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DOC concentrations and spectroscopic characteristics in surface runoff from contrasting wetland ecosystems: a case study in the Sanjiang Plain, Northeast China

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Abstract

Dissolved organic carbon (DOC) is a significant component of carbon and nutrient cycling in fluvial ecosystems. Natural wetlands, as important DOC sources for river and ocean ecosystems, have experienced extensive natural and anthropogenic disturbances such as climate change, hydrological variations and land use change in recent years. In this study, we examined the concentrations and spectroscopic characteristics of DOC in surface runoff from contrasting wetlands along the lower Amur River Basin in the Sanjiang Plain, Northeastern China. Surface runoff from seven sites (two natural phialiform wetlands, three natural riparian wetland, one degraded wetland, and one artificial wetland i.e. rice paddy) were monitored during the growing seasons of 2009 and 2010. Surface runoff from the natural wetland sites exhibited a wide range of DOC concentrations (10.06–48.73 mg l^{-1}) during the two-year sampling period. The specific ultraviolet absorbance (SUVA) and color values of DOC in surface runoff were also highly variable at different natural wetland sites. Our analysis also found that DOC values were significantly lower in the surface runoff at the artificial wetland site compared with those from surface runoff at the five natural wetland sites and one degraded wetland site ($P < 0.01$). The colour per carbon unit (C / C) ratio in surface runoff at the artificial wetland site was one to three times lower, while the E4 / E6 ratio (Abs^{465} / Abs^{665}) was reduced by 42.07 % to 55.36 %, compared to those from runoff water at the five natural wetland sites. The C / C ratios in surface runoff at the natural wetland sites were higher than that from surface runoff at the degraded wetland, which in turn has greater values than that from surface runoff at the artificial wetland site. Meanwhile, the E4 / E6 ratio in the surface runoff from the artificial wetland was lower compared to that in surface runoff at the degraded wetland site ($P < 0.05$). This implies that disturbance to DOC concentrations and spectroscopic characteristics in surface runoff is stronger from natural wetland conversion to rice paddy land than that from wetland degradation. The dataset from this study can provide insightful points for understanding the underlying

mechanisms of aquatic DOC dynamics from wetland ecosystems, and improve land use policy and management strategies in the future.

1 Introduction

Dissolved organic carbon (DOC) is a collective term for dissolved and colloidal organic compounds in various stages of decomposition, defined as the organic fractions that pass through a 0.45 µm filter (Roulet and Moore, 2006; Clay et al., 2009). It consists of a variety of molecules that range in size and structure from simple acids and sugars to complex humic substances (Thurman, 1985; Wallage et al., 2006). DOC from terrestrial sources forms the major component of the annual carbon budget of many headwater streams (Brooks et al., 1999). However, the transport of DOC into lakes and streams from water that percolates through soil and exits the system represent parts of the terrestrial carbon balance that is lost laterally without being measured (Cole et al., 2007). Thus, studies of fluvial DOC dynamics are becoming increasingly more important in order to better understand and accurately evaluate global carbon budgets.

Natural wetland ecosystems store a substantial amount of carbon (Post et al., 1982; Mitra et al., 2005), despite only occupying 4 to 6 % of the earth's land area (Matthews and Fung, 1987; Aselmann and Crutzen, 1989). Higher DOC concentrations are observed in natural wetland surface waters compared to groundwater or cropland surface water (Baker et al., 2008) and they are an important source of DOC to the fluvial environment (Koprivnjak and Moore, 1992; Worrall and Burt, 2005; Wallage et al., 2006). For example, DOC concentrations in streams draining 42 catchments showed consistent relationships with the variable percent wetland in the catchment (Eckhardt and Moore, 1990). However, land use change and associated degradation of natural wetland ecosystems is substantial in many parts of the world (Fu, 2001). In China, natural wetland area decreased by 50 % from the 1950s to the middle of 1990s; 14.83 % of natural wetland area disappeared from 1990 to 2000 (Zhang et al., 2004; Chen and Tian, 2007). DOC derived from managed wetlands can result in different concentrations and unique chemical characteristics compared to those from natural wetlands, which would influence microbial energy source (Raymond and Bauer, 2000) and the transport and degradation of pollutants (Morris and Hargreaves, 1997) downstream. Further, a change in DOC distribution in seas, in particular in the distribution of its semi-labile fraction, may have a strong impact on both the global carbon cycle and the whole marine ecosystem, since DOC plays a central role in marine food web (Santinelli et al., 2010). Given the recognition that wetland ecosystems are significant DOC sources to rivers and streams (Gergel et al., 1999; Freeman et al., 2001; Fellman et al., 2008), quantifying the concentrations and chemical characteristics of DOC from natural wetland ecosystems, converted wetlands and degraded wetlands is important for future forecasts of fluvial DOC dynamics and climate changes.

The Sanjiang Plain, a floodplain in Northeastern China, encompasses numerous natural freshwater wetlands (Zhao, 1999). The boreal climate and hydrogeological conditions lead to the distributions of various natural wetland types in the Sanjiang Plain. It is one of the largest marshy distribution regions along the Amur Basin, the longest free-flowing river in the Eastern Hemisphere (Simonov and Dahmer, 2008). However, the impact of human activity on the spatial pattern of wetlands in the last two decades in the Sanjiang Plain has been significant, such that huge amounts of wetlands were converted to paddy lands and uplands over the past 50 yr (Liu et al., 2005a, b). The natural wetland area decreased from about 3.53×10^6 ha in 1954 to 0.96×10^6 ha in 2005 due to the drainage and use of marshes for agricultural fields such as paddy land and upland in the past 50 yr (Song et al., 2008). The conversion of natural ecosystems to managed agricultural systems in the Sanjiang Plain has been accompanied by wetland degradation due to the decrease of standing water depth and input of nutrients during agricultural activities (fertilizer, pesticide application, etc.). Together with differences in soil carbon storages (Zhang et al., 2007; Wang et al., 2009), how these land use changes altered the concentrations and optical characteristics of DOC in surface runoff from wetlands is highly essential for accurate understanding of wetland

HESSD
9, 7919–7945, 2012

ecosystem feedback to environmental changes and for carbon-modelers to incorporate aquatic DOC into their regional carbon budgets in the future.

The objectives of this study were: (1) to determine the seasonal and annual differences in DOC concentrations from different types of wetland surface runoff (two natural phialiform wetlands, three natural riparian wetland, one degraded wetland, and one artificial wetland i.e. rice paddy); (2) to monitor the DOC aromatic characteristics with specific ultra-violet absorbance index (SUVA); and (3) to compare the colour per carbon unit (C / C) ratio and the E4 / E6 ratio (Abs^{465} / Abs^{665}) of DOC among different sites.

2 Site description and methods

2.1 Site description

The Sanjiang Plain (43°49′55″–48°27′56″ N, 129°11′20″–135°05′10″ E) is located in the eastern part of Heilongjiang province, Northeastern China (Fig. 1). It is formed by three major rivers: Amur River, Ussuri River and Songhuajiang River. There are also many tributary rivers, such as Nongjiang River, Yalv River, Bielahonghe River and Naoli River, distributed over this area. The typical geomorphic types in this region are the first terrace and the flood plains around these large rivers and their tributary rivers. Natural wetlands sourcing from the lowlands around the terrace (phialiform wetlands) and the flood plains near the rivers (riparian wetlands) are extensive and typical in this region. The Sanjiang Plain covers the largest freshwater wetland area in China, approximately 10 400 km^2 (Zhao, 1999). However, the Sanjiang Plain has experienced extensive influences from human activities (e.g., land conversion from herbaceous wetland to rice paddy lands) over the past 50 yr (Liu et al., 2005a, b). The proportion of natural wetland cover in the Sanjiang Plain reduced from 42.67 % in 1954 to 26.50 % in 2005 (Song et al., 2008).

HESSD
9, 7919–7945, 2012

Air temperatures in the Sanjiang Plain increase from January to August, and then decline until December. Nearly half of the annual rainfall occurs in July and August. The Sanjiang Experimental Station of Wetland Ecology, Chinese Academy of Sciences, was located in the Sanjiang Plain. The climate in the station can represent the regional pattern. The site-specific weather observations in the station showed that the mean air temperatures for the period of June to September were 17.83° in 2009 and 19.79° in 2010, respectively. The total rainfall during June and September was 509.40 mm for 2009 and 414.7 mm for 2010, respectively. This indicates that the general weather during our study period was warmer and drier in 2010 than that in 2009 (Fig. 2).

In this study, we chose two typical phialiform natural wetlands – *Calamagrostis angustifolia* phialiform wetland (CAPW), and *Carex lasiocarpa* phialiform wetland (CLPW), three riparian natural wetlands near three tributary rivers - Bielahonghe riparian wetland (BRW), Nongjiang riparian wetland (NRW) and Yalv riparian wetland (YRW), the artificial wetland (AW-rice paddy land) and the degraded wetland (DW). Additional hydrological and chemical characteristics of the study sites are listed in Table 1.

2.2 Water sample collection and analysis

From June to September in 2009 and April to September in 2010, surface water samples (pools within wetlands) were collected from CAPW, CLPW, BRW, NRW, YRW, DW and AW. From these different types of wetlands, triplicate surface runoff samples were collected in every site. During the study period altogether 30 samplings for every site were taken. Sampling was undertaken at the seven sites on the same day. The water samples were transported to laboratory immediately after sampling, and were filtered through 0.45 µm filters. The first 100 ml of each sample was used to rinse the filter three times. The remaining was filtered into separate vials without any head space to minimize degassing. Multi N/C 2100 Analyzer (Analytik Jena AG, Germany) was used to analyze Dissolved Total Carbon (DTC) and Dissolved Inorganic Carbon (DIC) of the water samples. The analyzer used a non-dispersive infrared detector to quantitatively measure CO_2 levels to get the concentrations of DIC and DTC. DOC concentrations were determined by DTC minus DIC. Each sample was injected at least two times to obtain a standard deviation of ≤ 2 %.

2.3 Determination of $SUVA_{254}$ (specific ultra-violet absorbance index), C / C and E4 / E6

DOC consists of a variety of molecules that range in size and structure from simple acids and sugars to complex humic substances (Thurman, 1985). As the ratio of these compounds varies, the samples will absorb different wavelengths of light and therefore provide different responses in spectrophotometric analysis. For example, humic acids have a greater reddish colour than fulvic acids, and thus have a greater level of absorbance at higher wavelengths in the light spectrum (Thurman, 1985). Thus, the optical characteristics of DOC could convey information about its chemical composition (Thurman, 1985; Wallage et al., 2006). For example, a high C / C ratio indicates that the DOC comprises a greater proportion of coloured humic substances compared to uncoloured non-humic substances. The C / C ratio of the samples was obtained by dividing the absorbance values at 400 nm (Abs^{400}) by the corresponding DOC concentrations (Wallage et al., 2006). The E4 / E6 ratio can be used to measure the proportion of fulvic acid to humic acid in the coloured humic component of DOC (Thurman, 1985; Wallage et al., 2006). The E4 / E6 ratio was determined by dividing the absorbance at 465 nm (Abs^{465}) by that at 665 nm (Abs^{665}) for the individual samples (Wallage et al., 2006). $SUVA_{254}$ is defined as the UV absorbance at 254 nm divided by the DOC concentration measured in milligrams per liter ($mg\,l^{-1}$). $SUVA_{254}$ is expressed as an index of the aromaticity of DOC (Weishaar et al., 2003). $SUVA_{254}$ is reported in units of $l\,(mg\,m)^{-1}$. $SUVA_{254}$ was analyzed from June to September in both 2009 and 2010, while the C / C and E4 / E6 ratios were conducted from April to September in 2010. The absorbance measurements of 254 nm, 400 nm, 465 nm and 665 nm were made

HESSD
9, 7919–7945, 2012

on a UV-7504 spectrophotometer using deionized water as a blank. A quartz cell with a 1.0-cm path length was used.

2.4 Statistical analysis

The SPSS 11.5 and Origin 7.5 statistical packages were used in the statistical analysis. The difference in DOC, $SUVA_{254}$, C / C and E4 / E6 ratios among different sites was tested by the one-way repeated measures ANOVA. In analyses where $P < 0.05$, the comparisons were considered statistically significant.

3 Results

3.1 DOC concentrations

During the study period, both pronounced inter-seasonal and extreme inter-annual variations of DOC concentrations were identified in the surface runoff at different types of wetlands (Fig. 3). The averaged values for DOC during the two-years' samplings ranged from 7.08 ± 1.38 to $48.73 \pm 3.26\,mg\,l^{-1}$ at seven sites with the highest values found in the surface runoff at the CAPW site ($48.73 \pm 3.26\,mg\,l^{-1}$), followed by the CLPW site ($29.33 \pm 1.75\,mg\,l^{-1}$), the DW site ($18.48 \pm 2.67\,mg\,l^{-1}$), NRW site ($15.21 \pm 3.51\,mg\,l^{-1}$), YRW ($12.91 \pm 1.67\,mg\,l^{-1}$) and BRW sites ($10.06 \pm 0.72\,mg\,l^{-1}$). The lowest two-year mean DOC concentrations were observed in the surface runoff at the AW site ($7.08 \pm 1.38\,mg\,l^{-1}$). Of interest in this study was the observation that the highest monthly averaged DOC concentrations in the surface runoff among the seven sites all occurred in the surface runoff of the CAPW sites with a range from $40.36 \pm 2.63\,mg\,l^{-1}$ to $67.34 \pm 3.33\,mg\,l^{-1}$ in 2009 and from $39.52 \pm 0.22\,mg\,l^{-1}$ to $54.62 \pm 2.93\,mg\,l^{-1}$ in 2010. The lowest monthly DOC concentration was observed in the surface runoff at BRW site for June in 2009, whereas it all occurred in the surface runoff at the AW site from July to September 2009 and from June to September 2010. The monthly maximum for the surface runoff at all the sites in 2009 occurred in the

HESSD
9, 7919–7945, 2012

June at the CAPW site, while it was postponed to July at the CAPW site for 2010. The monthly minimum in the surface runoff among the seven sites all occurred in the surface runoff at AW site in September in 2009 ($3.63 \pm 0.26\,\mathrm{mg\,l^{-1}}$) and in August in 2010 ($4.74 \pm 0.75\,\mathrm{mg\,l^{-1}}$). As for between year difference, the DOC concentration in the surface runoff from CLPW site in 2009 was significantly greater than in 2010 ($P < 0.05$). No significances of DOC concentrations were observed between 2009 and 2010 for the surface runoff at the other six sites ($P > 0.05$).

3.2 Specific ultraviolet absorbance ($SUVA_{254}$) of DOC

As shown in Table 2 and Fig. 4, the specific UV absorbance ($SUVA_{254}$) revealed clear monthly differences in the chemical composition of the DOC between the seven sites. Two-years' averaged $SUVA_{254}$ values for the surface runoff at the seven sites ranged from 1.60 to $3.85\,\mathrm{l\,(mg\,m)^{-1}}$ with the maximum observed in the surface runoff at the CAPW site, while the minimum was from the surface runoff at the AW site followed by DW site. It is notable that the averaged $SUVA_{254}$ values in 2009 were higher than those in 2010 for surface runoff at all the seven sites, suggesting an increased contribution of small organic molecules to DOC in 2010 than occurred in 2009. This interannual difference, however, was only significant for the surface runoff at the NRW site ($P < 0.05$). Monthly mean $SUVA_{254}$ values ranged from 1.02 to $4.98\,\mathrm{l\,mg\,m^{-1}}$ in surface runoff of the seven sites over the two years' study. The minimum for surface runoff at the seven sites was observed at the artificial wetland site in June for 2009 and in September for 2010. A maximum was observed at the BRW site in September for 2009 ($4.38\,\mathrm{l\,(mg\,m)^{-1}}$), while it occurred at the CLPW site in June for 2010 ($4.98\,\mathrm{l\,(mg\,m)^{-1}}$).

3.3 Color-carbon relationship and E4/E6 ratio

The color per carbon unit (C/C) ratio ranged from 0.06 to 0.65 for the surface runoff we sampled from April to September in 2010 (Table 3 and Fig. 5). The lowest value was observed in the surface runoff at AW site in September, while C/C value in the surface runoff at CAPW site in May showed the maximum. Compared to those in the other six sites, monthly C / C value in the surface runoff at the CAPW site was the highest from April to September. With exceptions in May and June, monthly C / C values in the surface runoff at the artificial wetland were the lowest among the seven sites during the whole observation period. The seasonal averaged amount of colour per carbon unit in the surface runoff of the two natural phialiform wetlands exhibited the highest values (0.47 ± 0.06 in CAPW site and 0.40 ± 0.05 in CLPW site), followed by those at the natural riparian wetlands with the values of 0.32 ± 0.05 (NRW site), 0.30 ± 0.02 (BRW site) and 0.27 ± 0.04 (YRW site), while the minimum values were observed in the surface runoff of the two non-natural wetlands (0.26 ± 0.02 in DW site and 0.18 ± 0.04 in AW site). Interestingly, the C / C ratios in surface runoff at the rice paddy site were one to three times lower, compared to those from the five natural wetland sites. The differences between the C / C ratios for the sample sets demonstrates that, per carbon unit, the DOC at the surface runoff of the AW and DW sites actually contains less color compared to those of the natural wetland sites, with the least color per carbon unit observed in surface runoff of the artificial wetland.

E4 / E6 ratio of DOC in the surface runoff under different types of wetlands is presented in Table 3 and Fig. 6. The E4 / E6 ratio in surface runoff of the five natural wetlands showed no significant differences ($P > 0.05$). Meanwhile, the values of E4 / E6 ratio in the surface runoff at the DW site was not significantly different to those in the natural wetland sites ($P > 0.05$), but the seasonal averaged E4 / E6 ratio in the surface runoff at the AW site was significantly lower than those in the natural wetlands sites ($P < 0.05$). The E4 / E6 ratio in surface runoff of the AW site was reduced by 42.07 % to 55.36 % compared to those from the natural wetland sites ($P < 0.05$). Furthermore, E4 / E6 ratio in the surface runoff of the AW site revealed significantly lower values than those in the DW site ($P < 0.05$). This clear difference in E4 / E6 between the surface runoff of artificial wetland and the other sites highlights the fact that the DOC in surface runoff might be changed in chemical composition if natural wetlands are converted to rice paddies.

HESSD
9, 7919–7945, 2012

4 Discussion

4.1 Comparisons with other studies

Natural wetlands, as significant carbon pools, have been increasingly recognized as important DOC sources for adjacent waters (Wallage et al., 2006; Dawson and Smith, 2007; Baker et al., 2008). Much work has been completed concerning the concentration and bioavailability of soil dissolved organic carbon from wetland ecosystems in the Sanjiang Plain (Zhang et al., 2005, 2008). Of interest is that surface runoff from wetland ecosystems has a much closer link with adjacent rivers or streams than soil and pore water, yet little information is available on how the dynamics of DOC derived from surface runoff from wetland ecosystems of the Sanjiang Plain. In this study, we determined that the averaged values of DOC were 23.25 mg l^{-1} for the surface runoff at the five natural wetland sites in the Sanjiang Plain during the two-year samplings. Nagao et al. (2007) showed that DOC concentrations in river waters from tributaries of the Amur River in the Sanjiang Plain were generally lower than 10 mg l^{-1}. The higher concentrations we recorded suggests that the natural wetlands in our study could serve as alternative DOC sources for tributaries along the Amur River in the Sanjiang Plain. Similarly, Waiser and Robarts (2004) reported that natural wetlands across the Canadian prairies exhibited high DOC concentrations (> 10 mg l^{-1}), acting as significant DOC pools for adjacent waters. Raphael et al. (1996) and Arrigoni et al. (2008) pointed out that the Tivoli Bays freshwater tidal wetlands exported DOC to the main channel of the Hudson River, but the magnitude of DOC concentrations (< 7 mg l^{-1}) in their studies were much lower compared to our study. These variations might result from different rates of DOC production, solubility and transport under freshwater and tidal wetlands. Alternatively, this study together with previous studies provided substantial evidence for the importance of natural wetlands on DOC export to adjacent rivers. This is also confirmed by Hope et al. (1997)'s study that invoked a significant relationship between average DOC concentration in 11 Scottish catchments and percentage of natural wetland cover.

HESSD
9, 7919–7945, 2012

Ultraviolet/visible absorbance, such as 254 nm, 280 nm, and 400 nm etc., has been extensively examined in water bodies to infer DOC aromatic characteristics or bioavailability (Thurman, 1985; Weishaar et al., 2003; Wallage et al., 2006; Fellman et al., 2008; Krupa et al., 2012). To our best knowledge, the information about the relationship between different spectroscopic measures has been less reported. In this study, we found that the DOC absorbance values at 400 nm for surface runoff at the seven sites were significantly correlated with those at 254 nm and 465 nm ($P < 0.01$, data not shown), except the non-significant relationships with 254 nm at the YRW site and 465 nm at the NRW site ($P = 0.153$; $P = 0.263$, respectively). It implied that the different DOC chemical composition might be highly correlated variables following the same general pattern, which might provide potentially useful information about DOC character changes.

4.2 Variations between different natural wetlands

Our study found that $SUVA_{254}$ and C / C ratio values from surface runoff at the CAPW site was significantly higher than those in the riparian wetlands, while E4 / E6 showed no clear differences between those two types of wetlands. In this study, we found that DOC concentrations from surface runoff exhibited great variance among different natural wetlands with DOC concentrations decreasing by the order of CAPW ($48.73 \pm 3.26\,\mathrm{mg\,l^{-1}}$) > CLPW ($29.33 \pm 1.75\,\mathrm{mg\,l^{-1}}$) > riparian wetlands ($10.06 \sim 15.21\,\mathrm{mg\,l^{-1}}$) during our two years' study. The significant differences in two-year DOC concentrations between CAPW and CLPW ($P < 0.001$) might come from the fact that they are located in different positions of the phialiform. The outside position with higher terrain for CAPW resulted in lower water depth, possibly allowing more carbon to be released from plants and soil (Zhang, 2006), producing higher aquatic DOC concentrations compared to those at CLPW site where longer waterlogging duration time occurred. Also, the greater DOC values from surface runoff of phialiform wetlands compared to those in the riparian wetlands might result from the varying waterlogging duration time in the different types of wetlands (Table 1). Compared to the two phialiform wetlands, riparian wetlands were flooded with higher water level (Table 1), which would lead to more anaerobic condition, lower soil carbon decomposition rates and thus less release of DOC from soil and litter decomposition to runoff water. Another potential driver of the observed differences might be the contrasting nutrient content of the wetlands. Although no correlations between nutrient factors and DOC concentrations were conducted in this study, the total nitrogen in surface runoff, soil organic matter and soil total nitrogen showed higher values in the surface runoff at phialiform wetland sites (Table 1) compared to those in riparian wetlands. Studies in UK have also reported that the ranked DOC releases from different wetland types matched rankings based on nutritional grounds (Mitsch and Gosselink, 1993; Freeman et al., 2004).

4.3 Effects of natural wetland conversion and associated degradation on DOC dynamics

In our study, averaged DOC concentration in the surface runoff at the artificial wetland is the lowest compared to those in surface runoff at both the natural and degraded wetlands. Moreover, the averaged $SUVA_{254}$, C / C and E4 / E6 values during our study period were also the lowest in surface runoff of the artificial site than those at the other sites. This implies that wetland conversion to rice paddy land reduced aquatic DOC concentrations and also changed the spectroscopic characteristics compared to those at the natural sites. Furthermore, the $SUVA_{254}$ and C / C ratio in the surface runoff at the degraded site were lower than those at the natural sites, though there were no consistent differences in DOC concentrations and E4 / E6 ratio between the surface runoff at the natural wetland sites and degraded site. Our comparison also found that E4 / E6 ratio in surface runoff at the AW site was significantly lower compared to those in the DW site ($P < 0.05$), together with lower DOC concentrations and C / C ratio. This indicates that natural wetland conversion to rice paddies has stronger effects on aquatic DOC concentrations and chemical characteristics compared to that from wetland degradation. This study could provide information for the question how wetland conversion leads to changes in both concentrations and spectroscopic characteristics of DOC.

HESSD
9, 7919–7945, 2012

Wetland conversion will exert influences on DOC export from wetlands, accounting for DOC dynamics in adjacent rivers and even seas (Santinelli et al., 2010). Therefore, it seems prudent to manage these vulnerable wetland conversion in order to minimize DOC losses through good land-use practices.

5 Conclusions

On the basis of two-year observation of DOC concentrations and spectroscopic characteristics in surface runoff from seven sites of wetlands in the Sanjiang Plain, we revealed seasonal and inter-annual variations of DOC concentrations and chemical characteristics in the study sites. DOC concentrations, $SUVA_{254}$, C / C and E4 / E6 ratios showed substantial variances among different types of wetlands. Surface runoff from the five natural wetlands showed wide ranges of DOC concentrations (10.06 ~ 48.73 $mg\,l^{-1}$), $SUVA_{254}$ (2.96 ~ 3.62 $l\,(mg\,m)^{-1}$), C / C (0.27 ~ 0.47) and E4 / E6 ratios (5.61 ~ 7.28). This suggests that conditions in the varying natural wetlands might drive different DOC production and consumption scenarios. The lowest two-year average DOC concentrations, C / C and E4 / E6 ratios were found from surface runoff in the artificial wetland (rice paddy), which indicated that wetland conversion to cropland modifies the spectroscopic characteristics of DOC together with the decreases in DOC concentrations. In particular, our study found that heightened DOC concentrations, C / C and E4 / E6 ratios were observed in the degraded site compared to those at the artificial site, implying that disturbance to DOC concentrations and spectroscopic characteristics within natural wetlands is stronger from the wetland conversion to rice paddies than that from wetland degradation. This work will enrich our knowledge of future aquatic DOC characteristics in the context of land use change and climate change.

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HESSD
9, 7919–7945, 2012

HESSD
9, 7919–7945, 2012

Table 1. Characteristics of the seven studying sites in the Sanjiang Plain, Northeastern China.

Site	Water level (cm)	Waterlogging duration Time (year)	Total N ($g\,kg^{-1}$)	SOM (%)	Soil total N ($g\,kg^{-1}$)
CAPW	12.49 ± 2.49	180 days	1.68 ± 0.27	9.47 ± 0.43	6.67 ± 0.61
CLPW	23.79 ± 1.71	365 days	1.29 ± 0.23	20.77 ± 0.71	21.17 ± 1.17
BRW	23.99 ± 4.51	365 days	0.69 ± 0.09	7.30 ± 0.23	5.77 ± 0.18
NRW	24.61 ± 1.48	365 days	1.01 ± 0.24	7.43±0.44	5.23±0.17
YRW	25.52 ± 1.94	365 days	0.74 ± 0.14	7.73 ± 0.22	5.83 ± 0.33
DW	8.83 ± 0.49	170 days	0.64 ± 0.24	5.57 ± 0.38	3.73 ± 0.19
AW	8.75 ± 0.79	160 days	1.17 ± 0.41	4.07 ± 0.23	2.67 ± 0.15

HESSD
9, 7919–7945, 2012

DOC characteristics from contrasting wetland ecosystems

L. Wang et al.

Table 2. $SUVA_{254}$ in surface runoff from contrasting wetlands in the Sanjiang Plain during the growing season of 2009 and 2010.

	Sites						
	CAPW	CLPW	BRW	NRW	YRW	DW	AW
2009 Abs^{254}	1.87 ± 0.18	1.06 ± 0.09	0.31 ± 0.04	0.66 ± 0.03	0.58 ± 0.10	0.52 ± 0.18	0.23 ± 0.05
$SUVA_{254}$	3.85 ± 0.10	3.77 ± 0.08	3.30 ± 0.37	3.73 ± 0.06	3.82 ± 0.12	3.11 ± 0.36	3.33 ± 0.38
2010 Abs^{254}	1.61 ± 0.12	1.00 ± 0.11	0.31 ± 0.04	0.35 ± 0.02	0.26 ± 0.02	0.49 ± 0.04	0.20 ± 0.00
$SUVA_{254}$	3.40 ± 0.46	3.38 ± 0.54	2.94 ± 0.33	3.49 ± 0.49	2.10 ± 0.25	2.43±0.16	1.60±0.26
Mean(2009–2010) Abs^{254}	1.74 ± 0.11	1.03 ± 0.07	0.31 ± 0.03	0.51 ± 0.02	0.42 ± 0.08	0.51 ± 0.09	0.21 ± 0.02
$SUVA_{254}$	3.62 ± 0.23	3.57 ± 0.26	3.12 ± 0.24	3.61 ± 0.23	2.96 ± 0.35	2.77 ± 0.22	2.47 ± 0.39

Note: average is (mean ± SE); unit of $SUVA_{254}$ is $l\,(mg\,m)^{-1}$; unit of Abs^{254} is $au\,cm^{-1}$.

Table 3. C / C and E4 / E6 ratios in surface runoff from contrasting wetlands in the Sanjiang Plain during the growing season of 2010.

		Sites						
		CAPW	CLPW	BLRW	NLRW	YLRW	DW	AW
Abs^{400}	Range	13.83 ~ 24.83	6.60 ~ 12.70	1.70 ~ 3.67	2.50 ~ 3.47	1.70 ~ 5.97	3.83 ~ 5.60	1.20 ~ 6.20
	Average	18.80 ± 1.70	9.52 ± 1.07	2.71 ± 0.28	3.23 ± 0.15	3.16 ± 0.64	4.70 ± 0.29	2.57 ± 0.74
C / C ratio	Range	0.33 ~ 0.65	0.26 ~ 0.58	0.24 ~ 0.37	0.21 ~ 0.55	0.17 ~ 0.45	0.22 ~ 0.32	0.06 ~ 0.35
	Average	0.47 ± 0.06	0.40 ± 0.05	0.30 ± 0.02	0.32 ± 0.05	0.27 ± 0.04	0.26 ± 0.02	0.18 ± 0.04
Abs^{465}	Range	5.27 ~ 9.60	2.40 ~ 4.67	0.70–1.17	0.8 ~ 1.35	0.45 ~ 2.23	1.40 ~ 1.80	0.35 ~ 1.57
	Average	7.33 ± 0.66	3.51 ± 0.41	0.99 ± 0.08	1.09 ± 0.07	1.00 ± 0.30	1.61 ± 0.07	0.67 ± 0.18
Abs^{665}	Range	0.95 ~ 1.73	0.35 ~ 0.67	0.10 ~ 0.20	0.07 ~ 0.33	0.10 ~ 0.53	0.20 ~ 0.33	0.13 ~ 0.43
	Average	1.26 ± 0.11	0.54 ± 0.06	0.15 ± 0.02	0.17 ± 0.02	0.20 ± 0.07	0.27 ± 0.02	0.20 ± 0.05
E4 / E6 ratio	Range	4.27 ~ 6.45	6.07 ~ 7.00	4.67 ~ 11.67	4.00 ~ 11.00	4.19 ~ 7.5	5.25 ~ 9.00	2.33 ~ 3.62
	Average	5.71 ± 0.32	6.53 ± 0.16	7.28 ± 1.16	6.98 ± 0.95	5.61 ± 0.59	6.21 ± 0.58	3.25 ± 0.21

Note: average is (mean ± SE); units of Abs^{400}, Abs^{465} and Abs^{665} are aum^{-1}.

HESSD
9, 7919–7945, 2012

DOC characteristics from contrasting wetland ecosystems

L. Wang et al.

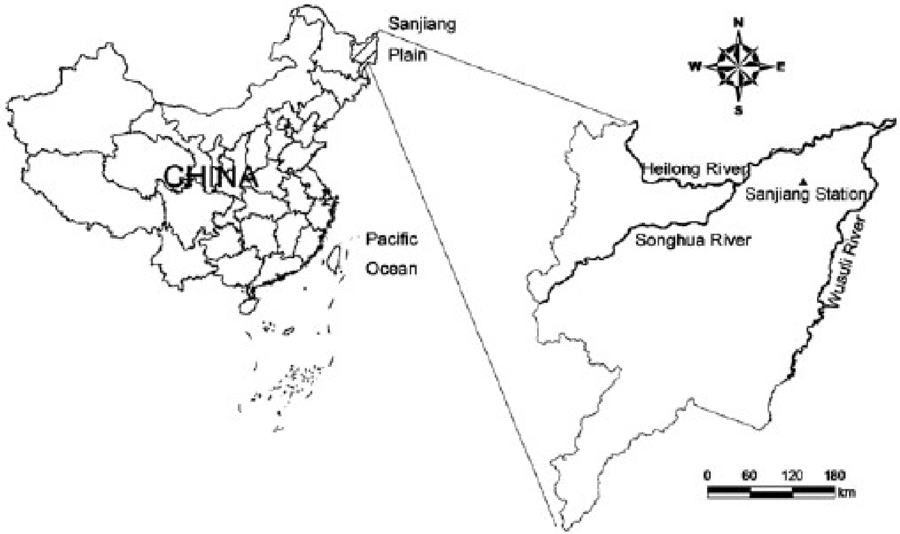

Fig. 1. The location of the Sanjiang Plain, Northeast China (Wu, 2009).

HESSD
9, 7919–7945, 2012

DOC characteristics from contrasting wetland ecosystems

L. Wang et al.

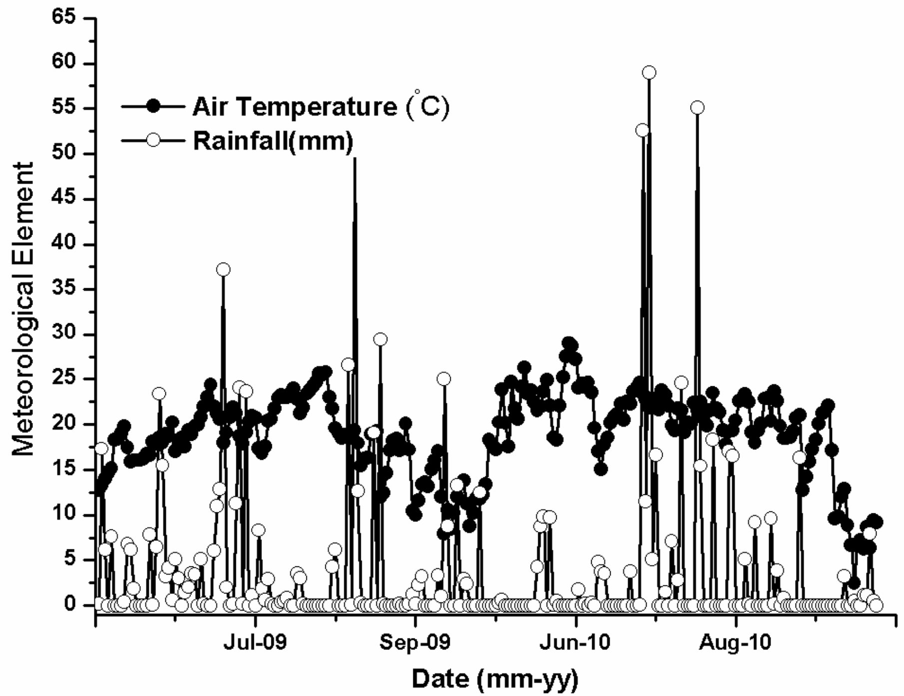

Fig. 2. Air temperature and rainfall in the Sanjiang Plain Mire Station during the growing season of 2009 and 2010.

HESSD

9, 7919–7945, 2012

DOC characteristics from contrasting wetland ecosystems

L. Wang et al.

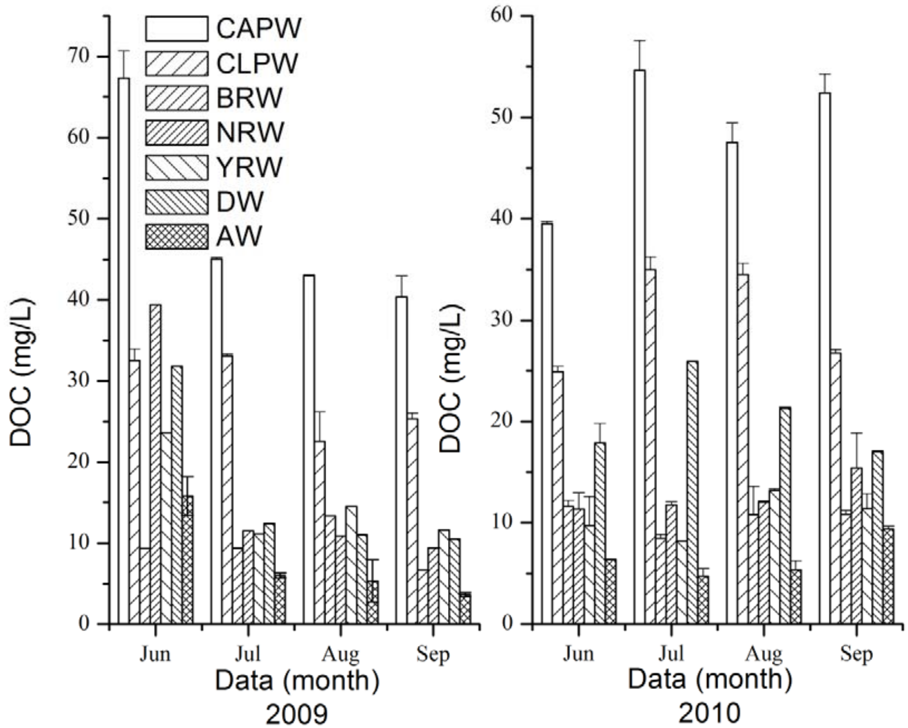

Fig. 3. Monthly DOC concentrations in surface runoff from contrasting wetland ecosystems in the Sanjiang Plain during the growing seasons of 2009 and 2010.

HESSD
9, 7919–7945, 2012

DOC characteristics from contrasting wetland ecosystems

L. Wang et al.

Title Page
Abstract
Introduction
Conclusions
References
Tables
Figures
Back
Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

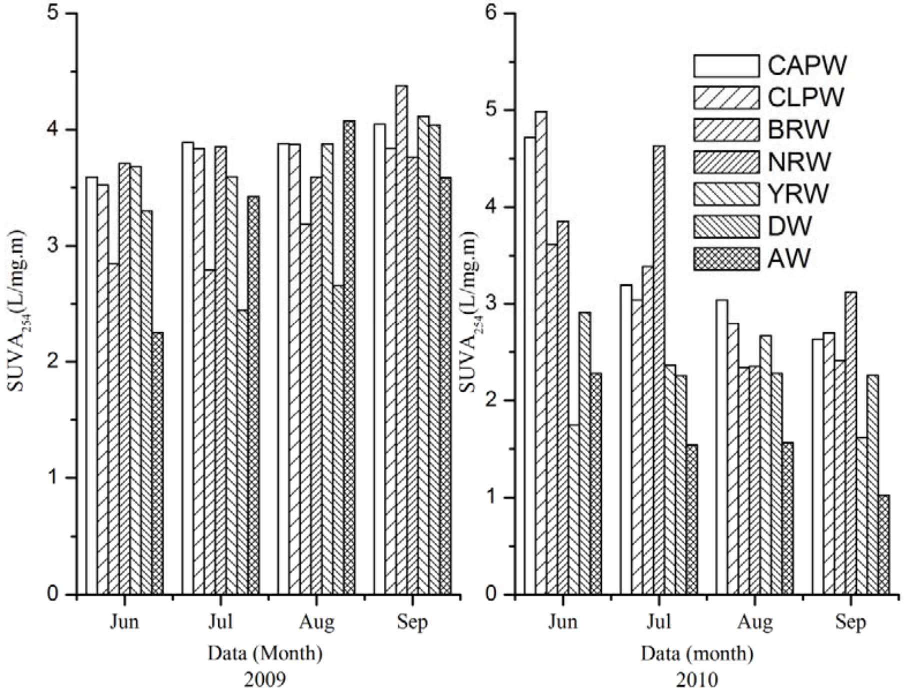

Fig. 4. Monthly $SUVA_{254}$ in surface runoff from contrasting wetland ecosystems in the Sanjiang Plain.

HESSD
9, 7919–7945, 2012

DOC characteristics from contrasting wetland ecosystems

L. Wang et al.

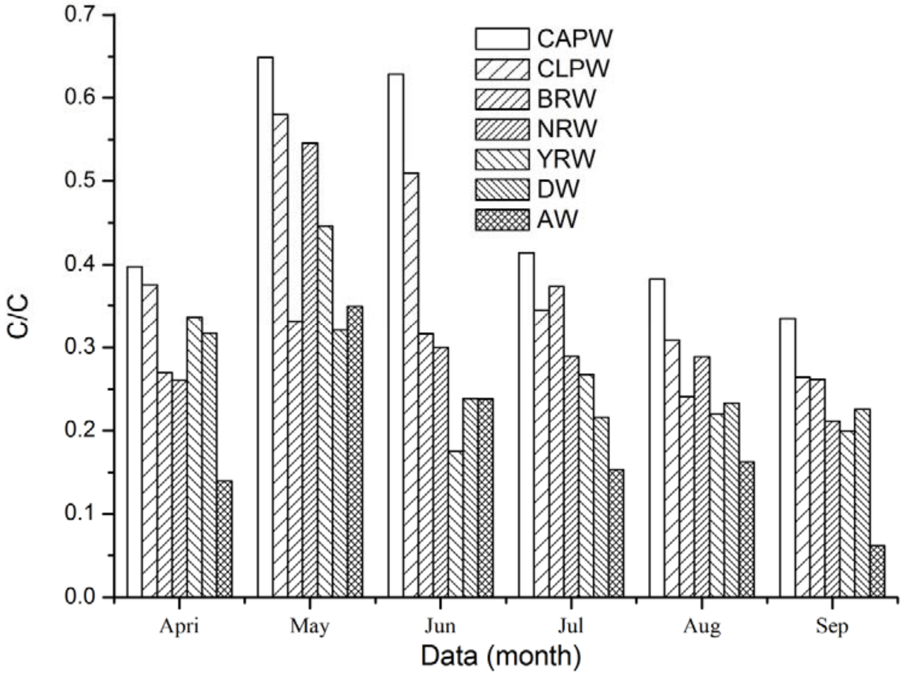

Fig. 5. Monthly C / C ratio in surface runoff from contrasting wetland ecosystems in the Sanjiang Plain.

HESSD
9, 7919–7945, 2012

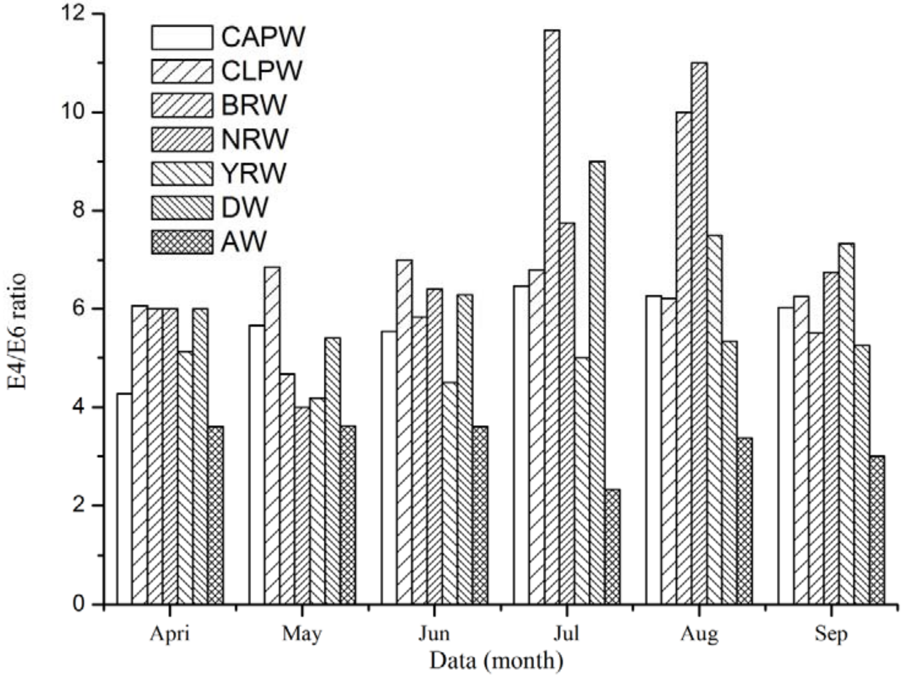

Fig. 6. Monthly E4 / E6 in surface runoff from contrasting wetland ecosystems in the Sanjiang Plain.

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HESSD

9, 7919–7945, 2012

DOC characteristics from contrasting wetland ecosystems

L. Wang et al.