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Seasonal and Spatial Variability of Water Quality and Nutrient Removal Efficiency of Restored Wetland: A Case Study in Fujin National Wetland Park, China

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Abstract: To investigate the spatio-temporal and compositional variation of selected water quality parameters and understand the purifying effects of wetland in Fujin National Wetland Park (FNWP), China, the trophic level index (TLI), paired samples *t*-test and correlation analysis were used for the statistical analysis of a set of 10 water quality parameters. The analyses were based on water samples collected from 22 stations in FNWP between 2014 and 2016. Results initially reveal that total nitrogen (TN) concentrations are above class V levels (2 mg/L), total phosphorus (TP) concentrations are below class III levels (0.2 mg/L), and that all other parameters fall within standard ranges. Highest values for TN, pH, and Chlorophyll-a were recorded in 2016, while the levels of chemical oxygen demand (COD_{Mn}) and biochemical oxygen demand (BOD_5) were lowest during this year. Similarly, TN values were highest between 2014 and 2016 while dissolved oxygen (DO) concentrations were lowest in the summer and TP concentrations were highest in the autumn. Significant variations were also found in Secchi depth (SD), TN, COD_{Mn} ($P < 0.01$), TP, and DO levels ($P < 0.05$) between the inlet and outlet of the park. High-to-low levels of TN, TP, and TDS were found in cattails, reeds, and open water (the opposite trend was seen in SD levels). Tested wetland water had a light eutrophication status in most cases and TN and TP removal rates were between 7.54%–84.36% and 37.50%–70.83%, respectively. Data also show no significant annual changes in water quality within this wetland, although obvious affects from surrounding agricultural drainage were nevertheless recorded. Results reveal a high major nutrient removal efficiency (N and P). The upper limits of these phenomena should be addressed in future research alongside a more efficient and scientific agricultural layout for the regions in and around the FNWP.

Keywords: restored wetland; water quality; purification; nutrient removal; seasonal and spatial variability; Fujin National Wetland Park (FNWP)

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1 Introduction

Wetlands perform a range of key ecological functions including flood protection (Adusumilli, 2015), groundwater recharge (Katara and Dev, 2016), and water purification (Palma et al., 2010; Yu et al., 2015), and are also critical wildlife habitats (Smalling et al., 2015). The water purification function of wetlands has caused sub-

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stantial concern in recent years, because this phenomenon is essential for biological growth and reproduction and also has direct effects on other key functions (Yu et al., 2015). The structure and ecological functions of wetlands have been seriously threatened (Zacharias et al., 2003) because of many years of ongoing water pollution and unreasonable utilization (Qadir et al., 2008; Vörösmarty et al., 2010). The restoration of damaged wetland ecosystems has therefore received a great deal of research attention in recent years (Lu, 2008; McCauley et al., 2013). Indeed, wetland purification is now quite well understood (Solidoro et al., 2004; Ge, 2008) and ecologists have been able to turn theories into practical research applications with regard to the purification function of these habitats (Trebitz et al., 2007; Montgomery and Eames, 2008; Maassen et al., 2012). This phenomenon is mainly embodied by the fact that wetlands are able to intercept, transform, and remove nutrients such as nitrogen (N) and phosphorus (P) from water (Steinmann et al., 2003; Gunes et al., 2012). These research efforts mean that the treatment effects of artificial wetlands are now also very good. Studies have shown that the N and P purification effects of some artificial ecosystems can be higher than 50% in America and in some European countries (Vymazal, 2007; Guo et al., 2010).

The Sanjiang Plain, located in the east of Heilongjiang Province, northeastern China, is an alluvial floodplain that includes one of the largest national areas of freshwater wetland (Zhao, 1999). In the past 50 years, wetlands have been extensively drained and used for agriculture in the Sanjiang Plain. In 1954, wetlands covered over half of the total land area but have decreased by 77% until 2003 (Wang et al., 2011). The reclamation of natural wetlands remains one of the main threats to ecology on the Sanjiang Plain. With this in mind, the Heilongjiang Provincial Government proposed banning large-scale reclamation in 2003, and also planned to restore 150 000 hr of farmland to wetlands across the region. Although a large amount of research has been carried out on natural wetlands and water quality surveys in the Sanjiang Plain (Gong et al., 2016; Li et al., 2017), little attention has been afforded to restored habitats of this type, especially in Fujin City (Ma, 2012). Several observational studies have been published that address changes in water quality over time (Li et al., 2010). But long-term continuous restored wetland monitoring has not been undertaken even though significant differences in sediment between farmlands, ditches, and areas of water within natural habitats of this type on the Sanjiang Plain have been reported (Su et al., 2015). A number of previous researchers (2008; Khan et al., 2013) have concluded that farmland drainage provides the main explanation for wetland eutrophication, but the extent to which restored habitats of this type can remove nutrients in different seasons and years remains poorly understood. It is therefore vital to study the effects of agricultural activities on water quality as well as the nutrient removal efficiency of restored Sanjiang Plain wetlands.

The Fujin National Wetland Park (FNWP) is the focus for this research as this region provides one example of a restored wetland on the Sanjiang Plain. Water quality dynamics were monitored seasonally within the FNWP between 2014 and 2016 in order to investigate spatio-temporal and compositional changes in major variables as well as to better understand the purifying capabilities of these habitats. The results of this study provide a series of criteria that can be utilized in the future to evaluate the success of wetland restoration and also furnish a clear scientific basis for the restoration and management.

2 Materials and Methods

2.1 Study area

The FNWP is located in the middle of the Sanjiang Plain (46°55′52.72″N, 131°44′51.33″E), to the south of the Songhua River, and is part of the town of Jinshan within Fujin City, Heilongjiang Province, China. This wetland area was restored from farmland in 2005 and encompasses an area of 1200 hr (Li and He, 2013) mainly composed of impact sediments and marshes across a low flood plain (Li, 2005). The entire wetland area is also relatively flat, although the southwestern region is a little more elevated than the northeast. It has been dammed outside the northeastern region and the dam is the only outlet of the wetland. Precipitation recharge from seasonal rainfall is one of the key water sources for this region and, alongside farm drainage from the southern wetland, exerts the greatest impact on the wetland. Drainage is controlled by just a single outlet that is under the control of a flash board in the northern wetland, and hydrological conditions are affected by both climate change and farmland irrigation return water in different seasons. The FNWP falls in the warm temperate zone of China and this area experiences a semi-humid continental monsoonal climate. Farmers drain wetland water in early July, in August, and before the harvest period that extends between late September and early October. Restored wetlands in FNWP are significantly affected by these agricultural activities, and engineering construction work is also underway via the main park channel that aims to reduce the contaminating influence of farm drainage. The abundantly vegetated landscape of this region can be subdivided into reeds and cattail communities as well as open wetland water.

2.2 Sample collection

The water samples analyzed in this study were collected during spring (May), summer (August), and autumn (October) seasons each year between 2014 and 2016. Samples from all 22 sections across the wetland were collected on two consecutive days each season. We divided the wetland survey area into seven components comprising irrigation ditch 1, irrigation ditch 2, the inlet for agricultural drainage, the area overgrown with cattails, the area overgrown with reeds, deep waters, and the outlet side (Fig. 1). Three replicated samples were collected from each site.

2.3 Water quality measurements

We measured temperature, oxidation-reduction potential (ORP), total dissolved solids (TDS), dissolved oxygen (DO), pH, conductivity, salinity, Chlorophyll-a, Secchi depth (SD), and chloride using a YSI 6920 (YSI, Yellow Spings, USA) device.

The parameters analyzed in the laboratory were total nitrogen (TN), total phosphorus (TP), NH_4-N, NO_3-N, Mercury (Hg), Iron (Fe), total organic carbon (TOC), biochemical oxygen demand (BOD_5), and chemical oxygen demand (COD_{Mn}). Tests for all of these variables were carried out based on China National Environmental Protection Agency standards-Standard Examination Methods for Drinking Water (SmartChem300, AMS, Paris, France; Ministry of Health of the People's Republic of China, China National Standardization Management Committee, 2006, GB5750-2006).

2.4 Data analysis

We evaluated water quality via five standard parameters (Chlorophyll-a, COD_{Mn}, TN, TP, and SD) and by utilizing the trophic level index (TLI), as first applied by Carlson (1977) and revised by Aizaki (1981) (Table 1). Water sample data were then statistically analyzed using a paired sample *t*-test and correlations between relational parameters were assessed using the software SPSS20.0.

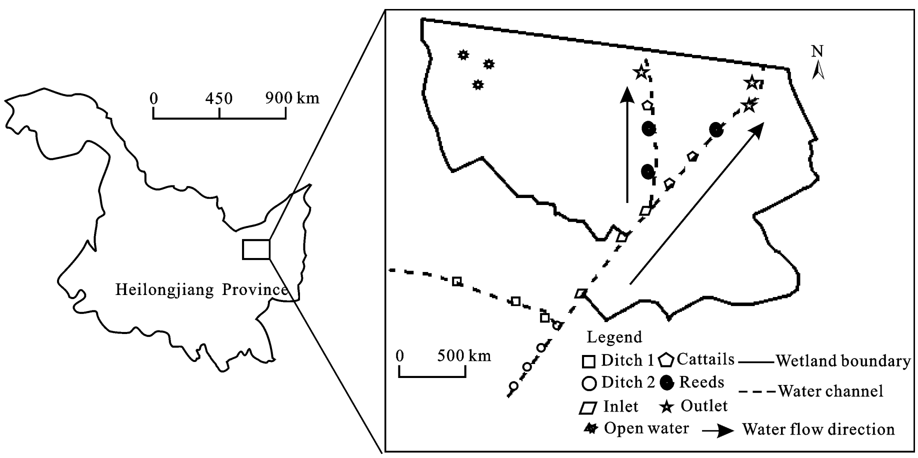


Fig. 1 Sampling locations within the Fujin National Wetland Park

Table 1 Trophic level index (TLI) and its corresponding eutrophication state

$TLI(\Sigma)$	Eutrophication state	Category
$0 < TLI(\Sigma) < 30$	Oligotrophic	I
$30 < TLI(\Sigma) < 50$	Mesotrophic	II
$50 < TLI(\Sigma) < 60$	Light eutrophication	III
$60 < TLI(\Sigma) < 70$	Medium eutrophication	IV
$TLI(\Sigma) > 70$	Hyper eutrophication	V

Notes: $TLI(\Sigma)$, Comprehensive trophic level index of different water parameters

3 Results

3.1 Spatio-temporal variation in water quality parameters

The results of this study reveal significant spatio-temporal variance of temperature, pH, and Secchi depth (SD) as well as of TP, TN and NH_4-N, of COD_{Mn} and BOD_5, and of DO and Chlorophyll-a (Fig. 2).

All the water samples considered here were alkaline (pH values between 7.75 and 8.93). Data show that the average pH value recorded in 2016 was higher than that in 2014 and 2015. Average SD values ranged between 0.27 m and 1.27 m. All TN concentrations were significantly higher than the standard (GB3838-2002) of class V (2 mg/L), and all TP concentrations were below the standard of class III (0.2 mg/L). Similarly, BOD_5 values fell below, or within, desirable levels between 3 mg/L and 4 mg/L, and COD_{Mn} values met the standards (within 15 mg/L) of class I and class II water quality. In addition to the inlet, samples from all sites (including wetland, and outlet) in 2016 had good water quality, with the values of Chlorophyll-a below 10 μg/L.

We analyzed ten water quality parameters using a paired sample *t*-test to compare differences in water quality between inlet and outlet of the FNWP (Table 2). Although the results of this analysis revealed no remarkable spatial variations among the five sampling locations in terms of water temperature, pH, TDS, BOD, and Chlorophyll-a, highly significant variations in SD, TN, and COD ($P < 0.01$) were found alongside significant variations in TP and DO ($P < 0.05$).

Data show that several parameters exhibited significant seasonal variation over the course of this analysis within the FNWP ($P < 0.05$) (Table 3). Most importantly, DO concentration reached a maximum of 9.99 mg/L during spring and a maximum of 7.35 mg/L in summer, while TN, TDS, COD_{Mn}, and Chlorophyll-a also reached maximum levels in summer (6.83 mg/L, 410.73 mg/L, 6.25 mg/L, and 7.66 mg/L, respectively) and fell to their lowest levels in either the autumn or spring (1.98 mg/L, 377.67 mg/L, 5.17 mg/L, and 3.11 mg/L, respectively).

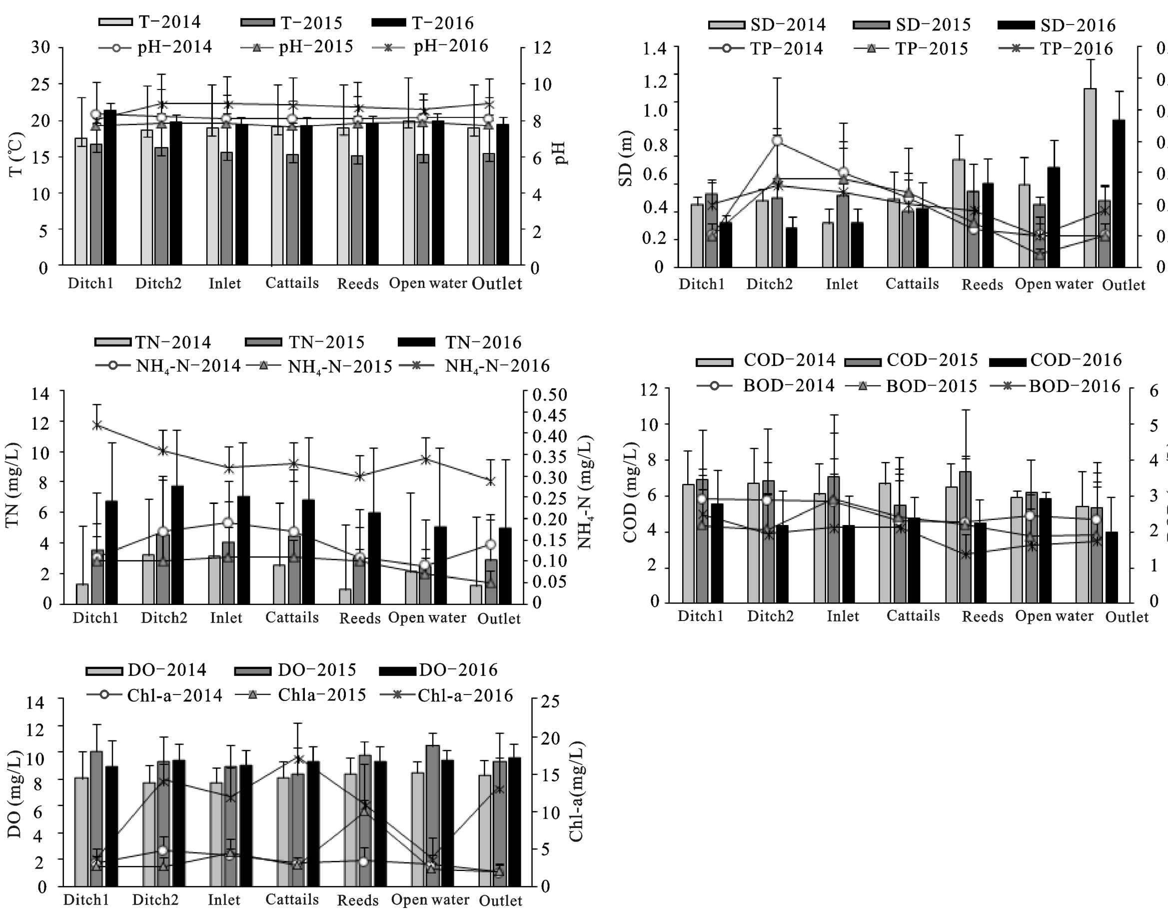


Fig. 2 Spatio-temporal variability of ten water quality parameters in FNWP (Chl-a on the figure is Chlorophyll-a)

Table 2 Mean sample values including standard deviations (in parentheses) for different water quality parameters measured at five locationsin FNWP between 2014 and 2016

Sampling site	T (℃)	pH	SD (m)	TN (mg/L)	TP (mg/L)	TDS (mg/L)	DO (mg/L)	COD_{Mn} (mg/L)	BOD_5 (mg/L)	Chloroph-yll-a (μg/L)	NH_4-N (mg/L)
Irrigation ditch 1	18.57 (2.48)	8.04 (0.35)	0.43 (0.11)	3.84 (2.74)	0.07 (0.03)	300 (40)	9.01 (0.99)	6.38 (0.69)	2.53 (0.37)	3.23 (0.57)	0.21 (0.18)
Irrigation ditch 2	18.27 (1.79)	8.34 (0.57)	0.42 (0.12)	5.15 (2.34)	0.16 (0.04)	320 (40)	8.79 (0.91)	5.98 (1.39)	2.30 (0.51)	7.19 (6.16)	0.21 (0.13)
Inlet	18.03 (2.07)	8.30 (0.57)	0.39 (0.12)	4.73 (2.07)	0.14 (0.02)	300 (40)	8.56 (0.74)	5.86 (1.39)	2.63 (0.44)	6.87 (4.43)	0.21 (0.11)
Cattails	17.96 (2.30)	8.23 (0.62)	0.44 (0.05)	4.60 (2.13)	0.11 (0.01)	280 (20)	8.57 (0.61)	5.66 (0.96)	2.28 (0.14)	7.70 (8.22)	0.20 (0.11)
Reeds	17.94 (2.44)	8.22 (0.47)	0.65 (0.12)	3.29 (2.53)	0.07 (0.02)	270 (20)	9.13 (0.71)	6.13 (1.45)	1.95 (0.49)	8.11 (4.11)	0.17 (0.11)
Open water	18.41 (2.70)	8.22 (0.35)	0.59 (0.14)	3.21 (1.60)	0.04 (0.02)	250 (20)	9.45 (1.01)	6.00 (0.22)	1.98 (0.42)	2.98 (0.75)	0.17 (0.15)
Outlet	17.98 (2.19)	8.28 (0.60)	0.95 (0.42)	2.99 (1.89)	0.06 (0.02)	260 (30)	9.06 (0.66)	4.93 (0.81)	2.00 (0.30)	5.69 (6.51)	0.16 (0.12)
P	0.854	0.645	< 0.01	< 0.01	< 0.01	0.110	< 0.05	0.080	< 0.01	0.509	< 0.05

Table 3 Mean sample values including standard deviations (in parentheses) for different water quality variables measured in different seasons and years in FNWP between 2014 and 2016

	T (℃)	pH	SD (m)	TN (mg/L)	TP (mg/L)	TDS (mg/L)	DO (mg/L)	COD_{Mn} (mg/L)	BOD_5 (mg/L)	Chloroph-yll-a (μg/L)	NH_4-N (mg/L)
Spring	13.35 (2.04)	8.03 (0.22)	0.64 (0.36)	2.24 (1.86)	0.06 (0.03)	409.67 (123.6)	9.94 (0.70)	5.95 (0.94)	3.04 (1.16)	3.11 (1.56)	0.17 (0.06)
Summer	26.55 (1.76)	8.18 (0.40)	0.57 (0.31)	6.83 (3.66)	0.07 (0.03)	410.73 (323.0)	7.35 (1.22)	6.25 (1.77)	1.21 (0.46)	7.66 (8.47)	0.29 (0.22)
Autumn	14.56 (3.94)	8.45 (1.15)	0.52 (0.31)	1.98 (0.81)	0.12 (0.06)	377.67 (168.0)	9.71 (1.36)	5.17 (1.66)	2.17 (1.20)	5.04 (3.64)	0.11 (0.10)
2014	19.08 (0.77)	8.17 (0.10)	0.59 (0.30)	1.93 (0.56)	0.08 (0.04)	396.6 (106.3)	8.18 (0.23)	6.22 (0.54)	2.55 (0.28)	3.12 (0.92)	0.14 (0.08)
2015	15.58 (0.50)	7.80 (0.05)	0.54 (0.07)	3.28 (0.65)	0.07 (0.04)	380.8 (125.0)	9.53 (0.56)	6.23 (0.76)	2.09 (0.38)	3.31 (1.93)	0.09 (0.05)
2016	19.79 (0.47)	8.69 (0.28)	0.67 (0.39)	5.83 (1.01)	0.09 (0.02)	421.0 (262.9)	9.29 (0.15)	4.91 (0.69)	1.79 (0.25)	9.39 (4.54)	0.34 (0.19)

3.2 TLI values of wetland water in FNWP

As discussed, we evaluated the water quality of FNWP using five standard parameters (i.e., Chlorophyll-a, COD_{Mn}, TN, TP, and SD) in addition to the TLI. Results show that wetland water was mostly within the light eutrophication category, with the exception of two mesotrophic time periods in springs of 2014 and 2015, and one medium-level eutrophication period during summer of 2016 (Table 4).

3.3 Nutrient removal rates

The data assembled in this study show that nutrient removal rates varied over both seasons and years (Table 5). In particular, during 2014 to 2016, TN removal rates ranged between 7.54% and 84.36% with the two lowest values (below 10%) recorded in the summers of 2015 and 2016 (Table 5). Recorded TP removal rates ranged between 37.50% and 70.83% between 2014 and 2016, with the exception of the lowest value (–22.22%) in the summer of 2016 (Table 5).

4 Discussion

4.1 Seasonal and spatial variability in water quality parameters

The pH level influences the solubility of heavy metals,

Table 4 TLI values of wetland water in FNWP between 2014 and 2016

	TLI (*Σ*)	Eutrophication status	Category
2014 spring	49.6	Mesotrophic	II
2014 summer	50.9	Light eutrophication	III
2014 autumn	54.6	Light eutrophication	III
2015 spring	48.5	Mesotrophic	II
2015 summer	58.2	Light eutrophication	III
2015 autumn	52.6	Light eutrophication	III
2016 spring	53.6	Light eutrophication	III
2016 summer	61.3	Medium eutrophication	IV
2016 autumn	54.0	Light eutrophication	III

Table 5 Nutrient values in outlet and nutrient removal rate in different years in FNWP

Time	TN		TP	
	Water outlet content (mg/L)	Removal rate (%)	Water outlet content (mg/L)	Removal rate (%)
2014 spring	1.08	39.66	0.05	37.50
2014 summer	0.81	84.36	0.04	66.67
2014 autumn	1.60	31.62	0.07	70.83
2015 spring	0.74	59.34	0.03	70.00
2015 summer	6.39	9.23	0.04	63.64
2015 autumn	1.49	54.15	0.07	66.67
2016 spring	2.58	56.64	0.04	42.86
2016 summer	10.18	7.54	0.11	–22.22
2016 autumn	2.03	52.01	0.12	40.00

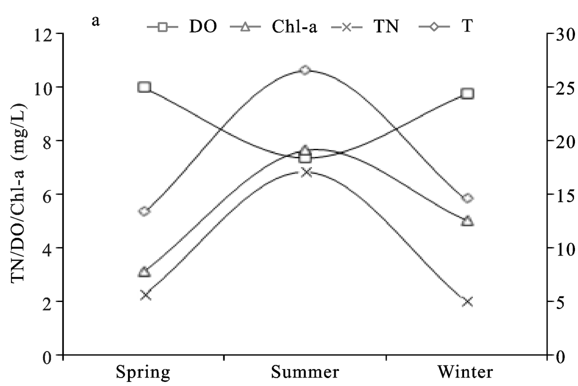
Note: Nutrient removal rates = (Values inlet – Values outlet) / Values inlet

and is one of the most important indicators of water quality in aquatic ecosystems (Khan et al., 2013; Wang et al., 2017). All of the samples analyzed here fell within the recommended range of pH values, between pH 6.5 and pH 8.5 (World Health Organization, 1997) with the exception of two values for 2016. Data also show that pH values of wetland water in FNWP were higher than that in QiXinghe wetland, a natural wetland around FNWP (Li et al., 2007), probably because of the presence of less humus and an increase in algae photosynthesis which led to the production of more hydroxyl. High transparence levels generally indicate cleaner water or better quality. The data presented in Table 2 reveal that water quality around the outlet was superior to that around the inlet, which implies excellent purification processes within the wetland park. It is also well known that N and P are both nutrients that can promote the growth of nuisance aquatic plants and can cause algal blooms when they occur at within a certain concentration range (Girija et al., 2007). The main source for these increased concentrations is likely fertilizer runoff from farmland drainage as the values of nutrients around the outlet and within the wetland was lower than those in the inlet. Data also show that the average value for Chlorophyll-a in summer was greater than in other seasons. Values of BOD_5 and COD_{Mn} also fall below, or within, desirable levels (3–4 mg/L). That phenomenon-can probably be attributed to the higher levels of nutrients and temperature during this season. This result indicates that the water was not polluted by organic compounds and conforms to National Standards of Environment Quality (State Environmental Protection Administration,the People's Republic of China, State Administration for Quality Supervision and Inspection and Quarantine, 2002, GB3838-2002).

Analysis of certain areas within the wetland also showed that the SD value in open water was higher than average values in reeds and cattails. Values of TN, TP, and TDS in open water were also all lower than in the surrounding reeds, as well as lower in this environment than in the cattails. These results therefore show that water quality was better in the open than around the reeds and cattails. That might be because although the direct source for the open water was the wetland, the source for the latter was farmland drainage. The open water is also located farther away from the inlet, which was less influenced by farmland drainage. And it is also possible that FNWP reeds possessed better nutrient removal efficiency than cattails.

At higher temperatures, DO concentration declined while Chlorophyll-a and TN reached maximum levels (Fig. 3a). Data show that DO concentration is negatively correlated with water temperature across the wetland (Fig. 3b), but that other parameters had no significant correlation. This latter result might be due to the geographic location and climate of the FNWP which result in obvious variations in temperature and landform features. Elevated water temperature and TN concentrations from farmland drainage create advantageous conditions and abundant nutrients for the growth of photoplankton and zooplankton (Pinto-Coelho et al., 2005; Caron et al., 2017; Tian et al., 2017). The DO concentration is reduced to some extent in warmer seasons, however, as plankton reproduction rate is elevated (Ahmed et al., 2016; Wu et al., 2016; Rivaro et al., 2017).

We evaluated the water quality in the restored wetland using five parameters. And a comparison of eutrophication states among years is presented in Table 6. The eutrophication state of this environment was light overall, although this value slightly increased in 2016 and a different level was recorded in 2009. Diversity indices for both phytoplankton and zooplankton were also used to evaluate contamination over the time period of this analysis, but no TLI was determined in 2009. It is therefore important to address the question of why eutrophication was slightly higher in 2016. One potential reason might be that extremely high concentrations of nutrients from farmland drainage canals resulted in an increased load within the wetland. Another might be that engineering construction work dried out the main drainage and caused mass waste water inflow. The trophic levels in other similar water bodies have also been assessed efficiently and accurately using the same analytical methods. Both Taihu Lake and Xixi National Wetland Park have been shown to exhibit similar eutrophication potentials as discussed here. While Dayanghan Wetland showed no sign of eutrophication in 2011. Research on the Shifosi Constructed Wetland within



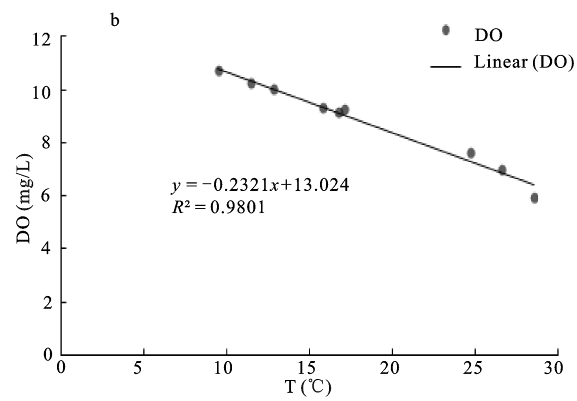


Fig. 3 Seasonal variations in DO, Chlorophyll-a (Chl-a on the figure), and TN with respect to temperature (a) and the relationship between DO and temperature (b)

Table 6 Comparison of FNWP eutrophication levels with those from other water bodies

Region	Sampling year	TLI (mean or range)	Eutrophication status	Reference
FNWP	2014	51.7	Light eutrophication	This study
FNWP	2015	53.1	Light eutrophication	This study
FNWP	2016	56.3	Light eutrophication	This study
FNWP	2009	No data	Mesotrophic	Ma (2012)
Taihu Lake	2008–2010	(51.3–55.6)	Light eutrophication	Sun et al. (2013)
Dayanghan Wetland	2011	35.2–45.5	Mesotrophic	Zuo et al. (2014)
Xixi National Wetland Park	2009–2010	53.9–60.0	Light eutrophication	Li et al. (2010)
Shifosi Constructed Wetland, Liaohe River	2009–2014	No data	Mesotrophic or light eutrophication	Guo et al. (2016)
Lake Idku, Egypt	2012–2013	71.5–84.7 (High drain)	High eutrophication	Ali and Khairy (2016)

Liaohe River revealed that this area also purified water from high eutrophication to mesotrophic or light eutrophication as reported here. Another chemical analysis carried out in Lake Idku, Egypt, revealed excessive nutrient influx into the water from four main discharging drains, again leading to high eutrophication levels.

4.2 Nutrients removal efficiency in different seasons and years

Wetland restoration projects generally aim to restore lost biodiversity and enable ecological functions such as flood protection, water purification, and wildlife habitats (Ahmed et al., 2016; Rivaro et al., 2017). It is noteworthy that the FNWP was converted from cultivated land. So its ecological functions are significant, especially with regard to water purification. The essence of nutrient removal is an integrated mixture of sedimentation, filtration, adsorption, biological absorption, and biochemical transformation processes with the assistance of wetland soils, microorganisms, and plants (Wang et al., 2009; Zuo et al., 2014). There are various removal rates in different seasons and years in the FNWP (Table 5). It exerts overall good degradation effects on certain major nutrients compared with other constructed wetlands but is not as efficient as natural examples (Table 7). This may be due to the fact that vegetation and sediment in natural wetlands are more efficient at purifying agricultural non-point pollution (Zhu et al., 2009).

The overall processes of N removal and retention include adsorption and filtration of soils, ammonia volatilization, absorption by plants, and nitrification and denitrification by microorganisms (Gray et al., 2000). Just a handful of processes ultimately remove total N from waste water and most can only convert this element into one of its various forms (Luederitz et al., 2002). Research has shown that the removal of TN from constructed wetlands ranged between 40% and 55%, depending on type and inflow loading (Vymaza, 2007). Other research (Whitehead et al., 2006; Krause et al., 2008) has also shown that the removal of N declines due to increasing soil release of this element at high temperatures. The removal of TN demonstrated here was not correlated with temperature. We nevertheless infer that one reason for the two low values less than 10% might be due to high concentrations of TN in the water inlet.

The soil P cycle is fundamentally different from its N counterpart due to removal processes of sorption, precipitation, plant uptake, and peat/soil accretion. Research has indicated that TP removal ranges between 40% and 60% in wetlands, depending on type and inflow loading (Vymazal et al., 2007). Efficient P removal by wetlands has mainly been attributed to sorption and precipitation by soil particles (Farzadkia et al., 2015). The fact that concentrations of TN and TP were high and water quality was poor adjacent to the inlet in this case might be because large quantities of nutrients flowed off the fields, far beyond the removal capacity of the wetland. This might also explain why nutrient removal efficiencies in the summer of 2016 were the lowest recorded throughout this analysis (i.e., TN, 7.54%; TP, –22.22%).

Table 7 Comparison of the FNWP nutrient removal rate with other water bodies

Region	Sampling year	Removal rate	Reference
FNWP	2014–2016	TN, 43.84% TP, 48.44%	This study
Four Constructed Wetlands	2005–2007	TN, 44.44%–58.50% TP, 87.82%–95.97%	Li et al. (2015)
Constructed Wetlands	2007	TN, 40%–55% TP, 40%–60%	Vymazal (2007)
Deyeuxia angustifolia simulated wetland on the Sanjiang Plain, China	2004	TN, 53.11% TP, 58.95%	Xu et al. (2005)
Hamatong River basin on the Sanjiang Plain, China	2006	TN, 80.36% TP, 61.90%	Zhu et al. (2009)
Porewater from drainage ditches on the Sanjiang Plain, China	2012	NH_4-N, 71.7%–87.6% NO_3-N, 38.4%–51.0% PO_4-P, 52.6%–78.3%	Zhang et al. (2013)

5 Conclusions

The analyses presented in this study show that all TN values were well above the class V limit of 2 mg/L, TP values were all below the class III limit of 0.2 mg/L, and all other parameters were normal within the FNWP. Results show that water was mostly of light eutrophication status within the FNWP. Highly significant variations were found between the inlet and outlet of the park for SD, TN, and COD, and significant variations were found for TP and DO. This wetland therefore has a good overall degradation effect in the case of certain major nutrients. It will be necessary to conduct further research in this region to investigate the upper nutrient removal capacity limit of the FNWP as well as to appropriately plan agricultural layouts. There was no significant annual change in water quality was reported here. But the water quality was obviously affected by surrounding agricultural drainage. Additional research should therefore emphasize the positive impacts and status of the FNWP as engineering construction work within the main channel is concluded.

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