA analysis with statistical significance larger than 0.05.

### 3.2 Soil organic carbon density

The amount of organic carbon per square meter of soil (kg $m^{-2}$) in 0–60 cm soils was calculated by Eq. (1). The spatiotemporal changes of 0–60 cm SOCD in coastal wetlands of the YRD were shown in Fig. 3. SOCD varied with vegetation type and growing seasons

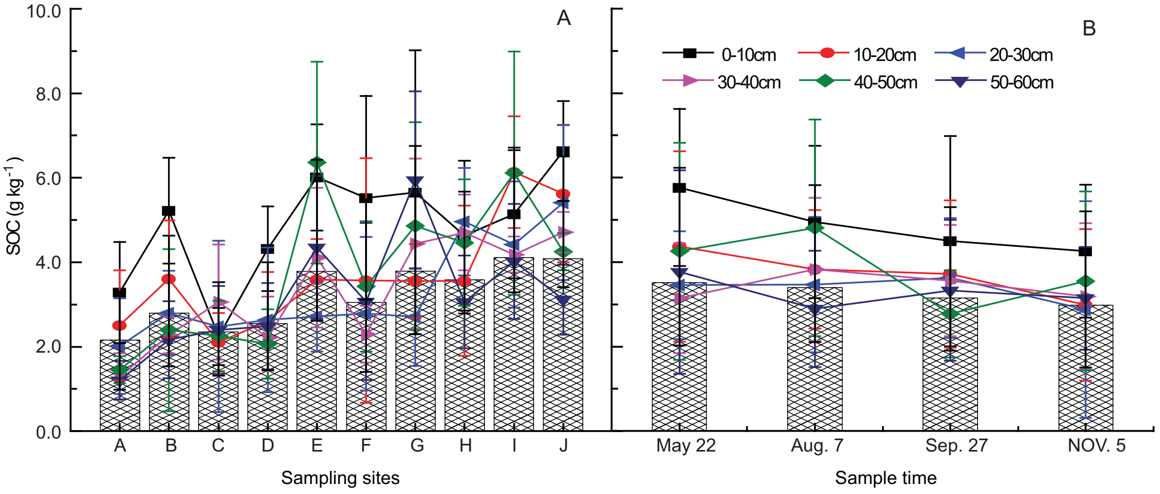

**Figure 2.** The spatiotemporal distribution characteristics of SOC, the column stands for mean values, and standard deviation is indicated by error bar.

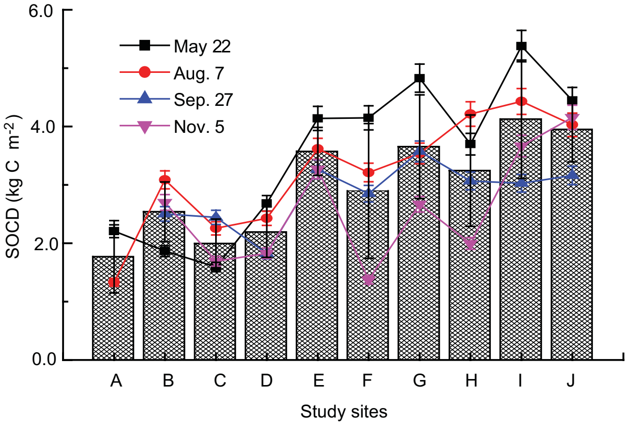

**Figure 3.** The spatiotemporal changes of 0–60 cm SOCD in coastal wetlands of YRD, the column stands for mean values, and the standard deviation is indicated by error bar.

apparently. The SOCD summed on a pit basis ranges from 2.202 to 5.374 kg C m$^{-2}$ in May, 1.327 to 4.425 kg C m$^{-2}$ in August, 1.82 to 3.569 kg C m$^{-2}$ in September, and 1.367 to 4.152 kg C m$^{-2}$ in November, and the average was 3.053 kg C m$^{-2}$. Among the vegetation types, the mean SOCD in site I was remarkably higher than that at other sites. For sites A, D, E, F, G, and I, the seasonal variations of SOCD appeared a decrease trend with time of plant growth period. The highest values of SOCD were 3.08 and 4.21 kg C m$^{-2}$ for sites B and H in August, respectively. The highest and the lowest SOCD for site C was occurred in September and May, respectively. Furthermore, the SOCD at site J was significantly greater than most of the studied sites. The statistical results showed that the difference of SOCD at different growing seasons was significant ($p < 0.05$).

## 3.3 The distribution of soil TN, pH, EC, BD, and grain size

The TN showed similar spatial patterns with the SOC across the studied sites and it ranged from 70.5 to 769.8 mg kg$^{-1}$ (Fig. 4A). The salinity (represented by EC) increased obviously from site A to site J (Fig. 4B), while the pH values ranged from 8.43 to 9.47 had an opposite changes from river flood land to salt beach (Fig. 4C). The mean soil BD in the study sites was about 1.37 g cm$^{-3}$ and similar values was observed in different sampling sites (Fig. 4D). The grain size of 0–60 cm soils was shown in Tab. 2. The measurement results of size distribution of individual particles showed that the silt (4–63 μm) was predominant for sampling soils, which accounted for 60.12–84.69% of the particles in the zones. The clay content (<4 μm) was <27%, and none in the bottom soil layers of A (river flood land). Moreover, the individual particles tended to become coarser from the salt beach (J) to the river flood land (A).

# 4 Discussion

Generally, there are two predominant sources of the SOC in the tidal flat wetland, one is the decomposition of animal and plant residues [32, 33], and the other comes from the sea and river [34, 35]. In our study, we found the SOC contents gradually increase from the river bank to the coastal beach (Fig. 2A), indicating that the SOC in newborn wetland of the YRD possibly came from materials by tide. As we

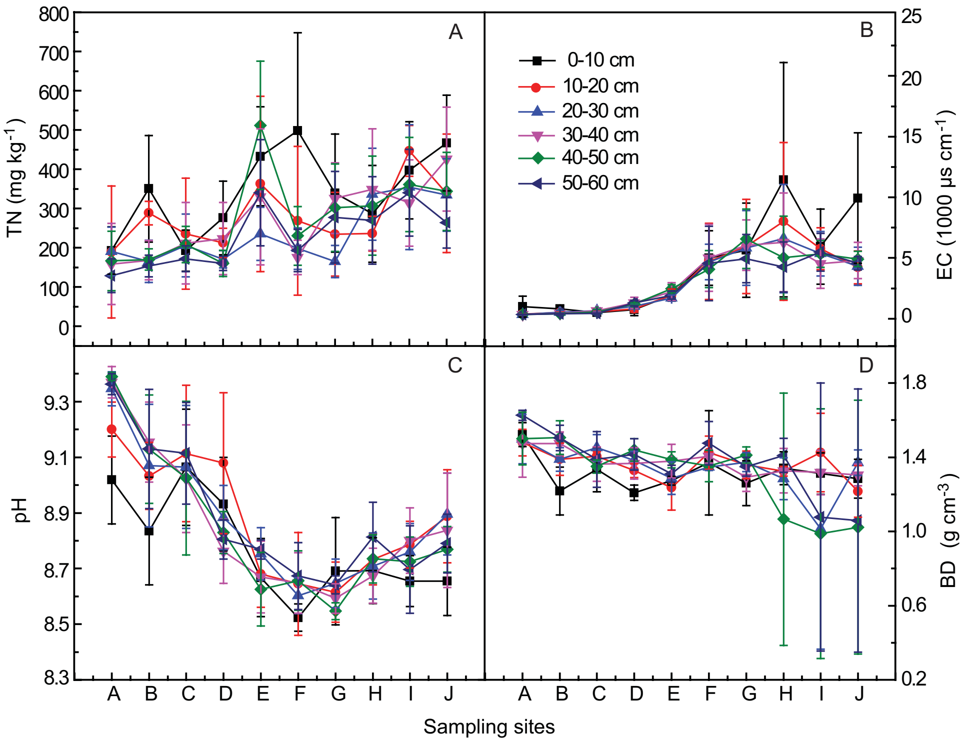

**Figure 4.** The distributions of soil TN, EC, pH, and BD in study sites, vertical bar stands for standard deviation.

**Table 2.** The size distribution of individual particles of 0–60 cm soil layers in sampling sites of coastal wetland of YRD

| Sites | | Sand >63.00 μm | Silt 4.00–63.00 μm | Clay <4.00 μm |
|---|---|---|---|---|
| A | 0–10 | 36.25 ± 0.15 | 60.98 ± 0.12 | 2.77 ± 0.02 |
| | 10–20 | 44.92 ± 0.74 | 52.90 ± 0.51 | 2.18 ± 0.24 |
| | 20–30 | 56.66 ± 0.18 | 41.53 ± 0.17 | 1.81 ± 0.01 |
| | 30–40 | 64.31 ± 0.17 | 35.69 ± 0.17 | 0.00 |
| | 40–50 | 72.39 ± 0.07 | 27.61 ± 0.07 | 0.00 |
| | 50–60 | 63.85 ± 0.10 | 36.15 ± 0.10 | 0.00 |
| B | 0–10 | 17.19 ± 0.26 | 77.88 ± 0.25 | 4.94 ± 0.02 |
| | 10–20 | 11.05 ± 0.14 | 84.69 ± 0.14 | 4.27 ± 0.02 |
| | 20–30 | 26.03 ± 0.25 | 70.19 ± 0.23 | 3.79 ± 0.02 |
| | 30–40 | 34.52 ± 0.51 | 62.66 ± 0.25 | 2.82 ± 0.36 |
| | 40–50 | 37.23 ± 0.10 | 60.12 ± 0.10 | 2.65 ± 0.01 |
| | 50–60 | 50.61 ± 0.74 | 47.29 ± 0.51 | 2.11 ± 0.23 |
| C | 0–10 | 8.76 ± 0.71 | 80.89 ± 0.59 | 10.35 ± 0.15 |
| | 10–20 | 8.84 ± 0.32 | 81.76 ± 0.31 | 9.40 ± 0.04 |
| | 20–30 | 17.04 ± 0.52 | 78.65 ± 0.14 | 4.30 ± 0.50 |
| | 30–40 | 27.53 ± 0.17 | 69.00 ± 0.17 | 3.48 ± 0.01 |
| | 40–50 | 31.69 ± 0.35 | 65.69 ± 0.19 | 2.62 ± 0.30 |
| | 50–60 | 30.69 ± 0.20 | 66.64 ± 0.18 | 2.67 ± 0.02 |
| D | 0–10 | 13.15 ± 1.09 | 79.87 ± 0.99 | 6.99 ± 0.10 |
| | 10–20 | 26.15 ± 0.14 | 70.12 ± 0.13 | 3.73 ± 0.02 |
| | 20–30 | 27.54 ± 0.07 | 69.85 ± 0.07 | 2.61 ± 0.01 |
| | 30–40 | 13.73 ± 0.21 | 77.91 ± 0.19 | 8.36 ± 0.06 |
| | 40–50 | 27.17 ± 0.16 | 70.14 ± 0.15 | 2.70 ± 0.01 |
| | 50–60 | 35.84 ± 0.16 | 61.74 ± 0.17 | 2.42 ± 0.01 |
| E | 0–10 | 7.30 ± 0.94 | 79.29 ± 0.94 | 13.41 ± 0.04 |
| | 10–20 | 11.94 ± 0.15 | 78.52 ± 0.13 | 9.55 ± 0.09 |
| | 20–30 | 4.03 ± 0.08 | 75.74 ± 0.04 | 20.23 ± 0.05 |
| | 30–40 | 5.29 ± 0.20 | 79.98 ± 0.09 | 14.73 ± 0.15 |
| | 40–50 | 14.06 ± 0.13 | 81.28 ± 0.57 | 4.66 ± 0.46 |
| | 50–60 | 9.11 ± 0.07 | 84.15 ± 0.09 | 6.74 ± 0.04 |
| F | 0–10 | 8.58 ± 0.62 | 77.97 ± 0.53 | 13.46 ± 0.09 |
| | 10–20 | 18.32 ± 0.04 | 78.21 ± 0.04 | 3.48 ± 0.01 |
| | 20–30 | 21.28 ± 0.22 | 75.30 ± 0.23 | 3.42 ± 0.37 |
| | 30–40 | 21.26 ± 0.37 | 74.11 ± 0.12 | 4.62 ± 0.44 |
| | 40–50 | 29.35 ± 0.14 | 65.66 ± 0.12 | 4.98 ± 0.03 |
| | 50–60 | 37.10 ± 0.20 | 59.67 ± 0.19 | 3.23 ± 0.04 |
| G | 0–10 | 1.42 ± 0.05 | 78.64 ± 0.12 | 19.94 ± 0.07 |
| | 10–20 | 12.83 ± 0.07 | 81.07 ± 0.04 | 6.10 ± 0.03 |
| | 20–30 | 7.49 ± 0.13 | 79.15 ± 0.16 | 13.36 ± 0.23 |
| | 30–40 | 5.22 ± 0.26 | 75.38 ± 0.07 | 19.40 ± 0.19 |
| | 40–50 | 14.40 ± 0.41 | 79.70 ± 0.52 | 5.91 ± 0.65 |
| | 50–60 | 12.50 ± 0.76 | 82.41 ± 0.34 | 5.10 ± 0.60 |
| H | 0–10 | 21.03 ± 0.21 | 74.53 ± 0.18 | 4.44 ± 0.04 |
| | 10–20 | 7.72 ± 0.56 | 78.15 ± 0.70 | 14.12 ± 1.25 |
| | 20–30 | 10.89 ± 0.55 | 78.47 ± 0.52 | 10.64 ± 0.85 |
| | 30–40 | 12.77 ± 0.09 | 80.33 ± 0.08 | 6.89 ± 0.02 |
| | 40–50 | 13.76 ± 1.69 | 71.17 ± 2.10 | 15.07 ± 0.76 |
| | 50–60 | 18.68 ± 0.35 | 71.44 ± 0.31 | 9.88 ± 0.04 |
| I | 0–10 | 8.80 ± 0.53 | 75.74 ± 0.77 | 15.46 ± 1.09 |
| | 10–20 | 1.67 ± 0.46 | 73.60 ± 0.39 | 24.73 ± 0.35 |
| | 20–30 | 5.79 ± 0.85 | 79.26 ± 1.36 | 14.95 ± 0.53 |
| | 30–40 | 7.57 ± 0.56 | 77.10 ± 0.21 | 15.33 ± 0.38 |
| | 40–50 | 4.33 ± 0.53 | 73.84 ± 0.30 | 21.83 ± 0.27 |
| | 50–60 | 6.20 ± 1.04 | 79.02 ± 0.69 | 14.78 ± 0.36 |
| J | 0–10 | 2.40 ± 0.16 | 79.27 ± 0.12 | 18.33 ± 0.21 |
| | 10–20 | 4.72 ± 0.53 | 79.91 ± 0.29 | 15.36 ± 0.27 |
| | 20–30 | 6.13 ± 0.25 | 72.57 ± 0.22 | 21.30 ± 0.05 |
| | 30–40 | 2.45 ± 0.24 | 71.52 ± 0.23 | 26.03 ± 0.02 |
| | 40–50 | 5.54 ± 0.31 | 80.62 ± 0.39 | 13.84 ± 0.39 |
| | 50–60 | 7.18 ± 0.35 | 79.11 ± 0.30 | 13.72 ± 0.05 |

observed in the newborn coastal wetland in the YRD, there were many large algae, the bodies, and excretion of marine animals. We thought it was why the SOC contents tended to increase from the river flood land to the salt beach. Furthermore, we observed that the saltiness (EC) gradually increased from the river bank to the coastal beach (Fig. 4B) and showed the similar distribution with SOC content (Fig. 2A). There was a significant positive relation ($p < 0.05$) between saltiness and SOC (Tab. 3), supporting previous point of the

**Table 3.** Matrix of correlation coefficient between pH values, TN, BD, clay contents, and SOC in coastal wetlands of YRD

| | Correlations | | | | | |
|---|---|---|---|---|---|---|
| | SOC | TN | BD | EC | pH | Clay contents |
| SOC | 1 | | | | | |
| TN | 0.698[a)] | 1 | | | | |
| BD | −0.250[a)] | −0.243[a)] | 1 | | | |
| EC | 0.348[a)] | 0.139[b)] | −0.162[b)] | 1 | | |
| pH | −0.453[a)] | −0.336[a)] | 0.216[a)] | −0.560[a)] | 1 | |
| Clay contents | 0.465[a)] | 0.504[a)] | −0.009 | 0.612[a)] | −0.624[a)] | 1 |

[a)] Correlation is significant at the 0.01 level (2-tailed).
[b)] Correlation is significant at the 0.05 level (2-tailed).

SOC in study sites related with materials from tide. Although the Yellow River flood could bring the deposit of nutrients and sands, the highest value of mean SOC content did not appear in A area but in E area. This might be explained by the fact that the vegetation cover and the amount of plant residues inputs were different within the five sites of A to E. The SOC contents ranged from 0.46 to 10.15 $g\,kg^{-1}$ in the studied area, which were similar with previous studied results in the 0–20 cm soil layer of $6.89 \pm 0.63\,g\,kg^{-1}$ in *Suaeda salsa* plant community, $4.11 \pm 0.12\,g\,kg^{-1}$ in *Phragmites communis* plant community and $1.40 \pm 0.31\,g\,kg^{-1}$ in the *Tamarix chinensis* plant community in restored coastal wetland in the YRD [30]. Compared with other coastal wetlands, SOC in the YRD was much lower than that in Louisiana coastal wetlands, Plum Island salt marshes, the Mai Po Marshes coastal wetland, and the Quanzhou Bay coastal wetlands and it was similar with Sundarban mangrove wetlands and other Chinese coastal wetlands (Tab. 4). Since the sediment in the YRD came from Loess Plateau by long transportation via the Yellow River, the major nutrients such as carbon and nitrogen were lost during the long transportation. That is why the SOC content is low in the YRD. The second reason is that the formation of coastal wetland in the YRD is less than 35 years (1976–2009). Therefore the return of plants with low productivity to the soil is weak in this region. These results indicated that the newborn coastal wetland in the YRD should be a potential sink of SOC.

As a major source of soil organic matter, plant litter inputs were significantly correlated positively with SOC contents ($p < 0.01$) [36]. The vegetation, through root shoot ratio and its vertical root distribution, affects the SOC content and vertical distribution [32]. The vegetation can change the surrounding environment such as soil moisture, pH value, and soil mechanical components to influence the SOC contents [37]. Therefore, plant functional type could remarkably alter the vertical distribution of SOC. We observed that SOC in the soil profile appeared different distribution pattern among different vegetation community areas (Fig. 2B). The relative high SOC content in reed area (site E) was deeper than other study sites because of its well-developed root system (up to 100 cm). Besides reed, the vegetation root of the studied sites was shallow, mainly distributed in soil layer of 0–30 cm. Therefore, the SOC contents in topsoil layers were higher than that in subsoil layers for most of sampling sites and the SOC contents were relative stable in bottom layer soils (Fig. 2A). During plant growth period, because a portion of plant litter returned to soil surface, the mean SOC contents in soil layers of 0–30 cm in study sites decreased with plant growth period, but the seasonal variation of those in the subsoil layers were not obvious (Fig. 2B). It is noteworthy that the studied area is a newborn wetland. Therefore, the low amount of plant litter inputs and the loss of plant residues by tide caused the difference of SOC contents in different plant growth seasons.

**Table 4.** SOC content of different coastal wetlands

| Wetland | SOC ($g\,kg^{-1}$) | Reference |
|---|---|---|
| Hangzhou Bay coastal wetlands | 4.41–8.58 | [41] |
| Changjiang Estuary salt marshes | 0.70–8.00 | [42] |
| Quanzhou Bay coastal wetlands | 9.39–20.57 | [43] |
| Yancheng tidal flat | 1.67–20.0 | [44] |
| Yancheng coastal wetland | 1.71–7.92 | [45] |
| The Mai Po Marshes coastal wetland | 19.20–23.30 | [46] |
| Plum Island salt marshes | 13.70–51.00 | [33] |
| Sundarban mangrove wetland | 0.40–10.40 | [47] |
| Louisiana coastal wetlands | 41.70–371.00 | [48] |
| Yellow River Delta wetlands | 0.46–10.15 | This study |

One of the sources of nitrogen in the natural soils is from the decomposition and mineralization of organic matters [8]. We also found that the TN showed a similar spatial change patterns with the SOC across the studied sites (Fig. 4A) and there was a significant relationship between TN and SOC in the study (Tab. 3). Soil pH can affect microbial activity in soils. Microbial activity is optimum in the range of pH 6–8, and would be inhibited in the alkali condition [38]. While the significant negative correlation between soil pH values and SOC contents were observed in our study (Tab. 3), although the soil pH values ranged from 8.43 to 9.47, indicating that the microbial activities could still affect the contents and spatial distributions of SOC in studied wetland soils. The clay contents (<4 μm) with large surface area can absorb SOC easily and protect SOC [39]. Therefore, area with high clay contents had high SOC content. To agree with this point, since we observed that the clay content was low (less than 27%) in the studied region and mainly distributed at salt beach (Tab. 2), the SOC content was low in the studied area and relatively high SOC content was monitored at salt beach (Fig. 2). It was confirmed by the significantly positive relation between SOC and clay contents as shown in Tab. 3.

Soils contain a huge and dynamic pool of carbon, that is a critical regulator of the global carbon cycle [40]. The SOCD is an indispensable parameter for SOC stock estimation in ecosystems. The average 0–60 cm SOCD in study area was $3.05\,kg\,C\,m^{-2}$, which was much lower than that in freshwater wetlands, forest, steppe, meadow, and cropland, but similar with the value in salt marsh (Tab. 5). Furthermore, we found that the seasonal variation of SOCD appeared a decrease trend with time of plant growth

**Table 5.** The SOCD of different biomes

| Biome | SOCD ($\mathrm{kg\,C}^{-2}$) | Depth (cm) | Reference |
|---|---|---|---|
| Daxing'anling wetlands | 11.90–36.60 | 0–50 | [49] |
| Shengjin Lake wetland | 10.82 ± 1.90 | 0–100 | [50] |
| Marsh in Sanjiang | 8–18 | 0–59 | [51] |
| Min River Salt Marsh | 5.3–10.05 | 0–60 | [52] |
| Forest | 7.5–23.2 | 0–100 | [53] |
| Steppe | 3.9–11.3 | 0–100 | |
| Meadow | 6.3–20.5 | 0–100 | |
| Crop | 5.6–13.4 | 0–100 | |

period (Fig. 3) which was consistent with that of SOC content (Fig. 2B).

## 5 Conclusions

In this work, the distribution and seasonal variation of SOC in newborn coastal wetland of the YRD estuary at eastern China were studied based on monitoring data in 2009 at two transects from the bank of the Yellow River to the seaside. Our results indicated that SOC contents of 0–60 cm soil layer in transects ranged from 0.46 to 10.15 $\mathrm{g\,kg^{-1}}$ and average values of soil profiles ranged from 2.15 to 5.00 $\mathrm{g\,kg^{-1}}$. The SOC contents tended to increase from the river flood land to the salt beach, which could be explained by the organic matters including large algae, the bodies, and excretion of marine animals due to the feedback of tides. Further analysis revealed that SOC was positively correlated with TN and clay contents. Our findings indicated that the newborn coastal wetland in the YRD should be a potential sink of SOC.

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