

BENTHIC MACROINVERTEBRATE DIVERSITY AND FUNCTIONAL FEEDING GROUPS IN RELATION TO PHYSICOCHEMICAL FACTORS IN SANJIANG PLAIN WETLANDS, NORTHEAST CHINA

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Abstract. Sanjiang plain wetland is the largest freshwater ecosystem in northeast China, and with its richness in animal and plant species, it displays a high biodiversity. This study provides information about benthic macroinvertebrate diversity and functional groups in association with physicochemical parameters in wetland habitats of Sanjiang plain. Benthic macroinvertebrate samples were collected using a D-frame aquatic net. Shannon-Wiener, Simpson and Pileou's evenness indices were calculated in terms of abundance. The relationship between measured physicochemical variables and benthic macroinvertebrate functional feeding groups (FFGs) was explored using CCA. A total of 57 macroinvertebrate taxa were collected from the 16 sampling sites. Aquatic insects were the most abundant with 11 families, Dytiscidae, Chironomidae, Leptophlebiidae, Belostomatidae, Corixidae, Gerridae, Corduliidae, Gomphidae, Macromiinae, Libellulidae and Phryganeidae. Chironomids were the most diverse and abundant with 26 taxa. The metrics of abundance, Shannon-Wiener, Simpson and Pileou's evenness indices differed significantly among the 16 sampling sites ($p = 0.0163$, $p = 0.0092$, $p = 0.0474$, $p = 0.0222$, respectively). The findings showed that these 57 benthic macroinvertebrate taxa were categorized in six functional feeding groups, including 19 predators, 15 gathering-collectors, 7 scrapers, 6 filtering-collectors, 5 omnivores and 5 shredders. CCA results displayed that benthic macroinvertebrate functional feeding groups had strong relationships with the physicochemical characteristics in the wetlands of Sanjiang plain.

Keywords: aquatic macroinvertebrate fauna, functional group composition, water parameters, wetland, China

Introduction

Wetland ecosystems account for 5-8% of the Earth's surface area (Sui et al., 2017) with their characteristic mix of land and water. They display the richest biodiversity, highest productivity, and highest ecological impact of all terrestrial ecosystems (Sui et al., 2017). They are important for the reduction of greenhouse gas emission, conservation of biodiversity, and contribute to regulating the balance of the Earth's ecosystem (Galloway et al., 2004; Dentener et al., 2006). Aquatic ecosystems are mostly affected by the large-scale agricultural expansion which influences the overall quality of the ecosystems by directly altering habitat, channel structure, and water quality posing severe threats to aquatic biodiversity (Vitousek et al., 1997; Allan, 2004; Azrina et al., 2006; Dudgeon et al., 2006; Smith and Lamp, 2008; Carlson et al., 2013;

Narangarvuu et al., 2014). Most aquatic macroinvertebrates reside in the benthic biotope for at least part of their life, relatively immobile, and very sensitive; therefore any disturbances in the aquatic environment may cause them to disappear or a reduction in their diversity (Hilsenhoff, 1988; Zamora-Muñoz et al., 1995; Morse et al., 2007; Narangarvuu et al., 2014). Hence, biomonitoring is considered as one of the alternatives for rapid assessment of the aquatic environment status (Tan and Beh, 2016).

Aquatic macroinvertebrates are widely used as biological indicators of the ecological conditions, their abundance and diversity being used to evaluate the occurrence of pollution (Abel, 1966; Hellawell, 1986; Metcafe, 1989; Lenat, 1993; Rosenberg and Resh, 1993; Rosenberg et al., 2008; Southerland et al., 2008; Shabani et al., 2016). While macroinvertebrates in wetlands share some of their attributes in streams and rivers useful such as ubiquity, sedentary nature, moderately long life cycles, environmental sensitivity (Rosenberg and Resh, 1993), they have many other attributes that reduce their ability to reflect environmental quality such as strong responses to weather and seasonality, and frequent dispersal into and out of habitats (Rosenberg et al., 2008).

In standing and flowing water ecosystems, aquatic macroinvertebrates are important elements in the ecological dynamics (Hynes, 1970), playing an important role in the cycle of materials and in trophic transfers (Cummins, 1974; Vannote et al., 1980; Cummins et al., 1989; Dunbar, 2010; Shabani et al., 2016; Safari et al., 2018). They are important animal organisms both economically and ecologically (Li et al., 2007).

Understanding the distribution and abundance of invertebrates in aquatic ecosystem has long been a goal of aquatic ecologists (Bergon, 1996). Immature stages of aquatic invertebrates are a vital link between primary producers and fish (Yapo et al., 2018). Most aquatic macroinvertebrates are sensitive to changes in pH, dissolved oxygen, temperature, salinity, turbidity, conductivity, availability of food and other changes in their biotope (Gage et al., 2004; Crisci-Bispo et al., 2007). They are useful surrogates of ecosystem attributes, and the relative abundance of functional groups reflects anthropogenic impact (Merritt et al., 2002; Cummins et al., 2005; Masese et al., 2014).

Sanjiang plain wetland is the largest freshwater wetland in northeast China (Zheng et al., 2013; Liu et al., 2014; Taufik et al., 2015; Wu et al., 2017), and with its richness in animals and plant species, it displays a high biodiversity. It is world-renowned for hosting many rare, large-sized water birds; several most notable ones are globally threatened cranes, such as the Oriental stork (*Ciconia boyciana*), white-naped crane (*Grus vipio*), and red-crowned crane (*G. japonensis*) (Zhang et al., 2009a). Its role in maintaining the ecological balance in the region is irreplaceable (Zheng et al., 2013; Liu et al., 2014). However, qualitative and quantitative studies of aquatic macroinvertebrates in the area remain generally scarce due to the lack of large-scale investigations and insufficient data. Thus, the conservation status of many benthic macroinvertebrates in the Sanjiang plain wetland is not yet assessed. In order to reach a rational and sustainable management of freshwater wetlands of Sanjiang plain, it is very crucial to implement a follow-up study program, to monitor and classify the freshwater macroinvertebrates (Shabani et al., 2016). The identification of species and their distribution patterns provide more information for monitoring and conserving these important ecosystems (Maneechan and Prommi, 2015). Community indices, diversity indices, and functional feeding groups (FFGs) were the most effective measures that can be used in water quality assessment, and have a response across a range of human influence (Rosenberg and Resh, 1993; Merritt et al., 1996, 2002; Karr and Chu, 1999;

Masese et al., 2014). FFGs are a classification approach that is based on morpho-behavioral mechanisms of food acquisition rather than taxonomic group (Merritt et al., 1996). This study aimed to collect benthic macroinvertebrate fauna, and explore the relationships between macroinvertebrate FFGs and water physicochemical properties in the wetland environments of Sanjiang plain.

Materials and methods

Study area

The Sanjiang Plain is located in the northeast boarder part of the Heilongjiang Province in NE China (Zhang et al., 2009a; *Fig. 1*). It is in a low alluvial plain of Heilong River, Songhua River, and Wusuli River (Zhou and Liu, 2005; Zhang et al., 2009a; Jiang et al., 2011), from 129°11E to 135°05E and from 43°49N to 48°27N, covering a total area of 108,900 km² (Liu and Ma, 2002; Jiang et al., 2011; Du et al., 2018). The Sanjiang plain supports one of the largest freshwater wetland complexes in China, and its wetland areas are strongly affected by agriculture drainage and reclamation efforts (Wu et al., 2017). Its elevation in the southwest is higher than in the northeast. The climate in this area belongs to the temperate humid or sub-humid continental monsoon climate. The mean annual temperature ranges from 1.4-4.3 °C (Du et al., 2018), with average maximum of 21-22 °C in July and average minimum -18 °C in January (Wang et al., 2015). The mean annual precipitation is 500-650 mm and 80% of rainfall occurs between May and September (Jin et al., 2015). The frost-free period is 120-140 days (Yang et al., 2018). Most of the rivers in the area have the characteristics of the wetland river: the slight gradient and large channel curve coefficient. There are four main soil types: meadow soil, swamp soil, washed and black soil. They account for more than 95% of the whole area. Main types of vegetation in Sanjiang plain include *Phragmites communis*, *Carex lasiocarpa*, *Carex pseudocuraica*, *Carex meyeriana*, *Alnus sibirica*, *Betula fruticosa*, *Salix brachypoda*, *Lythrum salicaria*, *Calamagrostis anagustifolia* (Wang et al., 2018), and the Sanjiang plain wetland has been designated within list of wetlands of international importance (Zhang et al., 2009). Due to the relatively cold weather, deep surface waters, large marsh patches, and sparse population, reclamation of small Sanjiang plain marshes started relatively late, and the Honghe National Nature Reserve and Sanjiang National Nature Reserve were created (Zhang et al., 2009; Du et al., 2018).

Benthic macroinvertebrate procedures

Sixteen sampling sites were selected based on prospected freshwater ecosystems and accessibility (catchment areas including sites 1, 2, 3, 4, 5 and 6; ponds: sites 7 and 15; marshes: site 8; rivers: sites 9, 11, 12, 13 and 16; lake: site 10; ditches: site 14). The latitude and longitude of the 16 sampling sites were determined using a portable global positioning system (GPS, *Table 1*). Benthic macroinvertebrates were collected using a D-frame aquatic net (30 × 30 cm frame, 500 µm mesh) and the sampling gears were washed thoroughly between sites during three seasons: autumn, spring and summer of year 2016. In each sampling period, 3 replicate samples were collected at each site and the sampled specimens were sieved through a 500 µm mesh sieve in the field for approximately 30-40 min. Macroinvertebrate populations were separated from the sand, mud and substrates by hand. The specimens were grouped according to the sites and

dates of sampling and placed in 100 ml labelled plastic containers, preserved in 95% ethanol, and then transported to the laboratory for further analysis.

In the laboratory, the macroinvertebrate communities were keyed to species or genus and counted using identification keys of Thorp and Covich (1991); Morse et al. (1994); Merritt et al. (1996); Tong (1996); Dudgeon (1999); Duan et al. (2010).

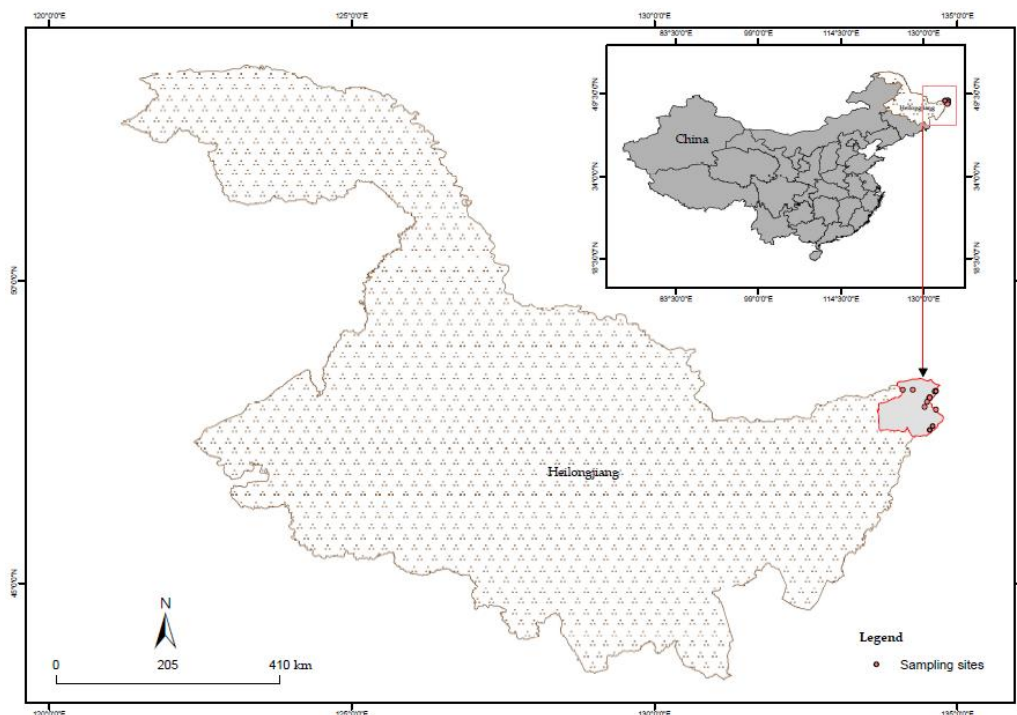


Figure 1. The location of study area with sampling sites within China

Functional group composition

Major functional feeding groups were assigned based on invertebrate morphological and behavioral adaptations for food acquisition (Merritt et al., 2002; Merritt et al., 1996) and 6 FFGs (shredders, scrapers, filtering-collectors, gathering-collectors, predators and Omnivores) that were identified. The FFGs are: 1) shredders (SH) feeding on coarse particulate organic matter >1 mm in size, either live aquatic macrophyte tissue or coarse terrestrial plant litter; 2) scrapers (SC) scraping off and consuming the organic matter attached to stones and other substrate surfaces, primarily live plant stems; 3) filtering-collectors (FC) sifting fine particulates 1000 to 0.45 μm from the flowing column of water; 4) gathering-collectors (GC) which gather fine particulates of organic matter from the debris and sediments on the stream beds; 5) predators (PR) feeding on other animals, i.e. live prey; and a sixth category, other, includes species that are omnivores (OM), or simply do not fit neatly into the other categories (Zhang et al., 2014; Masese et al., 2014; Fu et al., 2016).

Measurement of physicochemical factors

Simultaneously with benthic macroinvertebrate sampling, the water temperature (T °C), electrical conductivity (EC, $\mu\text{S}/\text{cm}$), pH, chlorine (Cl^- , mg/l), turbidity (NTU),

chlorophyll a (Chl, mg/l) were measured using multi-parameter probe YSI Professional (YSI 06E2512AG). The transparency (cm) was measured with a Secchi disc. Water samples were collected from each sampling site in 500 ml labelled plastic containers. Chemical parameters such as chemical oxygen demand (COD_{Mn}, mg/l), biological oxygen demand (BOD₅, mg/l), total nitrogen (TN, mg/l), ammonia-nitrogen (NH₃-N, mg/l), nitrate (NO₃⁻, mg/l), and total phosphorus (TP, mg/l) were analyzed in the laboratory based on standard methods procedures (APHA, 2012).

Data analysis

The Shannon-Wiener, Simpson, Pileou's evenness and alpha (α) biological diversity indices were calculated in terms of abundance using PAST software (Hammer et al., 2001; Hammer and Ryan, 2008). A principal component analysis (PCA) based on a correlation matrix among samples was used to analyze the physicochemical parameters. Canonical correspondence analysis (CCA) was also used to describe community trends in macroinvertebrate data and to identify physicochemical variables that best explained species distribution patterns at study sites. PCA and CCA were performed using RcmdrPlugin.FactorMineR and vegan packages, respectively in R software (version 3.5.1). One-way analysis of variance (ANOVA) test was used to test the significance of physicochemical factors on macroinvertebrate abundance and FFGs differences among the sixteen wetland sites. The non-parametric Kruskal-Wallis test was used if normality was not achieved after transformation (Zar, 1984). ANOVA and Kruskal-Wallis tests were computed using Rcmdr package in R software. Canonical correspondence analysis was used to select linear combinations of physicochemical variables that account for most of the variation in macroinvertebrate distributions (Niba and Sakwe, 2018).

Table 1. Sixteen sampling site coordinates

Site	Latitude	Longitude
1	N48°04'02"	E134°32'39"
2	N48°04'00"	E134°32'42"
3	N48°03'58"	E134°32'49"
4	N48°04'02"	E134°33'10"
5	N48°04'12"	E134°33'04"
6	N48°04'07"	E134°33'00"
7	N48°09'55"	E134°37'55"
8	N48°10'58"	E134°39'01"
9	N48°11'40"	E134°16'12"
10	N48°10'13"	E134°39'07"
11	N47°59'52"	E134°30'14"
12	N47°55'00"	E134°27'57"
13	N47°52'09"	E134°39'19"
14	N47°35'45"	E134°36'00"
15	N47°31'57"	E134°33'09"
16	N48°11'46"	E134°06'00"

Results and discussion

Benthic macroinvertebrate communities

A total of 57 benthic macroinvertebrate taxa belonging to 24 families were collected from the sixteen sampling sites. Insects were most caught with 11 families Dytiscidae, Chironomidae, Leptophlebiidae, Belostomatidae, Corixidae, Gerridae, Corduliidae, Gomphidae, Macromiinae, Libellulidae and Phryganeidae. In general, Chironomids were the most diverse and abundant family, which possessed 26 taxa followed by Gomphidae with 4 taxa (Table 2). Among all populations, *Cipangopaludina ussuriensis* (Viviparidae) was the most abundant species representing up to 18.2% and occurring at almost each sampling site except for sites 1, 2, 6 and 13. *Leander modestus* (Palaemonidae) was dominant on site 7, and *Cipangopaludina ussuriensis* on sites 16 and 10, respectively. Total taxon richness was higher in spring and at site 16. The Shannon-Wiener diversity index was higher at sites 8 and 14, respectively (Fig. 2). We observed that these sites were dominated abundantly by aquatic Poaceae vegetation. Aquatic vegetation plays an important role in structuring macroinvertebrate populations via the provision of living space (Angradi et al., 2001; Sipkay et al., 2005; Ali et al., 2007; Valinoti et al., 2011; Gleason et al., 2018) or the selecting species traits related to population dynamics and feeding habits (Céréghino et al., 2008).

Table 2. Diversity broad outline and relative abundance of benthic macroinvertebrates collected in Sanjiang plain wetland

Order	Family	Species	(%)
Arhynchobdellida	Haemopidae	<i>Whitmania laevis</i>	0.3
Coleoptera	Dytiscidae	<i>Cybister cimbatus</i>	0.3
Decapoda	Palaemonidae	<i>Leander modestus</i>	12.1
Diptera	Chironomidae	<i>Chironomus lugubris</i>	1.3
		<i>C. riparius</i>	1
		<i>C. salinarius</i>	2.5
		<i>C. anthracinus</i>	0.2
		<i>C. circumdatus</i>	0.3
		<i>C. flaviplumus</i>	0.5
		<i>C. kiiensis</i>	0.3
		<i>C. pallidivittatus</i>	0.2
		<i>C. plumosus</i>	2.5
		<i>Cricotopus anulator</i>	0.2
		<i>C. trifasciatus</i>	4.1
		<i>Cryptochironomus defectus</i>	0.2
		<i>Dicrotendipes tritonus</i>	0.3
		<i>D. nervosus</i>	0.3
		<i>Einfeldia dissident</i>	1.8
		<i>Glyptotendipes cauliginellus</i>	1.3
		<i>G. pauens</i>	2.3
		<i>G. tokunagaai</i>	1.6
<i>Orthocladius rousellae sponis</i>	0.2		
<i>Parachironomus arcuatus</i>	0.2		

		<i>Polypedilum nubifer</i>	0.5
		<i>P. nubeculosum</i>	2.5
		<i>Prosilocerus</i> sp.	2
		<i>Stictochironomus maculipennis</i>	0.5
		<i>Tanypus formosanus</i>	0.5
		<i>Tanytarsus mendex</i>	3
Ephemeroptera	Leptophlebiidae	<i>Leptophlebia</i> sp.	0.7
Erpobdelliformes	Erpobdellidae	<i>Erpobdella octoculata</i>	2
Eulamellibranchia	Sphaeriidae	<i>Sphaerium lacustre</i>	0.3
Heteroptera	Belostomatidae	<i>Kirkaldyia deyrollei</i>	0.7
	Corixidae	<i>Corixa substriata</i>	0.3
	Gerridae	<i>Ranatra chinensis</i>	0.5
Littorinimorpha	Bithyniidae	<i>Bithynia fuchsiana</i>	10
Hygrophila	Lymnaeidae	<i>Lymnaea stagnalis</i>	4.3
	Semisulcospiridae	<i>Semisulcospira amurensis</i>	2.3
Architaenioglossa	Viviparidae	<i>Cipangopaludina cathayensys</i>	0.3
		<i>C. ussuriensis</i>	18.2
		<i>Viviparus chui</i>	1.1
Odonata	Corduliidae	<i>Somatochlora</i> sp.	0.2
	Gomphidae	<i>Gastrogomphus</i> sp.	0.3
		<i>Gomphinae</i> sp.	0.5
		<i>Ictinogomphus</i> sp.	0.2
		<i>Sinictinogomphus</i> sp.	0.7
	Macromiinae	<i>Epophthalmia</i> sp.	0.8
Libellulidae	<i>Brachythemis</i> sp.	0.2	
Hygrophila	Planorbidae	<i>Gyraulus convexiusculus</i>	1.8
Rhynchobdellida	Glossiphoidae	<i>Glossiphonia lata</i>	0.3
		<i>Parabdella quadrioculata</i>	1.1
Trichoptera	Phryganeidae	<i>Phryganea</i> sp.	0.2
Tubificida	Naididae	<i>Nais simplex</i>	0.5
	Tubificidae	<i>Branchiura sowerbyi</i>	0.2
		<i>Limnodrilus amblysetus</i>	1.1
		<i>Limnodrilus hoffmeisteri</i>	1
Unionoida	Unionidae	<i>Unio douglasiae</i>	7.2

According to the ANOVA results, the abundance, Shannon-Wiener, Simpson and Pileou's evenness indices were significantly different ($p = 0.0163$, $p = 0.0092$, $p = 0.0474$, $p = 0.0222$, respectively) among the sixteen sampling sites. On the other hand, it appeared that there's no significant difference in the total abundance and taxa richness of macroinvertebrate communities caught during spring, summer and autumn seasons ($p = 0.229$, $p = 0.7662$, respectively, Fig. 2c).

Our results agreed with the findings of Wang et al. (2007); Zhao et al. (2012); Zhang et al. (2014); Rosser and Pearson (2018), who reported that insects represented the most diverse group and Chironomids were the most abundant family. Macroinvertebrate biodiversity is mainly determined by the number of taxa and individuals, and higher

diversity can be detected in complex habitats because of more living space or surface area (Shostell and Williams, 2007).

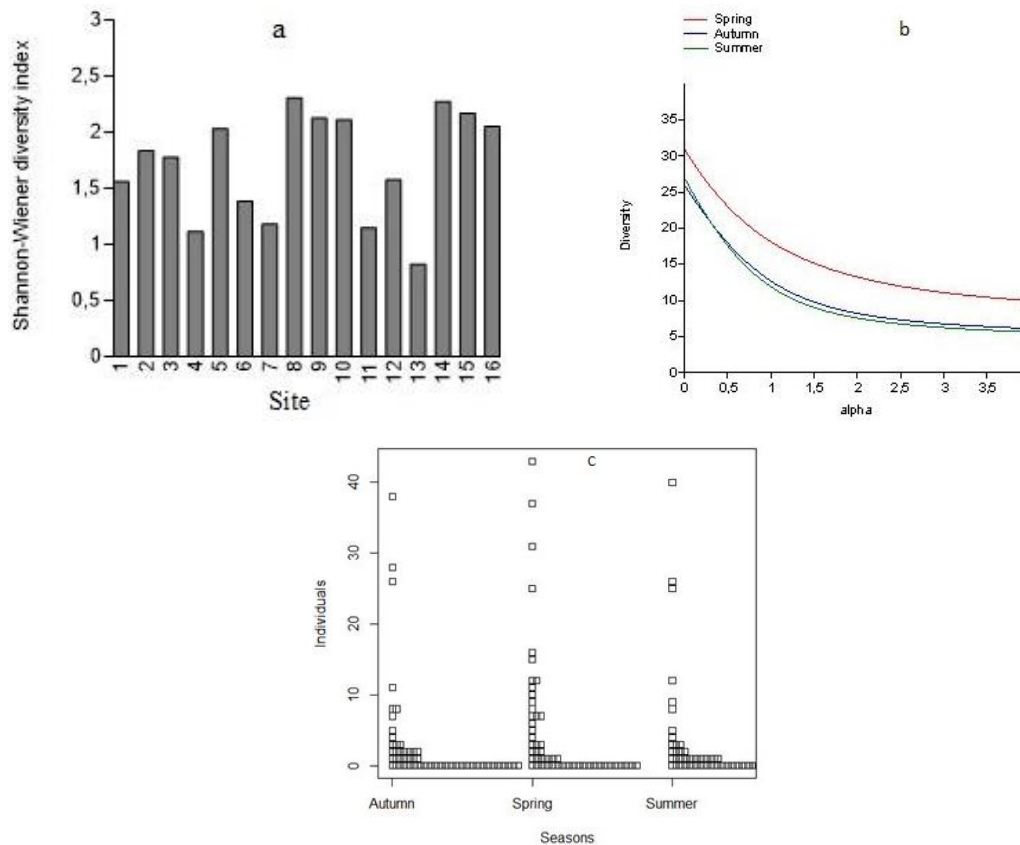


Figure 2. Trends in Shannon-Wiener (a) and alpha (b) diversity indices, and comparison of mean values (c) of the total abundance for each sampling site during autumn, spring and summer seasons. Autumn (26 species, $n_{ind} = 165$), spring (31 species, $n_{ind} = 287$) and summer (27 species, $n_{ind} = 158$)

Physicochemical variables at sites

As summarized in Table 3, some of the measured physicochemical characteristics changed with seasons. Temperature, chlorophyll a, TN, pH and COD_{Mn} (Kruskal–Wallis test, $p < 0.001$) and NO_3^- , TP, BOD_5 and turbidity (Kruskal–Wallis test, $p < 0.05$) significantly varied among the sampling sites during these three seasons. While conductivity, chlorine, NH_3-N and transparency did not vary significantly (Kruskal–Wallis test, $p > 0.05$) during autumn, spring and summer seasons. Temperature, conductivity, NO_3^- , transparency, TP, COD_{Mn} and BOD_5 increased during the summer, while chlorine, NH_3-N , turbidity and TN increased during the spring. Moreover, pH and chlorophyll increased during the autumn. The pH values indicating the waterbodies of Sanjiang plain tends to be neutral to alkaline. These pH values were nearly similar to those recorded by Narangarvuu et al. (2014) in the Xindian watershed, Taiwan. According to Grady et al. (2011), at this pH level, the denitrification process performs well and forms nitrate.

The sixteen sites were different in terms of water quality (*Fig. 3*); the first two axes accounted for 62.24% of the cumulative variance. The sites 1, 4 and 6 were characterized by high concentrations of total nitrogen, temperature, chemical oxygen demand, BOD₅ and chlorophyll a. While the sites 9, 11, 12, 15 and 16 were characterized by high concentrations of ammonia-nitrogen, conductivity, chlorine, turbidity and total phosphorus. The site 10 was characterized by concentrations of NO₃⁻ and pH. There was also a significant positive correlation between pH and NO₃⁻.

Table 3. Means and standard deviations of the physicochemical variables at 16 sites

Water parameters	Spring	Summer	Autumn	p-value
T °C	22.19 ± 1.74	31.36 ± 2.80	18.93 ± 1.81	0.0000***
Conductivity (µS/cm)	118.68 ± 73.41	119.53 ± 70.57	70.73 ± 40.21	0.0847
pH	7.19 ± 0.44	7.42 ± 0.72	7.78 ± 0.30	0.0006***
Cl ⁻ (mg/l)	4.76 ± 4.21	2.83 ± 2.03	2.33 ± 1.02	0.4304
NH ₃ -N (mg/l)	0.43 ± 0.21	0.30 ± 0.11	0.41 ± 0.19	0.1122
NO ₃ ⁻ (mg/l)	0.63 ± 0.48	1.18 ± 1.26	1.14 ± 0.37	0.0104*
Turbidity (NTU)	82.54 ± 83.08	15.00 ± 10.59	24.46 ± 17.58	0.0420*
Chlorophyll a (mg/l)	3.60 ± 3.69	3.65 ± 4.21	13.19 ± 9.75	0.0001***
Transparency (cm)	29.43 ± 19.79	35.40 ± 28.07	34.00 ± 24.71	0.6164
TN (mg/l)	8.67 ± 3.35	4.81 ± 1.96	3.98 ± 1.91	0.0001***
TP (mg/l)	0.20 ± 0.15	0.39 ± 0.24	0.33 ± 0.21	0.0127*
COD _{Mn} (mg/l)	6.47 ± 8.08	45.15 ± 36.94	18.27 ± 14.79	0.0006***
BOD ₅ (mg/l)	1.04 ± 0.73	1.93 ± 1.31	1.813 ± 0.89	0.0153*

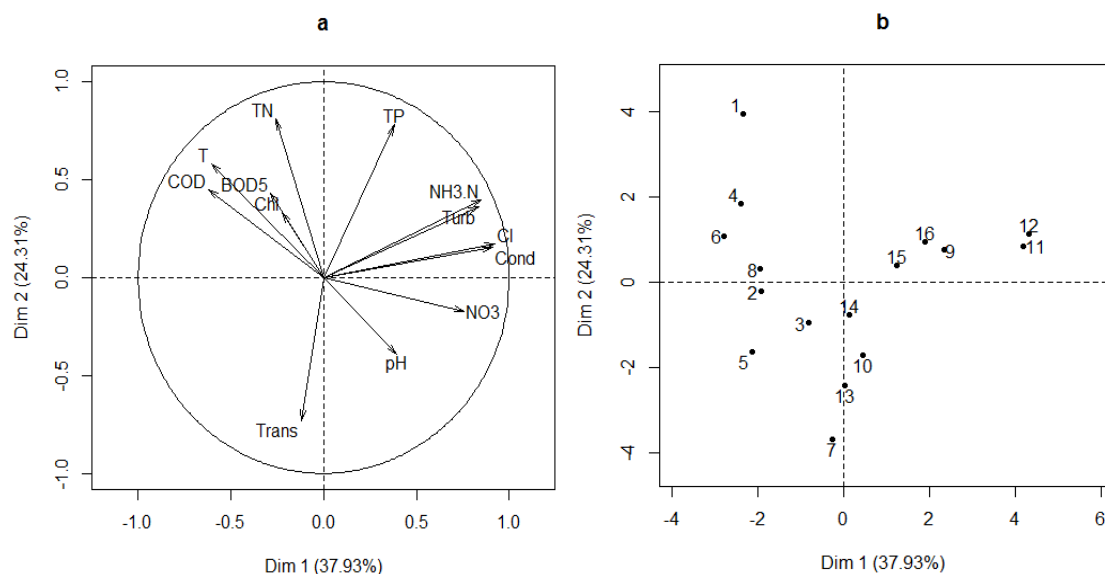


Figure 3. Principal Component Analysis (PCA, a&b) of the first 2 principal components expressing the relationship sites and physicochemical parameters. T = temperature, Cond = conductivity, Turb = turbidity, Cl⁻ = chlorine, Chl = chlorophyll a, Trans = transparency, COD_{Mn} = chemical oxygen demand, BOD₅ = biological oxygen demand, TN = total nitrogen, NH₃-N = ammonia-nitrogen, NO₃⁻ = nitrate, TP = total phosphorus

Relationships between physicochemical variables and macroinvertebrate FFGs

The CCA identified 13 physicochemical variables that were significantly correlated with the benthic macroinvertebrate FFGs within the sites (Fig. 4). The first two CCA axes respectively explained 38.27 and 30.58% of macroinvertebrate FFGs variance, with eigenvalues of 0.33 and 0.27.

The 57 benthic macroinvertebrate taxa were categorized as follows: 19 predators, 15 gathering-collectors, 7 scrapers, 6 filtering-collectors, 5 omnivores and 5 shredders. According to the percentage contributions of the various macroinvertebrate FFGs (abundance data) within sites, scrapers dominated the benthic communities and accounted for 38.4% of the total abundance followed by omnivores (17.4%), filtering-collectors (15.7%), predators (11.1%), gathering-collectors (10.0%) and shredders (7.4%). Our findings are similar to the results from Zhang et al. (2014), scrapers were the most widely distributed and made up the largest proportion in streams and rivers of a highly developed region, lake Taihu basin, China. Fu et al. (2016) found that predators made up the most contributions to the FFGs (25 taxa) in the Dongjiang River basin, southeast China. Fu et al. (2016) added that shredders and predators mainly included insects, while scrapers were mainly gastropods.

As shown in the Fig. 4, the distribution of scrapers including *Bithynia fuchsiana*, *Cipangopaludina cathayensis*, *Cipangopaludina ussuriensis*, *Gyraulus convexiusculus*, *Lymnaea stagnalis*, *Semisulcospira amurensis* and *Viviparus chui* at sites 8, 9 and 16, which consume algae and associated material were largely influenced by TP and BOD₅. McCormick et al. (2004) reported that TP is an important factor controlling the macroinvertebrate FFG communities. Turbidity, conductivity, ammonia-nitrogen, nitrate, chlorine and TN were the most important variables to impact the distribution of the filtering-collector FFGs (*Glyptotendipes cauliginellus*, *G. pauens*, *G. tokunagaai*, *Sphaerium lacustre*, *Tanytarsus mendex* and *Unio douglasiae*), which collect FPOM from the water column using a variety of filters at sites 3, 11, 12 and 13.

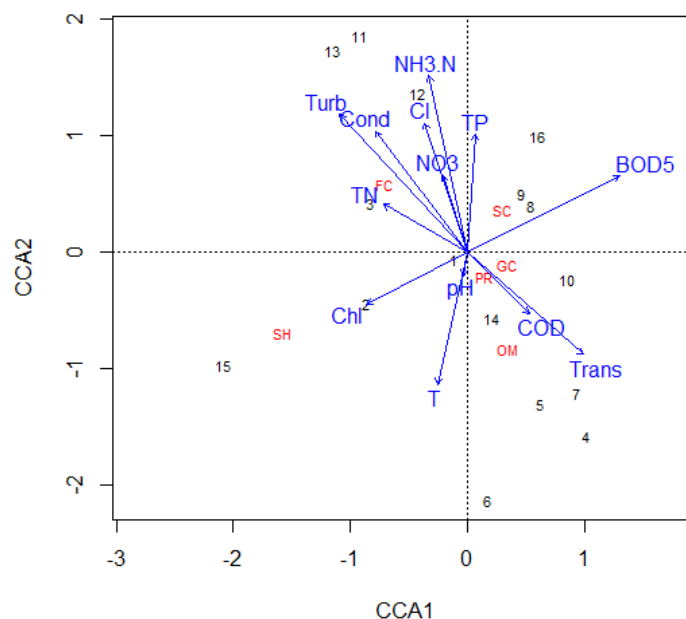


Figure 4. Canonical Correspondence Analysis (CCA) lot relating the macroinvertebrate FFGs to physicochemical factors. SH = shredders, SC = scrapers, FC = filtering-collectors, GC = gathering-collectors, PR = predators, OM = omnivores

The distribution of gathering-collectors (*Branchiura sowerbyi*, *Chironomus anthracinus*, *C. circumdatus*, *C. flaviplumus*, *C. kiiensis*, *C. pallidivittatus*, *C. plumosus*, *Dicrotendipes tritonus*, *D. nervosus*, *Einfeldia dissident*, *Leptophlebia* sp., *Limnodrilus amblysetus*, *L. hoffmeisteri*, *Nais simplex* and *Orthocladius rousellae saponis*), predators (*Brachythemis* sp., *Corixa substriata*, *Cryptochironomus defectus*, *Cybister cimbatus*, *Epophthalmia* sp., *Erpobdella octoculata*, *Gastrogomphus* sp., *Glossiphonia lata*, *Gomphinae* sp., *Ictinogomphus* sp., *Kirkaldyia deyrollei*, *Parabdella quadrioculata*, *Parachironomus arcuatus*, *Propsilocerus* sp., *Ranatra chinensis*, *Sinictinogomphus* sp., *Somatochlora* sp., *Tanytus formosanus* and *Whitmania laevis*), and omnivores (*Chironomus lugubris*, *C. riparius*, *C. salinarius*, *Leander modestus* and *Stictochironomus maculipennis*) at sites 4, 5, 6, 7, 10 and 14 was strongly associated with transparency and COD_{Mn}. Fu et al. (2016) found that many gathering-collectors are tolerant to disturbance and organic pollution, such as *Tubifex* spp., *Limnodrilus* spp., *Branchiura* sp., and *Chironomids*, which are abundant in polluted rivers. Niba and Sakwe (2018) suggested that benthic macroinvertebrate species populations differently respond to disturbance regimes, and many species have various habitat requirements at each stage of their developmental life cycle (Simaika and Samways, 2011).

The physicochemical factors, such as chlorophyll a, pH and temperature correlated with the composition of shredders (*Cricotopus anulator*, *C. trifasciatus*, *Phryganea* sp., *Polypedilum bubifer* and *P. nubeculosum*) which consume leaf litter or other CPOM, were ordinated on the negative part of CCA axis 1 (Fig. 4). Jonsson et al. (2001); Fu et al. (2016) noted that shredders are an important ecological guild in headwater streams, playing a vital role in the process of leaf litter decomposition. They facilitate the release of nutrients into stream ecosystems and provide other invertebrates with food sources in the form of coarse particulate organic matter (CPOM) and fine particulate organic matter (FPOM) (Li and Dudgeon, 2008, 2009; Yule and Gomez, 2009). Nutrient loads could influence macroinvertebrate community structure as a consequence of increased food availability where nutrients stimulate primary production (Gao et al., 2011; Wu et al., 2011; Zhang et al., 2014). Niba and Sakwe (2018) concluded that habitat patch level management along the aquatic ecosystem should aim at preserving sufficient indigenous vegetation categories (riparian, aquatic macrophytes and algae), especially during summer season when habitat requirements are optimal for most growth stages of benthic macroinvertebrate species. The results of Wang and Tan (2017) showed that macroinvertebrate assemblage variations were better explained by water quality factors than land use based on variance partitioning procedures.

Conclusion

During the three sampling seasons in the wetlands of Sanjiang plain, we recorded 57 taxa of benthic macroinvertebrates belonging to 6 FFGs, including predators, gathering-collectors, scrapers, filtering-collectors, omnivores and shredders. Insects were the most species-rich group, with 39 taxa and occurred at all sites during spring, summer and autumn. We found higher numbers of macroinvertebrate species and individuals in spring. The results of this study contributed the interesting information about benthic macroinvertebrates FFGs and their relationships with physicochemical parameters in the wetland ecosystems. It was found that predator and scraper FFGs may serve as potential candidates for assessing the health of wetlands. These findings might recommend a need for conservation and management to be targeted in the wetland environments. We

suggest that further research should be complemented on the composition and structure of macroinvertebrate fauna with an evaluation of density and biomass of FFGs to observe changes from a functional perspective and to obtain an overview on the wetlands of Sanjiang region.

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