

*Type of the Paper (Article)*

**Characteristics of soil organic carbon and total nitrogen along various vegetation types in Hongqipao reservoir, Northeast China**

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**Abstract:** This study investigated the spatial variability of soil organic carbon (SOC), total nitrogen (TN), soil microbial biomass carbon (SMBC) and soil microbial biomass nitrogen (SMBN) in Hongqipao reservoir dominated by different vegetation types and the possible relationships with other soil properties. Top 0–50cm soil samples were collected in sites dominated by different vegetation types within the reservoir littoral zone. There was high spatial variability for SOC, TN, SMBC and SMBN in the Hongqipao reservoir. In addition, the SOC, TN, SMBC and SMBN contents decreased with increasing soil depth. This could be attributed by the fact that when plants detritus decompose, most of their organic matter is mineralized and a new soil layer which contains a greater amount of organic carbon is formed at the top. According to Pearson's correlation values and redundancy analysis (RDA) results, SOC was significantly and positively correlated with TN likely because the vegetation organic matter and liter could be the main nitrogen sources. Similarly, soil moisture content (MC) was significant positive correlated with SOC and TN. Conversely, BD was significant negative correlated with SOC and TN contents in the 0-50 cm soil profiles. However, no significant correlations were observed between SOC, TN, SMBC and SMBN contents

and soil pH values. SMBN was significantly and positive correlated with C:N ratio and BD and negative related with MC. Multiple linear regression model revealed that all measures soil properties in this study could explain higher significant variability of the response variables (SOC, TN, SMBC and SMBN contents). This implies that all the measured soil variables within the different vegetation types in the reservoir played a crucial role in determining the contents of SOC, TN, SMBC and SMBN. This study further suggests that vegetation types play a major role in determining the spatial characteristics of SOC and TN. Any changes in the vegetation types in the reservoir may influence the distribution of SOC and TN. This may affect the global carbon budget and the atmospheric greenhouse gas concentration significantly.

**Keywords:** Total organic carbon; Total nitrogen; Soil microbial biomass; Vegetation types; Hongqipao reservoir

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## 1. Introduction

Soil carbon and nitrogen are essential elements of sustainable soil fertility and productivity and can substantially affect climate change through carbon and nitrogen emissions (including carbon dioxide, methane and nitrous oxide) <sup>1-3</sup>. As one important pool of soil organic matter in wetland ecosystems, wetland soils serve as sources, sinks and transfers of nutrients and chemical pollutants<sup>4-5</sup>. It is estimated that 202–377 Gt carbon is stored in the top 100 cm of wetland soil since wetlands provide an optimum environmental conditions for the sequestration and long-term storage of carbon <sup>6-7</sup>. Reservoirs are an important type of wetland, whose combined area across the world has increased in recent years to now occupy approximately  $5 \times 10^5$  km<sup>2</sup>, which is 1/3 the size of all natural lakes <sup>8</sup>. Among the reasons of large development of reservoirs is their potential as a clean energy source, although uncertainties in their role in greenhouse gas contribution have led some scientists to question whether they are as clean as people believe <sup>9</sup>. Since reservoirs have major impacts on biogeochemical cycles by acting as a storage of soil organic carbon at the local and global scales, several researchers have insisted that the reservoirs requires more scientific study <sup>2, 10-11</sup>. The Ministry of Water Resources of the People's Republic of China has stated that China has over 80,000

reservoirs, large and small<sup>12</sup>. However, limited studies have been carried out to determine the role of reservoirs in storage of soil organic carbon and nitrogen<sup>2, 13</sup>.

Studies have revealed that the spatial variation, accumulation and distribution characteristics of organic carbon and nitrogen in wetland soil is influenced by the vegetation types, hydrology (water level fluctuation), soil microbial community, pH, salinity, temperature, soil moisture among many others may have a strong influence on soil organic carbon and nitrogen storage<sup>14-15</sup>. Changes in the hydrological regime can have substantial effects on soil properties, particularly carbon and nitrogen accumulation and release due to alterations in their chemical forms and spatial movements<sup>16-17</sup>. Wetlands littoral zones with abundant vegetation and soil microbes has been reported to have higher capacity of carbon deposition than other land types<sup>18</sup>. Bahn, et al.<sup>19</sup> noted that different types of vegetation communities and their development will have obvious influence on soil organic carbon contents, and soils with high primary productivity have high organic carbon storage. Soil mechanical composition, bulk density, salinity, and nutritional status will influence the capacity of vegetation directly and affect the input and output of soil carbon<sup>20</sup>. Moreover, the vegetation in growth process affects the soil organic carbon content and distribution through changing the surrounding environment, especially the rhizosphere microenvironment (such as soil salinity, pH value, water, etc.)<sup>21</sup>.

Studies on spatial variability of SOC and TN have been one of the hotspot in soil ecology in the past decades<sup>1, 3, 22</sup>. For example, Wang, et al.<sup>3</sup> characterized the spatial patterns of SOC and TN within 0–80 cm for minesoils in the Loess Plateau area. Bai, et al.<sup>23</sup> determined the spatial variability of soil carbon, nitrogen, and phosphorus content and storage in an alpine wetland in the Qinghai–Tibet Plateau, China. More studies on spatial variability of soil properties have been conducted in the southeast of Xi'an, Shannxi, China<sup>24</sup>, and the Three Gorges Reservoir area<sup>13</sup>. However, similar studies is lacking in Hongqipao reservoir, Northeast China despite the fact that this reservoir is characterized by different vegetation types including *Phragmites communis*, *Typha angustifolia*, *Scirpus tabernaemontani*, *Potamogeton pectinatus*, *Potamogeton crispus*, *Spirodela polyrhiza*, *Scirpus yagara*, and *Echinochloa crusgalli* which creates high environment heterogeneity.

The objectives of this study were (i) to determine the spatial distribution characteristics of SOC, TN, SMBC and SMBN in the Hongqipao reservoir dominated by different vegetation types; (ii) to assess

the effect environmental factors on SOC, TN, SMBC and SMBN in the Hongqipao reservoir, and (iii) to evaluate the total SOC, TN, SMBC and SMBN in the soils collected from sites dominated by different vegetation types in the Hongqipao reservoir.

## 2. Materials and Methods

### 2.1 Study Area

The study was conducted in Hongqipao reservoir littoral zone located in Nenjiang plain between Anda and Daqing city in Heilongjiang Province (Figure 1). The size of the reservoir is 35km<sup>2</sup> with a capacity of 116,000,000m<sup>3</sup>. This study area lies in an area which is under the influence of a mid-temperate continental monsoon climate characterized by long and cold winters and high-temperature and rainy summers. The mean annual temperature in this area is 3.3°C with the lowest and highest temperature values measured in January and July of -37.2°C and 38.3°C, respectively. Moreover, the average precipitation received in this study area is 426 mm per year. During winter, the maximum depth of frozen soil is 2.14m. The reservoir is the source of water to the people living in Daqing city. Ecological, Hongqipao reservoir provides habitats for about 40 kinds of fishes and kinds of rare birds. This reservoir is characterized by different species of plants including *Phragmites communis*, *Typha angustifolia*, *Scirpus tabernaemontani*, *Potamogeton pectinatus*, *Potamogeton crispus*, *Spirodela polyrhiza*, *Scirpus yagara*, and *Echinochloa crusgalli*.

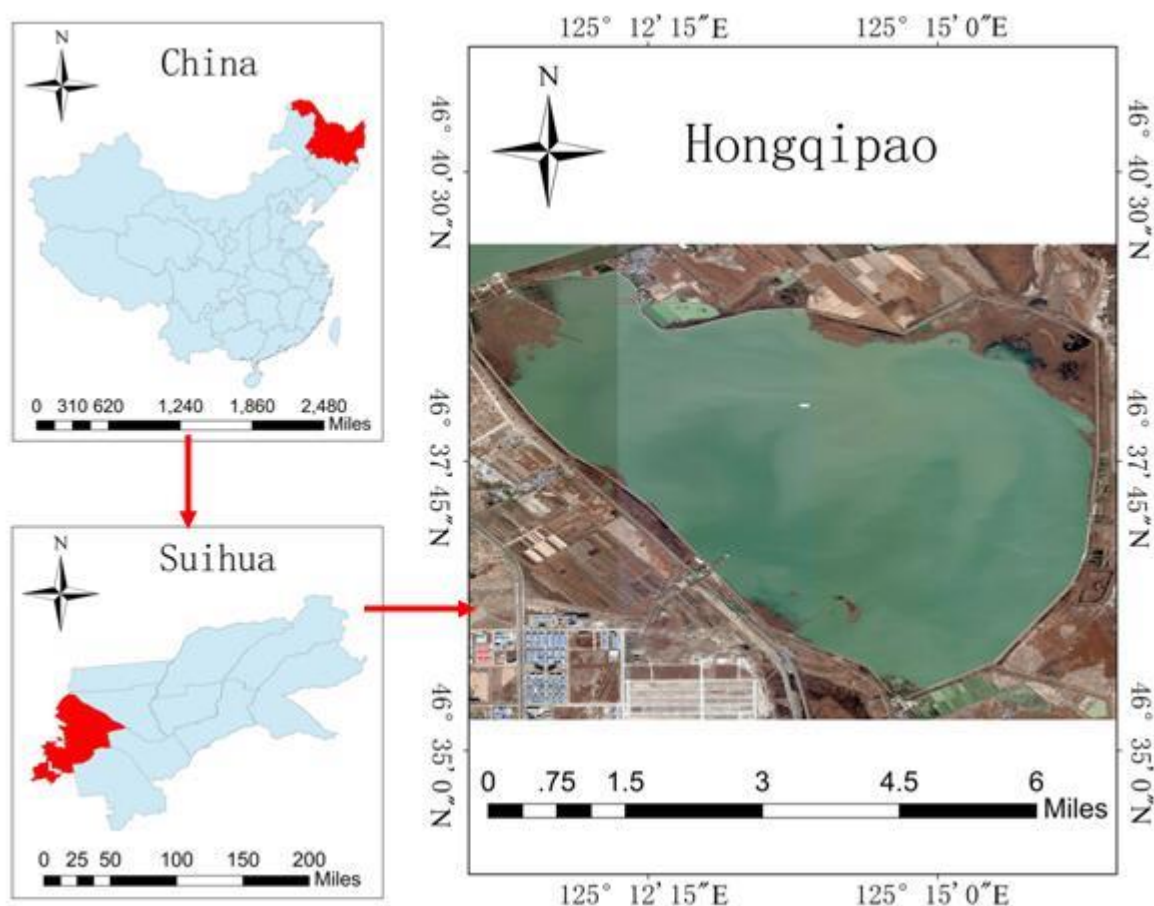


Figure 1 Location of the study area. Top left is the map of China and bottom right is the Hongqipao reservoir.

## 2.2 Soil sampling and laboratory analyses

Soil samples were collected from 7 georeferenced sites (coded as A-G). These sites were selected based on their dominant plant species and whether the site is inundation or dry (Table 1). The soil profiles with three replicates for each sampling site were sectioned into five depths at 10 cm intervals (0-10, 10-20, 20-30, 30-40, and 40-50 cm) and mixed with the same soil layers to form composite samples. Moreover, soil samples for analysis of soil bulk densities (BD) and moistures content (MC) were collected at each sampling site. The collected soil samples were portioned into two for every soil layer. One part of the sample for each soil layer was stored at 4 °C in sealed plastic bags to limit microorganism activity for the determination of soil microbial biomass carbon (SMBC) and soil microbial biomass nitrogen (SMBN). The second portion of the sample of each soil layer were air-dried at room temperature in the laboratory for three weeks, and stones, roots and coarse debris were removed. The dried soil samples were ground to fine power using a mill (FW100,

Taisite in Tianjin, China), and then sieved through a 100-mesh sieve. The Sieved soil samples were treated with 2 M HCl for 24 h at room temperature to remove carbonates <sup>25-26</sup>. The soil was then washed to pH>5 with distilled water and dried at 40 °C. The SOC and TN were determined using an automatic elemental analyzer (Flash EA 1112, Italy). Soil pH was measured using a digital pH meter in the supernatants of 1:5 soil:water mixtures. The soil BD and MC were calculated on a dry weight basis. Soil MC was determined by the oven drying method (weighing before and after drying at 105 °C for 24 h). Soil BD was calculated by dividing the total dry weight of the soil sample by the volume of the core <sup>27</sup>. All results were expressed on a dry gram basis.

The soil microbial biomass carbon (MBC) and the soil microbial biomass nitrogen (MBN) were determined using the soil microbial biomass chloroform fumigation extraction method <sup>28-30</sup>. The extraction was performed using K<sub>2</sub>SO<sub>4</sub> (0.5 mol L<sup>-1</sup>) on un-fumigated samples and fumigated samples in alcohol-free chloroform. Soil organic carbon and total nitrogen in fumigated and un-fumigated extracts was measured with Multi N/C 3100 SOC/TN analyzer (Analytik Jena, Germany). The MBC and MBN were calculated as the concentration of organic carbon and total nitrogen in fumigated samples subtracted by that in un-fumigated (control) samples with a conversion factor of 0.45 for microbial carbon and 0.54 for microbial nitrogen <sup>31</sup>.

Table 1 Sampling sites and their characteristics

Sampling site	Dominant vegetation types	Hydrology (Inundated or dry)
A	<i>Poa annua</i> L., <i>Imperata cylindrica</i> , <i>Polygonum</i>	Dry
B	<i>Phragmites australis</i> , <i>Mongolian wormwood</i>	Inundated
C	<i>Tamarix chinensis</i> Lour., <i>Polygonum amphibium</i> L.	Inundated
D	<i>Scirpus fluviatilis</i> , <i>Polygonum amphibium</i> L., <i>Carex</i> <i>tristachya</i>	Inundated
E	<i>Phragmites australis</i>	Inundated
F	<i>Leymus chinensis</i>	Dry
G	<i>Poa annua</i> L.	Dry

### 2.3 Determination of vegetation aboveground biomass

Three quadrants (1 m × 1 m) were established at each sampling sites. The vegetation in the quadrants were manually cut close to the soil surface, harvested and weighed immediately while fresh. The weighed samples were then taken to the laboratory and oven dried at 80°C, to a constant weight. The dry biomass was calculated by multiplying the fresh weight of the harvested vegetation and the dry/wet ratios of the samples.

### 2.4 Calculations and Statistical Analysis

Total SOC (*TSOC*; g C m<sup>-2</sup>), total TN (*TSN*, g N m<sup>-2</sup>), total SMBC (*TSMBC*; mg C m<sup>-2</sup>) and total SMBN (*TSMBN*; mg C m<sup>-2</sup>) on the ground-area basis to a 50-cm depth were calculated according to the formula proposed by Wang, et al. <sup>32</sup> as follows:

$$TSOC = \sum Di \times Pi \times SOCi \times S \quad [1]$$

$$TSN = \sum Di \times Pi \times TNi \times S \quad [2]$$

$$TSMBC = \sum Di \times Pi \times MBCi \times S \quad [3]$$

$$TSMBN = \sum Di \times Pi \times MBNi \times S \quad [4]$$

where *Di*, *Pi*, *SOCi*, *TNi*, *MBCi*, *MBNi* and *S* represent soil thickness (cm), bulk density (g cm<sup>-3</sup>), organic carbon concentration (g kg<sup>-1</sup>), total nitrogen concentration (g kg<sup>-1</sup>), microbial biomass carbon (mg kg<sup>-1</sup>), microbial biomass nitrogen (mg kg<sup>-1</sup>) and cross-sectional area (cm<sup>2</sup>) of the *i*th layer (*i* = 1, 2, 3, 4, and 5).

Data were statistically analysed using SPSS (version 19.0). A one-way analysis of variance (ANOVA) was conducted to test the spatial variation of SOC, TN, SMBC, SMBN and other soil properties. Correlation analyses were carried out to evaluate the relationships between SOC, TN, SMBC, SMBN and soil properties. Multivariable linear regressions were used to build regression models for SOC, TN, SMBC and SMBN. The figures were drawn using Origin 9 and Canoco 5 softwares.

## 3. Results

### 3.1 Spatial variation of SOC, TN, SMBC, SMBN and other soil properties

The spatial soil characteristics from the seven sites sampled are presented in (Table 2 and Figure 2). In all the sites, SOC decreased with increasing soil depth (Figure 2). One-way ANOVA revealed that

the overall mean values of SOC differed significantly among sites ( $F_{(6,28)} = 7.067$ ,  $p < 0.05$ ) with the highest value of  $33.14 \pm 2.27$  g C m<sup>-2</sup> recorded in sampling site D and the least value of  $17.40 \pm 0.60$  g C m<sup>-2</sup> measured at site A (Table 2). Just like SOC, the mean TN also differed significantly among the sites ( $F_{(6,28)} = 5.188$ ,  $p < 0.05$ ). The mean soil TN from sampling site D dominated by *Scirpus fluviatilis*, *Polygonum amphibium* L., and *Carex tristachya* vegetation was highest ( $1.54 \pm 0.23$  g N m<sup>-2</sup>) while that from site A dominated by *Poa annua* L., *Imperata cylindrica*, *Polygonum* of  $0.27 \pm 0.02$  g N m<sup>-2</sup> was the least. Moreover, soil TN varied with depth with remarkably higher mean values being recorded in the top soil profiles (0-10, 10-20 and 20-30 cm depth) (Figure 2).

The soil microbial biomass which is an important parameter of nutrient cycling in ecosystems also revealed spatial variations. One-way ANOVA analysis showed that both SMBC and SMBN differed significantly among sites (Table 2). With exception of sampling site C, the SMBC in site B dominated by *Phragmites australis* and *Mongolian wormwood* of  $650.80 \pm 147.66$  mg C m<sup>-2</sup> was more than three times higher than the other sites. The overall mean SMBN values of  $58.47 \pm 17.67$  and  $45.34 \pm 16.75$  mg C m<sup>-2</sup> recorded in sites A and B, respectively were significantly higher than the other sites. Unlike SOC and TN which showed a clear decreasing trend with soil depth in all sites, there was no clear pattern of SMBC and SMBN with soil depth (Figure 2). The SMBC and SMBN values were lower and higher in the upper soil layers, respectively in both site A and D. In site B higher SMBN values were observed on top soil profiles (0~20 cm depth).

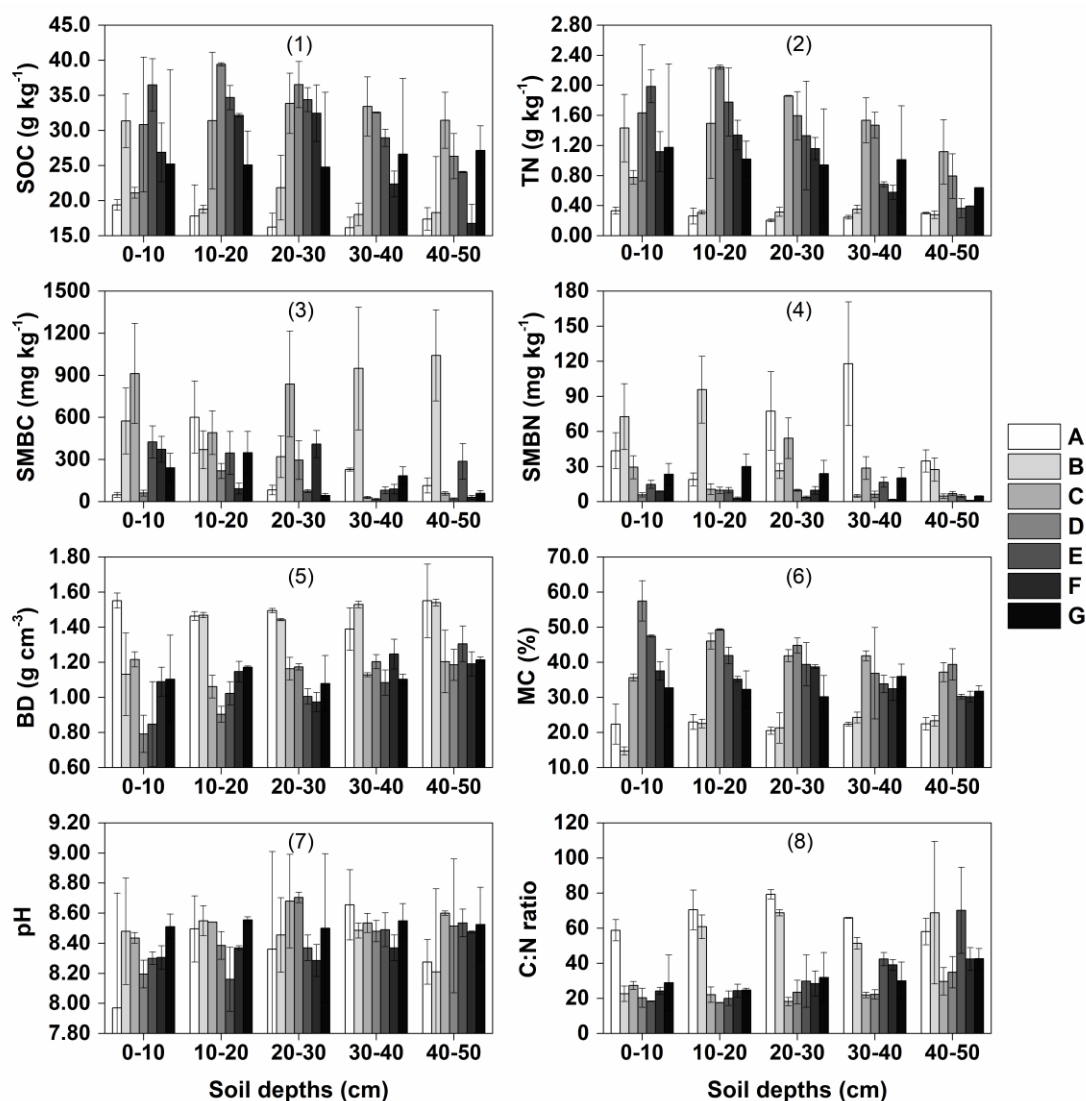
Bulk densities (BD) increased with increasing soil depth in all sites. One-way ANOVA revealed significant difference in BD among the sites ( $F_{(6,28)} = 9.589$ ,  $p < 0.05$ ). The highest overall mean BD was recorded in site A ( $1.49 \pm 0.03$  g cm<sup>-3</sup>) and the least was measured in sites D and E ( $1.05 \pm 0.09$  and  $1.05 \pm 0.07$  g cm<sup>-3</sup>, respectively). The overall mean values of MC also differed significantly among the sites ( $F_{(6,28)} = 17.992$ ,  $p < 0.05$ ) while that of soil pH did not differ  $F_{(6,28)} = 1.521$ ,  $p > 0.05$ ).

**Table 2.** Overall means values (Standard error) of soil properties measured during the study period from different sites dominated by different vegetation types in Hongqipao reservoir.

	A	B	C	D	E	F	G	p-value
SOC	17.40 (0.60)	21.66 (2.53)	30.25 (2.34)	33.14 (2.27)	31.72 (2.29)	26.12 (2.99)	25.78 (0.46)	0.000
TN	0.27 (0.02)	0.54 (0.22)	1.36 (0.19)	1.54 (0.23)	1.23 (0.31)	0.92 (0.18)	0.96 (0.09)	0.001
C:N ratio	66.20 (4.21)	53.50 (8.38)	23.26 (1.87)	22.99 (2.77)	34.27 (8.83)	31.50 (3.92)	28.23 (3.66)	0.000
SMBC	214.96 (101.17)	650.80 (147.66)	466.11 (186.52)	122.03 (57.39)	242.78 (70.94)	199.02 (79.42)	175.32 (57.14)	0.021
SMBN	58.47 (17.67)	45.34 (16.75)	25.55 (8.70)	7.68 (0.85)	9.90 (2.57)	4.83 (1.86)	20.53 (4.23)	0.040
BD	1.49 (0.03)	1.42 (0.08)	1.15 (0.02)	1.05 (0.09)	1.05 (0.07)	1.13 (0.05)	1.13 (0.02)	0.000
MC	22.14 (0.42)	21.23 (1.70)	40.52 (1.85)	45.57 (3.68)	38.59 (3.03)	34.82 (1.58)	32.58 (0.096)	0.000
pH	8.35 (0.11)	8.44 (0.06)	8.56 (0.04)	8.46 (0.08)	8.37 (0.07)	8.36 (0.03)	8.53 (0.01)	0.208

### 3.2 Correlation analysis between SOC, TN, SMBC, SMBN and other soil properties

The correlation coefficient between between SOC, TN, SMBC, SMBN and other soil properties are listed in [Table 3](#). The SOC was significant positive correlated with TN and negative correlated with SMBN, BD, MC and C:N ratio. Soil TN was correlated positively with MC and negatively with BD and C:N ratio. SMBN was weakly positive correlated with C:N ratio and BD and strongly negative correlated with soil MC. Soil C:N ration was positive and negative correlated with BD and MC, respectively. Soil MC was negative correlated with BD. Soil pH and SMBC were not significant correlated with any other variable.

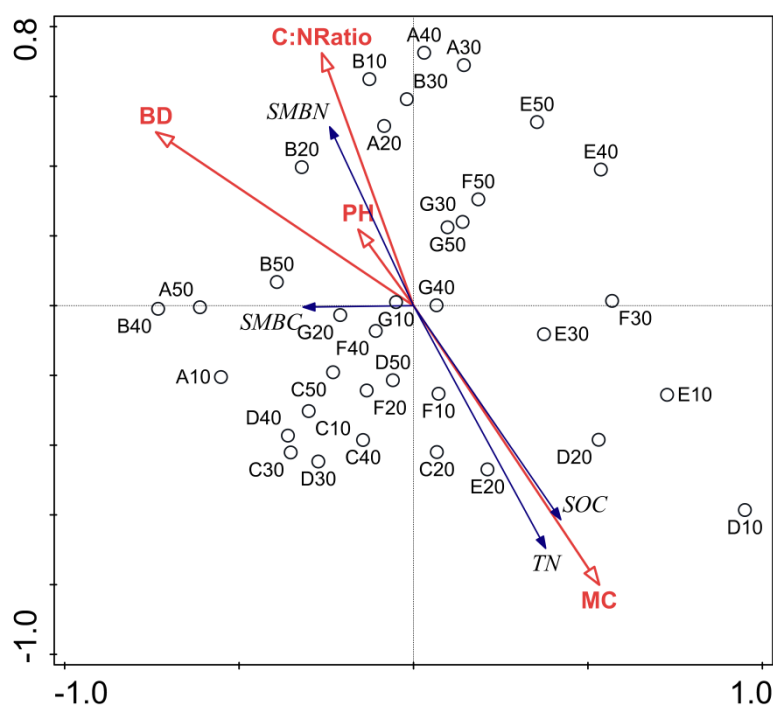


**Figure 2.** Soil organic carbon (SOC), TN, SMBC, SMBN, BD, MC, pH and C:N ratio at different soil depth from sites (seven sites) dominated by different vegetation types

Redundancy analysis (RDA) was carried out to determine the relationship between SOC, TN, SMBC, SMBN and other soil properties measured in this study. From the RDA biplot (Figure 3), soil MC had a positive significant influence on SOC and TN and negative influence on SMBN. Soil BD and C:N ratio had a significant positive influence on SMBN and negative influence on SOC and TN. The RDA results further revealed that pH had little influence on SOC, TN, SMBC and SMBN.

**Table 3.** Pearson correlation coefficients among SOC, TN, SMBC, SMBN and soil properties; \*p < 0.05; \*\*p < 0.01; p < 0.001

	SOC	TN	SMBC	SMBN	C:N ratio	MC	BD
SOC							
TN	0.93***						
SMBC	-0.15	-0.04					
SMBN	-0.40*	-0.30	0.15				
C:N ratio	-0.81***	-0.89***	0.08	0.42*			
MC	0.76***	0.79***	-0.17	-0.54***	-0.75***		
BD	-0.80***	-0.83***	0.23	0.42*	0.84***	-0.82***	
pH	0.07	0.03	0.05	0.17	-0.09	-0.01	-0.01



**Figure 3.** RDA ordination diagram of the relationships between SOC, TN, SMBC and SMBN (blue lines) and BD, MC, pH and C:N ratio (red lines). Circles numbered indicates soil layer at the different sampling sites

### 3.3 Multiply regression models for SOC, TN, SMBC, SMBN and other measured soil factors

A multiple regression analysis was done to model the relationship among SOC, TN, SMBC, SMBN and other soil properties measures. Table 4 present the results of the regression analysis. For every response variable, two models were presented. One is correlated model in which only those soil variables which were significant correlated with the response variable under the Pearson correlation analysis (Table 3). The second model included all the soil factors measures. From the results (Table 4), 89.6% of SOC contents variability could be explained by only the correlated variables. However, when the full model was run, 91.3% of SOC contents variability was explained by all the factors. The correlated variables explained 92.0% of soil TN variability while when all factors were included in the model, 95.4% of soil TN variability could be explained. Only 29.1% variability of SMBC could be explained by the correlated variables while 55.4% could be explained by all variables.

**Table 4.** Multiply regression models for SOC, TN, SMBC, SMBN and other soil properties measured during the study period

Y	Factors	Equation	R <sup>2</sup>	P
SOC	Correlated	$Y = 21.242 + 12.258X_2 - 0.044X_4 + 0.082X_5 - 0.080X_6 - 4.856X_7$	0.896	0.000***
	All	$Y = -18.260 + 13.209X_2 - 0.002X_3 - 0.052X_4 + 0.098X_5 - 0.098X_6 - 3.391X_7 + 4.466X_8$	0.913	0.000***
TN	Correlated	$Y = -0.248 + 0.051X_1 - 0.011X_5 + 0.006X_6 + 0.067X_7$	0.920	0.000***
	All	$Y = 2.001 + 0.051X_1 + 0.000X_3 + 0.004X_4 - 0.011X_5 + 0.012X_6 + 0.053X_7 - 0.306X_8$	0.954	0.000***
SMBC	Correlated	None	None	None
	All	$Y = -1776.208 - 37.174X_1 + 685.508X_2 - 1.694X_4 + 1.811X_5 - 5.873X_6 + 682.059X_7 + 206.630X_8$	0.212	0.428

Correlated	$Y = 91.997 + 0.098X_1 + 0.169X_5 - 1.648X_6 - 17.303X_7$	0.291	0.031*
SMBN	$Y = -283.215 - 4.373X_1 + 85.588X_2 - 0.009X_3 + 1.144X_5 -$		
All	$2.051X_6 - 23.803X_7 + 47.233X_8$	0.554	0.000***

$X_1$ , SOC;  $X_2$ , TN;  $X_3$ , SMBC;  $X_4$ , SMBN;  $X_5$ , C:N ratio;  $X_6$ , MC;  $X_7$ , BD;  $X_8$ , pH.

\*, \*\*, \*\*\*, Significant correlation at  $p < 0.05$ , 0.01, and 0.001, respectively.

### 3.4 Total SOC, TN, SMBC and SMBN Storage

In the 0~50 cm depth, total SOC ranged from 12.98 to 17.39 kg C m<sup>-2</sup> across the sampled sites dominated by different vegetation types in Hongqipao reservoir. TSOC differed significantly among the sites ( $P < 0.05$ ) (Table 5). Sites which were inundated had relative higher TSOC values than the dry sites. Site D recorded the highest TSOC, while site B had the highest TSMBC. The TSMBN was remarkable higher in site A dominated by *Poa annua L.*, *Imperata cylindrica*, and *Polygonum*. Sampling sites which were not inundated (site which were dry during the sampling period) had the lowest TSOC.

**Table 5.** Total SOC, TN, SMBC and SMBN storage

Sampling site	TSOC (kg C m <sup>-2</sup> )	TSN (kg N m <sup>-2</sup> )	TSMBC (g C m <sup>-2</sup> )	TSMBN (g N m <sup>-2</sup> )
A	12.98±0.31	0.20±0.02	157.07±39.88	43.30±9.79
B	15.01±0.49	0.35±0.04	473.34±97.55	30.74±8.09
C	17.35±1.47	0.77±0.11	270.71±98.73	14.75±0.03
D	17.39±1.19	0.80±0.04	63.12±18.61	4.05±0.33
E	16.32±0.34	0.60±0.12	126.81±15.18	5.04±0.03
F	14.58±0.89	0.51±0.06	105.25±13.09	2.58±0.35
G	14.36±1.75	0.52±0.21	98.66±24.54	11.53±3.44

### 3.5 Aboveground biomass production

The results of aboveground plant biomass are presented on Table 6. In site C which was dominated by *Tamarix chinensis* Lour. and *Polygonum amphibium* L. the biomass was  $3.74 \pm 1.73 \text{ kg m}^{-2}$  which was about ten times higher than that of site A of  $0.38 \pm 0.21 \text{ kg m}^{-2}$  which was the lowest. Site E which was dominated by *Phragmites australis* had the second relative high value of  $0.91 \pm 0.08 \text{ kg m}^{-2}$  which was about four times lower than that of site C. The aboveground biomass production of most of the sites did not exceed  $1 \text{ kg m}^{-2}$  (Table 6).

**Table 6.** Aboveground biomass production of the vegetation from the different sampling sites in Hongqipao reservoir.

Sampling sites	Plant species	Biomass ( $\text{kg m}^{-2}$ )
A	<i>Poa annua</i> L., <i>Imperata cylindrica</i> , <i>Polygonum</i>	$0.38 \pm 0.21$
B	<i>Phragmites australis</i> , Mongolian wormwood	$0.71 \pm 0.03$
C	<i>Tamarix chinensis</i> Lour., <i>Polygonum amphibium</i> L.	$3.74 \pm 1.73$
D	<i>Scirpus fluviatilis</i> , <i>Polygonum amphibium</i> L., <i>Carex tristachya</i>	$0.55 \pm 0.19$
E	<i>Phragmites australis</i>	$0.91 \pm 0.08$
F	<i>Leymus chinensis</i>	$0.64 \pm 0.17$
G	<i>Poa annua</i> L.	$0.58 \pm 0.01$

## 4. Discussion

### 4.1 Soil Organic Carbon (SOC) and TN variations among vegetation types and soil depths

In the recent past, studies on terrestrial ecosystem carbon and nitrogen have received much attention global because emissions of carbon and nitrogen oxides into the atmosphere play a critical role in driving climate change<sup>32</sup>. Studies have illustrated the spatial variation of SOC, TN and SMB in relation to litter input, vegetation distribution, water-level fluctuation, soil moisture, temperature, and nutrient conditions<sup>33-34</sup>. However, similar studies have not been done in the Hongqipao reservoir dominated by different plant communities. In this study, spatial variation of SOC, TN, SMBC, SMBN and other soil properties were determined in Hongqipao reservoir. As observed in this study, BD increased with increasing soil depth. The upper soil profile (0-10cm) in all the sampled sites had the lowest mean values of the BD compared to the other soil profiles. This is due

to the fact that soil BD is considered to be the basic property that varies with the soil structural conditions, and increases with soil depth, due to changes in porosity, soil texture, and organic matter content <sup>35</sup>. The mean BD among sites differed significantly with sampling site A and B having remarkable high values. This could have been likely due to mineral sedimentation since these sites were located close to reservoir shoreline where the inflowing rivers pour water into the reservoir. Wang, et al. <sup>36</sup> observed relative high BD over a depth of 24 cm from site located near influent of a river flowing in a freshwater marsh. These authors attributed their findings to rates of mineral sediment accumulation which tend to increase towards the lake/open water in a wetland than in the interior marshes <sup>37</sup>. Another possible reason for the relative high soil BD in sites A and B could be due to sediment settling out of the water column which is then transformed into a soil layer that bonds with the preexisting surface, thus decreasing pore space, resulting in increased BD <sup>38</sup>.

Unlike BD, the SOC and TN decreased with depth from the soil surface to the bottom of the soil profile, reflecting the variations in growth and distribution of roots and rhizome, and the decomposition with depth. According to Huang, et al. <sup>39</sup> the difference between organic matter input and output determines the amount of soil organic matter and carbon. The vertical profile of SOC from the soil collected in the sites dominated by different vegetation types in Hongqipao reservoir showed that the plants detritus decreased with depth. When plants detritus decompose, most of their organic matter is mineralized and a new soil layer which contains a greater amount of organic carbon is formed <sup>39-40</sup>. This therefore led to higher SOC and TN in the top soil profiles than in the lower soil profiles.

Our study further revealed spatial variation of SOC and TN in the Hongqipao reservoir. Sites C, D and E had remarkable higher SOC and TN than the other sites. The reasons for this observation may be that: firstly, likely high SOC and TN in the soil from these sites can probably be explained by additional organic matter supply by the vegetation through litter fall associated with their relative high productivity. Litter fall from *Polygonum amphibium* L which was dominant in site B and C is documented in the literature to have high concentration of carbon, magnesium, and phosphorus <sup>41</sup>. While determining storage of organic carbon, nitrogen and phosphorus in the soil-plant system of *Phragmites australis* stand from eutrophicated Mediterranean marsh, González-Alcaraz, et al. <sup>42</sup>

reported that the litter falls of *Phragmites australis* were important reservoirs of organic carbon which were mineralized into the soil. Zhang, et al.<sup>43</sup> and Gower, et al.<sup>44</sup> noted in their studies that accumulation of organic carbon in soil and the proportion of carbon fixed to soil carbon pool with different turnover rates tend to vary with vegetation types. Secondly, since sites A, F and G were located on dry places within the littoral zone of the reservoir, then their relative low SOC concentration could probably be because mineralization was favoured since the soil was dry most of the time. Scores of studies have shown that hydrological processes (such as groundwater level, depth, duration and frequency of flooding) affect the decomposition of litter hence soil SOC and TN<sup>45</sup>.

Soil microbial biomass (SMB), plays an important role in SOC mineralization and nutrient cycling<sup>46-47</sup>. The composition of vegetation species and soil water availability in wetlands greatly influences the soil microbial biomass<sup>48-49</sup>. In this study, the overall mean SMBC did not differ significantly among the sites dominated by different vegetation types. However, relative high mean values were observed in site B which was mainly dominated by *Phragmites australis* and *Mongolian wormwood*. Sturz and Christie<sup>50</sup> and Kyambadde, et al.<sup>51</sup> noted in their study that the vigorous root system of *Phragmites* community vegetation increase the level of soil microbial activity hence its biomass. These authors further noted that higher organic matter from *Phragmites* community increases the carbon enrichment of the soil, which then helped maintain the microbial activities in the soil. More importantly, the mean SMBN which differ significantly among the sites was relatively higher at site B.

Although there was no clear vertical profile pattern of the SMBC and SMBN, relative high values were observed in the top soil profile (0-10 and 10-20cm). This could be explained by the fact that the upper soil profile contained higher SOC and TN. While investigating the responses of SOC and TN mineralization to change in microbial biomass and SOC, TN and phosphorus stoichiometry, Ashraf, et al.<sup>46</sup> observed that increase in SOC and nitrogen accumulation resulted into increase in SMBC and SMBN. During soil organic matter mineralization which mostly happens on the top soil profiles (0-20cm) as observed in this study, most crucial fractions of SOC and nitrogen become part of microbe, such as phospholipids and proteins which are then released upon microbial turnover<sup>52</sup>.

Correspondingly, the relative high SMBC and SMBN at the top soil profiles indicate higher microbial metabolic activities in these profiles.

#### *4.2 Soil Organic Carbon (SOC) and TN relationships with other soil properties*

According to Bi, et al.<sup>53</sup> the carbon cycle is closely linked with nitrogen cycle through production and decomposition. Our study also revealed that the soil TN concentration was significant positive related with SOC concentration in the 0-50cm soil layer of the different vegetation types (Table 3 and Figure 3). This observation could be because the main nitrogen sources were the vegetation organic matter, litter, and biological nitrogen fixation<sup>54</sup>. The Pearson correlation analysis and RDA also showed that soil MC was positive correlated with SOC and TN. This concurs with finding of other studies<sup>55-56</sup>. Under high soil MC conditions, the anoxic decomposition of soil organic matter tends to be inhibited resulting in the accumulation of SOC. Importantly, soil MC also affects nitrogen since higher soil MC can hinder soil microbial activities, creating environment which is not conducive to the mineralization and decomposition of soil organic nitrogen<sup>57</sup>. This therefore implies a high soil MC can lead to a high soil TN concentration.

Unlike soil MC which was significantly positively correlated with SOC and TN, the soil BD was significant negative correlated with SOC and TN concentration in the 0-50 cm soil profiles (Table 3 and Figure 3). While assessing stock and thresholds detection of SOC and nitrogen along an altitude gradient in an east Africa mountain ecosystem, Njeru, et al.<sup>58</sup> observed that BD was negative correlated with SOC and TN. This observation could be likely due to the fact that mineralization of SOC and nitrification of nitrogen were suppressed in soils with high BD values<sup>53, 59</sup>. It is documented in the literature that low BD soil can store more SOC and TN as SOC and TN can be mobilized in porous spaces within soil matrix<sup>60</sup>.

Soil microbial biomass plays an important role in maintaining of soil structure, facilitating microbial metabolic processes and regulating the release of nutrients. Study performed by Zhang, et al.<sup>61</sup> on the effects of heavy metals and soil physicochemical properties on wetland soil microbial biomass and bacterial community structure showed a strong relationship between soil physicochemical properties and soil microbial biomass. In this study, the Pearson's correlation analysis showed that SMBC was not significantly related with any other soil properties including SOC. This could be attributed to the quality of organic carbon<sup>62</sup>.

From the multiple regression models results in this study, it is quite clear that all measured soil variables played a major role in influencing SOC, TN, SMBC and SMBN. A comparison of the two models (for each response variable; SOC, TN, SMB and SMBN), one including all the soil variables measured and the other one including only those significantly correlated with the response revealed a slight difference. The variability of the response variable could be explained more when all the predictor variables measured in this study were included in the model. This implies that all the measure soil variables play a role in influencing the response variable.

## 5. Conclusions

Some conclusions could be drawn from this study: There is high spatial variability for SOC, TN, SMBC and SMBN in the Hongqipao reservoir. Sites which were dominated by *Phragmites australis*, *Polygonum amphibium* L, *Carex tristachya* and inundate during the study period (C, D and E) had remarkable higher SOC and TN than the other sites. This could probably be attributed to high organic matter supply by the vegetation through litter fall associated with their relative high productivity. Moreover, inundation could be creating unfavorable condition for mineralization of SOC by soil microbial communities. Sites which were located on dry places within the littoral zone of the reservoir, had relative low SOC concentration probably because mineralization was favored since the soil was dry most of the time. The SOC, TN, SMBC and SMBN contents decreased with increasing soil depth. This could be attributed by the fact that when plants detritus decompose, most of their organic matter is mineralized and a new soil layer which contains a greater amount of organic carbon is formed. SOC was significantly and positively correlated with TN contents in the 0-50 cm soil profiles likely because the vegetation organic matter and liter could be the main nitrogen sources. Moreover, MC was significant positive correlated with SOC and TN. In contrast to MC, BD was significant negative correlated with SOC and TN contents. No significant correlations were observed between SOC, TN, SMBC and SMBN contents and soil pH values. Soil microbial biomass showed weak relationship with other soil properties. All measures soil properties in this study could explain higher significant variability of the response variables (SOC, TN, SMBC and SMBN contents), suggesting that all the measured soil variables within the different vegetation types in the reservoir played a crucial role in determining the contents of SOC, TN, SMBC and SMBN. This study further suggests that vegetation types play a major role in determining the

spatial characteristics of SOC and TN. Any changes in the vegetation types in the littoral area of the reservoir may influence the distribution of SOC, TN, SMBC, SMBN and other soil properties. This may affect the global carbon budget and the atmospheric greenhouse gas concentration significantly.

**Author Contributions:** Conceptualization, B.Y. and J.L.; methodology, B.Y. and Y.L.; software, B.Y.; validation, B.Y. and X.L.; formal analysis, J.L.; investigation, B.Y. and X.L.; resources, H.W.; data curation, B.Y.; writing—original draft preparation, B.Y. and P.C.M; writing—review and editing, P.C.M.; visualization, X.W.; supervision, B.Y. and J.L.; project administration, B.Y.; funding acquisition, B.Y. and J.L. All authors have read and agreed to the published version of the manuscript.

**Funding:** This study was funded by the Fundamental Research Funds for the Central Universities (2572017CA14), and the postdoctoral scientific research developmental fund of Heilongjiang Province (LBH-Q15006).

**Acknowledgments:** We want to acknowledge all those who contributed to the accomplishment of this paper.

**Conflicts of Interest:** The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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