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Terrestrial dissolved organic carbon consumption by heterotrophic bacterioplankton in the Huanghe River estuary during water and sediment regulation*

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Abstract Nearly 20%–50% of the annual terrestrial dissolved organic carbon (DOC) from the Huanghe (Yellow) River was transported to the estuary during the 5–14 d of water and sediment regulation. The concentration of DOC increased sharply during the period of water and sediment regulation, which may promote the terrestrial DOC consumption by heterotrophic bacterioplankton. Water and sediment regulation provides an ideal condition for the study of terrestrial DOC consumption by heterotrophic bacterioplankton when terrestrial DOC increases sharply in rainy season, which may help to seek the fates of terrestrial DOC in the estuaries and coasts. In this study, the concentration and stable isotope of DOC, the biomass, growth, and respiration of heterotrophic bacterioplankton were determined. By the study, we found both average percent contribution of terrestrial DOC to the DOC pool and Contribution of terrestrial DOC to the carbon composition of heterotrophic bacterioplankton decreased as distance from the river mouth increased offshore, which was deceased from (39.2±4.0)%, (37.5±4.3)% to (30.3±3.9)%, (28.2±3.9)% respectively. 255–484 μg C/(L·d) terrestrial DOC was consumed by heterotrophic bacterioplankton. And 29%–45% terrestrial DOC consumed by heterotrophic bacterioplankton releasing as CO_2 by respiration. Comparing with tropical estuary, terrestrial DOC consumed by heterotrophic bacterioplankton was lower in temperate estuary (this study). Temperature may limit the consumption of terrestrial DOC by heterotrophic bacterioplankton.

Keyword: terrestrial dissolved organic carbon; heterotrophic bacterioplankton; carbon stable isotope; biogeochemical cycles

1 INTRODUCTION

Global rivers transport 0.40 GT of terrestrial organic carbon to the ocean every year, of which 60% is dissolved organic carbon (DOC). The fluxes of terrestrial DOC are twice the amount of ocean inventory DOC each year (Schlesinger and Melack, 1981). However, stable isotope and biomarker evidence indicate that terrestrial DOC account for only 0.7%–2.4% of DOC in the ocean (Hedges et al., 1997). Thus, it seems that only a fraction of terrestrial DOC enters the open ocean. The question of fates of terrestrial DOC has intrigued scientists for decades. The chemical composition, distribution, and quantity of DOC may vary significantly in coastal environments, before it's delivered to the ocean. In a study utilizing ^{14}C analysis of DOC ($DO^{14}C$), Raymond and Bauer (2001) found that much of the younger terrestrial DOC was selectively degraded over the residence times of rivers and in coastal waters

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(~1 yr), leaving the older and more refractory component for oceanic export. Some studies considered that heterotrophic bacterioplankton play an important role in the degradation of terrestrial DOC through its uptake in the estuaries and coasts (Moran and Hodson, 1994; Hitchcock et al., 2016a, b). By a bioassay study, Moran and Hodson (1994) found that heterotrophic bacterioplankton can use terrestrial DOC as metabolic carbon source. Through field and in-situ mesocosm studies, Hitchcock et al. (2016a, b) considered that terrestrial DOC is transformed into bacterial biomass (BB) by anabolic processes, and than enter into the coastal ecosystem through the “microbial loop”. Under the action of “microbial loop”, many species of invertebrate and vertebrate in the estuaries and coasts revealed that terrestrial DOC is important carbon source for them (Abrantes and Sheaves, 2008; Abrantes and Sheaves, 2010; Abrantes et al., 2013). Besides supporting the high trophic level organsims, the terrestrial DOC transformed by bacterial is lost in the form of CO_2. Some studies considered that in the respiration of heterotrophic bacterioplankton, it prefered to transform the carbon from terrestrial DOC into CO_2 than that from autochthonous DOC (Karlsson et al., 2007; McCallister and Del Giorgil, 2008). By the respiration of heterotrophic bacterioplankton, terrestrial DOC became an important source of CO_2 outgassing from estuaries and coasts (Mayorga et al., 2005; Laruelle et al., 2010). By the study of consumption of terrestrial DOC, it helps to know the fates of terrestrial DOC in estuaries and coasts.

The Huanghe (Yellow) River is the second-longest river in China and the sixth-longest river in the world. It has second-largest sediment load in the world, with nearly 1.2×10^9 t sediment transported by the river each year. By the reason of heavily sediment load, the riverbed is elevated annually which increases the risk of flood, especially in summer rainfall increasing. Rainfall also increases the water level of dam in the middle and low reaches of the Huanghe River. To desilt sediment in the riverbed, the dams drain water for 5–15 days each summer in accordance with rainfall and capacity of dams. At that period, rain washes a quantity of terrestrial DOC from catchment into river and dams. Under the action of water and sediment regulation, terrestrial DOC is transported by river increases sharply. From 2002–2012, (1.52–8.25)$\times10^4$ t terrestrial DOC was transported to the coast, accounting for 11.5%–47.7% of the total annual terrestrial DOC load (Liu, 2014).

For most rivers in the world, as the increasing of flow in rainy season, terrestrial DOC transported via estuaries increased. And the biomass of heterotrophic bacterioplankton and zooplankton in estuaries and coasts increased, which mean that more terrestrial DOC was consumed (Wang et al., 2011; Wang, 2013; Zhang et al., 2013; Hitchcock et al., 2016a, b). Sharply increasing of flow in a short time is an important factor for terrestrial DOC consumption by heterotrophic bacterioplankton, which may impact the fates of terrestrial DOC in estuaries and coasts (Hitchcock and Mitrovic, 2015). Because of the water and sediment regulation, the efficiency of transporting terrestrial DOC by Huanghe River in a short time is higher than other rivers in the world (Liu, 2014). It provides an ideal condition for the study of consumption of terrestrial DOC by heterotrophic bacterioplankton when terrestrial DOC increases sharply in a short time, which is the goal of this study.

2 MATERIAL AND METHOD

2.1 Study area

The study area is located on the coast within 10 km of the mouth of the Huanghe River. Three sections were designed for examination, and they included distances at 2.5, 5, and 10 km from the mouth of Huanghe River. There were 3 stations in the 2.5 km section and 5 stations in both the 5 and 10 km sections (Fig.1). Water and sediment regulation of Huanghe River lasted for 11 days in July 2014. During that period, 2.4×10^4 t terrestrial DOC was transported via estuary. This amount of DOC accounts for 60% of the delivery in 2014 to the Huanghe River estuary, which resulted in the concentration of DOC raising comparing in non-regulated times (Liu, 2014; Wu et al., 2015). Under the action of water and sediment regulation, the concentration of DOC in the estuary was increased 15%–20% comparing to non-regulated times (Liu, 2014; Wu et al., 2015). The samples were taken during the water and sediment regulation period, at this time, water and sediment reached the coast within 3–5 days. During the investigation, the study area became a mixture of freshwater and seawater because of the fresh water discharge, a salinity range of 5–28. The 2.5, 5, and 10 km sections were in the low, middle, and high salinity zones, with a salinity range of 5–7, 16–18, and 24–28, respectively. Nearly all station became turbid for the heavily sediment load, while only stations in the 2.5 km section is muddy in non-regulated times.

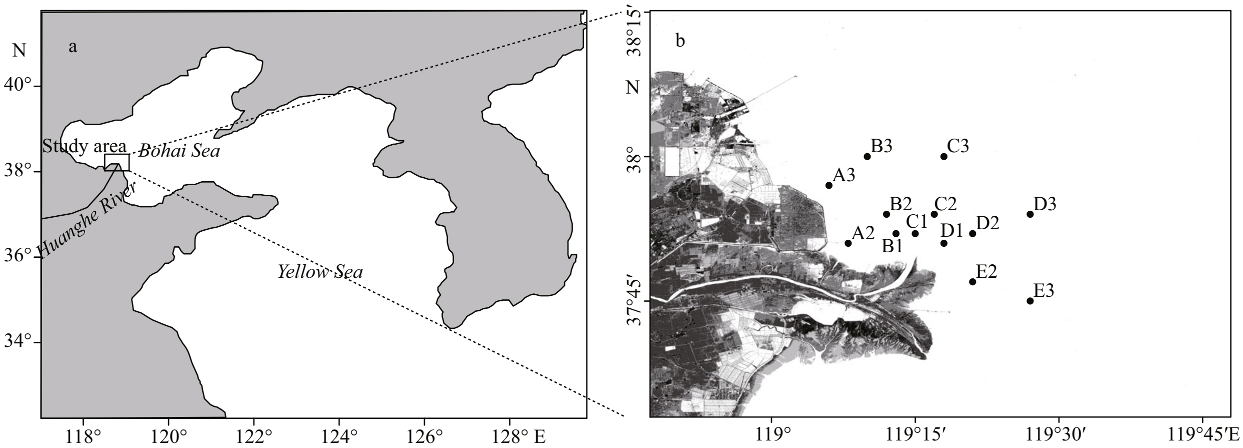

Fig.1 Location map of the study sites

Three sections were designed for examination, which were at 2.5, 5, and 10 km from the mouth of Huanghe River respectively. B1, C1, and D1 were the stations at 2.5 km section; A2, B2, C2, D2, and E2 were the stations at 5 km section; A3, B3, C3, D3, and E3 were the stations at 10 km section.

2.2 Sampling and sample analyses

2.2.1 DOC and DOδ¹³C

At each station, 200 mL surface water was filtered through 0.7 μm GF/F filters, which burned in 450°C for 4 h to remove organic impurities before use. The filtered water was transferred into two 100 mL acid washed polyethylene bottles. Then, the samples were frozen in the dark during transport to the laboratory. The concentration of DOC was measured by total organic C analyzer (Shimadzu TOC-VCPH). The standards were 400 mg C/L of $KHC_8H_4O_4$ and 400 mg C/L mixture of Na_2CO_3 and $NaHCO_3$, respectively, used for organic carbon and inorganic carbon. The $\delta^{13}C$ of DOC was determined by coupling Shimadzu TOC-VCPH analyzer to an isotope ratio mass spectrometer (Delta V Advantage, Thermo Fisher Scientific) using cryogenic traps. Acidified and sparged water samples were introduced to the Shimadzu analyzer and combusted. The resulting CO_2 was stripped from the carrier gas and introduced to the isotope ratio mass spectrometer using a series of cryogenic traps (Kaldy et al., 2005). Prior to analysis, standards were run to ensure data quality and to provide measurements of the instrument blanks. Isotope values were expressed in δ-notation (‰):

$$\delta=(R_{sample}/R_{standard}-1)\times1000, \quad (1)$$

where R is the ratio of ^{13}C:^{12}C in the sample (R_{sample}) and in the standard ($R_{standard}$). $\delta^{13}C$ is expressed in terms of its value relative to Pee Dee Belemnite (PDB).

2.2.2 Bacterial Biomass (BB) and δ¹³C of bacteria

Surface water was placed in an Eppendorf tube and stored frozen in darkness until the analysis of bacterial abundance (BA) and BB. The BA was measured by 4',6-diamidino-2-phenylindole (DAPI) staining. Samples (1 mL) were filtered through 0.2 μm MF-Millipore filters, and then stained with 1 mL of 10 μg/mL DAPI for 5–10 min. Bacteria were counted under 1 000× amplification using an Olympus BX-51 fluorescence microscope. Ten fields of view were randomly selected for the counts. BA was calculated by:

$$BA=A\times S_1/[S_2\times(1-0.05)\times V], \quad (2)$$

where A was the average number of bacterial cells in 10 fields of view (individuals: ind.), S_1 was the effective filtering area of the filters (m^2), S_2 was the area of the field of view (m^2), and V was the volume of filtered water. BB was calculated by assuming that the C content of each bacterial cell was 20 fg C/cell. (Hou et al., 2015).

The $\delta^{13}C$ of heterotrophic bacterioplankton was challenging to measure directly because the samples cannot be completely separated by filtration from fine detrital particles in seawater. Thus, a bacterial growth bioassay to measure the isotopic composition of estuarine bacteria described by Coffin et al. (1989) was used. Surface water was filtered through 0.2 μm MF-Millipore filters to remove all particles including bacteria; this water was then used as the growth medium. Another sample was filtered through 1 μm MF-Millipore filters to remove large particles and most predators >1 μm. The 0.2 μm MF-Millipore filtered water was then inoculated with 1% by volume of the 1 μm MF-Millipore filtered water containing bacteria from the same station, then incubated in 1 L acid washed Teflon bottles in darkness. Incubations were stopped near the end of log-phase growth,

Table 1 Terrestrial, estuarine, and marine content (mean±SD) in the DOC pool in coastal water of Huanghe River estuary during water and sediment regulation 2014

Distance from river mouth (km)	Terrstrial (%)	Estuarine (‰)	Marine (%)
2.5	39.2±4.0[a]	28.4±3.7[a]	33.3±8.6[a]
5	33.7±3.5[b]	25.7±2.4[a]	40.6±5.6[b]
10	30.3±3.9[b]	22.2±2.4[b]	48.0±5.2[c]

The average percent contribution was calculated by IsoSource. Means with identical letters were not significantly different. $P<0.05$ was significantly different.

generally within 24–32 h. Bacteria were filtered on pre- burned 0.7 μm Whatman GF/F filters before for stable isotope analysis.

2.2.3 Bacterial specific growth rate (μ), bacterial growth efficiency (BGE) and bacterial respiration rate (BR)

Bacterial specific growth rate (μ) was measured during the bacterial growth bioassay for stable isotope analysis. BA was measured at the beginning and end of the incubation period. μ was calculated using Eq.3:

$$\mu=(\ln N_t-\ln N_0)/t, \quad (3)$$

where N_0 and N_t were the BA at the beginning and end of the incubation period, respectively, and t was incubation time.

Surface water (2 L) was filtered through 1 μm MF-Millipore filters then filled into 3–5 acid cleaned, 300 mL bottles. The bottles were sealed and immersed in a constant temperature bath with 20°C for 24 h. One bottle was used to measure BB, DOC concentration, and dissolved oxygen (DO) before inoculation. Other bottles were used for the measure that above after 24 h inoculation. DO was measured by the modified Winkler method (Hitchman, 1978). BGE was calculated by the equation described by Carlson and Ducklow (1996):

$$BGE=\Delta BB/(-\Delta DOC). \quad (4)$$

BR was calculated from the rate of oxygen used, assuming a respiration quotient of 1:1 for O_2:CO_2 (Pollard and Ducklow, 2011).

2.3 Data analysis

The terrestrial DOC content of the DOC pool and the carbon contribution of terrestrial DOC to heterotrophic bacterioplankton demand were calculated using IsoSource 1.3.1. In the study area, there were three DOC sources: terrestrial, estuarine, and marine DOC (Zhang et al., 2014). According to the results of

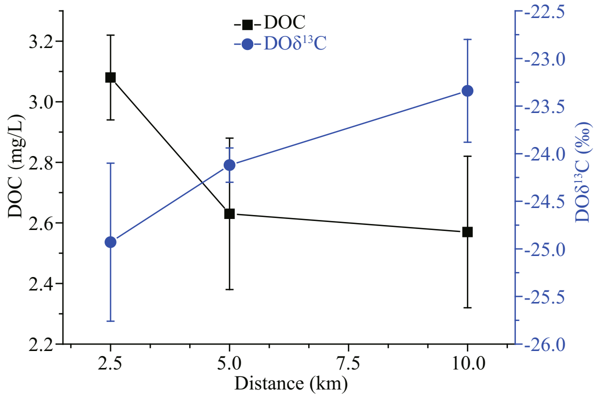

Fig.2 The concentration (square) and δ13C of dissolved organic carbon (DOδ13C) (circle) in coastal water of Huanghe River estuary during water and sediment regulation 2014

other studies, the $\delta^{13}C$ of terrestrial, estuarine, and marine DOC are (-27±0.4)‰, (-30±0.4)‰, and (-18±0.9)‰ [mean±Standard Deviation (SD)], respectively (Middelburg and Nieuwenhuize, 1998; Zhang et al., 2014). The fractionation factor used for fractionation of $\delta^{13}C$ during the anabolism of heterotrophic bacterioplankton was 2.3‰ (Coffin et al., 1990). All the results were analyzed using 1-way analysis of variance (ANOVA) using SPSS 19.0. When the ANOVA identified a significant main effect ($P<0.05$), a post hoc pairwise comparison was performed using Tukey's honestly significant difference (HSD) test. And line regression of concentration of DOC and BB was performed by SPSS 19.0.

3 RESULT

3.1 Characteristics of DOC in water and sediment regulation

During the period of water and sediment regulation, the concentrations of DOC in the middle and high salinity zones were significantly lower than that in the low salinity zone ($P<0.05$); however, the concentrations of DOC in the middle and high salinity zones were similar ($P>0.05$). Generally, the concentrations of DOC gradually decreased as distance from the river mouth increased offshore (Fig.2). In contrast to the DOC concentrations, the DO$\delta^{13}C$ values significantly differed among zones ($P<0.05$), which gradually decreased as distance from the river mouth increased offshore (Fig.2).

The average percent contribution of terrestrial, estuarine, and marine DOC to the DOC pool changed with distance from the river mouth to offshore significantly ($P<0.05$) (Table 1). In the low salinity

Table 2 Bacterial biomass (BB), $\delta^{13}C$ of bacteria ($\delta^{13}C_{Bacteria}$), Bacterial specific growth rates (μ), bacterial growth efficiency (BGE), and bacterial respiration rate (BR) (mean±SD) in coastal water of Huanghe River estuary during water and sediment regulation 2014

Distance from river mouth (km)	BB (μg C/L)	$\delta^{13}C_{Bacteria}$ (‰)	μ	BGE (%)	BR (μg C/(L·d))
2.5	107±28[a]	-22.38±0.75[a]	0.98±0.07[a]	71±5.3[a]	453±61[a]
5	36±13[b]	-21.55±0.67[b]	0.82±0.08[b]	56.6±5.3[b]	354±43[b]
10	73±19[c]	-20.76±0.66[c]	0.76±0.08[c]	61±6.7[c]	369±27[c]

Means with identical letters were not significantly different. $P<0.05$ was significantly different.

Table 3 Contribution of terrestrial, estuarine, and marine DOC to the carbon composition of heterotrophic bacterioplankton (mean±SD) in coastal water of Huanghe River estuary during water and sediment regulation 2014

Distance from river mouth (km)	Terrstrial (%)	Estuarine (‰)	Marine (%)
2.5	37.5±4.3[a]	27.6±3.0[a]	34.9±7.3[a]
5	32.0±4.1[b]	24.5±2.7[b]	43.5±6.7[b]
10	28.2±3.9[c]	21.0±2.7[c]	50.8±6.5[c]

The average percent contribution was calculated by IsoSource. Means with identical letters were not significantly different. $P<0.05$ was significantly different.

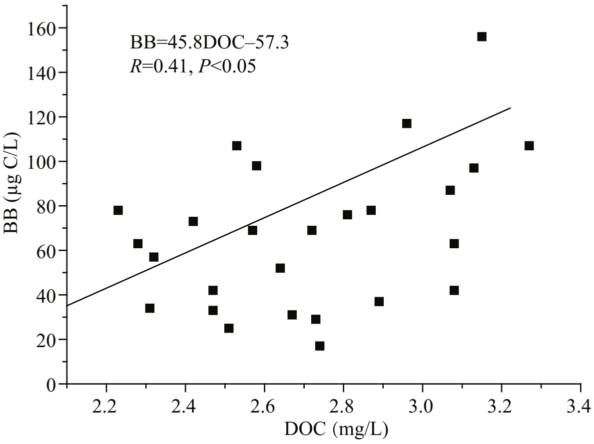

Fig.3 The correlation of bacterial biomass (BB) and concentration of dissolved organic carbon (DOC) in coastal water of Huanghe River estuary during water and sediment regulation 2014

zone, terrestrial DOC was the dominant component of DOC pool, with marine DOC second. Whereas marine DOC became dominant source and terrestrial DOC became second in the middle and high salinity zones. Both terrestrial and estuarine DOC decreased as distance from the river mouth increased offshore. Likewise, marine DOC increased as distance offshore increased (Table 1).

3.2 Characteristics of heterotrophic bacterioplankton in water and sediment regulation

BB, $\delta^{13}C$ of bacteria ($\delta^{13}C_{Bacteria}$), μ, BGE, and BR changed with by distance from river mouth to offshore significantly ($P<0.05$) (Table 2). BB, BGE, and BR decreased at the middle salinity zone, and then increased in the high salinity zone, whereas $\delta^{13}C_{Bacteria}$ increased as distance from the river mouth increased offshore, and μ decreased as distance from the river mouth increased offshore. BB was closely correlated with the DOC concentrations ($R=0.411$, $P<0.05$) (Fig.3), which showed the importance of DOC for heterotrophic bacterioplankton.

The contribution of terrestrial, estuarine, and marine DOC to heterotrophic bacterioplankton changed with distance from river mouth to offshore significantly ($P<0.05$) (Table 3). In the low salinity zone, the terrestrial DOC was the dominant carbon source composition to heterotrophic bacterioplankton, with marine DOC second. Whereas marine DOC became dominant carbon source and terrestrial DOC became second in the middle and high salinity zones. Both terrestrial and estuarine DOC decreased as distance from the river mouth increased offshore. The importance of marine DOC increased as distance offshore increased (Table 3).

4 DISCUSSION

4.1 Impacts on the composition of DOC by water and sediment regulation

For most rivers in the world, more terrestrial DOC was transported in rainy season for the reason that rainfall washed a quantity of terrestrial DOC from the catchments into rivers (Wang et al., 2011; Wang, 2013; Zhang et al., 2013; Hitchcock et al., 2016a, b). Water and sediment regulation further promoted the terrestrial DOC transporting in rainy season. In the water and sediment regulation, both the concentration of DOC and the contribution of terrestrial DOC to DOC pool increased (Liu, 2014). However, the concentration of DOC and the contribution of terrestrial DOC to DOC pool were decreased as distance from the river mouth increased offshore in the water and sediment regulation, which was similar as the study of Liu (2014). That might be not only for the reason of mixture of fresh water and seawater, but also the light limitation for phytoplankton (Atwood et al., 2012). As the distance from the river mouth increased offshore, the mixture of fresh water and seawater decreased which resulted in the concentration of DOC decreasing. During the period of water and sediment regulation, muddy water reduced light absorption of phytoplankton which led to the decreasing of concentration of marine DOC (Mead and Wiegner, 2010). As the distance from the river mouth increased offshore, light limitation was gradually decreasing, which resulted in the concentrations of marine DOC gradually increased.

4.2 Metabolism of terrestrial DOC by heterotrophic bacterioplankton

As the increasing of concentration of DOC in the water and sediment regulation, the growth of bacteria was promoted. Wang (2013) found that BB was significantly higher than that before and after water and sediment regulation. In this study, we found that BB was closely correlated with the DOC concentration, which showed the importance of DOC for heterotrophic bacterioplankton (Fig.3). Bai et al. (2003) also found that the main limiting factor for growth of heterotrophic bacterioplankton was DOC in the Bohai Sea, where the Huanghe River estuary is located. In the low salinity zone, highest concentration of DOC sustained the highest BB. Though the concentration of DOC was similar in the middle and high salinity zone, the BB in the middle salinity zone was higher than that in the high salinity zone significantly. That might be the reason of the growth of heterotrophic bacterioplankton was affected not only by the quantity of DOC, but also by the DOC composition. During the period of water and sediment regulation, the concentration of terrestrial DOC and marine DOC was increased and decreased respectively, as distance from the river mouth increased offshore (Table 1). The main composition of marine DOC was carbohydrate, lipids, and proteins, whereas the main composition of terrestrial DOC was humus, so marine DOC was more bio-available than terrestrial DOC (Moran et al., 1999; Raymond and Bauer, 2000; Asmala et al., 2013). For the reason of variation of DOC composition, the bioavailability of DOC was decreased as distance from the river mouth increased offshore during the period of water and sediment regulation. Hitchcock and Mitrovic (2015) also found in the flood period of Bega River estuary, the bioavailability of DOC was decreased 70%–90% for the variation of DOC composition. In this study, marine DOC was enriched in the heterotrophic bacterioplankton when compared with those in the DOC pool, which showed the selectivity of heterotrophic bacterioplankton for marine DOC over terrestrial DOC (Tables 1, 3). As distance from the river mouth increased offshore, the variation of composition of DOC and carbon source selectivity of heterotrophic bacterioplankton result the contribution of terrestrial DOC gradually decreased (Table 3). In the study of Hudson River and York River estuary, terrestrial DOC was also found as important organic carbon source for heterotrophic bacterioplankton, which importance also decreased as the increase of salinity, similar as this study (McCallister et al., 2004). Terrestrial DOC flux transporting by Huanghe River played an important role in the estuarine and coastal ecosystem, nearly 20%–30% of secondary productivity of zooplankton was sustained by terrestrial DOC (Zhang et al., 2018). More terrestrial DOC may enter in coastal ecosystem by “microbial loop”, for the reason of promotion of growth of heterotrophic bacterioplankton in water and sediment regulation.

The variation of DOC composition also impacted the BR of heterotrophic bacterioplankton. Though Smith and Kemp (2003) found that cell-specific respiration increased as the increasing of salinity in estuaries, significant difference of BB led to the BR has the same spatial variation of BB (Table 3). In heterotrophic aquatic systems, BR was mainly based on terrestrial DOC and strongly correlated with the terrestrial DOC export (Jansson et al., 2008). As the reason of increasing of terrestrial DOC transporting during the period of water and sediment regulation, BR may exceed that in non-regulation times. Liu et al. (2014) also found that the CO_2 releasing by biodegradation of terrestrial DOC increased during the period of water and sediment regulation.

4.3 Conversion of terrestrial DOC into bacterial production and CO_2

For the reason of heterotrophism of estuarine system, terrestrial DOC provided additional material and energy for heterotrophic bacterioplankton (Gattuso et al., 1998; Sun et al., 2011). In this study, nearly 30% of BCD was supported by terrestrial

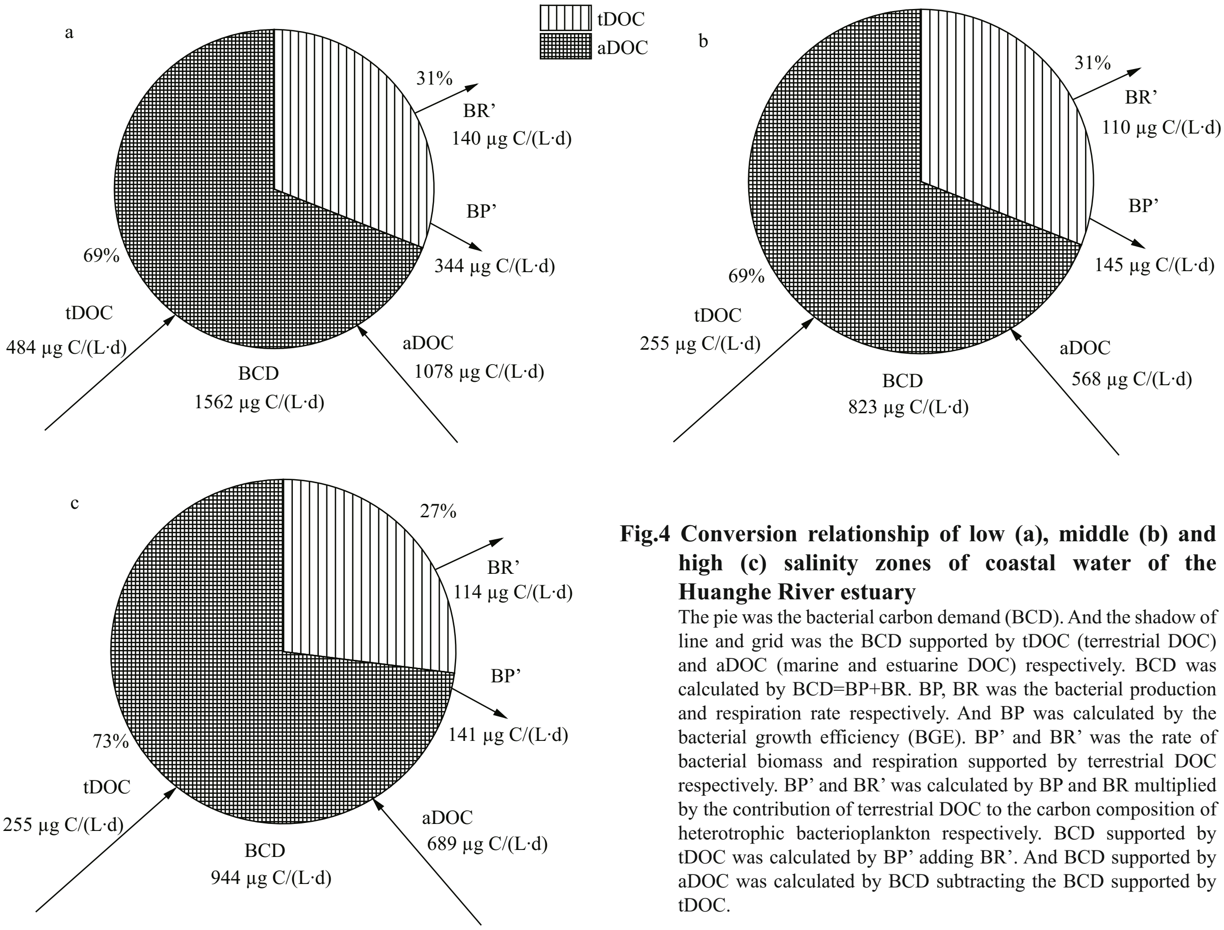

Fig.4 Conversion relationship of low (a), middle (b) and high (c) salinity zones of coastal water of the Huanghe River estuary

The pie was the bacterial carbon demand (BCD). And the shadow of line and grid was the BCD supported by tDOC (terrestrial DOC) and aDOC (marine and estuarine DOC) respectively. BCD was calculated by BCD=BP+BR. BP, BR was the bacterial production and respiration rate respectively. And BP was calculated by the bacterial growth efficiency (BGE). BP' and BR' was the rate of bacterial biomass and respiration supported by terrestrial DOC respectively. BP' and BR' was calculated by BP and BR multiplied by the contribution of terrestrial DOC to the carbon composition of heterotrophic bacterioplankton respectively. BCD supported by tDOC was calculated by BP' adding BR'. And BCD supported by aDOC was calculated by BCD subtracting the BCD supported by tDOC.

DOC, which revealed the importance of terrestrial DOC for heterotrophic bacterioplankton (Fig.4). BCD supported by terrestrial DOC reflected the terrestrial DOC consumption by heterotrophic bacterioplankton. In the study area, 255–484 μg C/(L·d) terrestrial DOC was consumed by heterotrophic bacterioplankton. And 29%–45% terrestrial DOC consumed by heterotrophic bacterioplankton releasing as CO_2 by respiration. Generally, a quantity of terrestrial DOC was consumed by heterotrophic bacterioplankton during the period of water and sediment regulation. However, these were few, only a study investigating the rate of terrestrial DOC consumption by heterotrophic bacterioplankton in estuary. In the study of Bremer River estuary, located in east of Australia, nearly 99% of BCD was supported by terrestrial DOC in rainy season (Pollard and Ducklow, 2011). And BCD was 3–6 times of that in Huanghe River estuary in same season. In the study of Bremer River estuary, the rates of terrestrial DOC transforming into bacterial production (BP) and CO_2 were 10–20 times of that in study area. That may be the reason that heterotrophic bacterioplankton was more active in tropical estuary, for the higher temperature.

5 CONCLUSION

During the period of water and sediment regulation of the Huanghe River, the concentration of DOC and the contribution of terrestrial DOC to DOC pool increased. And all of that decreased significantly as distance from the river mouth increased offshore (P<0.05). As the variation of metabolism substrate for heterotrophic bacterioplankton, BB, μ, BGE, BR, and contribution of terrestrial DOC to heterotrophic bacterioplankton were different significantly in the low, middle, and high salinity zones (P<0.05). A quantity of terrestrial DOC was consumed and conversed into BB and CO_2 during the period of water and sediment regulation of the Huanghe River.

6 DATA AVAILABILITY STATEMENT

Data these support the findings of this study are available from the corresponding author upon reasonable request.

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