Chin. Geogra. Sci. 2018 Vol. 28 No. 3 pp. 400–410
https://doi.org/10.1007/s11769-018-0956-4
Springer Science Press
www.springerlink.com/content/1002-0063

Effects of Anthropogenic Disturbance on Sediment Organic Carbon Mineralization Under Different Water Conditions in Coastal Wetland of a Subtropical Estuary

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Abstract: The changes in soil organic carbon (C) mineralization as affected by anthropogenic disturbance directly determine the role of soils as C source or sink in the global C budget. The objectives of this study were to investigate the effects of anthropogenic disturbance (aquaculture pond, pollutant discharge and agricultural activity) on soil organic C mineralization under different water conditions in the Minjiang River estuary wetland, Southeast China. The results showed that the organic C mineralization in the wetland soils was significantly affected by human disturbance and water conditions ($P < 0.001$), and the interaction between human disturbance activities and water conditions was also significant ($P < 0.01$). The C mineralization rate and the cumulative mineralized carbon dioxide-carbon (CO_2-C) (at the 49th day) ranked from highest to lowest as follows: *Phragmites australis* wetland soil > aquaculture pond sediment > soil near the discharge outlet > rice paddy soil. This indicated that human disturbance inhibited the mineralization of C in soils of the Minjiang River estuary wetland, and the inhibition increased with the intensity of human disturbance. The data for cumulative mineralized CO_2-C showed a good fit ($R^2 > 0.91$) to the first-order kinetic model $C_t = C_0(1 - \exp(-kt))$. The kinetic parameters C_0, k and C_0k were significantly affected by human disturbance and water conditions. In addition, the total amount of mineralized C (in 49 d) was positively related to C_0, C_0k and electrical conductivity of soils. These findings indicated that anthropogenic disturbance suppressed the organic C mineralization potential in subtropical coastal wetland soils, and changes of water pattern as affected by human activities in the future would have a strong influence on C cycling in the subtropical estuarine wetlands.
Keywords: human disturbance; carbon mineralization; water conditions; coastal wetland

Citation: MOU Xiaojie, LIU Xingtu, SUN Zhigao, TONG Chuan, HUANG Jiafang, WAN Siang, WANG Chun, WEN Bolong, 2018. Effects of Anthropogenic Disturbance on Sediment Organic Carbon Mineralization Under Different Water Conditions in Coastal Wetland of a Subtropical Estuary. *Chinese Geographical Science*, 28(3): 400–410. https://doi.org/10.1007/s11769-018-0956-4

1 Introduction

Coastal wetlands play a crucial role in the global carbon (C) cycle by acting as natural C sinks (Choi and Wang, 2004; Castillo et al., 2017). Coastal wetlands accumulate organic C because of their high net primary productivity and low decomposition rates of accumulated organic C (Vicari et al., 2011). However, with the expansion of human activities, large areas of coastal wetlands are suffering from intense disturbance, pollution and reclamation in many parts of the world (Laffoley and Grimsditch, 2009). It was estimated that more than 50%

Received date: 2017-05-12; accepted date: 2017-08-10
Foundation item: Under the auspices of National Basic Research Program of China (No. 2012CB956100), National Natural Science Foundation of China (No. 41301085), the Key Foundation of Science and Technology Department of Fujian Province (No. 2016R1032-1)
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of the global wetlands have been reclaimed, altered, degraded, or even lost because of anthropogenic activities (O'Connell, 2003; Verhoeven and Setter, 2010). In China, approximately 8.59×10^6 ha of coastal wetlands, including swamp, salt marsh, estuary, gulf, and mangroves, were reclaimed or destroyed from 1991 to 2011, with a total loss rate of 88.92%, which seriously endangered the diversity and security of the coastal zone (Sun et al., 2014). Disturbance of wetlands might accelerate the decomposition of soil organic matter, thus influencing C cycling in wetlands (Santín et al., 2009; Wang et al., 2010b; Han et al., 2014).

Mineralization of soil organic C is a key process of soil C dynamics; it can affect soil fertility and is influenced by many factors, such as soil type, soil quality, moisture content, temperature, soil texture and profile depth (Riffaldi et al., 1996; Ryan and Law, 2005; Llorente and Turrión, 2010; Wang et al., 2010a). Reclamation can affect wetland hydrology, which consequently changes the temperature and aeration conditions in wetlands, influencing the C dynamics. When oxygen enters soils after reclamation, large amounts of C are released into the atmosphere in the form of CO_2 and CH_4 (Crooks et al., 2011). Moreover, anthropogenic disturbance can influence the C sequestration rate and soil C stores in coastal wetlands (Howe et al., 2009; Bai et al., 2013; Bu et al., 2015) through changes in the plant community composition, productivity, or belowground allocation in wetlands (Keller et al., 2004). The changes in soil properties as affected by human disturbance can significantly affect the C turnover process in wetlands (Llorente and Turrión, 2010). Thus, it will be important to quantify the changes in C mineralization caused by the disturbances in wetlands. However, very limited information is available on the effects of anthropogenic disturbance on soil C mineralization in coastal wetlands.

Soil moisture can provide important abiotic controls on C mineralization (Taggart et al., 2012). Many studies found that moisture could significantly affect C mineralization in wetland soils (Howard and Howard), 1993; Zhang et al., 2005; Yang et al., 2008; Wang et al., 2010a; Gao et al., 2011). Generally, the mineralization rate of organic C is lower under submerged conditions because oxygen availability is limited and microbial activity is inhibited (Leirós et al., 1999; Wang et al., 2010a). However, submerged conditions can also increase the dissolution of water soluble organic C, which stimulated microbial activity, thus increasing the mineralization of soil organic C (Beyer et al., 1995; Gao et al., 2011). The optimal water content for soil organic C mineralization depends on the characteristics of the soil substrates (Zhang et al., 2005; Wang et al., 2010a). Song et al. (2004) showed that water holding capacity of soil decreased by about 50% after 7 years of wetland reclamation. Reclamation increased the decomposition rate of soil organic matter because of the change in wetland hydrology, which consequently increased the soil bulk capacity and specific gravity and decreased the soil pore space, thus influencing the water holding capacity of soil in wetlands. At present, little is known about the interaction effects of reclamation and water conditions on soil C mineralization in wetlands.

The coastal wetlands of the Minjiang River estuary are very typical wetlands in the subtropical zone of China; they are known as an important halfway station for shorebirds migrating along the East Asian–Australasian flyway, one of the eight major migratory flyways of the world. Chinese Lesser Crested Tern (*Sterna bernsteini*), Black-faced Spoonbill (*Platalea minor*) and Spoon-billed Sandpiper (*Eurynorhynchus pygmeus*) are three very important endangered species, and they have been called the 'Auspicious sambo' of the Minjiang River estuary wetland. The 'legendary bird', Chinese Lesser Crested Tern, was considered an extinct species for more than 60 years; to date, the number of simultaneous global observations is less than 50, 16 of which were observed in the Minjiang River estuary. In recent years, the development and utilization of the Minjiang River estuary wetland has been increasing because of the intensification of human activities. However, the influence of different human disturbances on soil organic C mineralization in the Minjiang River estuary wetland has not been reported.

The primary objectives of the present study were: 1) to determine the effects of human disturbance on organic C mineralization in coastal wetland soils; 2) to measure the effects of water conditions on C mineralization of different soils in the coastal zone of the subtropical estuary; and 3) to evaluate the relationship between the soil properties and the mineralization parameters.

2 Methods

2.1 Site description

This study was conducted in the Shanyutan marsh

(26°00'36"N–26°03'42"N, 119°34'12"E–119°40'40"E, Fig. 1), which is the largest tidal marsh with typical semi-diurnal tides in the Minjiang River estuary, Southeast China. The local climate is warm and wet, with a mean annual temperature of 19.6℃ and a mean annual precipitation of 1350 mm. The vegetation is a mosaic of vegetation types dominated by *Cyperus malaccensis*, *Phragmites australis*, *Scirpus triqueter* and the invasive *Spartina alterniflora*. In the 19th century, most of the wetlands were reclaimed and converted to aquaculture ponds and agricultural land. There are discharge outlets in the study area, where sewage is discharged to the sea through the wetlands.

2.2 Sample collection and analyses

In June 2012, based on the investigation of the existing land use types in the Minjiang River estuarine wetland, the natural *P. australis* wetland and three kinds of land use types converted from the *P. australis* wetland, including bare land near the discharge outlet, aquaculture pond and rice paddy, were selected as the study objects. Three typical sampling areas were selected for each type of land use; in each sample area three top soil samples were randomly collected and mixed. A total of 12 soil samples were collected. The samples were placed in polyethylene bags and taken back to the laboratory. All samples were air-dried at room temperature and sieved through a 2-mm nylon sieve to remove roots, organic residues and stones. A portion of the soil samples were passed through a 0.149-mm sieve for the determination of soil chemical properties; the rest of the soil samples were passed through a 1-mm sieve for the incubation experiment.

Soil organic carbon (SOC) was measured using the dichromate oxidation method, total nitrogen (TN) contents were analyzed by the Kjeldahl digest method, and total

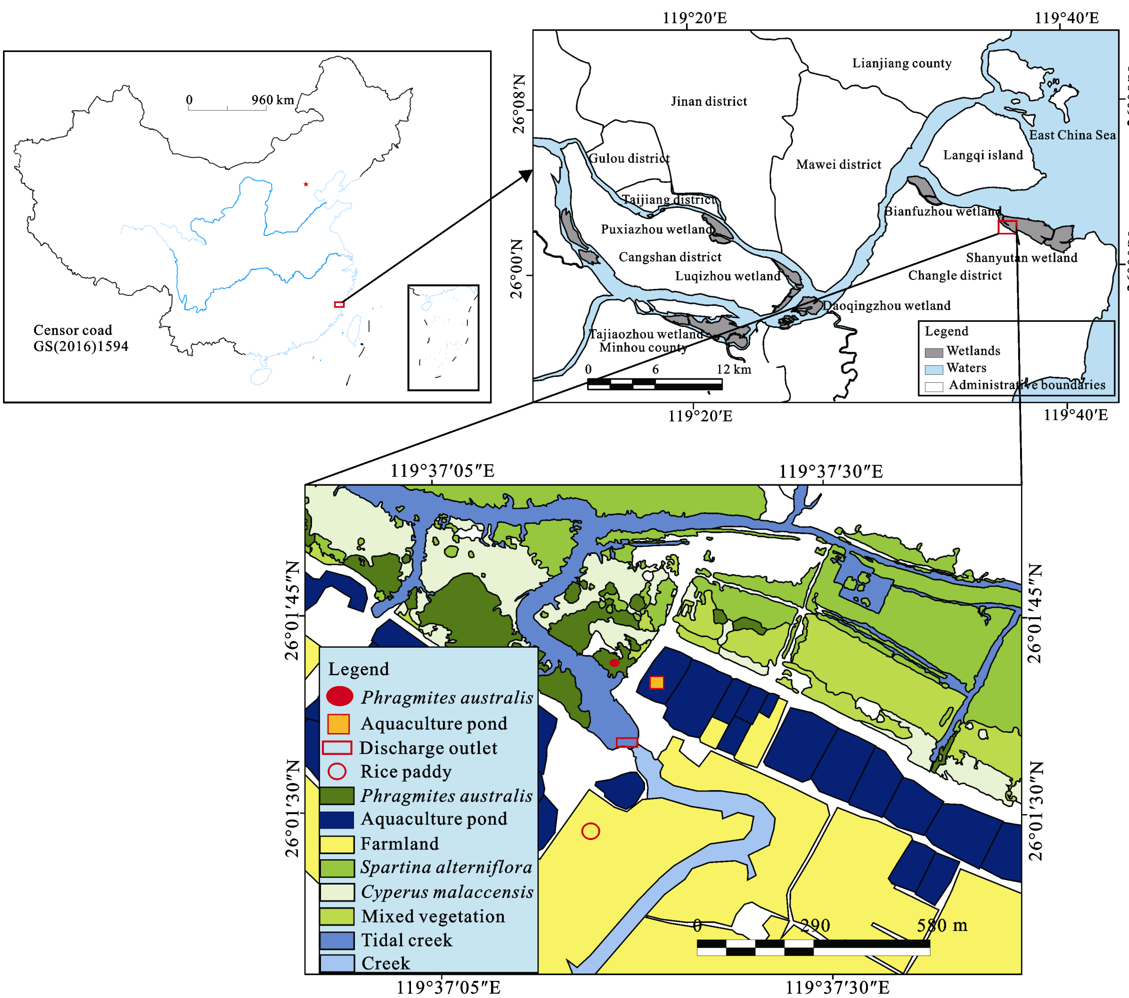

Fig. 1 Sketch map of study area

phosphorus (TP) contents by molybdate-ascorbic acid colorimetry. The ammonium (NH_4^+-N) and nitrate (NO_3^--N) were extracted with 2 mol/L KCl and analyzed by a sequence flow analyzer (SKALAR San++, the Netherlands). Total dissolved C (TDC), dissolved organic C (DOC) and dissolved inorganic C (DIC) were determined on a total organic C analyzer (TOC-V CPH, Shimadzu). The pH (soil : water, 1 : 5) was measured with a pH-meter, and electrical conductivity (EC; soil : water, 1 : 5) with an EC-meter. Detailed data on chemical properties in the four types of soils were given in Table 1.

2.3 Incubation experiment

An incubation experiment was designed to study the effects of human disturbance on organic C mineralization of wetland soils under different water conditions. Dry soil samples (20 g) of the four types of soil were placed in 250 mL glass bottles, and they were pre-wetted to 30% water holding capacity (WHC) (W1), 60% WHC (W2) and 120% WHC (W3) at the start of incubation, each with three replicates. The bottles were then plugged with rubber stoppers, and the gaps between bottles and stoppers were sealed using glue. The rubber stoppers were drilled with a small hole in the middle and a glass tube was inserted; a silicone hose was set on the top of the tube, with a suitable silicone plug tight hose connector, as a gas sampling port. The bottles were incubated at a constant temperature of 30℃ in the dark. Gas samples (20 mL) were collected on days 2, 5, 12, 21, 27, 33, 39 and 49 with syringes. The bottles were opened for 2 h after each gas sample collection to balance the internal and external gas, and then the bottles were resealed and the incubation was continued. During the incubation, any losses of soil water were replaced by adding distilled water on a weight basis every week. The CO_2 concentrations were measured using gas chromatography (Agilent 7890, America) and the C mineralization was calculated by the discharge of CO_2 during the incubation period (Zheng et al., 2007). C mineralization kinetics were determined following a first-order kinetic model:

$$C_t = C_0(1 - \exp(-kt)) \quad (1)$$

where C_t is the cumulative C released after time t (mg/g); C_0 is the potentially mineralizable C (mg/g); t is incubation days (d); and k is the mineralization rate constant.

2.4 Statistical analyses

The results were presented as means of the three replicates, with standard error (SE). Figures were drawn by Origin 7.5 software, while statistical analyses were carried out with SPSS 13.0. A two-way analysis of variance (ANOVA) test was performed to evaluate the main effects of land uses, water conditions, and their interactions on the parameters analyzed. The least significant difference (LSD) test at the 95% probability level was applied to the results. Pearson correlation analyses were used to examine the relationships between mineralization and the measured soil chemical characteristics. For all tests, differences were considered significant only if $P < 0.05$.

3 Results

3.1 Soil organic carbon mineralization rate

Human disturbance had significant effects on SOC mineralization rates under different water conditions ($P < 0.01$) (Fig. 2). SOC mineralization rates under different water conditions were highest at the beginning of the incubation because of the rapid depletion of easily mineralizable C but decreased progressively with time, except in the natural *P. australis* wetland soil, in which SOC mineralization rates under 30% WHC and 120% WHC reached the highest values on day 5. At the end of the incubation period, mineralization rates dropped to 6.57%–28.38% of the rates at the beginning. The largest CO_2-C mineralization rates of *P. australis* wetland soil

Table 1 Comparison of main chemical properties of different soils

Site	SOC (g/kg)	TN (mg/kg)	TP (mg/kg)	NH_4^+-N (mg/kg)	NO_3^--N (mg/kg)	TDC (mg/L)	DIC (mg/L)	DOC (mg/L)	pH	EC (mS/cm)
P. australis wetland	35.64	1512.10	591.79	14.67	5.15	27.54	2.11	25.44	6.97	3.35
Discharge outlet	27.52	1095.72	525.87	18.33	2.78	33.55	3.51	30.04	7.20	2.11
Aquaculture pond	32.72	1702.87	951.38	19.00	55.07	35.64	7.98	49.89	7.41	1.36
Rice paddy	25.66	1396.22	1493.82	8.28	16.11	62.36	12.47	27.66	7.43	0.43

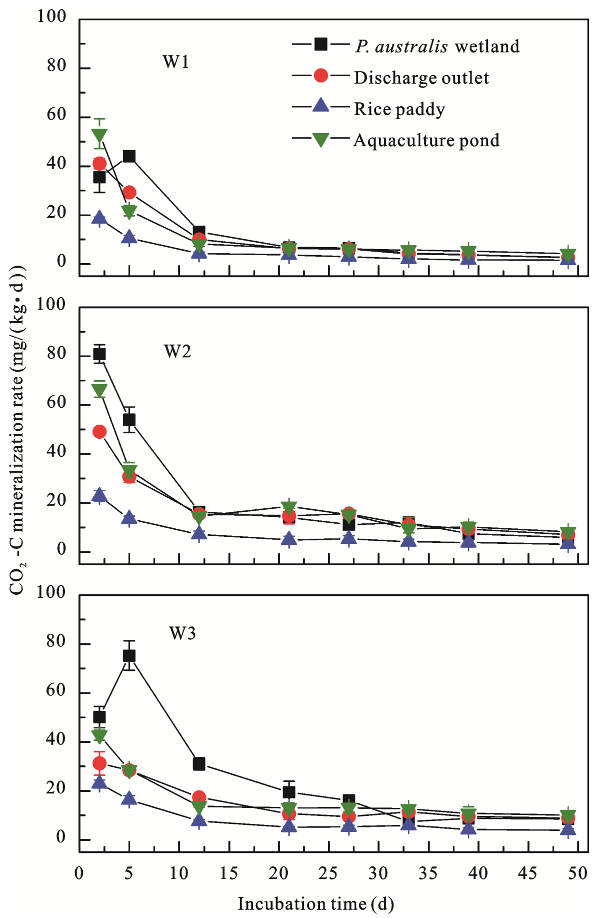

Fig. 2 Effect of human disturbance on carbon dioxide-carbon (CO_2-C) mineralization rate under 30% water holding capacity (WHC) (W1), 60% WHC (W2) and 120% WHC (W3)

(25.25 mg/(kg·d)), soil near the discharge outlet (19.17 mg/(kg·d)), rice paddy soil (8.12 mg/(kg·d)) and aquaculture pond sediment (22.06 mg/(kg·d)) occurred at 60% WHC during the entire experiment (Fig. 2). During the 49-day incubation period, the mean rates of mineralization among soil types under different humidity conditions displayed the following order: *P. australis* wetland soil > aquaculture pond sediment > soil near the discharge outlet > rice paddy soil (Fig. 3). The mean mineralization rates of *P. australis* wetland soil and rice paddy soil increased with the increase in water content, while those of the aquaculture pond sediment and soil near the discharge outlet were highest at 60% WHC and lowest at 30% WHC. Repeated-measures ANOVA (Table 2) showed that human disturbance activities and water conditions had significant effects on SOC mineralization ($P < 0.001$), and the interaction effects were also significant ($P < 0.01$). In addition, incubation time had significant effects on SOC mineralization of different soils ($P < 0.001$), and the interaction effects of time and soil type or water condition were also significant ($P < 0.001$).

3.2 Cumulative soil organic carbon mineralization

The cumulative mineralized C of *P. australis* wetland soil was higher than those of the other three types of soil under different water conditions with incubation time (Fig. 4). The cumulative C of aquaculture pond sediment and soil near the discharge outlet were similar to that of *P. australis* wetland soil at 30% WHC and 60% WHC ($P > 0.05$), but significantly different from that of *P. australis* wetland soil at 120% WHC ($P < 0.05$). The cumulative C of rice paddy soil increased slowly during the incubation period, and was significantly different from those of the *P. australis* wetland soil under different water conditions ($P < 0.05$). The total mineralized C at 49 days in the three human disturbed soils were lower than those in the *P. australis* wetland, in the order: *P. australis* wetland soil > aquaculture pond sediment > soil near the discharge outlet > rice paddy soil. These results indicated that human disturbance inhibited C mineralization in the Minjiang River wetland, and the inhibition decreased with the intensity of human disturbance. The cumulative C mineralization of *P. australis* wetland soil, aquaculture pond sediment and rice paddy soil increased with increasing water content, while that of the soil near the discharge outlet was largest at 60% WHC and lowest at 30% WHC. Repeated-measures ANOVA (Table 2) showed that human disturbance activities and water conditions had significant effects on cumulative SOC mineralization ($P < 0.001$) and the

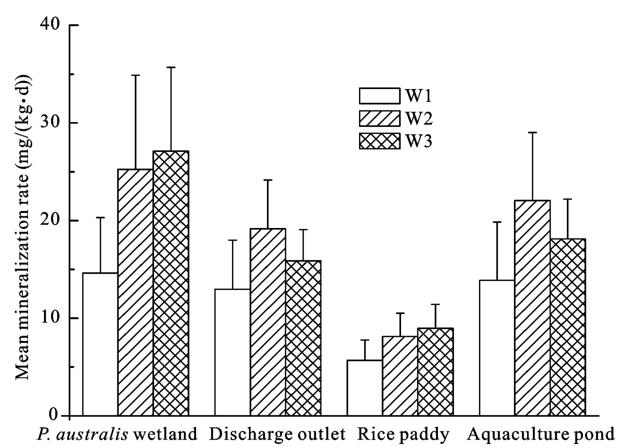

Fig. 3 Mean carbon dioxide-carbon (CO_2-C) mineralization rates of soils under different water conditions

Table 2 Repeated-measures analysis of variance of carbon dioxide-carbon (CO_2-C) mineralization rates and CO_2-C cumulative mineralization as affected by human disturbance and water conditions

	df	Mineralization rate			Cumulative mineralization		
		Mean Square	*F*	*P*	Mean Square	*F*	*P*
Between subjects							
Soil types	3	2758.769	81.244	<0.001	1471597.530	67.937	<0.001
Waters	2	1302.118	38.347	<0.001	760422.221	35.105	<0.001
Soil × Water	6	164.061	4.832	<0.01	113721.818	5.250	<0.01
Within subjects							
Time	7	18745.077	786.561	<0.001	6181702.446	811.850	<0.001
Time × Soil	21	1273.379	53.432	<0.001	226028.865	29.685	<0.001
Time × Water	14	449.979	18.882	<0.001	234597.242	30.810	<0.001
Time × Soil × Water	42	185.016	7.763	<0.001	25868.867	3.397	<0.001

interaction effect was also significant ($P < 0.01$). In addition, incubation time had significant effects on cumulative SOC mineralization of different soils ($P < 0.001$), and the interaction effects of time and soil type or water condition were also significant ($P < 0.001$).

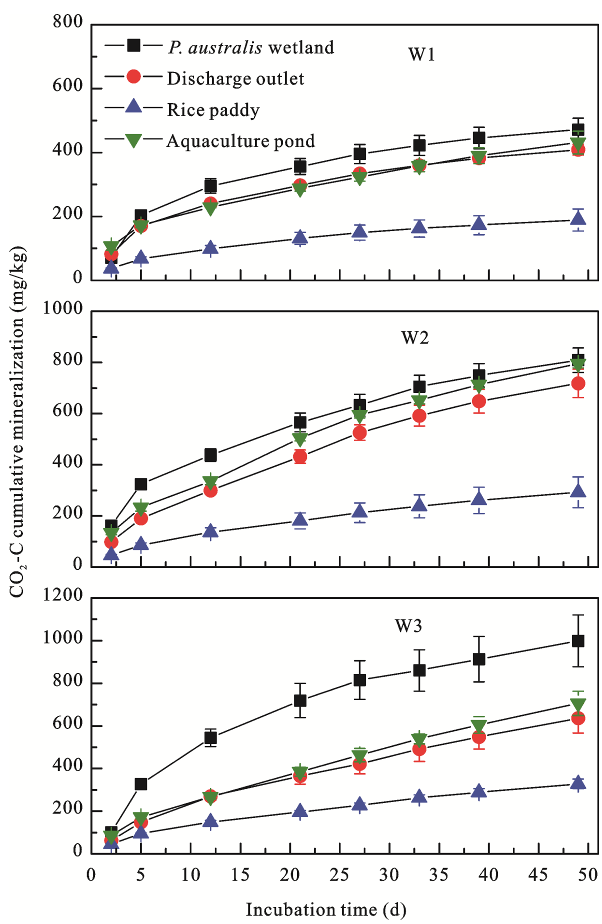

Fig. 4 Effect of human disturbance on carbon dioxide-carbon (CO_2-C) cumulative mineralization under different water conditions

The first-order equation $C_t = C_0 (1 - \exp(-kt))$ provided a good description of the C mineralization kinetics, and the correlation coefficients ranged from 0.907 to 0.992 (Table 3). The potentially mineralizable C (C_0) of *P. australis* wetland soil, aquaculture pond sediment, and rice paddy soil increased with the increase in humidity, but C_0 of soil near the discharge outlet was highest at 60% WHC and lowest at 30% WHC. Furthermore, under 30% WHC and 120% WHC, C_0 was in the order of *P. australis* wetland soil > aquaculture pond sediment > soil near the discharge outlet > rice paddy soil, and under 60% WHC the order was aquaculture pond sediment > soil near the discharge outlet > *P. australis* wetland soil > rice paddy soil. There was a positive association between potentially mineralizable C and the cumulative mineralized C observed after 49 days of incubation ($R^2 = 0.960$, $P < 0.001$) (Table 4). The rate constant of C mineralization (k) of the four soils decreased with the increase in humidity, and k values of the human disturbed soils were lower than that of the *P. australis* wetland soil. All values fell within a relatively narrow range from 0.026–0.090 (Table 3). No significant correlations were found between k and C_0, while the k values were significantly correlated with DOC and DIC ($P < 0.05$) (Table 4). The initial potential rate of C mineralization (C_0k) of the *P. australis* wetland soil was higher than for the other three types of soil. The C_0k of the *P. australis* wetland and rice paddy soils increased with increasing water content, while the C_0k of soil near the discharge outlet decreased with increasing water content. The C_0k values varied from 12.343–63.703 mg/(kg·d). A close relationship was found between C_0k and the total amount of C mineralized at the end of the incubation (R^2 = 0.806, P < 0.01), C_0 (R^2 = 0.622, P < 0.05) or EC (R^2 = 0.835, P < 0.01) (Table 4). Analysis of variance (Table 3) showed that human disturbance activities and water conditions had significant effects on C_0, k and C_0k (P < 0.05 or P < 0.001), and the interaction effect was significant for C_0k (P < 0.001), but not for C_0 and k (P > 0.05).

3.3 Dissolved C

After the incubation, the highest DOC and TDC contents occurred in the *P. australis* wetland soil under 30% WHC (Table 5). The aquaculture pond sediment had the highest DIC contents under different water conditions, and the DIC contents of the four soil types were highest at 120% WHC. Soil types and water had significant effects on soil DOC, TDC and DIC (P < 0.01 or P < 0.001), and the interaction effects were also significant (P < 0.05 or P < 0.01).

3.4 pH and EC

After the incubation, soil EC of the *P. australis* wetland, soil near the discharge outlet and aquaculture pond sediment decreased with the increase in water content, but this trend was not observed for rice paddy soil. Human disturbance had significant effects on soil EC (P < 0.001) (Table 5) and under different water conditions, the order of EC was *P. australis* wetland soil > soil near the discharge outlet > aquaculture pond sediment > rice paddy soil; water conditions and interactions of soil types and water had no significant effects on soil EC (P > 0.05). The EC values were significantly related to the cumulative mineralized C after 49 days of incubation (P < 0.05) (Table 4). Soil pH showed a different pattern from that of EC (Table 5). After the incubation, soil pH of soil near the discharge outlet, aquaculture pond sediment and rice paddy increased with the increase in water content, whereas this trend was not observed for the *P.*

Table 3 Effect of human disturbance on cumulative soil organic carbon (C) mineralization under different water conditions

Site	Water	Cumulated mineralized C (49 d)	C_0 (mg/kg)	K (1/d)	C_0k (mg/(kg·d))	R^2
	W1	471.263	452.081	0.090	40.506	0.975
P. australis wetland	W2	808.877	784.338	0.073	56.927	0.952
	W3	998.488	1007.635	0.063	63.703	0.992
	W1	409.056	390.119	0.084	32.899	0.961
Discharge outlet	W2	718.523	843.224	0.037	31.343	0.987
	W3	636.666	785.542	0.031	24.438	0.987
	W1	188.896	186.613	0.066	12.343	0.967
Rice paddy	W2	292.500	314.709	0.045	14.241	0.975
	W3	328.071	363.408	0.041	14.783	0.973
	W1	431.326	406.245	0.073	29.806	0.907
Aquaculture pond	W2	795.239	876.851	0.043	37.985	0.977
	W3	706.374	945.076	0.026	24.988	0.983
	Soil type	<0.001**	<0.001**	0.021	<0.001**	–
ANOVA	Water	<0.001**	<0.001**	<0.001**	0.037*	–
	Soil × Water	0.019*	0.171	0.624	<0.001**	–

Notes: *significant at < 0.05; ** significant at < 0.001

Table 4 Correlation coefficients between carbon (C)-mineralization parameters and soil characteristics at end of incubation

	C-CO_2 (49 d)	C_0	k	C_0k	DOC	TDC	DIC	EC	pH
C-CO_2 (49d)	1	0.960***	–0.202	0.806**	0.171	0.137	0.355	0.579*	–0.040
C_0	0.960***	1	–	0.622*	0.051	0.100	0.554	0.436	0.097
k	–0.202	–0.428	1	0.397	0.605*	0.303	–0.620*	0.516	–0.546
C_0k	0.806**	0.622*	0.397	1	0.504	0.280	–	0.835**	–0.347

Notes: * significant at < 0.05; ** significant at < 0.01; *** significant at < 0.001

Table 5 DOC, TDC, DIC, pH and EC in soils under different water conditions after 49 days' incubation

	Water	DOC	TDC	DIC	pH	EC
P. australis wetland	W1	24.307±0.586	26.213±0.547	1.907±0.168	6.907±0.007	5.693±0.037
	W2	8.867±1.969	10.203±1.993	1.336±0.024	6.877±0.015	4.967±0.829
	W3	20.950±7.212	23.830±7.435	2.880±0.229	7.043±0.047	4.607±0.738
Discharge outlet	W1	18.877±0.275	20.313±0.298	1.437±0.047	6.743±0.009	3.643±0.015
	W2	6.637±0.572	7.844±0.459	1.207±0.193	6.787±0.022	3.220±0.140
	W3	11.263±0.254	14.437±0.334	3.173±0.103	6.977±0.026	3.083±0.168
Rice paddy	W1	9.182±0.985	12.600±0.846	3.418±0.192	7.070±0.074	0.677±0.018
	W2	7.445±0.162	11.293±0.521	3.848±0.371	7.157±0.022	0.770±0.006
	W3	9.277±0.252	15.130±1.090	5.853±0.838	7.180±0.049	0.703±0.037
Aquaculture pond	W1	9.030±0.490	12.843±0.471	3.814±0.164	7.090±0.095	2.140±0.026
	W2	10.129±0.338	14.627±0.527	4.497±0.076	7.197±0.007	2.127±0.019
	W3	10.343±0.182	17.460±0.503	7.117±0.378	7.387±0.015	2.070±0.012
ANOVA	Soil type	<0.001***	0.007**	<0.001***	<0.001***	<0.001***
	Water	0.001**	<0.001***	<0.001***	<0.001***	0.203
	Soil × Water	0.012*	0.010*	0.006**	0.177	0.681

Notes: * significant at < 0.05; ** significant at < 0.01; *** significant at < 0.001

australis wetland soil. Human disturbance and water conditions had significant effects on soil pH ($P < 0.001$), but the interaction effects were not significant ($P > 0.05$).

4 Discussion

4.1 Effects of human disturbance on soil organic carbon mineralization

The soil C mineralization rate is an important indicator of soil organic matter decomposition, and the changes in soil C mineralization as affected by human disturbance have the potential to alter soil C storage in wetlands (Ross et al., 1999, Wang et al., 2014). In the present study, the average soil C mineralization rate and total mineralized C in the three human disturbed soils were lower than those in the *P. australis* wetland, following the order: *P. australis* wetland soil > aquaculture pond sediment > soil near the discharge outlet > rice paddy soil. This might be because of the influence of anthropogenic interference on SOC (Table 1), because substrate availability is usually considered as the fundamental driver of CO_2 emissions from soils when the environmental variables of temperature and moisture are similar (Niklińska and Klimek, 2007; Fissore et al., 2009; Wang et al., 2010a; Wang et al., 2014). Soil C storage is mainly determined by the relative balance of input and decomposition of soil organic matter. Wetlands have high vegetation productivity, and the decomposition rate of organic C in wetlands is relatively slow, which leads to accumulation of C in wetland ecosystems; this was confirmed with the *P. australis* wetland having the strongest C mineralization. The aquaculture pond sediment had high organic C because of the frequent anaerobic conditions, which are not conducive to the decomposition of organic C; the feeding of artificial bait and the accumulation of animal excreta can also lead to high organic matter content. Bare land near the discharge outlet has no C storage capacity because of the lack of vegetation, so the organic C content is low. The organic C content of the rice paddy soil was lowest, mainly because of the increasing soil C output intensity from farming, application of fertilizer and crop harvesting, which resulted in this soil type having the lowest CO_2 gas emission rates. Our results showed that the cumulative mineralized C was significantly related to EC, which was similar to the results from Weston et al. (2011) who found that salt-water intrusion accelerated the loss of organic C from tidal freshwater marsh soils through stimulating microbial decomposition.

Our study found that human disturbance had significant effects on C mineralization in the coastal wetland soils. For other ecosystems, human activities also significantly influenced the C mineralization. Huo (2013) showed that the SOC mineralization rate decreased after peat marsh was reclaimed to soybean and paddy fields.

Wang et al. (2014) found that soil C mineralization in thicket peatland was higher than that in the forest and fen. Wu et al. (2004) showed that the rate of SOC mineralization declined with the conversion from natural forests to cropland or rangeland and increased following afforestation of former croplands or rangelands. These results indicated that soil C mineralization rate is sensitive to changes in land use and land cover, which is an important mechanism for SOC storage change after land use change. However, other studies have shown that soil C mineralization rates were not affected by land use changes, such as the results from Kanda et al. (2002), indicating that the effects of land use change on SOC mineralization might be changed by other factors.

The mathematical description of the dynamics of C mineralization in incubation studies is useful for the prediction of the ability of soils to supply C_0 and to maintain the organic C balance (Riffaldi et al., 1996). The first-order equation provided a good description of the C mineralization kinetics for the four soils under different water conditions. The potentially mineralizable C (C_0) ranged from 186.613 to 1007.635 mg/(kg·d) soil, which are low in comparison with those of Llorente and Turrión (2010) and Goberna et al. (2006). There was a positive association between potentially mineralizable C and the cumulative mineralized C observed after 49 days of incubation, which was comparable to the results of Riffaldi et al. (1996). The rate constants of C mineralization (k) of the human disturbed soils were lower than that of the *P. australis* wetland soil, indicating that human disturbance reduced the availability of organic compounds metabolized by microbial respiration and decreased the C mineralization rate. No significant correlations were found between k and C_0, indicating that differences in k values among soils cannot be attributed to differences in the relative sizes of the C pools (Riffaldi et al., 1996). However, the k values were significantly related to DOC and DIC, because the short-term C mineralization mainly depended on the labile C pool (Alvarez and Alvarez, 2000). The initial potential rate of C mineralization (C_0k) can be a more precise estimate than the individual parameters; it was significantly related to the soil chemical composition (Saviozzi, 1993). We found higher C_0k values for the *P. australis* wetland soils than for the other three types of soils, which might be related to the changes in soil chemical characteristics as affected by the human disturbance. A positive relationship was found between C_0k and EC in the present study, while the results from Riffaldi et al. (1996) showed a lack of significant correlation between C_0k and soil properties.

4.2 Effects of water condition on soil organic carbon mineralization

Water is an important factor affecting soil C mineralization. Our results indicated that soils with different human disturbance have different water sensitivity. The mineralization rates in *P. australis* wetland soil and rice paddy soil increased with the increase in water, which was similar to the results of Wu et al. (2004) and Huo (2013). On the one hand, high water conditions were beneficial to the release of water soluble C, thus promoting C mineralization. On the other hand, the soils are often submerged or periodically submerged by water under natural conditions, and the microbes involved in C mineralization could adapt to the higher water content. However, for aquaculture pond sediment and soil near the discharge outlet, the optimum water for soil C mineralization occurred at 60% WHC. The optimum water contents for SOC mineralization in different soils were generally different. Taggart et al. (2012) showed that the rates of C mineralization were highest at 0.3 m^3/m^3 water conditions (volumetric water content). Zhang et al. (2005) showed that the optimal moisture content for C mineralization was about 66% WHC in marsh meadow and 30% WHC in fen, while Wang et al. (2010a) derived the optimal soil moisture as 60% WHC in permafrost peatland. The relatively lower C mineralization rates at 120% WHC in aquaculture pond sediment and soil near the discharge outlet were probably because the quantity and activity of microbes were low under anaerobic conditions, and the anaerobic decomposition rates of organic matter were slow (Sahrawat, 2004; Gao et al., 2011). Our results also showed that C mineralization rates of the four soils were all lowest under 30% WHC, indicating that low soil water content was not conducive to organic C mineralization in the subtropical wetland of the Minjiang River estuary. Allowing for some differences in approach, these results appear reasonably consistent with the results from Taggart et al. (2012) and Wang et al. (2010a). Under natural conditions, the four soils are all usually submerged or periodically submerged by water, so the microorganisms are not adapted to the low humidity conditions, therefore, the C mineralization rates were lowest under 30% WHC. On the whole, there are differences in the promotion or inhibition of organic C mineralization in various soils with changing water conditions. Other studies have found that water had no significant effect on the mineralization of organic C in wetlands (Bridgham et al., 1998; Kruse et al., 2004; Yang et al., 2008). Organic C mineralization might be dependent on the balance of microbial activities and the water-soluble C content in the soil under different water conditions.

5 Conclusions

Human disturbance (aquaculture pond, pollutant discharge and agricultural activity) significantly inhibited the mineralization rate and the cumulative mineralized CO_2-C in the coastal wetland soils of the Minjiang River estuary, and the inhibition increased with the intensity of human disturbance. The C mineralization of soils was significantly affected by moisture and soils with different human disturbance had different water sensitivity. The mineralization rates in *P. australis* wetland soil and rice paddy soil increased with the increase in water content, while for aquaculture pond sediment and soil near the discharge outlet, the optimum water content for soil C mineralization occurred at 60% WHC. Human disturbance and water conditions had significant interaction effects on C mineralization. However, the relationship between C mineralization and water content under human disturbance is still not very clear. The first-order kinetic model provided a good description of the C mineralization kinetics. The kinetic parameters C_0, k and C_0k were significantly affected by human disturbance and water conditions, which could be sensitive indicators of land use change. To better understand the responses of C mineralization to human disturbance and water change, future studies should focus on more detailed characterization of soil quality and microbial communities.

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