Benthic Invertebrates Monitoring of the Muling River basin in Northeast China

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Research

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Abstract

Background: Muling River is the fifth-largest river in Heilongjiang Province, and it is also the main feeding river to the Ussuri River which is the boundary river of China and Russia in Heilongjiang Province northeast of China. Muling River basin located in the south of Sanjiang Plain. Macroinvertebrate samples were collected using a D-frame net and Shannon-Wiener index were calculated in terms of abundance.

Results: A total of 158 genera or species macroinvertebrate were collected from the 28 sampling sites and classified into six functional feeding groups including 61 gatherers/collectors, 42 predators, 22 scrapers, 14 shredders, 11 filterers/collectors and 8 omnivores. The correlation and relationship between environmental variables and macroinvertebrate functional feeding groups was explored using Pearson analysis and redundancy analysis. The analysis results displayed that macroinvertebrate functional feeding groups had strong relationships with the environmental variables in the Muling River basin.

Conclusions: All FFGs, total abundance and Shannon-Wiener index were not significantly different. Total abundance of macroinvertebrates was higher in summer and biodiversity index was higher in autumn. Environmental factors of natural gradients and nutrition indicator were not significantly different, while others were significantly different.

Backgroud

Muling River basin located in the south of Sanjiang Plain with an area of 18427 km^2, and it is the fifth-largest river in Heilongjiang Province northeast of China, which is the main feeding river to the Ussuri River the boundary river of China and Russia [1]. The approximately length of the Muling River is 834 km with annual water flows of 2.35 billion m^3. The river flows through five counties or cities of Muling, Jixi, Jidong, Mishan and Hulin from the south to the northeast of Heilongjiang Province [2]. Upstream of the river is characterized by temperate continental climate with a hot summer rainy and long cold winter. The annual average precipitation in the upstream is 530 mm and mainly occurs from July to September. In the midstream, the climate is temperate and semi-humid monsoonal with annual average temperature of 3.1 °C (-18 °C ~ 21 °C). The annual precipitation is 522 mm and the frost-free period is 149 days. At downstream area, the climate is characterized by temperate continental monsoonal. In recent years, with the aggravation of agricultural non-point source pollution, industrial discharge pollution and urban living pollution in Muling River Basin, the water quality of Muling River is deteriorating, which has had a negative impact on the local people's production and life.

Functions of river ecosystem research mostly carried out based on the traditional classification of species. However, recent studies have shown that ecosystem functions are mainly subject to the diversity of functional traits, i.e. the distribution of functional traits and the spatial-temporal pattern of abundance [3]. Functional traits are sensitive to environmental changes and play a key role in the study of the relationship between biodiversity and ecosystem functions. Functional diversity based on biological traits is closely related to ecosystem processes and is the key to understand ecosystem and community functions [4]. Macroinvertebrates are widely used to monitor the damage of aquatic ecosystem, and they are also an important part of aquatic food web, which is the basis of nutrient cycle and ecological balance of ecosystem [5]. There are so many damages to the aquatic ecosystem in the Muling River basin, and the importance of monitoring water quality in the Muling River basin through macroinvertebrates is self-evident. The species characteristics of functional groups are more closely related to the environment, which can more directly reflect the ecological process of the ecological environment affecting aquatic communities, and better understand the water ecosystem and its biodiversity [6, 7]. In the river ecosystem, the functional diversity of macroinvertebrates can better reflect the function of ecosystem than community structure. Many studies showing that substrate type and aquatic vascular plants which affecting the growth and functional group distribution of macroinvertebrate [8–10].

This study aimed to collect macroinvertebrate fauna, and explore the relationships between macroinvertebrate functional feeding groups and environmental variables in the wetland environments of Muling River basin.

Materials And Methods

Study area

Muling River is the fifth-largest river in Heilongjiang Province, and it is also the main feeding river to the Ussuri River which is the boundary river of China and Russia (Fig. 1). According to the inland waters fishery natural resources investigation [11], and principles to the requirement of sampling sites, in combination with natural form of Muling River basin, 28 sampling sites were selected (Fig. 1).

Remote Sensing Image Of Land-use

Digital elevation model (DEM) data and Landsat Thematic Mapper imagery were used to delineate catchment boundaries and map the land use composition in Muling River basin (Fig. 2). The original and detailed land-use classes were organized into the following groups by combining the similar land-use types into one broad category: (1) Khanka Lake, including Xiaoxingkai Lake and Daxingkai Lake which in Chinese side; (2) forests, including wooded regions and mixed forest regions; (3) wetlands, including riverine marsh, bogs, fens, meadows, pond and bayou; (4) cities, including counties, towns and villages; (5) grassland, including meadow and lea; (6) farmland, including dry farmland and paddy field.

Environmental Variables Data Sampling

Samples were collected 3 times from 28 sampling sites of Muling River basin in May, July and September periods in 2015. Water transparency (SD) and water depth (WD) were measured in the field using a Secchi disk and graduated portable staff gauge, respectively. Electric conductivity (EC), dissolved oxygen (DO), pH and water temperature (T) also measured in the field using a portable multi-probe (YSI 6600, YSI Inc., USA). We used the Chinese standard methods proposed by Ministry of Environmental Protection of People's Republic of China [12] to determine the concentration of total nitrogen (TN), total phosphorus (TP), N:P ratio (N:P), ammonium nitrogen (NH_4^+-N), nitrate nitrogen (NO_3^--N), chemical oxygen demand (COD_{Mn}).

Macroinvertebrates Data Sampling

Three random subsamples were collected at locations of 1 m^2 at each sampling site by using a D-frame net (30-cm diameter, 500-mm mesh). All macroinvertebrates samples were composited into a single sample, preserved in 75% ethanol and transported to the laboratory for identification. In the laboratory, all samples were sorted on white porcelain pans, identified, and counted with a light stereomicroscope. All individuals were identified to genus or species using appropriate identification guides [13, 14]. Taxa were divided into six functional feeding groups according to Cummins et al. (1974) and Duan et al. (2010): predators (PR), omnivores (OM), gatherers/collectors (GC), filterers/collectors (FC), scrapers (SC) and shredders (SH) [15, 16].

Statistical Analyses

Variation of environmental variables and abundance of functional groups in different sampling periods were analyzed using One-way ANOVA in SPSS 19.0 software. Before analysis, the data was $\log_{10}(x + 1)$ transformed to manage variance heterogeneity and ensure the data is normally distributed. In this study, the gradient length of the first ordination axis was 0.404 in the detrended correspondence analysis (DCA). Therefore, redundancy analysis (RDA) with Monte Carlo simulations (499 permutations) ordination based on unimodal method was selected to analyze the relation by using CANOCO for Windows 4.5 software (Microcomputer Power, New York, USA). Pearson correlation analysis was carried out to confirm the significant relationships between environmental variables and the abundance of functional feeding group. Cluster and NMDS analyses were conducted using the PRIMER 7 software package [17].

Diversity of macroinvertebrate FFGs was represented by Shannon-Wiener index [18] as follows:

$$H' = -\sum_{i=1}^{s} P_i \log_2 P_i$$

Where, S is the number of FFGs within the given sample; and P_i is the percentage of FFGs i in the total number of individuals.

Results

Environmental variables

Among all sampling sties, natural gradients (e.g., dissolved oxygen and temperature) and nutrient indicators (e.g., total phosphorus, N:P ratio, ammonium nitrogen and nitrate nitrogen) were not significantly different ($p > 0.05$), but water transparency, water depth, electric conductivity, total nitrogen and chemical oxygen demand were significantly different ($p < 0.01$) (Table 1).

Table 1
One-Way ANOVA of environmental variables and macroinvertebrate FFGs abundance. Data are average values (with SE).

	2015May	**2015Jul.**	**2015Sep.**	***F***	***p*-value**
Environmental variables					
SD (m)	0.35(0.05)	0.32(0.07)	0.48(0.07)	10.418	0.000**
WD (m)	2.72(0.76)	3.13(1.04)	3.02(1.04)	75.232	0.000**
EC (ms/cm)	0.15(0.01)	0.15(0.01)	0.21(0.02)	2.472	0.002**
DO (mg/L)	7.45(0.29)	8.73(0.29)	7.49(0.56)	1.676	0.052
pH	7.42(0.12)	7.03(0.26)	7.99(0.06)	1.903	0.021*
T (℃)	14.81(0.47)	22.26(0.55)	6.89(0.43)	0.215	0.862
TN (mg/L)	1.73(0.14)	1.99(0.21)	1.62(0.16)	2.662	0.001**
TP (mg/L)	0.6(0.05)	0.69(0.04)	0.36(0.03)	0.456	0.986
N:P	3.86(0.56)	3.13(0.35)	6.56(1.6)	0.727	0.815
NH_4^+-N (mg/L)	0.22(0.02)	0.35(0.04)	0.13(0.01)	0.704	0.839
NO_3^--N (mg/L)	0.58(0.07)	1.52(0.5)	0.28(0.03)	1.143	0.329
COD_{Mn} (mg/L)	3.8(0.13)	3.98(0.1)	4.06(0.12)	3.410	0.000**
FFGs abundance					
PR (ind./m^2)	25.75(3.47)	46.75(2.68)	24.54(2.6)	0.614	0.916
OM (ind./m^2)	12.14(3.03)	5.68(0.85)	5.82(1.1)	0.701	0.842
GC (ind./m^2)	60.14(5.94)	114.54(6.51)	36.46(2.92)	0.351	0.998
FC (ind./m^2)	10.93(2.6)	11.86(2.02)	6.5(1.22)	1.615	0.065
SC (ind./m^2)	38.93(12.36)	30.46(4.67)	17.75(2.22)	2.335	0.004**
SH (ind./m^2)	6.68(1.66)	16.5(2.11)	11.54(2.62)	0.754	0.787
Total (ind./m^2)	154.57(14.29)	225.79(8.52)	102.61(6.2)	0.535	0.946
Shannon-Wiener (*H'*)	1.69(0.06)	1.85(0.04)	2.03(0.04)	0.566	0.961
*$P < 0.05$,					
**$P < 0.01$.					

Macroinvertebrate Functional Feeding Groups

During the sampling periods, a total of 13523 macroinvertebrate individuals belonging to 46 family 158 genera or species were identified from the study area, consisting of 61 gatherers/collectors, 42 predators, 22 scrapers, 14 shredders, 11 filterers/collectors and 8 omnivores (Appendix A). All FFGs, total abundance and Shannon-Wiener index were not significantly different ($p > 0.05$), while SC group was significantly different ($p < 0.01$) (Table 1, Fig. 3). Highest abundance of total macroinvertebrate was observed in summer, while the maximum value of Shannon-Wiener index presented in autumn (Fig. 4).

Correlation Analysis

Correlation analysis indicated that temperature was associated with all FFGs abundance ($p < 0.01$ or $p < 0.05$). By contrast, SD was negative significantly correlated with group FC ($p < 0.05$) and SH ($p < 0.05$) and DO displayed negative correlations with group PR ($p < 0.05$) and SH ($p < 0.01$). The pH value negatively correlated with group GC ($p < 0.01$) and SC ($p < 0.01$). However, WD, TN, TP and NH_4^+-N were only positive significantly correlated with one group, such as PR ($p < 0.05$), SH ($p < 0.01$) and GC ($p < 0.01$), respectively. While N:P ratio was negative significantly correlated with group GC ($p < 0.05$). COD_{Mn} positively correlated with group PR ($p < 0.01$) and SH ($p < 0.01$) and negatively correlated with group SC ($p < 0.05$).

On the other hand, environmental variables of WD, DO and N:P positively correlated with biodiversity index (*H'*) of PR, SH and GC groups, respectively. TP was both negatively correlated with group GC and SC biodiversity index. CODMn was positively correlated with group PR biodiversity index, while negatively correlated with group OM (Table 2).

Table 2
Correlation (Pearson) analysis between functional feeding groups abundance (ind./m^2), Shannon-Wiener index (*H'*) and environmental variables. Some variables without any significant correlation were not shown.

	Abundance						***H'***				
	PR	OM	GC	FC	SC	SH	PR	OM	GC	SC	SH
SD				-0.162*		-0.153*					
WD	0.153*						0.220*				
DO	-0.162*					-0.223**					0.260*
pH			-0.343**		-0.218**						
T	0.477**	0.255**	0.562**	0.303**	0.211**	0.319**					
TN						0.333**					
TP			0.271**						-0.224*	-0.230*	
N:P			-0.155*						0.228*		
NH_4^+-N					0.214**						
COD_{Mn}	0.242**				-0.202**	0.280**	0.274*	-0.218*			
**P* < 0.05,											
***P* < 0.01.											

Rda Analysis

Redundancy analysis (RDA) revealed clear clusters of sampling sites by macroinvertebrate abundance and environmental variables (Fig. 5), with several outliers (S2, S25 and S28). The results of Monte Carlo test revealed that the first canonical axis and all canonical axes were significantly different (F = 13.781, p = 0.002; F = 2.247, p = 0.004, respectively), indicating associations between macroinvertebrate FFGs and environmental variables existed. The first two axes of FFGs correlations to environmental variables were 0.91 and 0.761, which combined explained 87.4% of FFGs-environment relationship. In RDA biplot, TN and N:P had high inflation factors. Group SC and OM mainly impacted by T and NH_4^+-N at S26 and S27, and group GC and PR positively correlated with EC, WD and SD at S3, S4, S5, S20 and S24. Meanwhile, group SH has a positive correlation with TN, N:P and NO_3^--N at S6, S15, S21, S22 and S23. We also found that pH, DO and COD_{Mn} were the main factors at S7 ~ S14, S16, S17 and S19.

Discussion

Functional groups can respond to changes in living environment and have a certain impact on ecosystem functions [19]. The difference of abundance is the result of habitat filtering, that is, the rank character with higher abundance can be considered as the character with better adaptability to regional environment [20]. Ecosystem function is essentially dependent on the functional group of the species, and which has become a powerful and reliable method to study the dynamic change of community by functional characters [21–23]. The large difference in spatial pattern of functional groups is the response to environmental changes and the tradeoff between different functions

Globally, changes in land use, especially loss of riparian forests, can lead to a reduction or change in the structure, function and diversity of macroinvertebrates in some river basin [24–26]. Once the riparian zone lacks the shelter of riverside forest, the sun will direct to the water surface and cause the water temperature to rise. Because the water temperature is close to the heat-resistant limit in tropical areas, some species of macroinvertebrates adapted to cold water cannot survive [27, 28]. Moreover, the decrease of leaf litter is the main food source of shredders, which will block the growth and development of group SH and make the aquatic ecosystem unbalanced, and ultimately affect the structure and function of the ecosystem [7]. Serious soil erosion in Muling River Basin, soil and water loss in riparian zones causes large amounts of sediment to enter rivers. The surface of river sediment is covered by muddy soil, which affects the growth of algae [4, 29]. At the same time, these sediments will also adhere to the surface of the body, trachea, and gill of the benthic animals, which leading to the disappearance of macroinvertebrates [30].

In this study, we demonstrated the impacts of environmental variables on benthic macroinvertebrates feeding functional groups. No significant differences in the FFGs were observed along season gradient, except group SC (Table 1). Mollusk (group SC) dominated at sampling sites of S25 ~ S28 in the downstream of river, which close to floodplain wetlands along Ussuri River. Guan et al. (2017) sampled macroinvertebrate assemblages along Wusuli River (upstream, midstream, and downstream), and agreed with the emerging theory suggesting that aquatic invertebrate assemblages in floodplain wetlands should change longitudinally along a river's length and be affected by lateral connectivity of floodplain habitats with main river channels [31]. Wu et al. (2017) found that snails could be possess several attributes that should make them useful as potential environmental indicators in Sanjiang Plain, and the certain snail species may provide a robust and rapid indicator of environmental impacts in freshwater in Heilongjiang Province of China [32]. Next year, Guan et al. (2018) also confirmed that the snails (Mollusca: Gastropoda) can rapid assessments of wetland condition using aquatic invertebrates simple effective in northeastern China [33].

Macroinvertebrate community structure is usually determined by the physical structure and complexity of the habitat [34]. Aquatic vascular plants plays an important role in structuring macroinvertebrate species and selecting species related to functional groups dynamics and feeding habits [35, 36]. The distribution of macroinvertebrate is also determined by vegetation type, especially the structure and growth form of aquatic vascular plants [34]. Aquatic vascular plants affect the underwater climate and chemical properties by absorbing and releasing chemical substances (such as nutrients and antagonistic substances) [37]. However, as the growth of aquatic vascular plants in northern China is mainly affected by seasonal temperature changes, dominant communities can only be formed in summer and autumn [7].

In spring, the farmland near the Muling River basin contains a lot of nutrients (nitrogen and phosphorus) in the sediment of pesticide and chemical fertilizers. Chen et al. (2019) studies have shown that nitrogen can enter the water body through fish secretion and excretion [38]. Nitrogen-containing nutrients in the water body are absorbed by algae growth and carried down together through surface runoff to provide sufficient nutrients for the growth of plankton. Meanwhile, greatly increased the number of plankton which as the source of food for macroinvertebrates, such as group SH positively correlated with TN (Table 2).

Moreover, iron, as an element affecting chlorophyll synthesis in plants, is also a trace element needed for phytoplankton growth [39]. Trace element copper is an indispensable metal element for the metabolism of microelements and plants in cell membranes, which can affect the growth of plankton [40]. We guessing that heavy metal ion may contribute to primary productivity and indirectly affects secondary productivity by food chains in the aquatic ecosystems. Besides, hydrology is considered the paramount environmental control of freshwater wetlands, with temporary drying being a major constraint on aquatic insects [31–33, 41]. The movement group [7] of macroinvertebrates could be considered as a new method for monitoring and evaluating water quality in Muling River basin for further studies in the future.

Conclusions

During the three times sampling in Muling River basin, we collected 13523 macroinvertebrate individuals belonging to 46 family 158 genera or species were identified from the study area, consisting of 61 gatherers/collectors, 42 predators, 22 scrapers, 14 shredders, 11 filterers/collectors and 8 omnivores. All FFGs, total abundance and Shannon-Wiener index were not significantly different. Total abundance of macroinvertebrates was higher in summer and biodiversity index was higher in autumn. Environmental factors of natural gradients and nutrition indicator were not significantly different, while others were significantly different. We found that temperature was associated with all FFGs abundance and nutrients were the main influence factors in Muling River basin.

Declarations

Acknowledgements

Not applicable

Authors' contributions

Sun X and Yu HX conceived and designed the study. Sun X performed the sampling and analyzed the data. Sun X wrote the manuscript, and Yu HX edited the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

All data generated or analyzed during this study are included in this published article and its additional files.

Ethics approval and consent to participate

Animal procedures and protocols complied with guidelines and had the approval of the Animal Ethics Committee of the Northeast Forestry University.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests

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Figures

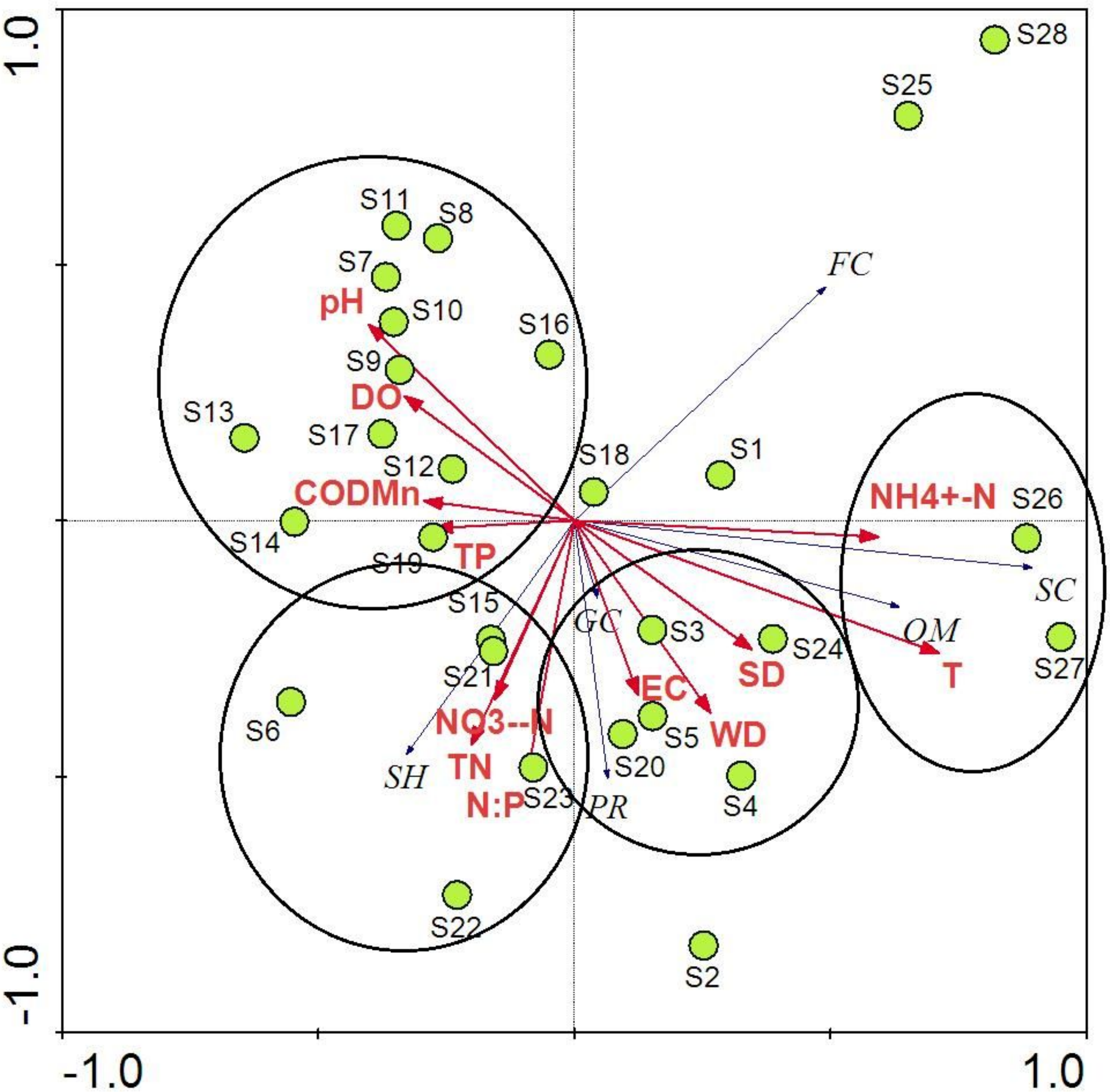

Figure 1

RDA biplot of FFGs abundance and environmental variables with sampling sites in Muling River basin.

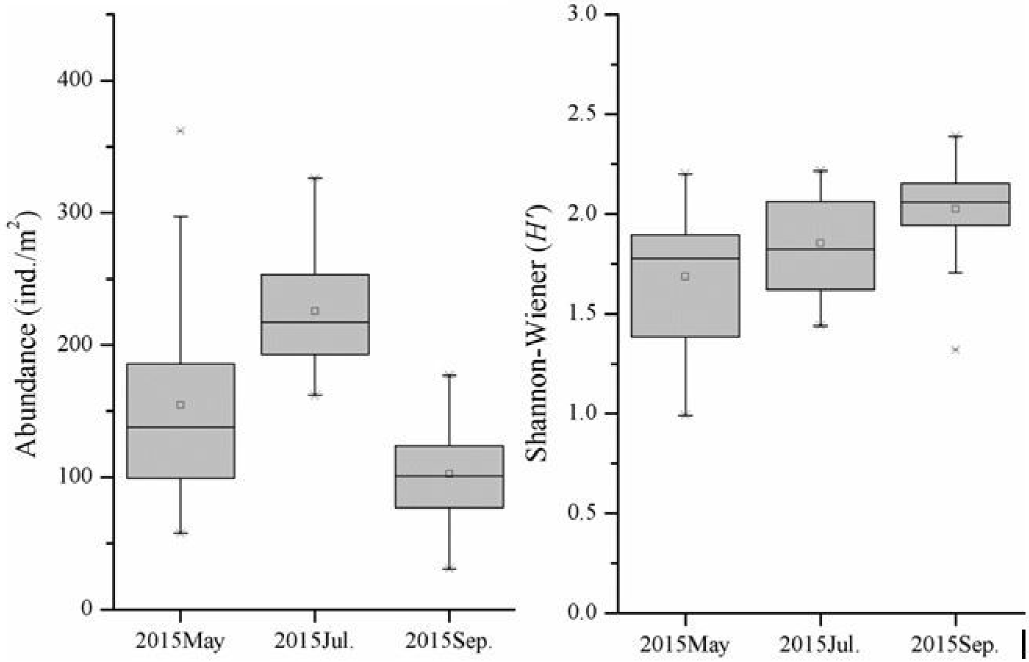

Figure 2

Boxplots of macroinvertebrate abundance and Shannon-Wiener index among seasons.

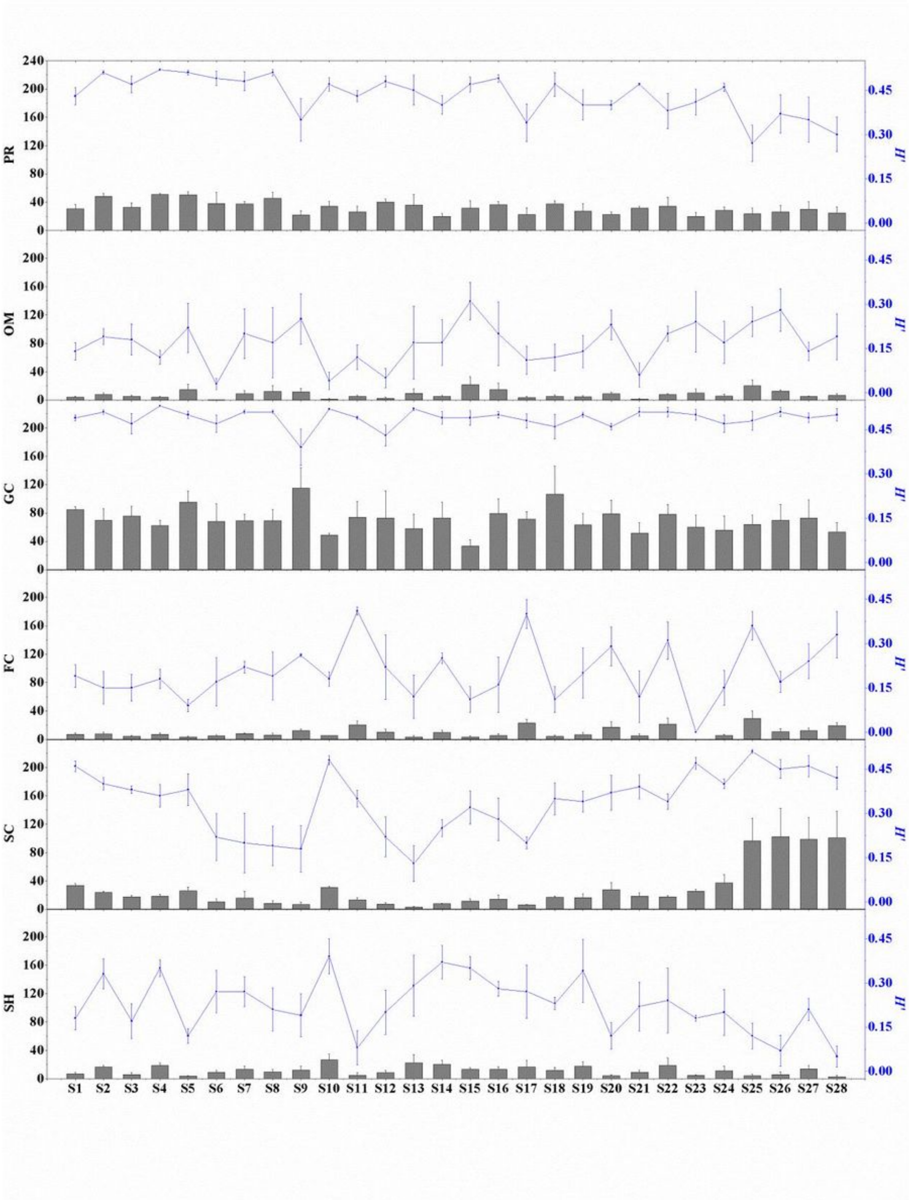

Figure 3

FFGs abundance (ind./m2) among sampling sites

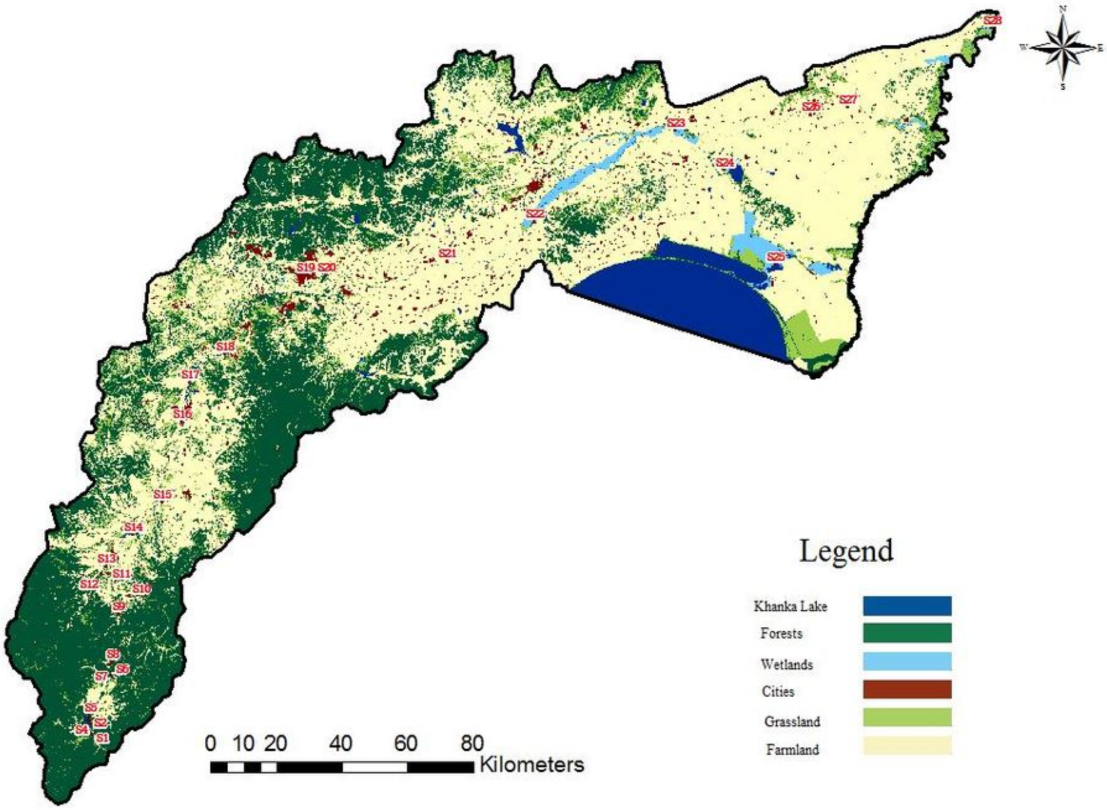

Figure 4

Remote sensing image of land-use of Muling River basin. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

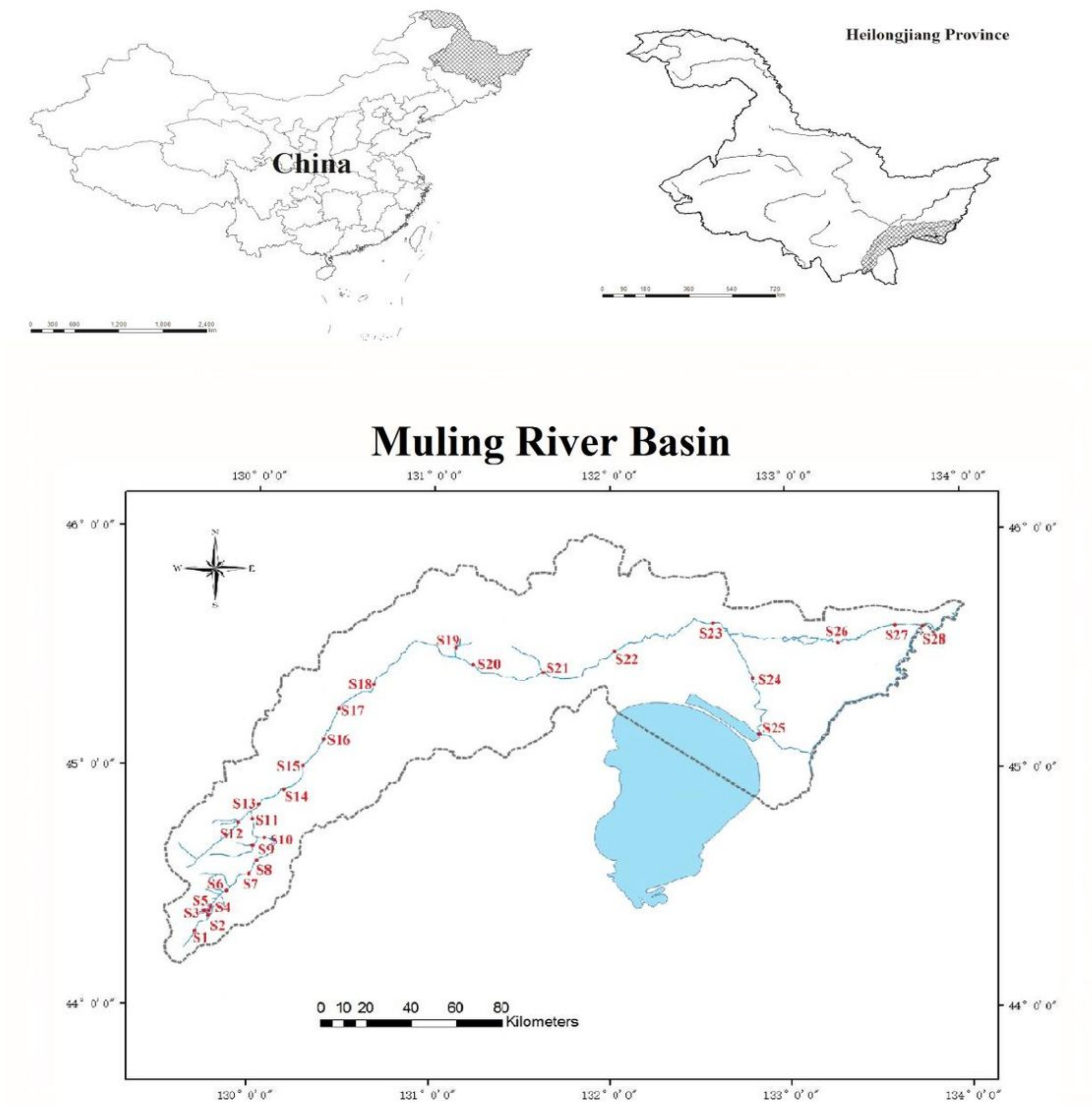

Figure 5

Location of 28 sampling sites in Muling River basin. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Supplementary Files

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- Appendix.docx
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