CHARACTERISTICS OF THE FISH COMMUNITY STRUCTURE AND ITS CORRELATION WITH ENVIRONMENTAL FACTORS IN THE TUANJIE RESERVOIR

WANG, Z. Q. – SUN, X. U.*

School of Management, Heilongjiang University of Science and Technology,
2468 Puyuan Road, Songbei District, Harbin, Heilongjiang, China

**Corresponding author*
e-mail: sunxu61204@163.com

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Abstract. Fish play an important role in aquatic ecosystems and are the most biologically diverse group of vertebrates. Fish are distributed in various water bodies around the world. In this study, fish sampling surveys were conducted at five sampling points in the Tuanjie Reservoir in May (spring), July (summer), and September (autumn) of 2022. The electric fish collection method was used to collect fish. The species, biomass, and number of fish caught were determined to reveal the community structure characteristics and provide data for water resources and environmental protection. In total, 22 fish species belonging to 17 genera and four orders were collected. The fish community was mainly composed of Cypriniformes, followed by Siluriformes, Perciformes, and Lampetiformes. *Cyprinus (cyprinus) carpio haematopterus* Linnaeus, *Carassius auratus gibelio* (Bloch), *Aristichthys nobilis*, *Hypophthalmichthys molitrix*, *Misgurnus mohoity* (Dybowski), and *Silurus asotus* Linnaeus were the main Cypriniformes species, *Perccottus glehni* was the main *Perccottus* species, and *Lampetra reissneri* (Dybowski) was the main *Lampetra* species. The catch-and-catch biomass at the S1 sampling point was the least, and the catch-and-catch biomass at the S5 sampling point was the greatest. There were significant spatial and temporal pattern changes in fish community composition in the Tuanjie Reservoir.

Keywords: *Tuanjie Reservoir, catches, biomass, spatial and temporal pattern, relationship*

Introduction

Rivers and lakes are the foundation of agricultural civilization and are closely linked with people. Although all the world’s rivers together constitute less than one thousandth of the Earth’s total water, rivers and lakes have a far greater impact on human society than oceans, glaciers, and other waters (Allan, 2007). Ancient human civilizations were dependent on rivers and lakes. Rivers have played an important role in the development and growth of the Chinese nation. With the continuous development of society, living standards are also improving. The connection between people and rivers and lakes has become more direct, and the contributions of rivers and lakes to human beings have increased, but at the same time, pollution in rivers and lakes has become increasingly serious. Therefore, the governance of rivers and lakes has become a topic of concern. The relationship between people and rivers and lakes is growing closer. Although rivers and lakes have brought wealth to people, they have also been polluted due to human activity. As a result, the problem of water control in rivers and lakes has also received increasing attention (Wu et al., 2014).

The study of the Muling River is very important (Xue et al., 2023). Muling River is in the Sanjiang Plain area of Heilongjiang Province and is the largest tributary on the left bank of the Wusuli River (Zhang et al., 2021; Wu et al., 2014). The Muxing Plain it flows through is an important commodity grain production base in China. The health of Muling River resources is of great significance for ensuring national food security and

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protecting the ecological health of farmland, and plays a key role in the research on and protection of fish resources (Sun, 2019; Cao, 2019). the Tuanjie Reservoir is built on the Muling River in the south of Gonghe Township. The reservoir submerges the three inflow riverbeds of Longzhua, Shuangning, and Muling River, with a reservoir surface area of 445 km^2. The Gonghe Reservoir includes a dam with a length of 280 m and a height of 35 m. The Muling River was cut off, and a flood discharge channel was constructed in the water conveyance channel to ensure the safety of the dam. The Muling River flows out of the water conveyance channel and into the Gonghe Basin along the foot of the Liufeng Mountain. The total irrigation area of this project is 120,000 mu, including 30,000 mu of direct irrigation and 90,000 mu of downstream compensatory irrigation. The aquaculture area is up to 6240 acres, and can be used to raise 50 tons of fish per year.

Fish play an important role in aquatic ecosystems and are distributed in various water bodies around the world. Fish are the most biologically diverse group of vertebrates, accounting for more than half of the vertebrate species on Earth, 40% of which live in freshwater. There are nearly 1000 species of freshwater fish in China, which are widely distributed in China’s major water systems (Li, 2008). During their evolutionary history, fish gradually colonized an extensive variety of habitats, leading to their diverse physiological and ecological characteristics. Since the 1990s, countries around the world have gradually realized the importance of fish resource management (Guo et al., 2023). The continuous development of advanced technologies in areas such as fish surveying and monitoring, the sustainable development and utilization of fish resources, and the processing of fishery products has improved water protection. The importance of environmental protection and fish species diversity have been recognized by major fishery countries (Sarkar et al., 2011). Research in these fields can not only provide a scientific basis for water environment assessment and fish resource development and utilization but also a scientific basis for fish protection and aquatic product production (Chen et al., 2019).

The community refers to the collection of various species populations gathered in the same space at the same time. Karl Möbius, a German zoologist, proposed the term biocenosis in 1877. The study of biocenosis focuses on defining the interactions between individual organisms living in the same habitat. According to Möbius, a certain number of organisms are supported by a biological community. Any biological community may produce excessive offspring under ideal conditions, but the space and food resources are limited. As a result, the growth of the total number of individuals in the biological community is limited, and the number of individuals returns to a more moderate state. In English, the term ecological community is commonly used to describe a collection of two or more different species gathered in the same space. The fish community structure described in this paper is a collection of different fish species that are connected to each other in the same water environment.

Studying the spatial heterogeneity and temporal changes of fish communities is important for studying the structure of fish communities (Zhang et al., 2023). For the temporal variation pattern of the fish community, scholars often study the variation of the fish community in the morning and evening, over four seasons, or over a longer time range (Xu et al., 2023). In terms of temporal research, most Chinese and international scholars have focused on the composition of fish species, changes in the fish resources, and changes in the fish community diversity in spring, summer, autumn, and winter (Ding et al., 2023). The differences in the species composition and diversity of fish community species are not only related to the seasonal changes in the habitat they live in but also to the competition between fish species or the competition and predation between other species, as well as human disturbance. The spatial heterogeneity of the fish community structure is also an important part of the study of fish community structure (Xiong, 2022). In this field, the main research directions of Chinese and international scholars are the spatial distribution of fish species composition, fish resources, and fish community diversity (Song, 2016).

To study the characteristics of the fish community structure in the Tuanjie Reservoir, the first step was finding a suitable method. To this end, Feng (2008) of the School of Fisheries and Life Sciences of Shanghai Ocean University described the characteristics of various sampling methods in the study of fish communities, such as underwater observations, gill nets, cover nets, electric capture, setting nets in fixed positions, purse seines, and trawl nets, and listed various index types reflecting the characteristics of fish community structure. The effects of environmental factors such as the water depth, aquatic plants, distance from shore, sediment, dissolved oxygen, temperature, and salinity on the characteristics of the fish community structure were also summarized, as well as the relationship between ecosystem function and fish community diversity, providing a theoretical reference for the study of fish community structure characteristics in future research and promoting the sustainable development of fishery production. Maitland (1995) also summarized several factors that caused great harm to fish community structures and their environment, including industrialization, water acidification, lake reclamation, dam construction, water level fluctuations, commercial fishing, aquaculture, invasive species, and global warming. Previous research found that the main type of fishing gear used was fixed gill nets, with the occasional use of drift gill nets, shrimp cages, and bait fishing. Catches were sampled on the spot, the species of fish were identified, and the body length and weight of each fish were measured (Zimmerman and Krueger, 2009). After measuring the body length and body weight, the fish that were not identified were tagged, fixed with 10% formalin solution, and transported back to the laboratory for identification (Liu et al., 2012). It was also found that the fish communities in the upper and lower reaches of the Tuanjie Reservoir were significantly different, which was similar to the conclusion that the fish community structure was significantly different between the lower reaches of the dam and the reservoir area after the reservoir impoundment (Bonner and Wilde, 2000; Jiang et al., 2007). This also demonstrates that reservoirs change the hydrological characteristics of the river itself, and then directly affect the characteristics of the fish community structure (Huang, 2006; Duan et al., 2008). Liu et al. (2021) from Nanjing Agricultural University studied some of the hydrological and geographical characteristics of the Qiantang River Estuary (Wenyan-Ganpu) and found that in addition to the obvious gradient, in which the influence of runoff was negatively correlated with the distance from the Fuchunjiang Reservoir, and the influence of saltwater intrusion was negatively correlated with the distance from the estuary, the height of the riverbed was positively correlated with the distance from the estuary. The main causes of the spatial differences in river fish community structure are differences in the water depth, salinity, and flow velocity. However, Liu’s survey can only be used as the starting point for the investigation of the fish community in the Qiantang River estuary in recent years. The West Lake section of the upper reaches of the estuary cannot fully reflect the fish habitat and fish community structure of the entire estuary (Liu et al., 2021). The results of research on the characteristics of the fish community structure in the Jiangsu section of Huaihe River by Liu et al. (2020) of the Jiangsu Freshwater Fisheries Research Institute showed that the fish community exhibited a state of moderate disturbance in winter, summer, and autumn, while it exhibited a state of severe disturbance in spring, which was probably affected by the individual size of dominant species. The dominant species in spring (*Coilia nasus*, *Carassius auratus gibelio* (Bloch) and *Acheilognathus chankaensis*) contained a certain number of newly hatched fish with small individuals, and the percentage by weight and percentage by number of dominant species were 37.14% and 56.34%, respectively. The abundance was more dominant than biomass, and the biomass curve was located below the abundance curve. There is a certain correlation between the water temperature and changes in the fish biodiversity index (Xu et al., 2007). With an increase in temperature, the vitality of fish gradually increases. There are fewer food organisms at lower temperatures, and food organisms are the most abundant when the temperature is suitable. In addition, the relationship between the fish community structure and other environmental factors (such as the water flow, chlorophyll a, total phosphorus, total nitrogen, and chemical oxygen demand) remains to be further studied. The use of nets will naturally affect the diversity index of monitored fish. The use of different types of fishing gear will have a great impact on the statistics of fishery resources (Mao et al., 2011). Using a single type of fishing gear to evaluate the structural characteristics of fishery communities will lead to errors, while the combination of multiple types of fishing gear can minimize errors (Liu et al., 2020).

The current research on fish populations is very diverse, both in terms of methods and research objects. Freshwater ecosystems appear more vulnerable to biodiversity loss due to several types of anthropogenic disturbances, and freshwater fish are particularly vulnerable to these impacts (Neetha et al., 2022). Research evaluating the potential behavioral and histological effects of environmental exposure to PFAS compounds within multiple trophic levels of aquatic ecosystems showed that fish critical swim speeds increased with PFAS exposure, which may lead to energetic and population concerns (Coy et al., 2022). Lais fish (*Phalacronotus micronemus*) live in the Musi watershed and contribute to its diverse biological resources. To maintain the population, researchers have analyzed the Lais stock in the Musi stream to provide policy support for fishery management (Wulandari, 2022). In terms of the definition of fish population quantity, people are biased toward the proportion of fish populations or communities that can be legally caught, making it is necessary to define the minimum length and spatial boundaries of the population (Reed, 2023). Baerwald et al. (2023) found that captive-reared delta smelt (*Hypomesus transpacificus*) exhibited high survival in natural conditions using in-situ enclosures. The conservation of endangered fishes commonly includes captive breeding, applied research, and management. Dahms and Killen (2023) analyzed published studies that met the criteria of reporting range shift responses to global warming in 115 taxa spanning all major oceanic regions, totaling 595 three-dimensional population responses (latitudinal, longitudinal, and depth), and found that temperature was identified as a significant driver. Kumari and Hansdah (2023) aimed to assess the pollution status of the mineral-rich industrial hub city Ranchi based on the analysis of metals or metalloids in abiotic (water and sediment) and biotic (fish and human) components. Tang et al. (2023) performed the mechanistic modeling of climate effects on redistribution and population growth in a community of fish species. Research examining the effects of climate change on fish has largely focused on redistribution. Nease (2019) investigated the environmental factors that influence vegetation abundance and distribution, with a focus on how vegetation abundance and distribution influences fish population abundance and size structure. Zimmerman and Krueger (2009) examined scientific questions related to the successful re-establishment of native deepwater fish communities in the Laurentian Great Lakes and proposed a conceptual model for native deepwater fish communities.

Materials and methods

Research area overview

The Tuanjie Reservoir is located in the center of Gonghe Township in the upper reaches of Muling River in Heilongjiang Province, China. The control basin area is 445 km^2. The reservoir is mainly focused on irrigation, and also provides flood control, hydropower generation, aquaculture, and other comprehensive utilization functions. The reservoir provides power resources and a water supply for the surrounding areas of Gonghe Township and is the local water source reserve and water supply regulation reservoir (Sun, 2019). According to statistical water conservancy records in Heilongjiang Province, the Tuanjie Reservoir is located in the center of Gonghe Township in the upper reaches of Muling River in Heilongjiang Province. The reservoir surface is 6.5 km wide from north to south, and 2–3 km wide from east to west. From top to bottom, the reservoir surface is Y-shaped, which is typical of mountain reservoirs. The reservoir area is located in the temperate continental monsoon climate zone. The area is semi-humid, with a long and cold winter. The freezing period lasts from October to April of the following year, and the frozen layer of ice on the surface can reach a thickness of 1.5–2 m. The summer is short and humid. The average annual evaporation of the Tuanjie Reservoir is about 950 mm. The average annual precipitation is about 534 mm. The precipitation from June to September accounts for 70% of the annual precipitation. The average annual runoff is 83.2 million m^3. The frost-free period is 126 days. The annual sunshine hours are 2613 h. The average annual temperature is 1°C, the highest temperature is 37.6°C, and the lowest temperature is -44.1°C.

Research methods

Investigation time

Nutrients in the Tuanjie Reservoir were sampled in spring, summer, and autumn in May, July, and September 2022. The specific time interval was two months, and monthly sampling helped to capture short-term changes in the water body, providing more detailed and comprehensive monitoring data. Monthly sampling can better reflect the rapid response of aquatic ecosystems to meteorological, climatic, and other factors. Therefore, this article selected three time points with significant characteristics in the Tuanjie Lake Reservoir for sample collection. Samples were collected in May because spring is a crucial period for biological reproduction and growth in the reservoir ecosystem, and the distribution and concentration of nutrients in the water may undergo significant changes. Sampling at this time can obtain benchmark data for the spring aquatic ecosystem. The fishing season in July occurs during a period of rising temperatures and increased sunshine, which may lead to changes in the temperature and dissolved oxygen in the water, and sampling during this period may help to reveal the nutrient dynamics and water quality of the water during the hot season. September fishing, during autumn, occurs during the season of plant withering and leaf decay, which may lead to the release and decomposition of organic matter in the water. Sampling during autumn can help researchers obtain the nutrient characteristics of water bodies during this period, providing important data for understanding the seasonal changes in reservoir ecosystems.

Sampling point setting

Choosing appropriate sampling points can improve fishing efficiency and quality. Using methods such as systematic sampling or random sampling, multiple sampling points can be uniformly selected in the reservoir, which can cover various biological communities as much as possible and reduce sampling errors. The shape and area of a reservoir can affect the selection of fishing samples. For different reservoirs, factors such as the shape, area, and water depth vary, which can affect the distribution and activity patterns of aquatic organisms. Climate factors such as temperature, humidity, and rainfall can also affect the activity and distribution of aquatic organisms. For example, certain organisms may migrate or seek suitable environments under specific seasonal or weather conditions, which may affect their distribution in reservoirs. In summary, the fishing points selected in this article not only considered the shape of the reservoir and the climate of the sampling points, but also considered whether the sampling at the selected points could be accomplished conveniently and safely. A total of five sampling sites were set up. In terms of survey methods, emphasis was placed on comprehensive layout, highlighting key points, combining field sampling with remote sensing monitoring, using satellite base maps, and flexibly using network models on the basis of historical surveys. The layout of the sampling points is shown in *Figure 1,* and the coordinates are provided in *Table 1*.

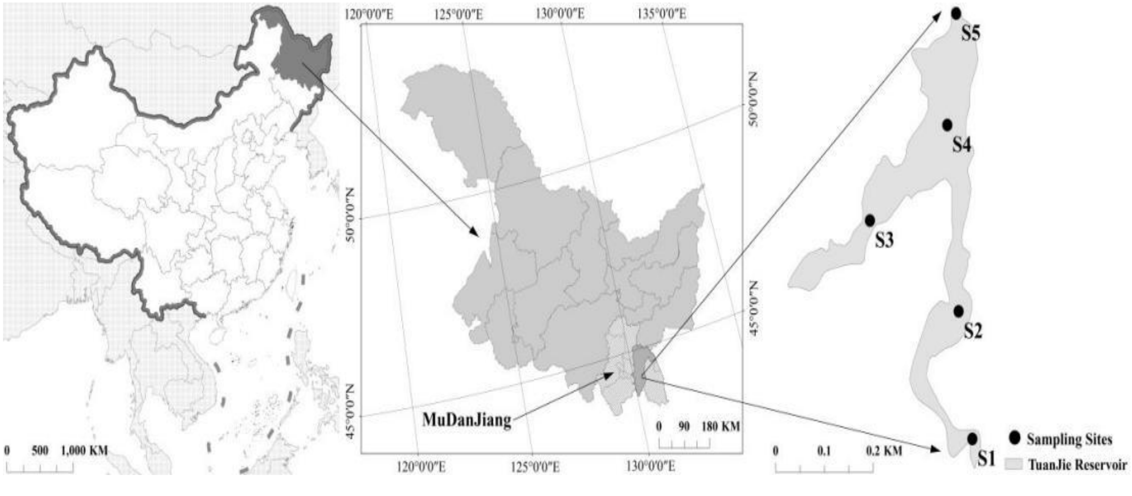

Figure 1. *Distribution of water sample sampling points in the Tuanjie Reservoir*

Investigation method

Sampling was performed three times: in spring (May), summer (July), and autumn (September) of 2022. Due to the freezing of the water surface in winter, no sampling was conducted. The electric fish collection method is convenient and can be used to stun fish of all sizes, but the range of action is small (Li, 2022). The electric fish method was used to assist in sampling so that samples could be widely collected. Sampling was conducted through on-site investigation and social visit investigation, with customized fishing nets used as the main method to obtain the catch. The fish specimens at the sampling points in the Tuanjie Reservoir were collected using a 40-m gill net with a mesh size of 3–7 cm. The net was set in the evening, and the catch was counted and relevant characteristic values were measured after 24 h. The fish specimens at other sampling points were collected using an electric fishing device (2000 W, 650 V). Unidentifiable species were marked and photographed on site for further processing in the laboratory. While sampling, local residents and fishermen were consulted to gain a deeper understanding of the current status of fish resources in the Muling River.

***Table 1.** The Tuanjie Reservoir sampling point names and coordinates*

	Sampling point	**Coordinates**
S1	Upper basin	44°1′44″N,130°11′13.6″E
S2	Dam No.10	44°2′45.9″N,130°10′28.3″E
S3	Mantoushan	44°3′14.6″N,130°8′49.3″E
S4	Core of the library	44°4′0.2″N,130°10′25.4″E
S5	Upstream of dam	44°4′32.6″N,130°10′36.3″E

Data analysis

To study the characteristics of the fish community structure, the catch was first collected, and then the various fish collected were classified and identified. Species identification was mainly conducted with reference to ‘The synopsis of freshwater fishes of China’ (Zhu, 1995), ‘Freshwater Fish in Northeast China’ (Xie, 2007), and ‘Fishes of Heilongjiang Province’ (Zhang, 1995). The mantissa for each species was calculated, and each sample was weighed to count the number of catches and the biomass distribution of fish in the Tuanjie Reservoir in spring, summer, and autumn.

According to the requirements of “Water and Wastewater Monitoring Method” (Fourth Edition) and the needs of on-site investigation, the following environmental factors were measured: the conductivity (COND), dissolved oxygen (DO), pH value (pH), water temperature (WT), oxidation-reduction potential (ORP), total nitrogen (TN), total phosphorus (TP), total dissolved solids (TD), nitrate nitrogen (NO_2-N), ammonium nitrogen (NH_4-N), nitrate (NO_3-N), chemical oxygen demand (COD), dissolved iron (Fe^{3+}), dissolved copper (Cu^{2+}), and water transparency (SD).

The changes of environmental factors in different seasons were analyzed using one-way analysis of variance (ANOVA) with the SPSS 19.0 software. Before the analysis, the data were subjected to lg (x + 1) conversion (except for pH) to ensure that the data were normally distributed. In this study, correlation analysis was performed using CANOCO 4.5 software (Microcomputer Power, New York, USA).

In this article, regularized discriminant analysis (RDA) was employed for statistical data processing. RDA is a multiple regression analysis method mainly used to study the impact of environmental factors on the structure of biological communities. The main steps were as follows. First, the dimensionality of environmental factors was reduced to obtain their principal components. Next, the same processing was performed on the biological community data to obtain its principal components. Canonical correlation analysis was performed on the principal components of environmental factors and biological community data to obtain their orthogonal axes. Based on the analysis results, the constraint scores for biotic community data and environmental factors were calculated. The correlation coefficient between the biological community data and environmental factors was calculated based on constraint scores. Finally, the distance between biological community data and environmental factors was calculated based on correlation coefficients.

Results and analysis

Fish community structure

A total of four orders, 17 genera, and 22 species of fish were collected from the Tuanjie Reservoir, among which the order Cypriniformes dominated with 14 genera and 19 species, accounting for 86.36%. There were one genus and one species of Perciformes, accounting for 4.55%; one genus and one species of Siluriformes, accounting for 4.55%; and one genus and one species in the order Lampetiformes, accounting for 4.55% (*Fig. 2*).

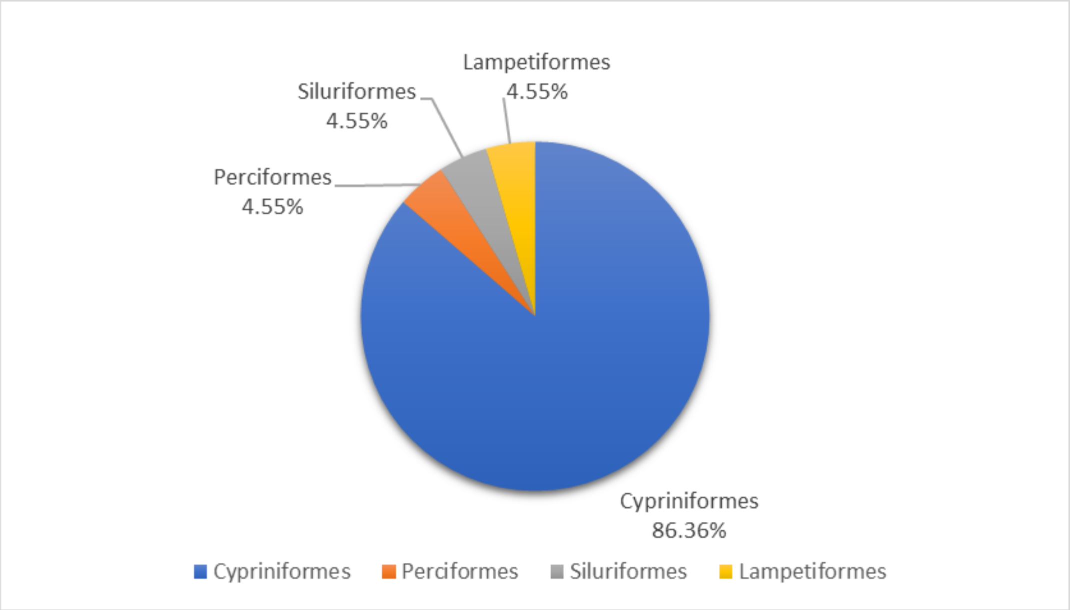

Figure 2. *Composition of fish species in the Tuanjie Reservoir*

The number of fish species collected at each sampling point fluctuated between six and 17 in spring, with the highest number of fish species collected at the S4 sampling point (17 species), the second highest collected at the S5 sampling point (16 species), and the lowest collected at the S1 sampling point (six species) (*Fig. 3*).

The number of fish species collected at each sampling point fluctuated between eight and 17 in summer, with the highest number of fish species collected at the S3, S4, and S5 sampling points (17 species), the second highest collected at the S2 sampling point (16 species), and the lowest collected at the being S1 sampling point (eight species) (*Fig. 3*).

The number of fish species collected at each sampling point fluctuated between seven and 19 in autumn, with the highest number of fish species collected at the S5 sampling point (19 species), the second highest collected at the S4 sampling point (17 species), and the lowest collected at the S1 sampling point (seven species) (*Fig. 3*).

The number of fish species in the upstream of the Tuanjie Reservoir was significantly higher than that in the downstream, and the distribution of fish species in various points in the Tuanjie Reservoir was uneven (*Table 2*).

Table 2. *Number of fish species caught in the Tuanjie Reservoir*

Sampling points	**Number of species caught**		
	Spring	**Summer**	**Autumn**
S1	6	8	7
S2	13	16	15
S3	15	17	16
S4	17	17	17
S5	16	17	19

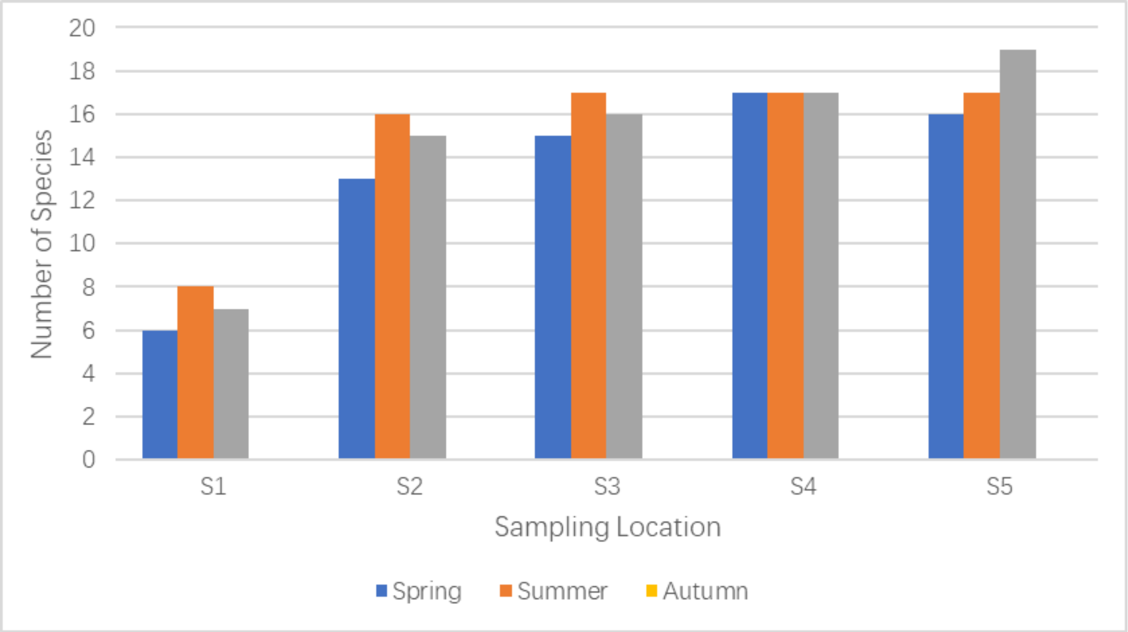

Figure 3. *Fish species at the Tuanjie Reservoir sampling points*

Quantity and biomass

Distribution of catches and biomass in spring

In the spring, a total of 22 species of fish were collected, namely, Lampetra reissneri, Ctenopharyngodon idellus, Phoxinus phoxinus, Phoxinus percnurus, Phoxinus czekanowskii Dybowski, Phoxinus lagowskii Dybowski, Hemiculter leucisclus, Pseudorasbora parva, Abbottina rivularis, Rostrogobio amurensisi Taranetz, Saurogobio dabryi Bleeker, Cyprinus carpio haematopterus Linnaeus, Carassius auratus gibelio, Aristichthys nobilis, Hypophthalmichthys molitrix, Lefua costata, Cobitis lutheri Rendahl, Cobitis granoci Rendahl, Misgurnus mohoity, Misgurnus bipartitus, Silurus asotus Linnaeus, and Perccottus glehni Dybowski.

In spring, the number of catches fluctuated between 21 and 472 (*Table 3*), with the highest number of catches at S5 (472), the second highest at S4 (398), and the lowest at S1 (21) (*Fig. 4*). Overall, the proportion of *H. molitrix* in the entire reservoir was the highest among various fish species, accounting for approximately 7.68%, followed by *A. nobilis, C. carpio haematopterus* Linnaeus, and *C. lutheri* Rendahl, which accounted for 7.14%, 6.87%, and 6.87%, respectively. The number of catches at the S1 sampling point was significantly smaller than the number of catches at other sampling points. At site S2, *C. idellus, P. percnurus, H. leucisclus, S. dabryi* Bleeker, *A. nobilis, C. lutheri* Rendahl, and *C. granoci* Rendahl were the main species; the major species at site S3 were *S. dabryi* Bleeker, *C. carpio haematopterus* Linnaeus, *S. asotus* Linnaeus, and *H. leucisclus*; at site S4, *C. idellus*, *C. granoci* Rendahl, *H. molitrix*, *C. auratus gibelio*, and *C. granoci* Rendahl comprised the majority of catches; and at site S5, *H. molitrix*, *M. mohoity, A. rivularis,* and *P. percnurus* were the main species. It could be seen that there were differences in the species of fish communities in the upstream and downstream of the Tuanjie Reservoir.

Table 3. *Distribution of catches in spring at the Tuanjie Reservoir (individuals)*

	S1	**S2**	**S3**	**S4**	**S5**
Lampetra reissneri (Dybowski)				7	
Ctenopharyngodon idellus (Curier et Valenciennes)		22	14	35	28
Phoxinus phoxinus (Linnaeus)	1				24
Phoxinus percnurus (Pallas)	4	23	6	16	35
Phoxinus czekanowskii Dybowski				12	
Phoxinus lagowskii Dybowski					18
Hemiculter leucisclus (Basilewsky)		23	31		32
Pseudorasbora parva (Temminck et schlegal)	1	6	23	25	
Abbottina rivularis (Basilewsky)	7		24		36
Rostrogobio amurensisi Taranetz				23	
Saurogobio dabryi Bleeker	3	24	34	14	12
Cyprinus (cyprinus) carpiohaematopterus Linnaeus		17	36	24	26
Carassius auratus gibelio (Bloch)			22	33	
Aristichthys nobilis (Richardson)		29	15	25	37
Hypophthalmichthys molitrix (Cuvier et Valenciennes)		20	23	30	41
Lefua costata (Kessler)			25		37
Cobitis lutheri Rendahl		23	24	23	32
Cobitis granoci Rendahl	5	26	13	35	22
Misgurnus mohoity (Dybowski)		14		23	42
Misgurnus bipartitus (Sauvage et Dabry)		4		35	25
Silurus asotus Linnaeus			35	23	25
Perccottus glehni Dybowski		13	24	15	
Total	21	244	349	398	472

The biomass of catch in spring at the Tuanjie Reservoir fluctuated at < 1 g/m^2. The highest biomass was found at site S5 (0.58 g/m^2), the second highest was at site S1 (0.54 g/m^2), and the lowest was at site S2 (0.3 g/m^2) (*Fig. 5*). Overall, among various fish species in the entire river, the biomass of *S. dabryi* Bleeker was the highest, accounting for approximately 11.23%, followed by *L. costata* and *M. bipartitus*, which accounted for 7.8% and 8.58%, respectively. There were significant differences in the species of fish communities in the upstream and downstream of the Tuanjie Reservoir in spring (*Table 4*).

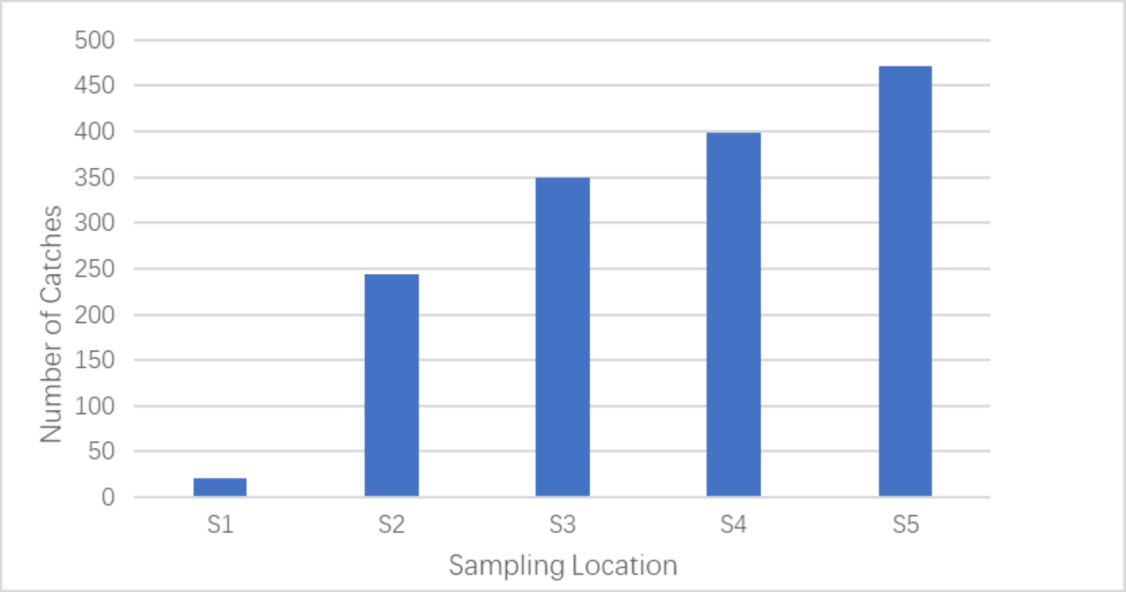

Figure 4. *Number of catches in spring at the Tuanjie Reservoir*

Table 4. *Distribution of spring catch biomass (g/m^2) in the Tuanjie Reservoir*

	S1	S2	S3	S4	S5
Lampetra reissneri (Dybowski)	0.02			0.009	0.01
Ctenopharyngodonidellus (Curier et Valenciennes)		0.03	0.01	0.004	0.01
Phoxinus phoxinus (Linnaeus)					0.04
Phoxinus percnurus (Pallas)		0.03	0.02	0.002	0.02
Phoxinus czekanowskii Dybowski	0.04		0.01		0.04
Phoxinus lagowskii Dybowski				0.015	0.01
Hemiculter leucisclus (Basilewsky)		0.03	0.02	0.015	
Pseudorasbora parva (Temminck et schlegal)		0.008		0.025	0.02
Abbottina rivularis (Basilewsky)				0.023	0.05
Rostrogobio amurensisi Taranetz	0.08		0.03		
Saurogobiodabryi Bleeker	0.12	0.03	0.01	0.046	0.04
Cyprinus (cyprinus) carpiohaematopterus Linnaeus		0.02	0.03	0.054	0.04
Carassius auratus gibelio (Bloch)			0.02	0.035	0.03
Aristichthys nobilis (Richardson)		0.04	0.03	0.048	0.05
Hypophthalmichthys molitrix (Cuvier et Valenciennes)		0.03	0.03	0.045	0.05
Lefua costata (Kessler)	0.12				0.03
Cobitis lutheri Rendahl	0.06	0.03	0.02	0.032	0.01
Cobitis granoci Rendahl		0.04	0.03	0.035	0.02
Misgurnus mohoity (Dybowski)		0.02	0.02	0.025	0.05
Misgurnus bipartitus (Sauvage et Dabry)	0.1	0.005	0.01	0.025	0.03
Silurus asotus Linnaeus			0.03	0.026	0.03
Perccottus glehni Dybowski		0.02	0.02		
Total	0.42	0.3	0.35	0.4	0.5

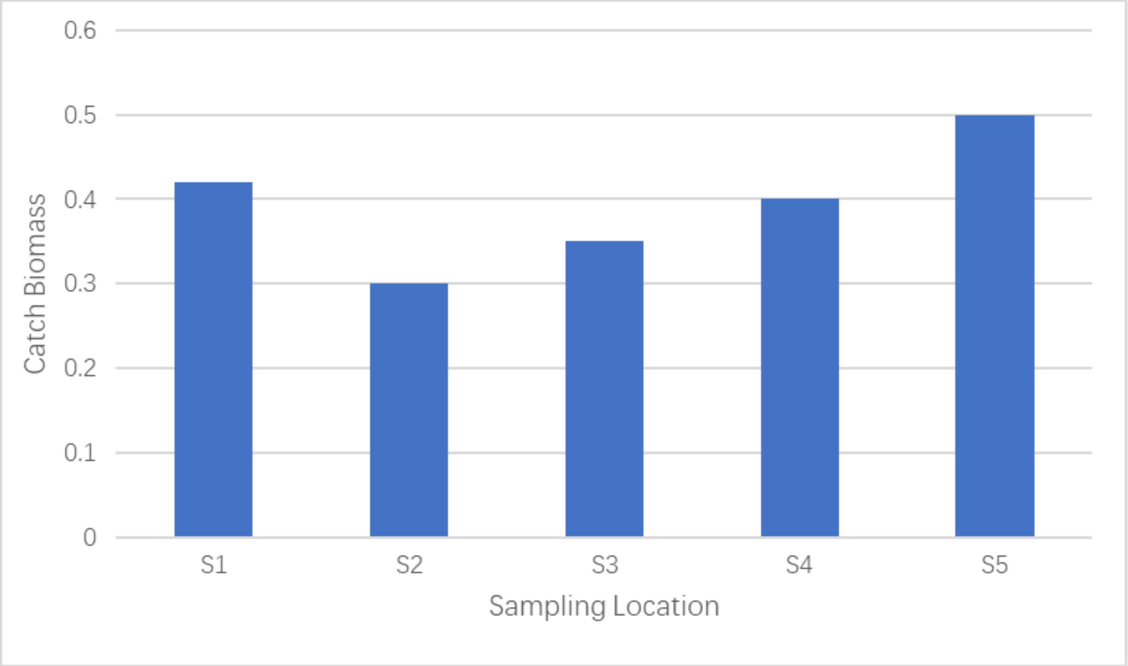

Figure 5. *Spring catch biomass at the Tuanjie Reservoir*

Distribution of catches and biomass in summer

In the summer, a total of 22 species of fish were collected, namely, L. reissneri, C. idellus, P. phoxinus, P. percnurus, P. czekanowskii Dybowski, P. lagowskii Dybowski, H. leucisclus, P. parva, A. rivularis, R. amurensisi Taranetz, S. dabryi Bleeker, C. carpio haematopterus Linnaeus, C. auratus gibelio, A. nobilis, H. molitrix, L. costata, C. lutheri Rendahl, C. granoci Rendahl, M. mohoity, M. bipartitus, S. asotus Linnaeus, and P. glehni Dybowski.

In summer, the number of catches fluctuated between 31 and 491 (*Table 5*), with the highest number of fish caught at site S5 (491), the second highest caught at site S4 (389), and the lowest caught at site S1 (31) (*Fig. 6*). Overall, in the entire reservoir, the three dominant species that accounted for the greatest proportion among various fish species were *C. granoci* Rendahl, *M. bipartitus*, and *S. dabryi* Bleeker, which accounted for 6.89%, 6.31%, and 5.86%, respectively. The number of catches at the S1 sampling point is significantly lower than the number of catches at other sampling points. Except for the catch at the S1 sampling point, there was no significant difference in the fish community structure between the upstream and downstream of the Tuanjie Reservoir.

The biomass of the summer catch in the Tuanjie Reservoir fluctuated between 11.8 g/m^2 and 197.75 g/m^2, with the highest biomass found at site S5 (197.75 g/m^2), the second highest found at site S4 (158.9 g/m^2), and the lowest biomass found at site S1 (11.8 g/m^2) (*Fig. 7*). Overall, *H. molitrix* had the highest proportion of catch biomass among various fish species in the entire river, accounting for 30.88%. The biomass of catch at the S1 sampling point was significantly lower than the biomass of catch at other sampling points. The majority of biomass at site S1 consisted of *C. lutheri* Rendahl and *M. bipartitus*; the biomass at site S2 mainly consisted of *H. molitrix*; the biomass at site S3 mainly consisted of *C. carpio haematopterus* Linnaeus, *A. nobilis*, and *H. molitrix*;

the biomass at site S4 mainly consisted of *C. carpio haematopterus* Linnaeus, *A. nobilis*, and *H. molitrix*; and the biomass at site S5 mainly consisted of *C. carpio haematopterus* Linnaeus, *A. nobilis*, and *H. molitrix* (*Table 6*).

Table 5. *Distribution of catches in summer at the Tuanjie Reservoir (ind.)*

	S1	S2	S3	S4	S5
Lampetra reissneri (Dybowski)		8	2		6
Ctenopharyngodon idellus (Curier et Valenciennes)		14	22	18	34
Phoxinus phoxinus (Linnaeus)		25			
Phoxinus percnurus (Pallas)	4	32	15	16	26
Phoxinus czekanowskii Dybowski			24		23
Phoxinus lagowskii Dybowski			35		
Hemiculter leucisclus (Basilewsky)		23		15	32
Pseudorasbora parva (Temminck et schlegal)	7		12	25	
Abbottina rivularis (Basilewsky)		23		26	24
Rostrogobio amurensisi Taranetz			14	23	
Saurogobio dabryi Bleeker	2	26	13	14	42
Cyprinus (cyprinus) carpio haematopterus Linnaeus		12	36	24	30
Carassius auratus gibelio (Bloch)	4	22		19	33
Aristichthys nobilis (Richardson)		12	19	31	31
Hypophthalmichthys molitrix (Cuvier et Valenciennes)		20	14	24	27
Lefua costata (Kessler)	2		13		32
Cobitis lutheri Rendahl	3	12		35	
Cobitis granoci Rendahl	4	24	24	33	22
Misgurnus mohoity (Dybowski)		14	25	32	42
Misgurnus bipartitus (Sauvage et Dabry)	5	17	32	24	20
Silurus asotus Linnaeus		22	25	7	35
Perccottus glehni Dybowski			12	23	32
Total	31	306	337	389	491

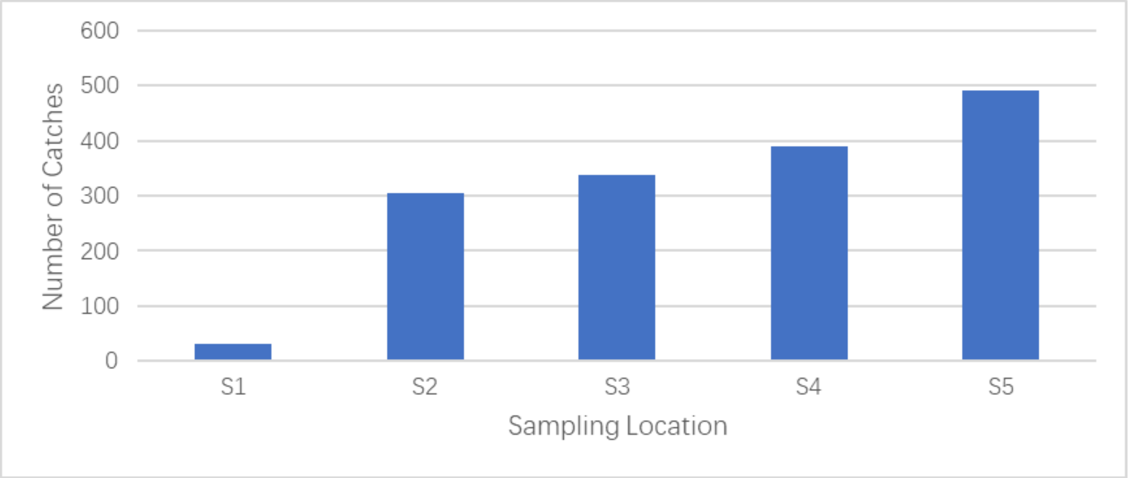

Figure 6. *Summer catch biomass of the Tuanjie Reservoir*

Table 6. *Distribution of catch biomass (g/m^2) in summer at the Tuanjie Reservoir*

	S1	S2	S3	S4	S5
Lampetra reissneri (Dybowski)		0.06	0.009		0.03
Ctenopharyngodon idellus (Curier et Valenciennes)		14	14.4	12	28
Phoxinus phoxinus (Linnaeus)		0.2			
Phoxinus percnurus (Pallas)	0.5	0.3	0.11	0.1	0.19
Phoxinus czekanowskii Dybowski			0.15		0.15
Phoxinus lagowskii Dybowski			0.25		
Hemiculter leucisclus (Basilewsky)		0.7		0.4	0.8
Pseudorasbora parva (Temminck et schlegal)	0.9		0.06	0.1	
Abbottina rivularis (Basilewsky)		0.3		0.3	0.24
Rostrogo bioamurensisi Taranetz			0.19	0.3	
Saurogobio dabryi Bleeker	0.7	0.6	0.22	0.3	0.72
Cyprinus (cyprinus) carpio haematopterus Linnaeus		22	45.4	30	37.8
Carassius auratus gibelio (Bloch)	2.3	0.8		0.5	0.82
Aristichthys nobilis (Richardson)		39	38.9	64	63.3
Hypophthalmichthys molitrix (Cuvier et Valenciennes)		51	26.3	45	52.3
Lefua costata (Kessler)	0.5		0.16		0.38
Cobitis lutheri Rendahl	2.7	0.4		0.8	
Cobitis granoci Rendahl	1.3	0.8	0.58	0.8	0.5
Misgurnus mohoity (Dybowski)		0.5	0.58	0.7	0.95
Misgurnus bipartitus (Sauvage et Dabry)	2.9	0.6	0.79	0.6	0.51
Silurus asotus Linnaeus		9	7.52	2.5	10.4
Perccottus glehni Dybowski			0.24	0.5	0.66
Total	11.8	140.26	135.859	158.9	197.75

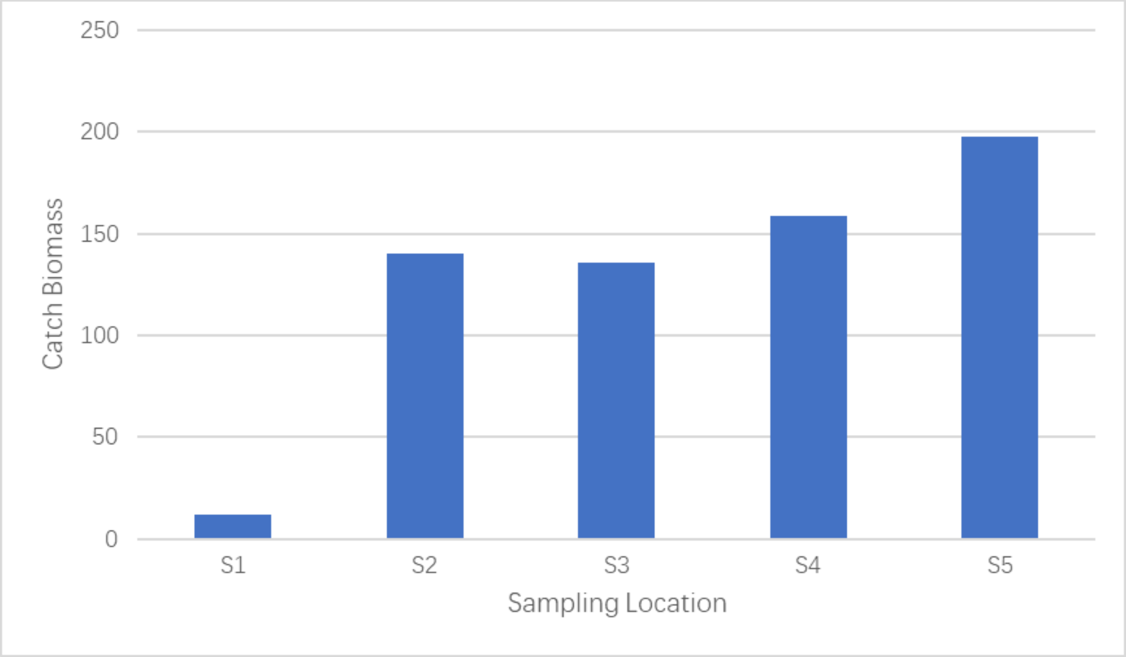

Figure 7. *Summer catch biomass of the Tuanjie Reservoir*

Distribution of catches and biomass in autumn

In the autumn, a total of 22 species of fish were collected, namely, L. reissneri, C. idellus, P. phoxinus, P. percnurus, P. czekanowskii Dybowski, P. lagowskii Dybowski, H. leucisclus, P. parva, A. rivularis, R. amurensisi Taranetz, S. dabryi Bleeker, C. carpio haematopterus Linnaeus, C. auratus gibelio, A. nobilis, H. molitrix, L. costata, C. lutheri Rendahl, C. granoci Rendahl, M. mohoity, M. bipartitus, S. asotus Linnaeus, and P. glehni Dybowski.

In autumn, the number of catches fluctuated between 27 and 576 (*Table 7*), with the highest number of catches at site S5 (576), the second highest at site S4 (464), and the lowest at site S1 (27) (*Fig. 8*). Overall, the three dominant fish species, *A. nobilis*, *H. molitrix*, and *C. carpio haematopterus* Linnaeus, accounted for the highest proportion of catches among all fish species in the entire reservoir at for 9.37%, 9.25%, and 8.41%, respectively. The number of catches at the S1 sampling point was significantly lower than those at other sampling points. Except for the catch at the S1 sampling point, there was no significant difference in the fish community structure between the upstream and downstream of the Tuanjie Reservoir.

Table 7. *Distribution of autumn catches in the Tuanjie Reservoir (ind.)*

	S1	**S2**	**S3**	**S4**	**S5**
Lampetra reissneri (Dybowski)	1			9	5
Ctenopharyngodon idellus (Curier et Valenciennes)		8	6	4	14
Phoxinus phoxinus (Linnaeus)					36
Phoxinus percnurus (Pallas)		13	16	2	22
Phoxinus czekanowskii Dybowski	2		12		36
Phoxinus lagowskii Dybowski				15	13
Hemiculter leucisclus (Basilewsky)		32	23	15	
Pseudorasbora parva (Temminck et schlegal)				25	24
Abbottina rivularis (Basilewsky)				23	46
Rostrogobio amurensisi Taranetz	4		25		
Saurogobio dabryi Bleeker	6	26	14	46	35
Cyprinus (cyprinus) carpio haematopterus Linnaeus		26	25	54	36
Carassius auratus gibelio (Bloch)		13	22	35	32
Aristichthys nobilis (Richardson)		26	30	48	53
Hypophthalmichthys molitrix (Cuvier et Valenciennes)		23	33	45	54
Lefua costata (Kessler)	6	24			25
Cobitis lutheri Rendahl	3	21	23	32	14
Cobitis granoci Rendahl		13	33	35	22
Misgurnus mohoity (Dybowski)		9	21	25	52
Misgurnus bipartitus (Sauvage et Dabry)	5	5	13	25	25
Silurus asotus Linnaeus		22	27	26	32
Perccottus glehni Dybowski		10	15		
Total	27	271	338	464	576

The biomass of autumn catch in the Tuanjie Reservoir fluctuated between 0.34 g/m^2 and 0.58 g/m^2, with the highest biomass found at site S5 (0.58 g/m^2), the second highest at site S1 (0.54 g/m^2), and the lowest at site S3 (0.34 g/m^2) (*Fig. 9*). Overall, in the entire river, *H. molitrix* accounted for the highest proportion of catch biomass among various fish species at 6.76% (*Table 8*).

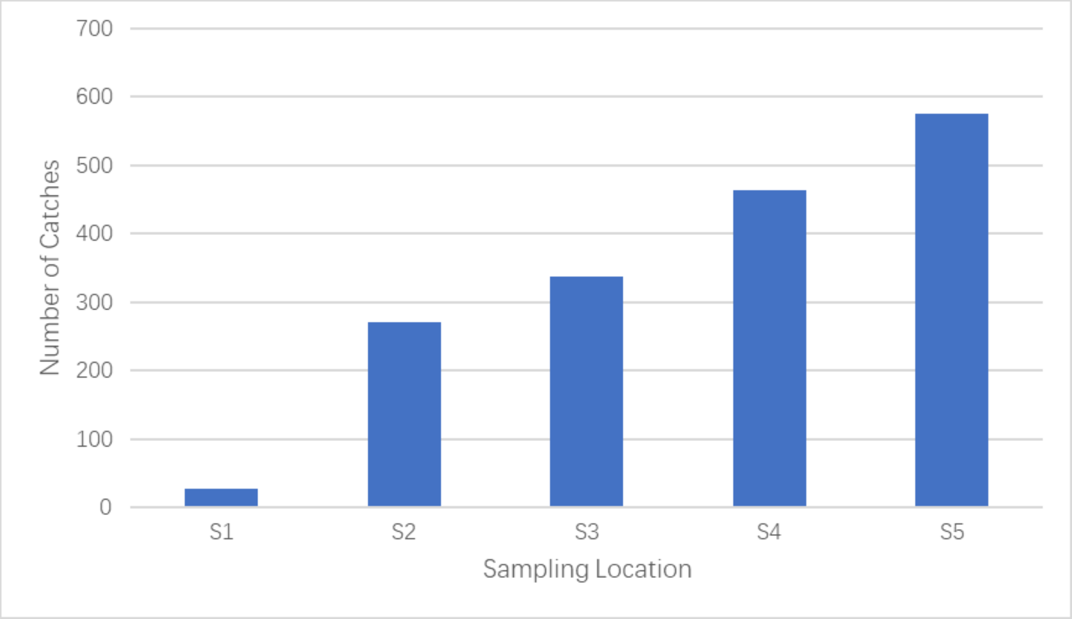

Figure 8. *Summer catch biomass of the Tuanjie Reservoir*

Table 8. *Distribution of catch biomass (g/m^2) in autumn at the Tuanjie Reservoir*

	S1	**S2**	**S3**	**S4**	**S5**
Lampetra reissneri (Dybowski)	0.02			0.009	0.005
Ctenopharyngodon idellus (Curier et Valenciennes)		0.01	0.006	0.004	0.01
Phoxinus phoxinus (Linnaeus)					0.04
Phoxinus percnurus (Pallas)		0.02	0.02	0.002	0.02
Phoxinus czekanowskii Dybowski	0.04		0.01		0.04
Phoxinus lagowskii Dybowski				0.015	0.01
Hemiculter leucisclus (Basilewsky)		0.04	0.02	0.015	
Pseudorasbora parva (Temminck et schlegal)				0.025	0.02
Abbottina rivularis (Basilewsky)				0.023	0.05
Rostrogobio amurensisi Taranetz	0.08		0.02		
Saurogobio dabryi Bleeker	0.12	0.04	0.01	0.045	0.04
Cyprinus (cyprinus) carpio haematopterus Linnaeus		0.04	0.02	0.054	0.04
Carassius auratus gibelio (Bloch)		0.02	0.02	0.035	0.03
Aristichthys nobilis (Richardson)		0.04	0.03	0.048	0.05
Hypophthalmichthys molitrix (Cuvier et Valenciennes)		0.03	0.03	0.045	0.05
Lefua costata (Kessler)	0.12	0.03			0.02
Cobitis lutheri Rendahl	0.06	0.03	0.02	0.032	0.01
Cobitis granoci Rendahl		0.02	0.03	0.035	0.02
Misgurnus mohoity (Dybowski)		0.01	0.02	0.025	0.05
Misgurnus bipartitus (Sauvage et Dabry)	0.1	0.007	0.01	0.025	0.02
Silurus asotus Linnaeus		0.03	0.03	0.026	0.03
Perccottus glehni Dybowski		0.01	0.02		
Total	0.54	0.37	0.34	0.464	0.58

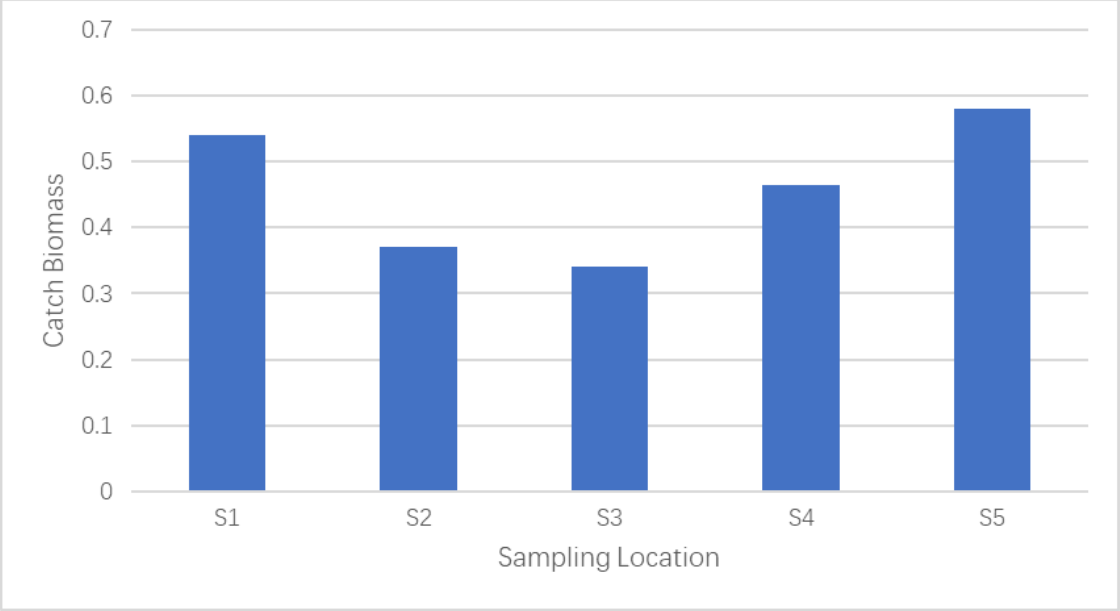

***Figure 9.** Autumn catch biomass of the Tuanjie Reservoir*

Composition of ecological types

The ecological composition of catches in the Tuanjie Reservoir was investigated based on four aspects: fish settlement type, living water layer, feeding habits, and spawning type. The summary is as follows (*Table 9; Fig. 10*). From the perspective of mantissa, *A. nobilis* had the highest mantissa of 356, accounting for 7.55% of the total, followed by *H. molitrix* with a mantissa of 354, accounting for 7.51% of the total, and *L. reissneri* had the lowest mantissa of 38, accounting for 0.81% of the total. From the perspective of ecological types, there were at most 14 species of sedentary fish, 13 species of benthic and omnivorous fish, and at least one species of phytophagous and floating spawning fish.

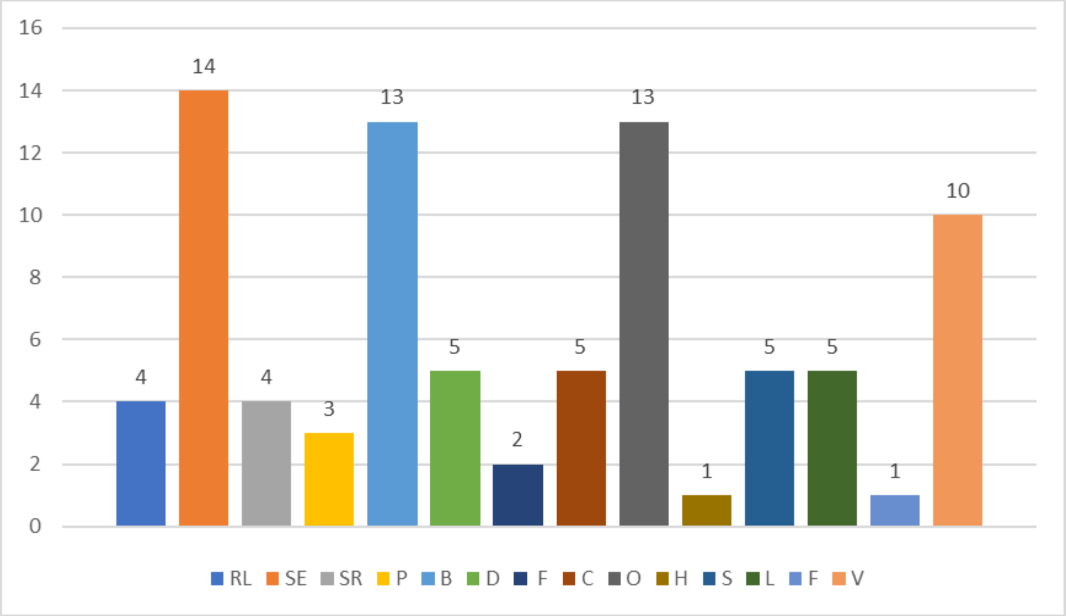

***Figure 10.** Number of fish species of various ecological types*

Table 9. *Ecological types of fish caught in the Muling River Basin*

Catches	Number	Proportion	Settlement type	Living water layer	Feeding habits	Spawning type
Lampetra reissneri	38	0.81%	SE	B	C	V
Ctenopharyngodon idellus	219	4.65%	RL	D	H	L
Phoxinus phoxinus phoxinus	86	1.82%	SR	D	H	V
Phoxinus percnurus	230	4.88%	SR	D	I	V
Phoxinus czekanowskii	109	2.31%	SR	D	P	V
Phoxinus lagowskii	81	1.72%	SR	D	H	V
Hemiculter leucisclus	226	4.79%	SE	P	B	F
Pseudorasbora parva	148	3.14%	SE	B	B	V
Abbottina rivularis	209	4.43%	SE	B	B	S
Rostrogobio amurensisi	89	1.89%	SE	B	P	L
Saurogobio dabryi	311	6.60%	SE	B	B	L
Cyprinus carpio	346	7.34%	RL	B	O	V
Carassius auratus gibelio	235	4.99%	SE	B	O	V
Aristichthys nobilis	356	7.55%	RL	P	Z	L
Hypophthalmichthys molitrix	354	7.51%	RL	P	P	L
Lefua costata	164	3.48%	SE	B	I	S
Cobitis lutheri	245	5.20%	SE	B	B	S
Cobitis granoci	311	6.60%	SE	B	B	S
Misgurnus mohoity	299	6.34%	SE	B	B	S
Misgurnus bipartitus	235	4.99%	SE	B	I	S
Silurus asotus	279	5.92%	SE	B	C	V
Perccottus glehni	144	3.05%	SE	B	C	V

RL: river–lake migration; SE: settled (i.e., non-migratory); SR: anadromous migration; P: upper layer; B: bottom layer; D: middle and lower layers; F: filter-feeder; C: carnivorous; O: omnivorous; H: herbivorous; S: sinking eggs; L: drifting eggs; F: floating eggs; V: viscous eggs

Environmental factor characteristics

The seasonal changes in EC, DO, pH, and NH_4-N were not significant ($P > 0.05$), while the changes in T, ORP, TP, TD, COD, SD, and D were significant ($P < 0.01$) (*Table 10*).

Correlation analysis between fish ecological types and environmental factors

After preliminary selection of environmental factors, a series of main environmental factors affecting fish reproductive activities, such as T, ORP, TN, TP, TD, NO_2-N, NO_3-N, COD, Fe^{3+}, Cu^{2+}, SD, and D, were selected ($P < 0.05$), and RDA analysis was conducted. The results are shown in *Tables 11–14*. *Tables 11–14* show the RDA analysis and statistical characteristics of fish settlement types, living water layers, feeding habits, spawning types, and environmental factors in the Tuanjie Reservoir.

According to *Table 11*, the statistical characteristics of RDA show that the cumulative interpretation rate of Axis 1 and Axis 2 reaches 95.66, indicating that the RDA analysis chart can well reflect the relationship between fish settlement types and environmental factors in the Tuanjie Reservoir.

Table 10. *One-way ANOVA of environmental factors*

	Spring	**Summer**	**Autumn**	***P***
EC (ms/cm)	0.12 ± 0.04	0.29 ± 0.14	0.25 ± 0.11	0.052
DO (mg/L)	7.78 ± 0.27	7.58 ± 0.55	8.84 ± 0.20	0.235
pH	7.38 ± 0.09	7.23 ± 0.17	7.74 ± 0.11	0.418
T (°C)	17.69 ± 1.24	23.16 ± 0.54	9.66 ± 0.95	0.000**
ORP (mv)	31.5 ± 4.2	29.68 ± 9.21	48.22 ± 3.05	0.000**
TN (mg/L)	1.04 ± 0.2	0.92 ± 0.09	0.9 ± 0.09	0.035*
TP (mg/L)	0.7 ± 0.16	0.56 ± 0.05	0.33 ± 0.07	0.000**
TD (mg/L)	0.35 ± 0.09	0.58 ± 0.08	0.17 ± 0.13	0.000**
NO_2-N (mg/L)	0.04 ± 0.01	0.02 ± 0.01	0.02 ± 0.02	0.016*
NH_4-N (mg/L)	0.13 ± 0.01	0.26 ± 0.05	0.14 ± 0.02	0.153
NO_3-N (mg/L)	0.38 ± 0.06	0.3 ± 0.08	0.24 ± 0.06	0.036*
COD (mg/L)	4.44 ± 0.08	3.86 ± 0.16	4.22 ± 0.05	0.008**
Fe^{3+}(mg/L)	0.35 ± 0.04	0.25 ± 0.09	0.42 ± 0.01	0.043*
Cu^{2+}(mg/L)	0.19 ± 0.04	0.15 ± 0.03	0.04 ± 0.02	0.012*
SD (m)	0.69 ± 0.11	0.94 ± 0.2	1.09 ± 0.15	0.000**
D (m)	10.74 ± 4.82	10.58 ± 4.74	9.81 ± 3.98	0.000**

*$P < 0.05$, **$P < 0.01$

Table 11. *RDA analysis and statistical characteristics of fish settlement types and environmental factors in the Tuanjie Reservoir*

Object	**Eigenvalue**	**Type cumulative interpretation rate (%)**	**Type - cumulative interpretation rate of environment (%)**	**Type- environmental correlation coefficient**
Axis 1	0.2564	25.60	79.84	0.6961
Axis 2	0.061	31.69	95.66	0.7334
Axis 3	0.0147	33.19	99.46	0.4787
Axis 4	0.0020	33.38	100	0.2433

According to *Table 12,* the statistical characteristics of RDA show that the cumulative interpretation rate of Axis 1 and Axis 2 reaches 93.77, indicating that the RDA analysis chart drawn can well reflect the relationship between the fish living layer and environmental factors in the Tuanjie Reservoir.

Table 12. *RDA analysis and statistical characteristics of fish living water layer and environmental factors in the Tuanjie Reservoir*

Object	**Eigenvalue**	**Type cumulative interpretation rate (%)**	**Type - cumulative interpretation rate of environment (%)**	**Type- environmental correlation coefficient**
Axis 1	0.2502	25.00	71.00	0.7741
Axis 2	0.0889	33.89	93.77	0.7429
Axis 3	0.0214	36.04	99.25	0.5226
Axis 4	0.0029	36.325	100.00	0.2618

According to *Table 13,* the statistical characteristics of RDA show that the cumulative interpretation rate of Axis 1 and Axis 2 reaches 96.59, indicating that the

RDA analysis chart drawn can well reflect the relationship between fish feeding habits and environmental factors in the Tuanjie Reservoir.

Table 13. *RDA analysis and statistical characteristics of fish feeding habits and environmental factors in the Tuanjie Reservoir*

Object	Eigenvalue	Type cumulative interpretation rate (%)	Type - cumulative interpretation rate of environment (%)	Type- environmental correlation coefficient
Axis 1	0.2594	25.90	84.26	0.6571
Axis 2	0.0470	30.595	96.59	0.7286
Axis 3	0.0113	31.77	99.56	0.4567
Axis 4	0.0016	31.91	100.00	0.2428

According to *Table 14,* the statistical characteristics of RDA show that the cumulative interpretation rate of Axis 1 and Axis 2 reaches 97.24, indicating that the RDA analysis chart drawn can well reflect the relationship between fish spawning types and environmental factors in the Tuanjie Reservoir.

Table 14. *RDA analysis and statistical characteristics of spawning types and environmental factors in the Tuanjie Reservoir*

Object	Eigenvalue	Type cumulative interpretation rate (%)	Type - cumulative interpretation rate of environment (%)	Type- environmental correlation coefficient
Axis 1	0.2787	29.35	89.31	0.7546
Axis 2	0.0152	35.34	97.24	0.7405
Axis 3	0.0113	36.33	99.30	0.5116
Axis 4	0.0103	38.59	100	0.2441

RDA revealed four fish ecotypes and environmental factors. From the perspective of fish settlement types (*Fig. 11a*), D, SD, NO_3-N, and ORP were the main environmental factors. Among them, SW was mainly affected by Cu^{2+}, RL was mainly affected by D and SD, and SR was mainly affected by SD and TD. From the perspective of the living water layer of fish (*Fig. 11b*), D, NO_3-N, ORP, TD, and SD were the main environmental factors. Among them, B and P were mainly affected by D, while D was mainly affected by SD and TD. From the perspective of fish feeding habits (*Fig. 11c*), D, SD, TD, NO_2-N, ORP, and NO_3-N were the main environmental factors. Among them, P, C, I, H, O, and Z were mainly affected by D and SD, while B was mainly affected by TD. From the perspective of fish spawning types (*Fig. 11d*), D, SD, TD, ORP, and NO_2-N were the main environmental factors, with S and V mainly affected by TD, SD, and D, while F and L were mainly affected by Cu^{2+}.

Discussion

Compared with other groups, fish occupy a unique position in the aquatic ecosystem (Song et al., 2023). In general, fish are the target of capture in most cases because fish are the climax community in aquatic ecosystems. There are many kinds of fish with complex interrelationships (Holmlund, 1999). Under the influence of different environmental factors, fish exhibit various adaptive changes to the environment. As the main component of the Tuanjie Reservoir ecosystem, the fish community plays an important regulatory role in the aquatic ecosystem for both material and energy cycling, and in turn, the quality of the aquatic environment affects the fish community structure. Therefore, the quality of the water ecosystem in the reservoir can be reflected by the dynamic changes of the fish community structure characteristics (Wu et al., 2014).

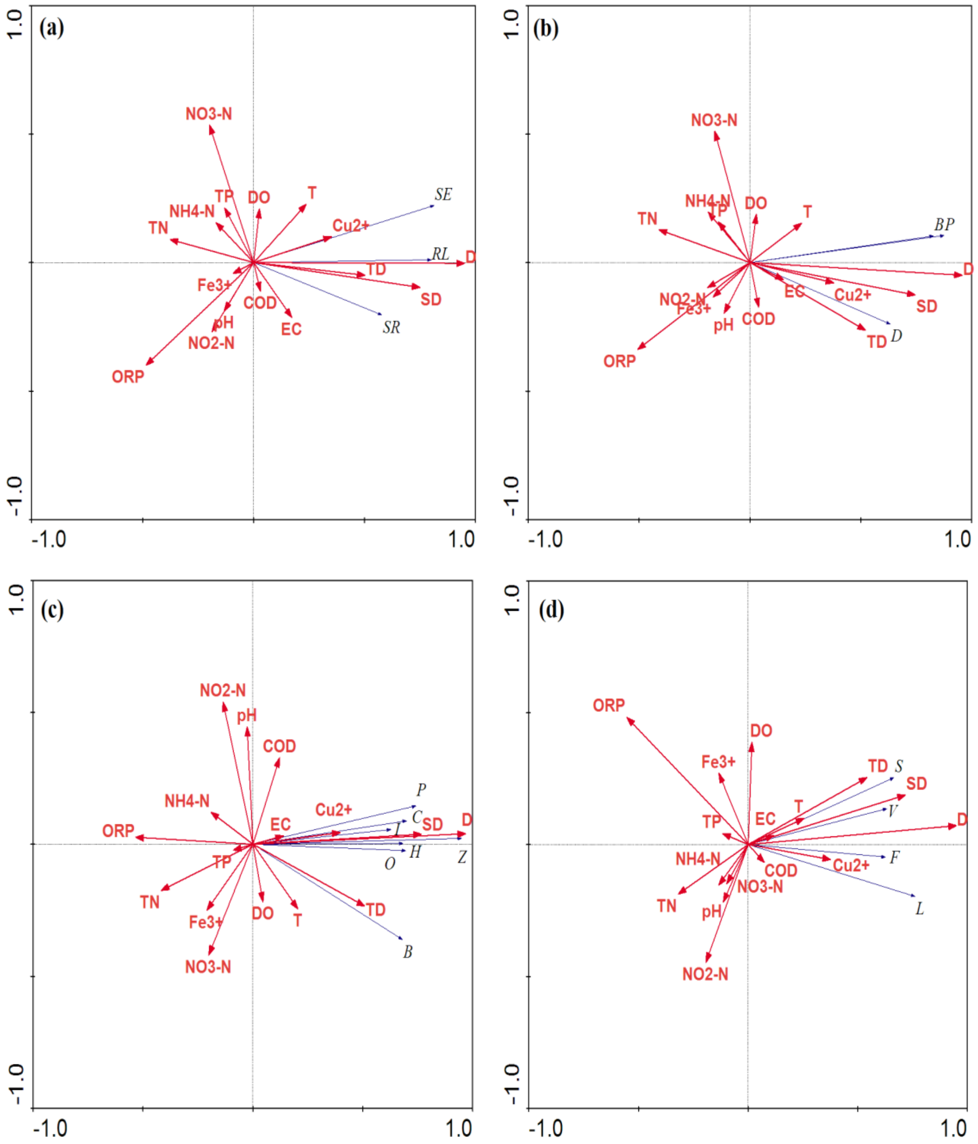

Figure 11. *RDA tri-plots of four fish ecotypes and environmental factors*

In this survey, the catch and catch biomass at the S1 sampling point were much less than those at the other four sampling points, which was also related to the water depth of the sampling point. At the same time, the dam will also destroy the diversity of the living environment of fish, resulting in the decrease or even disappearance of some fish adapted to the rapids, while the number of fish adapted to the slow areas will increase (Kaneh et al., 1997; Degani et al., 1998). In addition, this survey found that there were fewer fish producing planktonic eggs, while there were more fish producing sinking eggs and sticky eggs, which could be due to the slow flow rate of the river. The construction of buildings slows the flow velocity of the Tuanjie Reservoir, which is not conducive to the survival of fish that produce planktonic eggs (Wang et al., 2019). In addition, *H. molitrix*, *A. nobilis*, *C. (cyprinus) carpiohaematopterus* Linnaeus, and other fish accounted for the majority of fish, which indicated that the ecosystem of the local water body had been destroyed, the food chain had been simplified, and the nutrient sources had been lost. The analysis indicated that human factors have a great influence on the fish community structure of the Tuanjie Reservoir. The first is the problem of sewage discharge in production and life. The phenomenon of super-discharge of industrial wastewater often occurs. Domestic sewage without proper treatment is directly discharged into the water and chemical fertilizers, pesticides and garbage manure used in agriculture are discharged into the river at will. These behaviors will lead to eutrophication of water bodies and seriously affect the ecological environment of water bodies (Jia et al., 2013). Furthermore, the construction of water conservancy projects will also affect the ecological environment of the reservoir. The barrier effect of the dam will directly affect the growth and reproduction of migratory fish, and the reservoir will slow down the flow of water, which will not only affect the growth and reproduction of fish producing planktonic eggs, but also lead to the reduction of oxygen content in the water body (Zhou et al., 2022). In addition, the overfishing of river fish by humans has led to the reduction or even disappearance of economic fish and large fish in the water ecological environment, which has led to the phenomenon of species miniaturization or individual miniaturization in the fish community. Under the pressure of strong fishing, the composition of catches will gradually change to species with smaller individuals and low economic value (Xu et al., 2016). Finally, due to the shortage of land resources, rivers are landfilled (Zhong et al., 2005).

To optimize the fish community structure of the Tuanjie Reservoir and protect the diversity of fish, corresponding control measures must be taken. 1. Strengthen administration. The administrative department should strengthen the supervision and management of the water environment according to the relevant laws and regulations of the state, improve the ability of administrative law enforcement, crack down on illegal activities, and purify the water environment. 2. Saving water. Water conservancy departments should take effective measures to improve water use efficiency, control water pollution sources, provide high-quality water sources, and protect the water environment. 3. Reduce pollutant emissions. Industrial enterprises should take various technical measures to reduce pollutant emissions, such as the use of clean technology, recycling technology; agricultural enterprises should take effective measures to control the use of pesticides and reduce pollutant emissions. 4. Improve the water resources protection system. The water conservancy department should increase the protection of water resources, formulate a stricter water resources protection system, prohibit pollution of water bodies, and protect the water environment. 5. Strengthen social responsibility. Enterprises should actively take environmental protection measures in the production process, strengthen environmental protection awareness, publicize environmental protection knowledge, enhance social responsibility, and make positive contributions to the protection of water environment. The main purpose of treating the remaining sludge is to make it harmless and resourceful. Sludge can be used for agriculture or landfill and incineration through a series of operations such as concentration, digestion stability, dehydration, drying, and composting, so as to achieve harmless treatment (Li et al., 2020). At the same time, we should also increase the education of water conservation. Water conservation can not only alleviate the shortage of water resources, but also directly reduce the amount of sewage discharge. Finally, the local filter-feeding fish such as Hypophthalmichthys molitrix and Aristichthys nobilis can be added to filter the plankton in the water body, which can not only control the eutrophication of the river water body, but also supplement the composition of the fish feeding structure of the Tuanjie Reservoir (Yang et al., 2001).

Based on this, according to the requirements of water conservation in lakes and reservoirs, a graded protection zone should be designated in the lake area, and all economic and social activities and production methods that are not conducive to protecting the water conservation function of the ecosystem should be prohibited in the protected area (Liu et al., 2016). At the same time, in the shallow water area of the lake area, the ecological regulation ability of the water body should be enhanced by means of planting aquatic plants. In addition, while protecting water resources and water environment, it can provide strong support for regional ecological protection and high-quality development through scientific proliferation and release, rational use of water bodies, and fish-rearing water to achieve greater ecological benefits (Wang et al., 2008).

Conclusions

This article analyzes the ecological types and environmental factors of four fish species in the Tuanjie Reservoir using the RAD analysis method. From the perspective of fish settlement types, D, SD, NO_3-N, and ORP are the main environmental factors. From the perspective of fish living water layers, D, NO_3-N, ORP, TD, and SD are the main environmental factors. From the perspective of fish feeding habits, D, SD, TD, NO_2-N, ORP, and NO_3-N are the main environmental factors. From the perspective of fish spawning types, D, SD, TD, ORP, and NO_2-N are the main environmental factors. The D and SD factors plays a major role in the ecological environment and environmental factors of fish.

After sampling in three seasons and conducting data analysis of the Tuanjie Reservoir, it was found that the fish community in the reservoir was mainly composed of Cypriniformes, followed by Siluriformes, Perciformes, and Lampetiformes. Comparing the catch in three seasons showed that the S1 sampling point had the lowest catch and biomass, while the S5 sampling point had the highest catch and biomass. The reason for this finding is related to the water depth. This study also found that there were differences in the spatial and temporal patterns of fish communities in the Tuanjie Reservoir. A series of measures should be taken to optimize the fish community structure and protect the water environment of the Tuanjie Reservoir, such as appropriate fishing by the fishing industry and avoiding unsuitable fishing methods, increasing pollution discharge monitoring efforts and the reasonable treatment of sewage, and introducing local species in biological management to supplement the fish community structure of the Tuanjie Reservoir.

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