WATER ECOLOGICAL HEALTH ASSESSMENT OF THE MULING RIVER BASIN BASED ON ANALYTIC HIERARCHY PROCESS IN NORTHEAST CHINA

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Abstract. In order to explore the water ecological health of the Muling River, the largest tributary of Wusuli River in northeast China. The environmental factors and aquatic organisms of the Muling River were investigated in different seasons. During the investigation, 83 species and 17 functional groups of phytoplankton, and 36 species and seven functional groups of zooplankton, and 158 genera/species and six functional feending groups of macroinvertebrates, and 46 species and seven fish functional groups were found. The evaluation system of water ecological health in the Muling River Basin, including 27 indexes, was established by analytic hierarchy process by calculating, which values in each season were 0.4177, 0.4428, 0.5071, 0.4699, 0.4799 and 0.6434, respectively. The seasonal changes of water ecological health classification rise from level III to level II, and the health status rises from the general level to the sub-health level. The overall trend is rising, the average value is 0.4935, the health classification is level III, and the health status is general. Generally speaking, the water ecological health level of the Muling River Basin is the highest in autumn.

Keywords: *freshwater, wetland, aquatic life, functional groups, hydroecology*

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Introduction

Globally, most aquatic ecosystems including lakes, rivers, reservoirs, freshwater and marine wetlands have changed due to human disturbance caused by land use activities centered on human settlements, agriculture and industrial activities (Tockner et al., 2010). Phytoplankton are one of the most important primary producers, forming an important source of energy in the first trophic layer (Shen, 2014). They are also food for many aquatic animals, they also play an important role in the material cycle of aquatic ecosystems by controlling growth, reproductive capacity and population characteristics of aquatic organisms (Michele and Mark, 2006). Changes in physical and chemical factors of aquatic systems can directly affect the structure of aquatic communities (Ptacnik et al., 2008). Therefore, scientists use the composition of aquatic communities to study and understand aquatic ecosystems (Becker et al., 2009). Monitoring the composition of aquatic organisms to comprehensively evaluate the local water environment, the community structure of organisms in different water quality has obvious characteristics (Sukatar et al., 2020), and preliminary evaluation of the nutritional status of water bodies can be carried out in actual water quality monitoring (Li et al., 2021). The community structure and composition of aquatic organisms will directly affect the structure and function of aquatic ecology (Lu et al., 2019). At the same time, when the nutritional status of water changes, first it will be reflected in the changes in individual aquatic organisms, populations, communities, and productivity. The growth of aquatic organisms is affected by a variety of factors, such as predation, competition, and parasitism among organisms, and environmental factors such as water velocity, nutrients, temperature, and light (Nash et al., 2021). The changes of each of the above factors will cause certain changes in the structural state of individuals, populations and communities (Ren et al., 2021).

River ecosystems are one of the basic types of freshwater ecosystems, and can serve as a bridge connecting the two major ecosystems of the ocean and the land. Especially in the energy flow and substance cycles of the biosphere, which is vividly called the blood circulation of the Earth, has the characteristics of fluidity (Allan and Castillo, 2007). The river is vital to human development. It provides water and a range of services such as transportation, entertainment, and commerce. The river ecosystem is also an important channel for the material circulation of the global biosphere, which can transform and digest various nutrients and pollutants (Jungwirth et al., 2000). Therefore, it is necessary to monitor the phytoplankton functional group in the river. Most of the researches on the functions of river ecosystems are carried out on the basis of traditional species classification. However, recent studies have shown that ecosystem functions mainly depend on the diversity of functional traits, that is, the spatial and temporal patterns of the distribution and abundance of functional traits (Elliott and Quintino, 2010; Li et al., 2015). 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 characteristics is closely related to ecosystem processes and is the key to understanding ecosystem and community functions (Han, 2021). Macroinvertebrates are widely used to monitor the destruction of aquatic ecosystems (Lu et al., 2020). They are also an important part of the aquatic food web and are the basis for the nutrient cycle and ecological balance of the ecosystem (Mangadze et al., 2016). The species characteristics of functional groups are more closely related to the environment, can directly reflect the ecological process of the ecological environment on the aquatic community, and better understand the aquatic ecosystem and its biodiversity (Lu et al., 2021). Fish provide a powerful tool for assessing the aquatic environment (Chowdhury et al., 2011). The sensitivity of fish to most forms of human disturbance, their utility at all levels of biological tissue, and the favorable cost-benefit ratio of fish evaluation schemes (Wetzel, 2011). Fish can be used as indicators in a wide range of time and space, because they cover all nutritional levels of consumer ecology, and fish can effectively integrate all ecological processes in waterways. Fish play many different roles in assessing river health and monitoring the response to remedial management (Beaugrand et al., 2000). Plankton exists in almost all kinds of water bodies. Compared with other aquatic animals, they are numerous and have strong metabolic activity. Zooplankton feed on phytoplankton, bacteria, debris and other organisms. Zooplankton also participates in the decomposition and circulation of organic matter in the aquatic ecosystem through excretion and secretion, energy transfer from primary producers to advanced consumers (David et al., 2005). Changes in zooplankton can affect the structure of other nutrient levels in aquatic ecosystems (Lobry et al., 2008). The structure, abundance and biomass of zooplankton communities are affected by the upward and downward effects, and are one of the determinants of water quality, which is due to the interaction between biological organisms and environmental factors (Ejsmont-Karabin and Karabin, 2013).

Muling River Basin is located in the agricultural wetland ecological zone of the Sanjiang Plain in Heilongjiang Province, surrounded by cultivated land. Muling River has experienced long-term sand dredging activities, and the river bed has been seriously damaged. In addition, due to the continuous increase in agricultural non-point source pollution, industrial discharge pollution and urban life pollution in recent years, the water quality of Muling River has deteriorating, which has adversely affected the production and life of local people. This study objective is by investigating the aquatic organisms and environmental factors of the Muling River, it is very important to find out the environmental factors that affect the water quality of the Muling River Basin, which has important practical significance for the evaluation of the water ecological health of the Muling River Basin.

Materials and methods

Study area

Muling River (44°01′~45°58′ N, 130°11′~133°40′ E) is the largest tributary on the left bank of the Ussuri River, the border river between China and Russia. The length of the river is 834 km and the drainage area is 18427 km^2. The upper reaches have a temperate continental climate, with hot and rainy summers and long and cold winters. The upstream average annual precipitation is 530 mm, mainly in July to September. The midstream has a temperate semi-humid monsoon climate with an average annual temperature of 3.1℃ (-18℃~21℃). The annual water flow is 2.35 billion m^3, the annual precipitation is 522 mm, and the frost-free period is 149 days. The lower reaches have a temperate continental monsoon climate. Precipitation in the valley plains of the middle and lower reaches of the Muling River Basin is the main source of supplementary water, followed by surface water and paddy field infiltration. The flood lasts about 3~7 days, generally 15~30 days on the main stream, the sunshine duration is 2400~2800 h, and the annual evaporation is about 1100~1300 mm.

Field sampling

According to the local climate characteristics and ecological environment characteristics of the Muling River Basin, six sampling surveys were carried out in May (spring), July (summer) and September (autumn) in 2015 and 2017, and a total of 28 water plants were set up in the whole basin. Sampling points for biological and environmental factors, with 3 replicates for each sampling site (*Fig. 1*, *Table 1*).

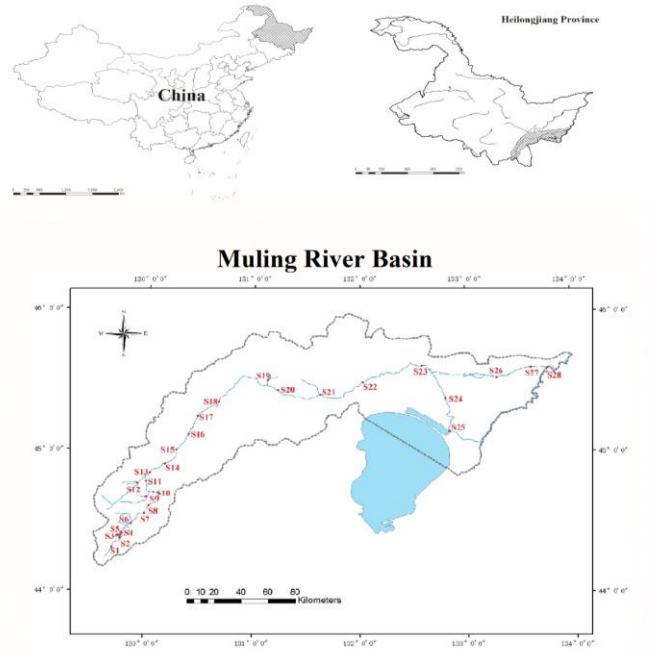

Figure 1. *Location of sampling sites in Muling River basin*

Table 1. *The sampling stations and coordinates in Muling River basin*

Sampling sites	Coordination	Altitude(m)	Sampling sites	Coordination	Altitude(m)
S1	44°01′48″N, 130°11′24″E	508	S15	44°40′12″N, 130°26′24″E	292
S2	44°03′36″N, 130°10′48″E	495	S16	44°53′24″N, 130°30′36″E	273
S3	44°03′00″N, 130°09′36″E	504	S17	45°00′00″N, 130°32′24″E	232
S4	44°04′12″N, 130°10′48″E	506	S18	45°04′48″N, 130°40′12″E	229
S5	44°04′48″N, 130°10′48″E	499	S19	45°18′00″N, 131°00′36″E	191
S6	44°11′24″N, 130°15′36″E	454	S20	45°18′00″N, 131°03′36″E	181
S7	44°13′12″N, 130°15′00″E	435	S21	45°20′24″N, 131°31′48″E	150
S8	44°13′48″N, 130°15′36″E	419	S22	45°27′00″N, 131°52′12″E	115
S9	44°21′36″N, 130°16′48″E	386	S23	45°42′00″N, 132°25′12″E	75
S10	44°24′36″N, 130°19′12″E	358	S24	45°35′24″N, 132°36′36″E	76
S11	44°28′12″N, 130°14′24″E	338	S25	45°19′48″N, 132°48′36″E	76
S12	44°28′12″N, 130°12′36″E	324	S26	45°44′24″N, 132°57′00″E	78
S13	44°29′24″N, 130°13′48″E	312	S27	45°45′36″N, 133°06′00″E	49
S14	44°34′48″N, 130°19′48″E	298	S28	45°58′12″N, 133°40′12″E	67

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Phytoplankton was collected with a 5 L plexiglass water harvester and 25# plankton net (mesh 0.064 mm), 1 L water sample was collected at each sampling point, 10~15 ml Luger reagent was added and shaken, and brought back to the laboratory for static Set aside for 1~2 d, draw the supernatant and concentrate to 30 ml. Zooplankton was collected with a 5 L plexiglass water collector to collect 20 L water samples, filter them through 25# plankton net (mesh 0.064 mm), and add 75% alcohol and 5% formaldehyde solution for storage. Macroinvertebrates were collected with a Peterson mud harvester (open area 1/16 m^2) and a D-net. The collected mud samples are filtered through a sample sieve and placed in a white porcelain dish. The specimens are selected and placed with a straw and tweezers. 75% alcohol solution preservation. Fish were collected with 40 m gill net (mesh 3~7 cm) and electric fish device (2000W, 650V), and relevant fish biological indicators were measured (eg. species classification and identification, abundance, and biomass, etc). Unidentified specimens were stored in 75% alcohol and brought back to the laboratory for further identification.

Environmental factors analysis

The environmental factors are measured in situ: transparency (SD, m), water depth (WD, m), electrical conductivity (EC, mS/cm), dissolved oxygen (DO, mg/L), pH value (pH), water temperature (T, °C), turbidity (NTU), oxidation-reduction potential (ORP, mv), and flow velocity (FV, m/s).

In the lab, total nitrogen (TN, mg/L), total phosphorus (TP, mg/L), ammonia nitrogen (NH_4^+-N, mg/L), nitrate nitrogen (NO_3^--N, mg/L), chemical oxygen demand (COD_{Mn}, mg/L), five day biochemical oxygen demand (BOD_5, mg/L) were measured by HACH laboratory/portable water quality analyzer, which according to the requirements of monitoring methods for water and wastewater (Fourth Edition) (Wei, 2002).

Aquatic organisms and functional groups classification

Phytoplankton species and functional groups (FGs) identifications refer to Hu and Wei (2006), and *Table 2*.

Table 2. *Phytoplankton functional groups of Muling River Basin*

FGs	Habitat characteristics
C	Eutrophic medium and small water bodies
D	Shallow and turbid water
F	Meso eutrophic lake, clean and mixed water body
H1	Eutrophic stratified water body, shallow water and low nitrogen content
J	High nutrient mixed shallow water body
L0	Deep water or shallow water, poor eutrophic, medium large water body
M	Diurnal mixed layer of small eutrophic lakes
MP	Disturbed turbid shallow water body
N	Continuous or semi continuous mesotrophic mixed water body
P	Continuous or semi continuous medium eutrophic mixed water body
S1	Turbid mixed water with low transparency
W1	Shallow water body polluted by organic pollutants
W2	Mesotrophic shallow water body
X1	Super eutrophic shallow water body with high mixing degree
X2	Medium eutrophic shallow water body with high mixing degree
X3	The mixing layer is a shallow water body with high degree of mixing and poor nutrition
Y	Still water body (wide adaptability)

Zooplankton species and functional groups identifications refer to Shen (1999), Wang (1961), Chiang and Du (1979), Shen et al. (1979) and *Table 3*.

Table 3. *Zooplankton functional groups of Muling River Basin*

FGs	Body size	Feeding habits
Protozoas filter feeders (PF)	<300μm	Filter feeders feed on bacteria, algae and organic matter
Rotifers filter feeders (RF)	<300μm	Filter feeders feed on bacteria, algae and organic matter
Small copepods and claocera filter feeders (SCF)	<0.7mm	Filter feeders feed on bacteria, algae, organic matter and protozoa
Middle copepods and claocera filter feeders (MCF)	0.7~1.5mm	Filter feeders feed on bacteria, algae, organic matter and protozoa
Middle copepods and claocera carnivora (MCC)	0.7~1.5mm	Predators feed on rotifers, cladocerans, Diptera insects (chironomid larvae) and oligochaetes
Large copepods filter feeders (LCF)	>1.5mm	Filter feeders feed on bacteria, algae, organic matter and protozoa
Large copepods carnivora (LCC)	>1.5mm	Predators feed on rotifers, cladocerans, Diptera insects (chironomid larvae) and oligochaetes

Macroinvertebrates species and functional groups identifications refer to Cummins (1973), Morse et al. (1984) and *Table 4*.

Table 4. *Macroinvertebrates functional groups of Muling River Basin*

FGs	Feeding habits
Predators (PR)	Direct swallowing or stabbing of prey
Omnicorous (OM)	Relying on the skin or gills to directly absorb the organic matter dissolved in water, it can also eat plant rotten leaves, small bivalves and crustaceans
Gather collectors (GC)	It mainly feeds on various organic particles at the bottom of the river
Filter collectors (FC)	Feed on fine organic particles (0.45mm < particle size < 1mm) in the water flow
Scrapers (SC)	It mainly feeds on various fixed living biological groups
Shredders (SH)	It mainly feeds on all kinds of falling objects and coarse organic particles (1mm ≤ particle size)

Fish species and functional groups identifications refer to Zhang and He (1993), Zhang (1995), Chen (1998), Zhu (1995) and *Table 5*.

Table 5. *Fish functional groups of Muling River Basin*

FGs	Catchments
Aquatic plant feeding habits (herbivores, HE)	*Ctenopharyngodon idellus, Phoxinus phoxinus, Phoxinus lagowskii*
Aquatic insect feeding habits (insectivores, IN)	*Phoxinus percnurus, Lefua costata, Misgurnus bipartitus*
Phytoplankton feeding habits (phytoplanktivores, PH)	*Phoxinus czekanowskii, Rostrogobio amurensisi, Hypophthalmichthys molitrix*
Zooplankton feeding habits (zooplanktivores, ZO)	*Aristichthys nobilis*
Benthic feeding habits (benthivores, BE)	*Hemiculter leucisclus, Pseudorasbora parva, Abbottina rivularis, Saurogobio dabryi, Cobitis lutheri, Cobitis granoci, Misgurnus mohoity*
Omnivorous (omnivores, OM)	*Cyprinus carpio, Carassius auratus gibelio*
Carnivorous (piscivores, PI)	*Silurus asotus, Perccottus glehni, Lampetra reissneri*

Data analysis

Normalization of evaluation system indicators: in order to unify the indicators of different orders of magnitude, dimensionless standardization is carried out on the original data:

$$X_{ij'} = \frac{X_{ij} - X_{min}}{X_{max} - X_{min}} \quad \text{(Eq.1)}$$

$$X_{ij} = 1/X' \quad \text{(Eq.2)}$$

where, $X_{ij'}$ is the standard data after normalization, X_{ij} is the actual value of the forward indicator, X' is the actual value of the reverse indicator, X_{max} is the actual maximum value, and X_{min} is the actual minimum value.

Analytic Hierarchy Process (AHP) is a systematic and hierarchical multi-objective decision ranking method combining qualitative and quantitative methods proposed by A. L. Saaty, Professor of operations research at the University of Pittsburgh in the 1970s (Cao, 2012). Its basic principle is to form a hierarchical structure of multiple objectives of a system according to the dominant relationship, group each level according to the dominant relationship, and determine the relative importance and quantitative ranking through the pairwise comparison of various factors. The model judgment matrix quantifies the importance by using the 1 ~ 9 proportional scale method proposed by Professor A. L. Saaty (Wang et al., 2005) (*Table 6*).

Table 6. *Judgment matrix scale and its meaning*

No.	Comparison of importance of indicators *i* and *j*	C_{ij} quantitative values
1	*i and j are equally important*	1
2	*i index is slightly more important than the j index*	3
3	*i index is significantly more important than j index*	5
4	*i index is more important than j index*	7
5	*i index is extremely important than the j index*	9
6	*i index is slightly less important than the j index*	1/3
7	*i index is significantly less important than the j index*	1/5
8	*i index is not strongly less important j index*	1/7
9	*i index is less important than the j index*	1/9

Note: C_{ij} = {2,4,6,8,1/2,1/4,1/6,1 /8} indicates the importance comparison of indicators I and j, between C_{ij} = {1,3,5,7,9,1/3,1/5,1 /7, and 1/9}

Water ecological health composite index (WEHCI) (Zuo et al., 2015):

$$WEHCI = \sum_{i=1}^{n} (W_i \times I_i) \quad \text{(Eq.3)}$$

where, W_i is the weight of the evaluation index, I_i is the normalized value of the evaluation index, and the water ecological health classification and health status are shown in *Table 7*.

Table 7. *Classification of water ecological health*

WEHCI	**0~0.2**	**0.2~0.4**	**0.4~0.6**	**0.6~0.8**	**0.8~1.0**
Health classification	V	IV	III	II	I
Health status	Sick	Sub-sick	General	Sub-health	Health

Results

Characteristics of aquatic life community structure

During the investigation, 83 species and variants of 43 genera and 7 phyla of phytoplankton were identified, with biomass ranging from 0.03 to 23.21 mg/L. According to the research of Padisák et al. (2009), 17 functional groups (C, D, F, H1, J, L0, M, MP, N, P, S1, W1, W2, X1, X2, X3, Y) were found, and seasonal succession is M+P→F+MP+P→MP+P→M→M+Y→M+MP+P *(Fig. 2a)*.

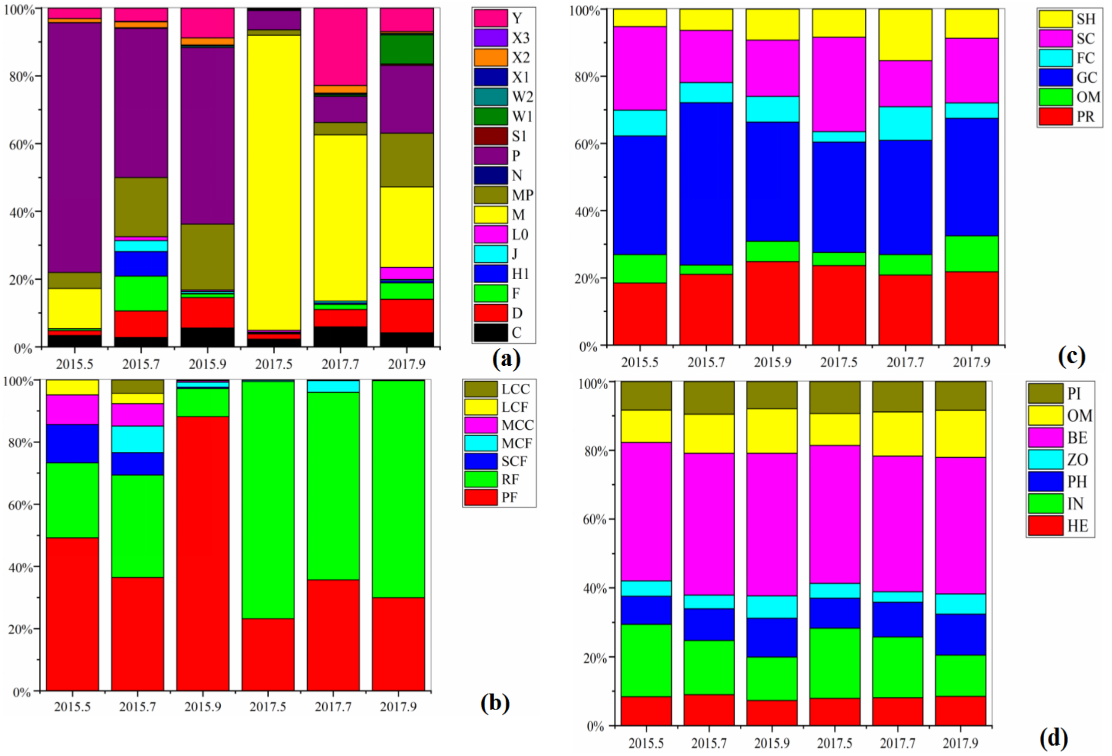

Figure 2. *Relative biomass or relative abundance of aquatic functional groups in different seasons in Muling River Basin*

There are 4 types of zooplankton, 27 genera and 36 species, with biomass ranging from 0.01 to 16.68 mg/L. According to the research of An et al. (2017), 7 functional groups (PF, RF, SCF, MCF, MCC, LCF, LCC) are divided into 7 functional groups (PF, RF, SCF, MCF, MCC, LCF, LCC, of which copepod nauplii is not divided into functional groups), and the seasonal succession is PF +RF+SCF→PF+RF→P→PF+RF→PF+RF→PF+RF *(Fig. 2b)*.

Macroinvertebrates fauna, 4 phyla, 13 orders, 46 families, 158 genera/species, with abundance ranging from 9.23 to 353.3 ind./m^2. According to the research of Cummins

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et al. (1973), 6 functional groups (PR, OM, GC, FC, SC, SH) are divided, and the seasonal succession is GC+SC→PR+GC→PR+GC→PR+GC+SC →PR+GC→PR+GC *(Fig. 2c)*.

There are 46 species of fishes in 5 orders, 12 families, and their biomass ranges from 8.22 to 770.36 g/m^3. According to the research of Ding and Liu (2011), 7 functional groups (HE, IN, PH, ZO, BE, OM, PI) are divided, and the seasonal succession is IN+BE→IN+BE+OM→IN+PH +BE+OM→IN+BE→IN+PH+BE+OM→IN+PH+BE+OM *(Fig. 2d)*.

Characteristics of environmental factors

The time distribution characteristics of environmental factors in the Muling River Basin are shown in *Table 8*.

Table 8. *Environmental factors values of Muling River Basin (Mean±SE)*

	2015.5	2015.7	2015.9	2017.5	2017.7	2017.9
SD	0.35±0.05	0.32±0.07	0.48±0.04	0.44±0.04	0.24±0.03	0.34±0.04
WD	2.72±0.76	3.13±1.04	3.02±0.95	3.23±0.89	4.12±1.18	3.18±0.96
EC	0.15±0.01	0.15±0.01	0.21±0.02	0.1±0.01	0.12±0.01	0.16±0.02
DO	7.45±0.29	8.73±0.29	7.5±0.56	7.95±0.39	3.74±0.44	9.91±0.4
pH	7.42±0.12	7.03±0.26	7.99±0.06	7.78±0.14	7.92±0.04	8.31±0.05
T	14.81±0.47	22.26±0.55	6.89±0.43	14.2±0.51	22±0.57	13.24±0.47
TN	1.73±0.14	1.99±0.21	1.62±0.16	1.54±0.2	4.73±0.16	3.66±0.25
TP	0.6±0.05	0.69±0.04	0.36±0.03	0.44±0.06	0.29±0.02	0.27±0.03
NH_4^+-N	0.22±0.02	0.35±0.04	0.13±0.01	0.51±0.26	0.16±0.01	0.54±0.09
NO_3^--N	0.58±0.07	1.52±0.5	0.28±0.03	1.05±0.09	2.46±0.19	5.01±0.68
COD_{Mn}	3.8±0.13	3.98±0.1	4.06±0.12	3.9±0.11	5.01±0.07	3.58±0.23
ORP	51.81±3.7	64.3±4.47	57.09±2.98	43.09±3.42	47.84±3.06	55.01±2.79
BOD_5	1.71±0.13	1.43±0.12	1.93±0.21	1.74±0.14	1.55±0.12	2.6±0.26
NTU	37.65±4.04	91.38±18.43	82.85±17.54	40.17±5.29	191.98±53.41	77.74±18.63
FV	0.17±0.02	0.2±0.04	0.08±0.01	0.14±0.02	0.15±0.04	0.08±0.01

Water transparency (SD), water depth (WD), electroconductibility (EC), dissolved oxygen (DO), pH value (pH), temperature (T), total nitrogen (TN), total phosphorus (TP), ammonium nitrogen (NH_4^+-N), nitrate (NO_3^--N), chemical oxygen demand (COD_{Mn}), oxidation-reduction potential (ORP), five-day biochemical oxygen demand (BOD_5), turbidity (NTU) and flow velocity (FV)

In May 2015 (spring), WD were significantly lower than other sampling seasons.

In July 2015 (summer), T, ORP and FV were significantly higher than other sampling seasons, while pH and BOD_5 were significantly lower than other sampling seasons.

In September 2015 (autumn), SD and EC were significantly lower than other sampling seasons, while T, NH_4^+-N and FV were significantly lower than other sampling seasons.

In May 2017 (spring), EC, TN, NO_3^--N and ORP were significantly lower than other sampling seasons.

In July 2017 (summer), WD, TN, NO_3^--N and NTU were significantly higher than other sampling seasons, while SD and DO were significantly lower than other sampling seasons.

In September 2017 (autumn), DO, pH, NH_4^+-N, NO_3^--N and BOD_5 were significantly higher than other sampling seasons. TP and COD_{Mn} were significantly lower than other sampling seasons.

Water ecological health evaluation

Water ecological health evaluation system of the Muling River Basin is set as follows, with 3 indicators at the target level, 6 indicators at the criterion level, and 27 indicators at the index level, and finally get the index weights of each level (*Table 9*). The climatological and hydrological data from Heilongjiang Provincial Department of water resources and Jixi Water Affairs Bureau

Table 9. *Weight table of ecosystem health assessment system in Muling River Basin*

Target layer	Criterion layer	Index layer	Weight
River water environmental factors(A1)	Physical factor(B1)	pH(C11)	0.059089
0.328508	0.333333	ORP(C12)	0.017895
		EC(C13)	0.032518
	Chemical factor(B2)	DO(C21)	0.084635
	0.666667	COD_{Mn}(C22)	0.005513
		BOD_5(C23)	0.005513
		TN(C24)	0.042511
		TP(C25)	0.042511
		NH_4^+-N(C26)	0.019161
		NO_3^--N(C27)	0.019161
River hydrological quality(A2)	River hydrology(B3)	SD(C31)	0.027547
0.266407	0.633975	NTU(C32)	0.008236
		WD(C33)	0.042967
		T(C34)	0.017541
		FV(C35)	0.007898
		Ecological runoff(C36)	0.064707
	River structure(B4)	River bottom(C41)	0.054978
	0.366025	River bending coefficient(C42)	0.005365
		Riparian vegetation coverage(C43)	0.025682
		Riparian habitat(C44)	0.011486
River ecosystem services(A3)	Bio-functional group diversity(B5)	Phytoplankton functional group diversity(C51)	0.120345
0.405085	0.636364	Zooplankton functional group diversity(C52)	0.071558
		Macroinvertebrates functional feeding group diversity(C53)	0.041314
		Fish functional group diversity(C54)	0.024565
	Social service function(B6)	Public satisfaction(C61)	0.058669
	0.363636	Water resources development and utilization rate(C62)	0.055647
		Flood control indicators(C63)	0.032988

Water transparency (SD), water depth (WD), electroconductibility (EC), dissolved oxygen (DO), pH value (pH), temperature (T), total nitrogen (TN), total phosphorus (TP), ammonium nitrogen (NH_4^+-N), nitrate (NO_3^--N), chemical oxygen demand (COD_{Mn}), oxidation-reduction potential (ORP), five day biochemical oxygen demand (BOD_5), turbidity (NTU) and flow velocity (FV)

Comprehensive water ecological health index of the target layer: The comprehensive water ecological health index of the 3 target layers of the Muling River Basin Water Ecological Health Evaluation System is between 0.2743 and 0.7526. The health classification and health status were at level IV sub-sick, III general, II sub-health status respectively (*Table 10*).

Table 10. *WEHCI of target layer*

Target layer	2015.5	2015.7	2015.9	2017.5	2017.7	2017.9	Average
River water environmental factors	0.3894	0.5509	0.4645	0.3717	0.331	0.7526	0.4767
Classification, status	IV, Sub-sick	III, General	III, General	IV, Sub-sick	IV, Sub-sick	II, Sub-health	III, General
River hydrological quality	0.4325	0.5657	0.4423	0.5006	0.6832	0.4233	0.5079
Classification, status	III, General	III, General	III, General	III, General	II, Sub-health	III, General	III, General
River ecosystem services	0.4309	0.2743	0.5842	0.5293	0.4671	0.6995	0.4975
Classification, status	III, General	IV, Sub-sick	III, General	III, General	III, General	II, Sub-health	III, General

Comprehensive index of water ecological health of the criterion level: The comprehensive index of water ecological health of the 6 criterion level of the Muling River Basin Water Ecological Health Evaluation System is between 0.256 and 0.8205. The health classification and health status were at IV sub-sick, III general, II sub-health, I health status, respectively (*Table 11*).

Table 11. *WEHCI of criterion layer*

Criterion layer	2015.5	2015.7	2015.9	2017.5	2017.7	2017.9	Average
Physical factor	0.3578	0.4049	0.7663	0.3349	0.4328	0.8205	0.5195
Classification, status	IV, Sub-sick	III, General	II, Sub-health	IV, Sub-sick	III, General	I, Health	III, General
Chemical factor	0.4052	0.6239	0.3136	0.3902	0.2801	0.7187	0.4553
Classification, status	III, General	II, Sub-health	IV, Sub-sick	IV, Sub-sick	IV, Sub-sick	II, Sub-health	III, General
River hydrology	0.3801	0.5360	0.3830	0.4424	0.6380	0.3057	0.4476
Classification, status	IV, Sub-sick	III, General	IV, Sub-sick	III, General	II, Sub-health	IV, Sub-sick	III, General
River structure	0.5233	0.6172	0.5449	0.6013	0.7616	0.6269	0.6125
Classification, status	III, General	II, Sub-health	III, General	II, Sub-health	II, Sub-health	II, Sub-health	II, Sub-health
Bio-functional group diversity	0.2936	0.2560	0.5567	0.4481	0.5591	0.7378	0.4752
Classification, status	IV, Sub-sick	IV, Sub-sick	III, General	III, General	III, General	II, Sub-health	III, General
Social service function	0.6713	0.3062	0.6324	0.6713	0.3062	0.6324	0.5366
Classification, status	II, Sub-health	IV, Sub-sick	II, Sub-health	II, Sub-health	IV, Sub-sick	II, Sub-health	III, General

Index layer water ecological health comprehensive index: The comprehensive target layer and criterion layer finally get the comprehensive water ecological health index of the Muling River Basin (*Table 12*). The ecological health classification rose from level III to level II, and the health status rose from general to sub-health level, with an overall upward trend. The average value was 0.4935, the health classification was level III, and the health status was average. In September 2017 (autumn), the Muling River Basin had the highest comprehensive water ecological health index, and the health status of the Muling River Basin improved.

Table 12. *WEHCI table of ecosystem health assessment system in Muling River Basin*

	2015.5	**2015.7**	**2015.9**	**2017.5**	**2017.7**	**2017.9**
pH(C11)	0.018839	0.0126149	0.0439227	0.0310095	0.0381506	0.0590892
ORP(C12)	0.0068347	0.0168284	0.0113673	0.0009107	0.0040845	0.0093535
EC(C13)	0.0135114	0.0148941	0.0286193	0.0047487	0.0051586	0.0214055
DO(C21)	0.0422883	0.0607683	0.041912	0.0519836	0.0012149	0.0841406
COD_{Mn}(C22)	0.0021349	0.0026173	0.0026368	0.002181	0.0055132	0.0008138
BOD_5(C23)	0.0012552	0.0011883	0.0026969	0.0018005	0.001629	0.0048939
TN(C24)	0.0095786	0.0182735	0.005607	0.0046809	0.0399681	0.0286367
TP(C25)	0.0258162	0.0379393	0.0157343	0.0144458	0.0023835	0.0024275
NH_4^+-N(C26)	0.0064664	0.0112471	9.284E-05	0.0074593	0.0019045	0.0173238
NO_3^--N(C27)	0.0011912	0.0045999	5.083E-20	0.0029019	0.0087295	0.0191609
SD(C31)	0.0121862	0.0076306	0.0222439	0.0207826	0.0044329	0.0125422
NTU(C32)	0.0003642	0.0030525	0.0033236	0.0005071	0.0075098	0.0030742
WD(C33)	0.0189015	0.0094863	0.013539	0.0218909	0.0281763	0.0044069
T(C34)	0.0087378	0.0172628	0.0002943	0.008506	0.0163435	0.0057532
FV(C35)	0.0053248	0.0067476	0.0003703	0.0043531	0.0049459	0.0006445
Ecological runoff(C36)	0.018688	0.0463469	0.0252158	0.018688	0.0463469	0.0252158
River bottom(C41)	0.0386493	0.0386493	0.0386493	0.0386493	0.0386493	0.0386493
River bending coefficient(C42)	0.0049532	0.0049532	0.0049532	0.0049532	0.0049532	0.0049532
Riparian vegetation coverage(C43)	0.0024462	0.0116039	0.0045479	0.0100525	0.0256825	0.0125531
Riparian habitat(C44)	0.0049789	0.0049789	0.0049789	0.0049789	0.0049789	0.0049789
Phytoplankton functional group diversity(C51)	0.0484634	0.0236319	0.1144441	0.0258784	0.0305872	0.0804393
Zooplankton functional group diversity(C52)	0.0051496	0.0140533	0.0091625	0.0540971	0.0699923	0.0642071
Macroinvertebrates functional feeding group diversity(C53)	0.006511	0.0069479	0.0047469	0.0248902	0.0271283	0.04058
Fish functional group diversity(C54)	0.0155561	0.0213589	0.0151496	0.0106452	0.0164109	0.0049635
Public satisfaction(C61)	0.0537792	0.0003649	0.048052	0.0537792	0.0016434	0.048052
Water resources development and utilization rate(C62)	0.0305368	0.0305368	0.0305368	0.0305368	0.0305368	0.0305368
Flood control indicators(C63)	0.0145699	0.0145699	0.0145699	0.0145699	0.0145699	0.0145699
WEHCI	0.4177	0.4428	0.5071	0.4699	0.4799	0.6434
Classification, status	III, General	III, General	III, General	III, General	III, General	II, Sub-health
WEHCI average: 0.4935; Health classification: III; Health status: General						

Discussion

Usage of pesticides does not result in an accumulation of nutrients in the water (Reed et al., 2000). The survey found that the trend of TN concentration in 2015 and 2017 was similar, and it was higher in summer than in spring and autumn. The higher concentration in summer is due to the increase of surface runoff by rainfall, which indirectly increases the concentration of nutrients in the river. The average concentration of TN (3.31 mg/L) in 2017 was twice that in 2015. A more obvious high concentration of TP was observed in July (summer) of the same year, which may be caused by villagers reclaiming farmland and using pesticides and fertilizers. The NH_4^+-N concentration in May 2017 (0.51 mg/L) was higher than that in May 2015 (0.22 mg/L); On the contrary, in July, the maximum concentration of NH_4^+-N was 2.731 mg / L > 1.5 mg / L (higher than class IV water), which was not suitable for human drinking. In September 2015, the concentration of NO_3^--N was as low as 0.28 mg / L. In 2017, the concentration continued to rise to 5.01 mg / L, 18 times higher than before. At the same time, nitrogen limitation and phosphorus limitation were also observed. The change trend of TN: TP ratio shows that it is nitrogen limited in 2015 (TN: TP < 16) (Redfield, 1934), reaching the lowest value in May 2017 (spring), but it is still nitrogen Limited (TN: TP = 5.21). In July (summer) of the same year, it increased rapidly, reached the peak (TN: TP = 17.97>16) and turned to phosphorus limit, which was still close to the critical value in autumn, up to 15.76. In addition, the change range of COD_{Mn} in 2015 was small, from 3.80 mg/L to 4.06 mg/L. In May 2017, it decreased to 3.90 mg/L in July 2017 (summer), the highest value was 5.01 mg/L, and rapidly decreased to 3.58 mg/L in September.

As Muling River Basin is located in the agricultural wetland ecological area of Sanjiang Plain, large-scale cultivation is carried out in spring, and the total biomass of phytoplankton reaches the maximum in spring and the minimum in summer. This survey result is consistent with that of Daning River (Zhu et al., 2013). The studies of Fasham et al. (1990) show that the increase of nutrient concentration will lead to the increase of plankton quantity, which is the main driving factor for the dynamic change of plankton community structure. Plankton is sensitive to environmental changes and is considered a good indicator (Jeppesen et al., 2011). In addition, the plankton community structure is affected by hydrological conditions (Rennie and Jackson, 2005). Summer rainfall raises the water level of Muling River, and the river continuously scours the exposed riparian zone, resulting in a significant increase in the concentration of suspended particulate matter, a decrease in the effective utilization rate of light, and an impact on the growth of plankton (Shi et al., 2020). At the same time, water and soil loss in the riparian zone leads to a large amount of sediment entering the river. The surface of river sediment is covered with muddy soil. These sediments will also adhere to the body surface, trachea and gills of macroinvertebrates, resulting in the inability of macroinvertebrates to breathe and finally die. Substrate types and aquatic vascular plants are factors affecting the growth and functional group distribution of macroinvertebrates. The community structure of macroinvertebrates is usually determined by the physical structure and complexity of habitat (Leason et al., 2018). Aquatic vascular plants play an important role in constructing benthic species and selecting species related to functional group dynamics and feeding habits (Li et al., 2022). The distribution of benthos also depends on vegetation types, especially the structure and growth form of aquatic vascular plants, which affect underwater climate and chemical properties by absorbing and releasing chemicals (such as nutrients and antagonists) (Valinti et al., 2011).

Ecosystem function essentially depends on the functional groups of species, which has become a powerful and reliable method to study the dynamic changes of community functional characteristics (Diaz et al., 2004). Functional groups are species with similar morphological and physiological characteristics. The great difference in their spatial pattern is the response to environmental changes and the trade-off between different functions, which can greatly simplify the food web (Morgan, 1985). According to Padisák et al. (2009), 17 phytoplankton functional groups were investigated in this study, which exceeded Mudanjiang (11) located in the same province (Yu et al., 2012). The density of zooplankton functional groups is affected by phytoplankton biomass of primary producers (Trevisan and Forsberg, 2007). Globally, land use change, especially the loss of riparian vegetation, may lead to the reduction or change of benthic community structure, function and diversity. Vegetation litter is the main food source of macroinvertebrates functional feeding group SH. the reduction of food will hinder their growth and development and imbalance the aquatic ecosystem (Liu et al., 2019).

The pollution and damage around Muling River Basin are serious, and the habitat is also investigated during the sampling period. As an integral part of the basin, the characteristics of Muling River are determined by the characteristics of the basin in the final analysis (Liang et al., 2021). River ecosystem is a complex, open, dynamic, non-equilibrium and nonlinear system. The core of understanding the essential characteristics of rivers is to understand the composition, structure and function of river ecosystem. Repairing damaged river ecosystem is river ecological restoration (Rakhit, 2021). To understand a river, we must first understand its physical geography, climate, geology and land use. The external influencing factors of the river ecosystem determine the physical and hydrochemical characteristics of the river, such as runoff, channel, matrix type, water and sediment characteristics (Boulion, 2020). At the same time, the river water ecosystem is easily affected by the areas around the shore. There is a correlation between the impact of local human activities on the water ecosystem in Muling River Basin and the changes of other ecosystems (Ajagbe, 2021). In addition, river is always an important and active ecological factor in terrestrial ecosystem, and the study of terrestrial ecosystem can never be carried out alone without the study of river (Haidri and Sabri, 2020). Therefore, it is very necessary to regard the watershed as a composite ecosystem and combine the research of river ecosystem and terrestrial ecosystem in theory and practice.

Conclusion

During the survey, 83 species of phytoplankton belonging to 43 genera and 7 phyla were found in Muling River Basin, which were divided into 17 functional groups. The seasonal succession was M+P→F+MP+P→MP+P→M→M+Y→M+MP+P. There are 4 classes, 27 genera and 36 species of zooplankton, which are divided into 7 functional groups. The seasonal succession is PF+RF+SCF→PF+RF→P→PF+RF→PF+RF→PF+RF. Macroinvertebrates belong to 4 phyla, 13 orders, 46 families and 158 genera/species, which are divided into 6 functional groups. The seasonal succession is GC+SC→PR+GC→PR+GC→PR+GC+SC→PR+GC→PR+GC→PR+GC. There are 46 species, 12 families and 5 orders of fish, are divided into 7 functional groups. The excellent seasonal succession is IN+BE→IN+BE+OM→IN+PH+BE+OM→IN+BE→IN+PH+BE+OM→IN+PH+BE+OM→IN+PH+BE+OM.

By calculating the comprehensive index of water ecological health in Muling River Basin, the index in the target layer is between 0.2743 and 0.7526, which is in the state of grade IV Sub-sick to grade II Sub-health. In the criterion layer, the index is between 0.256 and 0.8205, which is in grade IV Sub-sick to grade I Healthy state. The comprehensive index of water ecological health in Muling River Basin in each season is 0.4177, 0.4428, 0.5071, 0.4699, 0.4799 and 0.6434 respectively. The water ecological health rating rises from grade III to grade II, and the health status rises from the general level to the Sub-health level. The overall trend is upward, with an average value of 0.4935. The health rating is grade III, and the health status is General.

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REFERENCES

[1] Ajagbe, S. O. (2021): Impacts of loss of vegetation cover on biodiversity of Ikere-gorge, Oyo State Nigeria. – Nigerian Journal of Animal Production 48(4): 14-23.
[2] Allan, J. D., Castillo, M. M. (2007): Stream ecology: structure and function of running waters. – Springer Science & Business Media.
[3] An, R., Wang, F. Y., Yu, H. X., Ma, C. X. (2017): Seasonal dynamics of zooplankton functional groups and their relationships with environmental factors in the Sanhuanpao wetland reserve. – Acta Ecologica Sinica 37(6): 1851-1860. (in Chinese with English abstract).
[4] Beaugrand, G., Ibañez, F., Reid, P. C. (2000): Spatial, seasonal and long-term fluctuations of plankton in relation to hydroclimatic features in the English Channel, Celtic Sea and Bay of Biscay. – Marine Ecology Progress Series.
[5] Becker, V., Huszar, V. L. M., Crossetti, L. O. (2009): Responses of phytoplankton functional groups to the mixing regime in a deep subtropical reservoir. – Hydrobiologia 628(1): 137-151.
[6] Boulion, V. V. (2020): The Ratio between Primary Production Values of Lake and Terrestrial Ecosystems. – Doklady Biological Sciences 493(1): 107-109.
[7] Cao, M. L. (2012): Determination of evaluation index weight by analytic hierarchy process and excel calculation. – Jiangsu Science & Technology Information 2: 39-40. (in Chinese with English abstract).
[8] Chen, Y. Y. (1998): Chinese zoology, Osteichthyes. – Beijing: Science and Technology Press. (in Chinese).
[9] Chiang, S. C., Du, N. S. (1979): Freshwater Cladocera. – Beijing: Science Press. (in Chinese).

[10] Chowdhury, M., Hossain, M. S., Das, N. G., Barua, P. (2011): Environmental variables and fisheries diversity of the Naaf River Estuary, Bangladesh. – Journal of Coastal Conservation 15(1): 163-180.
[11] Cummins, K. W. (1973): Trophic Relations of Aquatic Insects. – Annual Review of Entomology 18(1): 183-206.
[12] David, V., Sautour, B., Chardy, P., Leconte, M. (2005): Long-term changes of the zooplankton variability in a turbid environment: The Gironde estuary (France). – Estuarine, Coastal and Shelf Science 64(2-3): 171-184.
[13] Diaz, S., Hodgson, J. G., Thompson, K., Cabido, M., Zak, M. R. (2004): The plant traits that drive ecosystems: evidence from three continents. – Journal of Vegetation Science 15(3): 295-304.
[14] Ding, B. Q., Liu, H. Z. (2011): Analysis of the Fish Feeding Guild Composition in the Yangtze River. – Sichuan Journal of Zoology 30(1): 31-35. (in Chinese with English abstract).
[15] Ejsmont-Karabin, J., Karabin, A. (2013): The suitability of zooplankton as lakes ecosystem indicators: crustacean trophic state index. – Polish Journal of Ecology 61(3): 561-573.
[16] Elliott, M., Quintino, V. (2010): Benthic Macroinvertebrate and Application in the Assessment of Stream Ecology. – Tsinghua University Press, Beijing.
[17] Fasham, M. J. R., Ducklow, H. W., Mckelvie, S. M. (1990): A nitrogen-based model of plankton dynamics in the oceanic mixed layer. – Journal of Marine Research 48(3): 591-639.
[18] Haidri, H., Sabri, A. (2020): Boratha Intersection Signal Design and Assess the Impact of Its Noise on The Surrounding Areas. – Solid State Technology 63(3): 5427-5442.
[19] Han, X. M., Gong, Z. L., Yang, X. M., Li, Y. Y., Chen, Z. J., Zhu, H. H., Wang, F. M. (2021): Diversity and Function Prediction of Bacterioplankton Under Human Disturbance in the Main Stream of the Laoguan River Before and After the Flood Season. – Environmental Science 42(2): 831-841. (in Chinese with English abstract).
[20] Hu, H. J., Wei, Y. X. (2006): The Freshwater Algae of China: Systematics, Taxonomy and Ecology. – Science press, Beijing China. (in Chinese).
[21] Jeppesen, E., Nõges, P., Davidson, T. A., Haberman, J., Noges, T., Blank, K., Lauridsen, T. L., Sondergaard, M., Sayer, C., Laugaste, R., Johansson, L. S., Bjerring, R., Amsinck, S. L. (2011): Zooplankton as indicators in lakes: a scientific-based plea for including zooplankton in the ecological quality assessment of lakes according to the European Water Framework Directive (WFD). – Hydrobiologia 676(1): 279-297.
[22] Jungwirth, M., Muhar, S., Schmutz, S. (2000): Assessing the ecological integrity of running waters. – Hydrobiologia 422-423(2): 85-97.
[23] Leason, G. J. E., Bortolotti, Y. J., Rooney, C. R. (2018): Wetland microhabitats support distinct communities of aquatic macroinvertebrates. – Journal of Freshwater Ecology 33(1): 73-82.
[24] Li, D. D., Xu, X. M., Hu, X. Q., Liu, Q. G., Wang, Z. C., Zhang, H. Z., Wang, H., Wei, M., Wang, H. Z., Liu, H. M., Li, C. H. (2015): Genome-wide analysis and heavy metal-induced expression profiling of the HMA gene family in Populus trichocarpa. – Frontiers in Plant Science 6: 1149.
[25] Li, L., Gou, M. M., Wang, N., Ma, W., Xiao, W. F., Liu, C. F., La, L. M. (2021): Landscape configuration mediates hydrology and nonpoint source pollution under climate change and agricultural expansion. – Ecological Indicators 129: 107959.
[26] Li, D. D., Yang, J. L., Pa, S., Zeng, M. Z., Sun, J. L., Yu, S., He, Y. T., Li, C. H. (2022): PuC3H35 confers drought tolerance by enhancing lignin and proanthocyanidin biosynthesis in the roots of Populus ussuriensis. – New phytologist 233(1): 390-408.
[27] Liang, X., Xie, Q., He, M., Liu, Q., Morozov, V. (2021): Reservoir Characteristics and Its Comprehensive Evaluation of Gray Relational Analysis on the Western Sulige Gas Field, Ordos Basin, China. – Geofluids 2: 1-12.

[28] Liu, M. H., Meng, Y., Cao, J. J., Cui, X. B., Al, M. N. (2019): Functional Traits of Macroinvertebrates in Naolihe Wetland. – Journal of Northeast Forestry University 47(1): 76-82. (in Chinese with English abstract).

[29] Lobry, J., David, V., Pasquaud, S., Lepage, M., Éric, R. (2008): Diversity and stability of an estuarine trophic network. – Marine Ecology Progress Series 358(1): 13-25.

[30] Lu, K., Wu, H., Xue, Z., Lu, X., Batzer, D. P. (2019): Development of a multi-metric index based on aquatic invertebrates to assess floodplain wetland condition. – Hydrobiologia 827(1): 141-153.

[31] Lu, K., Wu, H., Guan, Q., Lu, X. (2020): Aquatic invertebrate assemblages as potential indicators of restoration conditions in wetlands of northeastern china. – Restoration Ecology 29(1): e13283.

[32] Lu, K., Batzer, D. P., Wu, H. (2021): Aquatic invertebrate assemblages during the spring-thaw season in wetlands of northeastern china. – Hydrobiologia 848(1): 1-11.

[33] Mangadze, T., Bere, T., Mwedzi, T. (2016): Choice of biota in stream assessment and monitoring programs in tropical streams: a comparison of diatoms, macroinvertebrates and fish. – Ecological Indicators 63(4): 128-143.

[34] Michele, A. B., Mark, J. O. (2006): A comparison of phytoplankton community assemblages in artificially and naturally mixed subtropical water reservoirs. – Freshwater Biology 51(5): 973-982.

[35] Morgan, M. D. (1985): The Effect of Altered pH on Zooplankton Community Structure in a Disturbed New Jersey Pine Barrens Pond. – Journal of Freshwater Ecology 3(4): 467-476.

[36] Morse, J. C., Yang, L. F., Tian, L. X. (1984): Aquatic Insects of China useful for monitoring water quality. – Nanjing: Hohai University Press.

[37] Nash, J. A., Miesel, J. R., Bonito, G. M., Sakalidis, M. L., Ren, H., Warnock, D., Tiemann, L. K. (2021): Biochar restructures plant-soil-microbe relationships in a woody cropping system. – Soil Science Society of America Journal 85(6): 2019-2039.

[38] Padisák, J., Crossetti, L. O., Naselli-Flores, L. (2009): Use and misuse in the application of the phytoplankton functional classification: a critical review with updates. – Hydrobiologia 621(1): 1-19.

[39] Ptacnik, R., Lepistö, L., Willén, E., Brettum, P., Andersen, T., Rekolainen, S., Lyche Solheim, A., Carvalho, L. (2008): Quantitative responses of lake phytoplankton to eutrophication in Northern Europe. – Aquatic Ecology 42(2): 227-236.

[40] Rakshit, R. (2021): Macro-mechanical characteristics and their control on the strength of sandstones of western Indo-Burmese Rangers, NE India. – Acta Geodynamica et Geomaterialia 18(2): 241-252.

[41] Redfield, A. C. (1934): On the Proportions of Organic Derivatives in Sea Water and Their Relation to the Composition of Plankton. – University Press of Liverpool, Liverpool, UK.

[42] Reed, S. D., Grisso, R. D., Woldt, W. E., Niemeyer, S. M. (2000): Waste Assessment of Agricultural Chemicals, Petroleum Products and Maintenance Residuals on Farmsteads. – Applied Engineering in Agriculture 16(2): 175-190.

[43] Ren, H., Warnock, D. D., Tiemann, L. K., Quigley, K., Miesel, J. R. (2021): Evaluating foliar characteristics as early indicators of plant response to biochar amendments. – Forest Ecology and Management 489(42): 119047.

[44] Rennie, M. D., Jackson, L. J. (2005): The influence of habitat complexity on littoral invertebrate distributions: patterns differ in shallow prairie lakes with and without fish. – Canadian Journal of Fisheries and Aquatic Sciences 62(9): 2088-2099.

[45] Shen, J. R., Dai, A. Y., Song, R. X. (1979): Freshwater Copepods. – Beijing: Science Press. (in Chinese).

[46] Shen, Y. F. (1999): Protozoology. – Beijing: Science Press. (in Chinese).

[47] Shen, H. L. (2014): Phytoplankton functional groups in a high spatial heterogeneity subtropical reservoir in China. – Journal of Great Lakes Research 40(4): 859-869.

[48] Shi, P. C., Zhu, G. W., Yang, W. B., Xu, H., Zhu, M. Y., Liu, M. L., Yu, Z. M., Wu, Z. X., Zheng, W. T., Wang, Y. C., Da, W. Y., Hu, L. N. (2020): Spatial-temporal Distribution of Suspended Solids and Its Sedimentation Flux and Nutrients Effects in Xin’anjiang Reservoir, China. – Environmental Science 41(5): 2137-2148. (in Chinese with English abstract).
[49] Sukatar, A., Ertas, A., Gülle, S., Kizilkaya, N. T. (2020): Trophic State Assessment of Brackish Bafa Lake (Turkey) Based on Community Structure of Zooplankton. – LimnoFish - Journal of Limnology and Freshwater Fisheries Research 6(2): 88-99.
[50] Tockner, K. M., Pusch, D., Borchardt, M. S. L. (2010): Multiple stressors in coupled river-floodplain ecosystems. – Freshwater Biology 55(1): 135-151.
[51] Trevisan, G. V., Forsberg, B. R. (2007): Relationships among nitrogen and total phosphorus, algal biomass and zooplankton density in the central Amazonia lakes. – Hydrobiologia 586(1): 357-365.
[52] Valinoti, C. E., Ho, C. K., Armitage, A. R. (2011): Native and exotic submerged aquatic vegetation provide different nutritional and refuge values for macroinvertebrates. – Journal of Experimental Marine Biology and Ecology 409(1-2): 42-47.
[53] Wang, J. Y. (1961): Freshwater rotifers of China. – Beijing: Science Press. (in Chinese).
[54] Wang, B. X., Yang, L. F., Hu, B. J., Shan, L. N. (2005): A preliminary study on the assessment of stream ecosystem health in south of Anhui Province using Benthic-Index of Biotic Integrity. – Acta Ecologica Sinica 25(6): 1481-1490. (in Chinese with English abstract).
[55] Wei, F. S. (2002): Water and wastewater monitoring method (Fourth Edition). – Beijing: China Environmental Science Press. (in Chinese).
[56] Wetzel, R. G. (2001): Limnology. – Academic Press, San Diego, California, USA.
[57] Yu, H. X., Wu, J. H., Ma, C. X., Qin, X. B. (2012): Seasonal dynamics of phytoplankton functional groups and its relationship with the environment in river: a case study in northeast China. – Journal of freshwater ecology 27(3): 429-441.
[58] Zhang, J. M., He, Z. H. (1993): Inland waters fisheries natural resources survey manual. – Beijing: Science Press. (in Chinese).
[59] Zhang, J. M. (1995): Fishes of Heilongjiang Province. – Harbin: Heilongjiang Science & Technology Press. (in Chinese).
[60] Zhu, S. Q. (1995): The synopsis of freshwater fishes of China. – Nanjing: Jiangsu Science and Technology Press. (in Chinese).
[61] Zhu, K. X., Bi, Y. H., Hu, Z. Y. (2013): Responses of phytoplankton functional groups to the hydrologic regime in the Daning River, a tributary of Three Gorges Reservoir, China. – Science of the Total Environment 450-451(1): 169-177.
[62] Zuo, Q. T., Chen, H., Zhang, Y. Y. (2015): Impact factors and health assessment of aquatic ecosystem in Upper and Middle Huai River Basin. – Shuili Xuebao 46(9): 1019-1027. (in Chinese with English abstract).