Macroinvertebrate functional feeding groups and its relationship with environmental factors in the Jingui River of Shenzhen

Chen Sun[1], Lixian Xia[1], Min Zhang[2], Qianyun He[1], Naiqi Yu[1], Hongyong Xiang[1], and haijun Yang[1]

[1]Yunnan University
[2]Shenzhen Guanghuiyuan Environmental Water Co. Ltd.

March 16, 2023

Abstract

The differences in the functional diversity and species diversity of macroinvertebrates can be based to evaluate the changes in local environment. However, there are little available analysis on the effect mechanism of seasons on the functional characteristics of macroinvertebrate communities in the subtropical region. This work compared the functional feeding groups (FFG) of macroinvertebrates in wet season, normal season, and dry season of 2021 in Jingui River in Shenzhen. This work mainly was aimed to comprehend the connection between the environmental driving elements in the Jingui River and the seasonal distribution of the FFG of macroinvertebrates. The highest species diversity and abundance were found among the collector-gatherers (GC), while the largest biomass was observed among the predators. Overall, the functional diversity of the Jingui River exhibited a significantly seasonal change. In particular, the functional diversity decreased in wet season, implying a stronger disturbance. A multiple regression analysis revealed that the species diversity and stream environmental parameters might account for 12.8% - 72.9% of the functional diversity of macroinvertebrates.

Macroinvertebrate functional feeding groups and its relationship with environmental factors in the Jingui River of Shenzhen

Chen Sun[a], Lixian Xia[a], Min Zhang[b], Qianyun He[a], Naiqi Yu[a], Hongyong Xiang[a], Haijun Yang[a, *]

[a] *School of Ecology and Environmental Science, Yunnan University, Kunming* 650091*, China*

[b] *Shenzhen Guanghuiyuan Environmental Water Co. Ltd., Shenzhen* 518000*, China*

Abstract: The differences in the functional diversity and species diversity of macroinvertebrates can be based to evaluate the changes in local environment. However, there are little available analysis on the effect mechanism of seasons on the functional characteristics of macroinvertebrate communities in the subtropical region. This work compared the functional feeding groups (FFG) of macroinvertebrates in wet season, normal season, and dry season of 2021 in Jingui River in Shenzhen. This work mainly was aimed to comprehend the connection between the environmental driving elements in the Jingui River and the seasonal distribution of the FFG of macroinvertebrates. The highest species diversity and abundance were found among the collector-gatherers (GC), while the largest biomass was observed among the predators. Overall, the functional diversity of the Jingui River exhibited a significantly seasonal change. In particular, the functional diversity decreased in wet season, implying a stronger disturbance. A multiple regression analysis revealed that the species diversity and stream environmental parameters might account for 12.8% - 72.9% of the functional diversity of macroinvertebrates.

Keywords: Macroinvertebrate; Functional feeding groups; River ecosystem; Functional diversity

Introduction

The group of macroinvertebrates having the same ecological purpose is called the functional feeding groups (FFG) of macroinvertebrates (Liu et al., 2014). Traditional research on macroinvertebrates focuses more on community structure analysis and *Correspondence:

Corresponding Author: yanghaijun@ynu.edu.cn

species diversity instead of FFG and diversity(Brown et al., 2018). Applying FFG in the research on structure of the macroinvertebrate community helps to evaluate the ecosystem structure and function completely and to simplify the complicated internal relations(Mouton et al., 2020). In this case, differences in FFG of macroinvertebrates can be based to evaluate the mechanism of changes in the local environment(Zhong et al., 2020).

Functional diversity has recently received extensive attention to predict the connections among various ecological processes(Wang et al., 2019). The functional diversity is formed by fundamental variation among the interspecific functional features in clusters and the way those traits react to environmental stresses and interference(Baker et al., 2021). Evaluating the aquatic ecosystems is of high significance due to the variety of its forms and habits, which may respond to the environmental pressures in multiple ways(Ochieng et al., 2019). For examples, Talley used functional categories to examine the connection between macroinvertebrate habitats and communities in California Bay tidal flats(Talley et al., 2000), and Thrush investigated how macroinvertebrates contribute to the intertidal ecology(Thrush et al., 2006). The functional diversity is depended by the ability of biological communities to predict the rapidity and dependability of environmental processes(Mason et al., 2005). As a combination of many environmental factors, riverbed structure influences the community structure and functional diversity of macroinvertebrates directly or indirectly(Zhu et al., 2020). Meanwhile, the functional diversity displays greatly different functional features and can indicate how those traits react to environmental interference(Zhong et al., 2020). FFG and functional diversity indices demonstrate the responses to environmental stressors and reflect the changes in community organization(Li et al., 2022). In addition, functional diversity is generally handled by unique categories in the river benthic ecosystems(Wang et al., 2019). The environmental status depends on the biological traits that show how to respond to pressure from the external environment(Lavorel et al., 1997). Mason believed that the functional variety can't be effectively represented by a single index(Mason et al., 2005). Electing correct indexes is the essential for creating a functional diversity biological assessment system(Jiang et al., 2021). Villeger presented three multidimensional indices of consecutive function features to investigate the three distinct aspects of the functional diversity(Villeger et al., 2008). Currently, the river benthic habitats are rarely mentioned, and the functional diversity indices are primarily selected to investigate the terrestrial plant ecosystems(Chen et al., 2018; Liu et al., 2019).

The Jingui River is the secondary tributary of the Pingshan River, which is included in the Dongjiang River system. The Jingui River Basin accounts for roughly 50% of the area of the Chi'ao Reservoir and is the primary source of the reservoir. The ecological environment of the Jingui River has been somewhat put in danger by year-round sediment deposition, mountain torrents, and haphazard human activity. The Shenzhen Municipal Bureau of Planning and Natural Resources, therefore, started a comprehensive renovation for the limited watershed of the Jingui River in September 2020, which primarily consisted of flood control and ecological restoration. This work evaluated the biological characteristics and FFGs of the macroinvertebrates in the Jingui River, and analyzed the connection between species diversity and functional diversity. Results in this work may offer some useful information for assessing the community structure and ecosystem stability of the macroinvertebrates.

Materials and methods

Study area and macroinvertebrate sampling

The Jingui River was situated in the Pingshan New District of Shenzhen, Guangdong Province, China (Fig. 1). The Pingshan River Basin is affected by a subtropical marine monsoon climate, and the average annual temperature and precipitation are 22°C and 1,984 mm, respectively. The river originates on the southern slope of Tianxin Mountain and flows from southeast to northwest before accessing the Chi'ao Reservoir.

Macroinvertebrates in the Jingui River were sampled in July (wet season), October (normal season), and December (dry season) in 2021 using a Surber sampler (30 × 30 cm, 500 μm mesh) from three quantitative replicates. The samples covered the most representative macroinvertebrate microhabitats of each site. The sampled macroinvertebrates were preserved in 75% ethanol and then recognized and categorized in the laboratory with a stereo microscope (Olympus SZX7). The FFGs were employed to further classify the macroinvertebrates into shredder (SH), collector-filterer (FC), collector-gatherer (GC), scraper (SC) and predator (PR)(Lin et al., 2022).

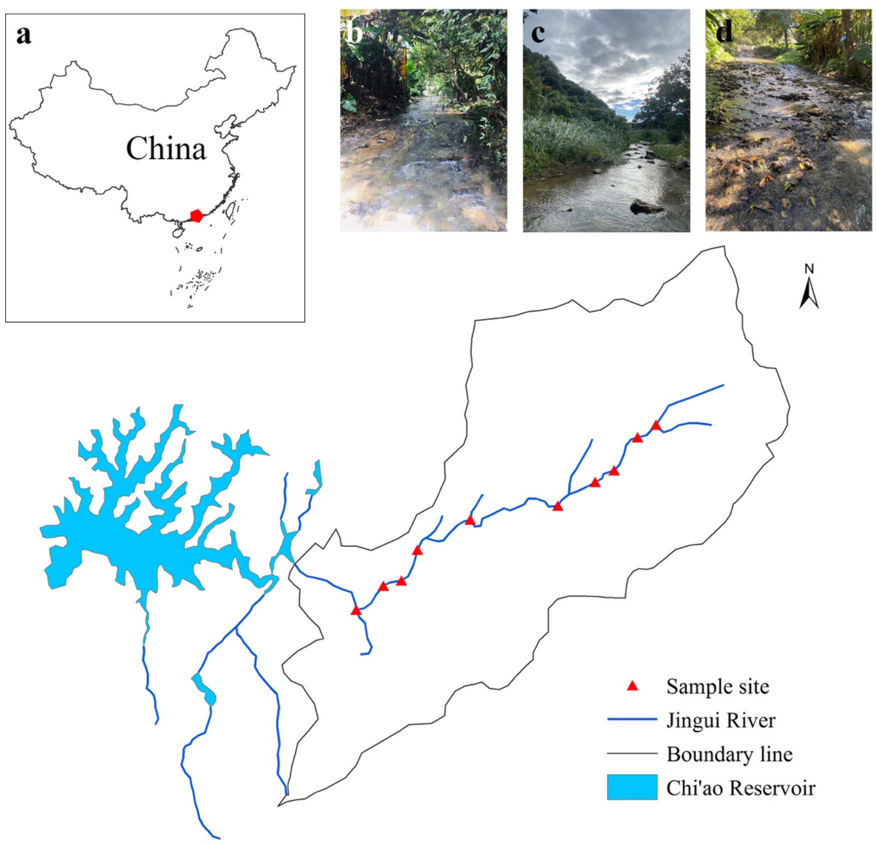

Fig. 1. Map showing the Jingui River Basin located in the People's Republic of China(a); The wet season(b). The normal season(c). The dry season(d).

Environmental factors

The water temperature (WT, °C), conductivity (Cond, μS/m), dissolved oxygen (DO, %), ammonia nitrogen (NH_4^+-N, mg/L), and Nitrogen (NO_3^--N, mg/L) were measured in situ using a portable multi-parameter probe water quality analyzer (YSI Professional Plus, USA). The turbidity (Tur, NTU) and pH value were measured on-site with a portable turbidimeter (Hach 2100Q, China) and a portable pH meter (Ohaus ST20, China), respectively. The water velocity (Vel, m/s) was measured by a portable velocity analyzer (LS-300A, China), and water depth and river width were measured using a graduated measuring rod and a laser rangefinder (Trueyard SP1500H, China). The integrated water samples were collected at each location and then stored in a cool box before arriving at the laboratory to determine the chemical compositions, including total nitrogen (TN), total phosphorus (TP), and chemical oxygen demand (COD_{Mn}).

The detrital and macrophyte cover in each site was investigated by wading and expressed as a percentage. Substratum composition was visually evaluated and expressed as a percentage based on the following categories: boulder (> 256 mm), cobbles (64 - 256 mm), pebbles (32 - 64 mm), gravel (2 - 32 mm), and sand and silt (< 2 mm)(Lin et al., 2022).

Data analysis

Parameters based on the macroinvertebrate data and identifications of three inter seasonal differences were subjected to the one-way analysis of variances (Tomanova et al.). The Pearson correlation analysis (PCA) was employed to analyze the relationship between macroinvertebrate abundance, biomass, and environmental factors of the Jingui River based on the International Business Machine (IBM) Statistic Package for Social Science (SPSS) 24.0. The species diversity indices included species richness (S), the Shannon-Wiener diversity index (H')(Shannon, 1997), the Margalef's richness index (d_M)(Margalef, 1978), the Pielou's evenness index (J)(Pielou, 1966), the Simpson's diversity index (D)(Simpson et al., 1997) and dominance index (Y)(Yan et al., 2017). They all were calculated by using the PRIMER 6.0.

The functional diversity (FD) indices included functional richness (FRic), functional evenness (FEve), functional dispersion (FDis), and Rao, a secondary entropy (RaoQ index) in this work. FRic and FEve represent the amount and regularity of niche space occupied by the community, respectively, which were determined by the distribution of each species' abundance through niche space. FDis is a multiple simulation of weighted average absolute deviation and is not affected by the species richness. RaoQ reflects the community diversity and distinction(Baker et al., 2021; Casanoves et al., 2011). The "dbFD" function from the functional diversity package in R (version 4.0.0) was selected to construct the functional diversity index system.

The relations among species diversity, physicochemical characteristics, and functional diversity were examined using the stepwise multiple regression analysis. Before analysis on the selected predictors, the potential collinear predictors were identified and removed (R[?]0.70), and the significance level was set at 0.05(Xiang et al., 2022). The data that support the findings of this study are openly available in repository name "figshare" at http://doi.org/10.6084/m9.figshare.22277359.

Results

3.1 Environmental variables

Environmental factors of the Jingui River exhibited significant changes in wet season, normal season, and dry season (Table 1). Great differences were detected in WT, Vel, Cond, NH_4^+-N, NO_3^--N, TN, TP, and COD_{Mn} of the river in the three seasons (P <0.05). WT, Cond, NO_3^--N, TP, TN, and pH value reached peaks in wet season. By contrast, DO and NH_4^+-N were higher in dry season than those in wet season and normal season. The river bottom environments exhibited considerable variation among Cobble, Macrophytes, Moss, Woody debris, and leaf packs (P <0.05). The remaining environmental factors presented no significant differences.

Table 1 Environmental factors of the Jingui River in three different seasons.

Factors	Wet season	Normal season	Dry season	F	*P*
WT (°C)	26.28±1.17a	24.67±0.95b	15.91±0.94c	**291.179**	**<0.001**
Dep (m)	20.71±9.14a	24.37±8.95a	17.18±7.53a	1.751	0.192
Wid (m)	4.37±1.54a	5.02±1.69a	3.53±1.64a	2.138	0.137
Vel (m/s)	0.20±0.06b	0.55±0.09a	0.11±0.05c	**103.141**	**<0.001**
DO (%)	8.18±0.71b	9.14±4.15ab	10.76±0.98a	2.938	0.069
Cond (μS/cm)	106.59±38.73a	68.65±20.36b	65.13±17.38b	**7.341**	**0.003**
NH_4^+-N (mg/L)	0.06±0.03b	0.03±0.01b	0.18±0.08a	**25.968**	**<0.001**
NO_3^--N (mg/L)	1.64±0.66a	0.55±0.24b	0.29±0.21b	**29.244**	**<0.001**
TP (mg/L)	0.04±0.03a	0.02±0.01a	0.03±0.02a	1.666	0.207
TN (mg/L)	0.80±0.13a	0.48±0.09b	0.52±0.42b	**4.835**	**0.016**
Tur	2.94±2.28a	4.47±2.30a	3.71±1.21a	0.738	0.487

Factors	Wet season	Normal season	Dry season	F	*P*
pH	7.25±0.12a	6.79±0.49b	6.40±0.66b	**8.657**	**0.001**
COD_{Mn} (mg/L)	6.17±2.32b	11.33±5.48a	5.49±3.27b	**6.873**	**0.004**
Boulder (%)	6.09±2.43	5.76±3.21	4.50±2.71	0.086	0.918
Cobble (%)	54.00±3.69a	42.72±3.98ab	38.30±4.86b	**3.769**	**0.035**
Pebbles (%)	0.00±0.00	2.12±2.12	0.30±0.30	0.828	0.447
Gravel (%)	18.81±2.59	24.85±6.52	26.50±3.45	2.269	0.121
Sand and silt (%)	20.18±4.25	26.82±5.16	29.80±6.15	0.898	0.419
Shading (%)	47.09±7.03	50.76±7.08	48.46±8.09	0.065	0.937
Deposition and scouring (%)	24.27±5.72a	9.24±1.94b	23.10±5.55a	3.245	0.053
Macrophytes (%)	1.00±0.47b	9.09±2.41a	8.72±2.43a	**5.482**	**0.010**
Moss (%)	21.91±8.30a	2.58±0.72b	11.72±3.31ab	**3.458**	**0.045**
Algae (%)	5.45±2.92	0.00±0.00	1.70±1.28	2.280	0.120
Woody debris and leaf packs (%)	6.91±2.01a	3.48±0.97a	20.98±3.86b	**13.630**	**<0.001**

Note: WT: Water temperature, Dep: Depth, Wid: Width, Vel: Velocity, DO: Dissolved oxygen, Cond: Conductivity, NH_4^+-N: Ammonium nitrogen, NO_3^--N: Nitrate nitrogen, TN: Total nitrogen, TP: Total phosphorus, Tur: Turbidity, pH: Potential of hydrogen, COD_{Mn}: Chemical oxygen demand. Values are expressed in the form of means ± standard deviation. Different lowercase letters in the same row indicate significant differences among different seasons (P <0.05).

Table2. Results of Pearson correlation for stream physicochemical characteristics

Factors	WT	Dep
Dep	0.309	
Wid	**0.388***	**0.540****
Vel	**0.475****	0.187
DO	**-.449***	-0.169
Cond	**0.514****	**0.364***
NH_4^+-N	**-.697****	-0.088
NO_3^--N	**0.671****	0.241
Turb	0.066	0.291
TN	0.014	-0.007
TP	0.337	-0.089
pH	**0.542****	0.302
COD_{Mn}	0.302	0.125
Significant at 0.05 level. ** Significant at 0.01 level.	*Significant at 0.05 level. ** Significant at 0.01 level.	*Significant a

The Pearson correlation results of the environmental factors revealed that many environmental factors are closely related. Table 2 reflected that the WT was highly positively correlated to Wid, Vel, Cond, NO_3^--N, and pH value and negatively associated with DO and NH_4^+-N. Vel was significantly positively correlated to COD_{Mn} and negatively associated with NH_4^+-N. Cond and NO_3^--N presented significant positive correlations.

3.2 Macroinvertebrate communities and functional feeding groups

During the sampling, 116 species comprising 3 phylum, 6 classes, 14 families, and 96 genera were observed and classified into annelids (2.25%), mollusks (8.99%), and arthropods (88.76%). Species with relative abundance exceeding 2% were dominant ones(Yan et al., 2017), which changed significantly among different seasons (Table 3). A total of 34 dominant species were identified (20 in wet season, 28 in normal season, and 24 in dry season). *Enochrus sp.* and *Elmomorphus brevicornis Sharp* were the only common dominant species in wet season.*Corbicula fluminea, Ephemerella sp., Brachythemis leucosticte,*and *Nehalennia speciosa* were in normal season. *Radix swinhoei and Micrasema sp.* were in dry season.

Table3. Dominant macroinvertebrate species and their dominance index in each season

FFG	Dominant species	Wet season	Normal season	Dry season
FC	*Simulium aemulum Rubtsov*	0.068	0.023	0.078
	Hydropsyche sp.	0.053	0.053	0.207
	Philopotamus sp.	0.152	0.308	0.069
	Calamoceras sp.	-	0.028	0.027
	Corbicula fluminea	-	0.138	-
GC	*Caridine denticulate sinensis*	0.156	0.372	0.140
	Chironominae sp.	0.504	0.107	0.280
	Orthodoclinae sp.	0.057	0.049	0.043
	Hexatoma (Eriocera) sp.	-	0.064	0.027
	Baetis sp. A	0.156	0.054	0.048
	Paraletophlebia sp.	0.065	0.064	-
	Ephemera pulcherrima Eaton	-	0.034	0.066
	Caenis sp.	-	0.033	0.082
	Ephemerella sp.	-	0.027	-
	Enochrus sp.	0.027	-	-
	Eriocheir sinensis H. Milne Edwards	0.036	0.031	-
	Radix swinhoei	-	-	0.021
PR	*Tanypodinae* sp.	0.100	0.102	0.189
	Paragnetina sp.	0.034	-	0.041
	Onychogomphus viridicostus Oguma	0.047	0.039	0.064
	Brachythemis leucosticta	-	0.038	-
	Macromia sp.	-	0.049	0.077
	Nehalennia speciosa	-	0.022	-
	Protohermes grandis Thunerg	-	0.026	0.038
SC	*Glossosoma* sp.	-	0.051	0.050
	Cinygmula sp.B	0.034	0.032	0.024
	Cyphon sp.	0.029	0.040	-
	Elmomorphus brevicornis Sharp	0.034	-	-
	Limnius	0.025	-	0.029
	Semisulcospira cancellata	0.026	0.047	0.066
	Melanoides tuberculata	0.057	0.068	-
	Bellamya purificata	0.029	0.025	0.024
SH	*Micrasema* sp.	-	-	0.091
	Stenocolus sp.	-	0.046	0.029

3.3 Biodiversity characteristics of macroinvertebrates

The overall distribution structure of the FFGs of macroinvertebrates in the Jingui River in dry season showed a higher abundance than that in the wet season and normal season (Fig. 2a). The species spanning five FFGs (FC, GC, PR, SC, and SH), were found in this survey.

Fig. 2 shows the variation in abundance and biomass of the five FFGs throughout the survey. As it demonstrated, all five FFGs fluctuated apparently with the season changes in abundance (Fig. 2a). SH showed the least seasonal variability and presented an increase in biomass in all three seasons. In contrast, GC exhibited the least abundance in normal season and most abundance in wet season; while SC, PR, and FC showed the most abundance in dry season and the least in normal season.

On the other hand, the biomass displayed different relative patterns in FFGs (Fig. 2b). The biomass of GC was comparatively high, with the lowest value in wet season and a significantly higher value in dry season. In contrast, biomass of SC is the highest in wet season compared with that in other seasons. In dry season, the biomass of PR displayed the most significant value. FC and SH showed apparent seasonal differences, and the biomass values in dry season were the highest.

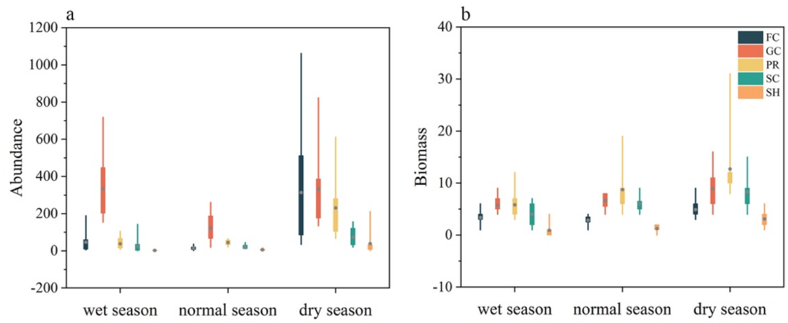

Fig. 2. Seasonable distribution of abundance and biomass of FFGs in the Jingui River

The Pearson correlation analysis revealed that the abundance of macroinvertebrates was positively correlated with COD_{Mn}in normal season and with TN in dry season. In contrast, biomass exhibited negative correlations with WT, Cond, and NO_3^--N in wet season, complete relationships with WT, Cond, and NO_3^--N in normal season, and positive an association with TN in dry season (Table 4).

Table4.Results of Pearson correlation analysis for abundance of macroinvertebrates, biomass, and environmental factors in the Jingui River in three seasons

		WT	Dep	Wid	Vel	DO	Cond	NH_4^+-N	NO_3^--N	Tur	T
Wet season	Abundance	0.240	-0.168	-0.346	-0.461	-0.232	-0.226	0.177	-0.462	-0.397	-0
	Biomass	**-0.769****	-0.146	-0.369	-0.248	0.380	**-0.679***	-0.500	**-0.655***	-0.453	0.
Normal season	Abundance	0.165	0.123	0.251	0.027	0.209	0.260	0.279	0.360	0.381	0.
	Biomass	**-0.819****	-0.369	-0.617	0.259	0.338	**-0.642***	-0.317	**-0.652***	-0.496	0.
Dry season	Abundance	0.439	-0.156	0.283	-0.218	**-0.684***	0.064	0.086	-0.186	0.523	-0
	Biomass	0.482	-0.513	-0.520	0.211	-0.337	-0.587	-0.564	-0.616	0.569	-0

*Significant at 0.05 level.

** Significant at 0.01 level.

Statistical analysis on temporal pattern of the FFG of macroinvertebrate communities revealed that the macroinvertebrates increase significantly in the Shannon-Wiener index and Pielou's evenness in normal season, and decrease in dry season. The Margalef's richness index increased gradually and exhibited a significant interaction in different seasons.

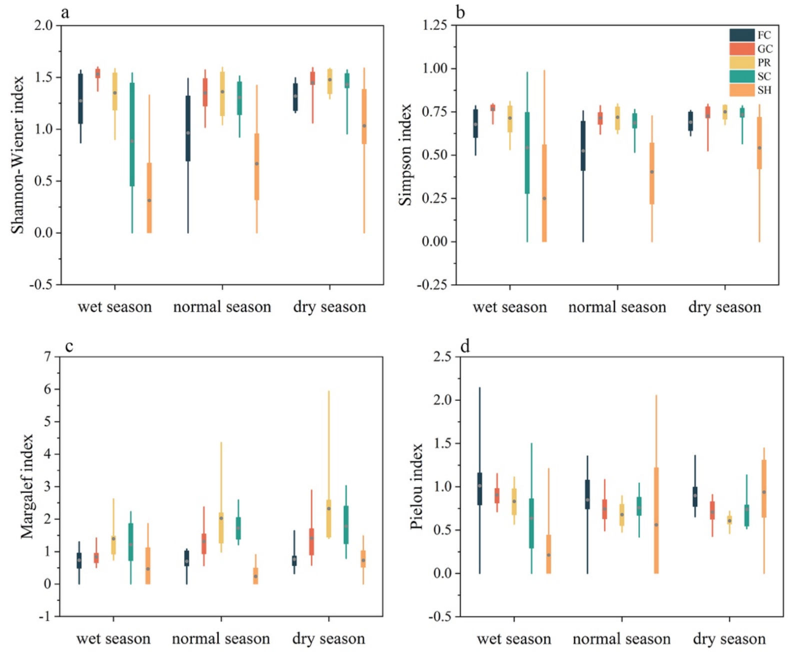

Fig. 3. Seasonal variations in diversity indexes of FFG of macroinvertebrates in Jingui River.

3.4 Relationship between species diversity and functional diversity

Using stepwise regression analysis to study the impact of species diversity on functional diversity, the lowest values of FEve and RaoQ were observed in wet season, and those of FRic and FDis were in normal season and dry season, respectively. FEve, FDis, and RaoQ showed the highest values in normal season, and FRic showed it in dry season (Fig. 4). Species richness varied greatly among Jingui river, ranging from 53 to 96 in each season, and FRic varied even more profoundly, ranging from 0.01 to 80.544 in each season (Fig. 4a). Moreover, species richness was significantly positively related with functional richness ($R^2 = 0.344$, $p < 0.001$; Fig. 5a). In addition, it indicated a rather strong correlation between FEve and Margalef index ($R^2 = 0.366$, $p< 0.001$; Fig. 5b). FDis was strongly correlated with Simpson index ($R^2 = 0.208$, $p < 0.01$; Fig. 5c). FDis varied between 0.066 and 0.271, and RaoQ varied between 4.294 and 13.445. Although RaoQ was also significantly positively related with Simpson index ($R^2 = 0.234$,$p < 0.01$; Fig. 5d), FDis was on average lower than RaoQ.

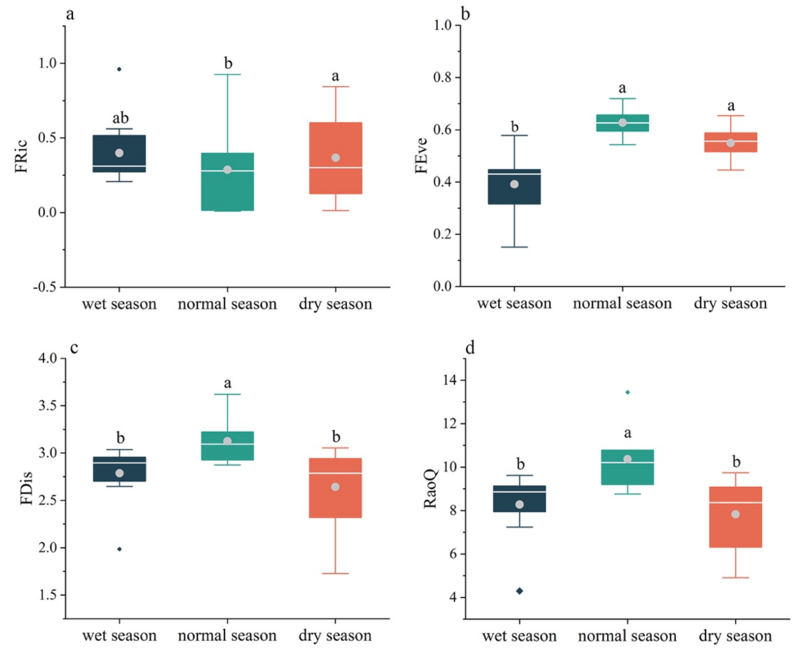

Fig. 4. Functional diversity of macroinvertebrates in the Jinguhi River

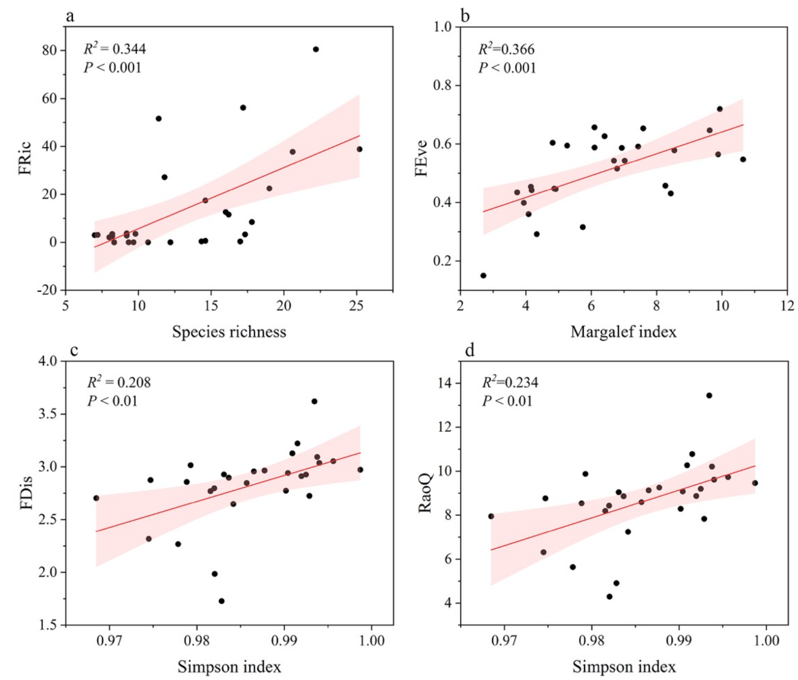

Fig. 5. Linear regression of the relationship between species diversity and functional diversity. The shaded areas are the 95% confidence

Intervals (Only P < 0.5 in the figure)

Discussion

4.1 Seasonal changes in community structure of macroinvertebrates

Community structure and functional diversity of macroinvertebrates can be affected by various environmental factors, and subjected to significant temporal and spatial variations(Sterling et al., 2016). Meanwhile, the spatiotemporal distribution of the macroinvertebrate communities can be affected by both hydrological and sedimentary conditions(Dou et al., 2022). Macroinvertebrates mostly inhabit the sediments or layers of river water-soil interface(Tews et al., 2004). Besides, the physical, chemical, and biological environments of the sediment all shared the community distribution(Schmera et al., 2017).

The population dynamics of macroinvertebrates are influenced by many factors like environmental variables(Magni et al., 2015). In the present study, affected by the subtropical marine monsoon climate, the Jingui River suffers from continuous rainfall in wet season, which is the primary natural disturbance to the river, resulting in more incredible flow velocity and changes in wet width. The compositions of macroinvertebrate communities are frequently influenced by flow velocity and are suitable for the survival of species that require different velocities and temperatures(Zhong et al., 2020). The water temperature and transparency are beneficial for the growth and reproduction of aquatic organisms(Jiang et al., 2021). The water velocity in dry season is slow, which is conductive to accumulation of sediments. Therefore, it provides habitats to predators, such as Plecoptera and Trichoptera, which are adapted to the riparian habitats(Chen et al., 2020). In this case, the number of species and quantity of zooplankton and aquatic vegetation increase dramatically, and the material basis and suitable habitats are provided to the macroinvertebrates with various life habits(Yang et al., 2017). Abundant material bases and complex habitats maintain the abundance of macroinvertebrates and the stability of ecosystem(Allen et al., 2002).

The environmental factors greatly affect the reproduction, growth, and population succession of macroinvertebrates, thus influencing the community structure and function of the entire stream ecosystem(Li et al., 2020). The distribution of FFG can be effectively reflected by classification of river nutrition which can be classified based on structure of FFG(Kelly et al., 2002). Meanwhile, macroinvertebrates can adapt to different environmental conditions by changing their feeding modes(Li et al., 2022). The abundance of FC increased in dry season, which indicated that a stable water flow rate is advantageous for the survival of the FC which are sensitive to disturbance and velocity. GC exhibited the most abundance in wet season when the organic matter fragments were relatively high(Yang et al., 2017). The results confirmed that increased collectors in the Jingui River were induced by the relatively abundant food resources. The quantity of periphytons, the essential food sources for scrapers, would inevitably increase in wet season, which improved the light usage of the stream(Zhong et al., 2020). Therefore, the exact potential mechanisms leading to seasonal dynamics of macroinvertebrates are worth further study.

4.2 Relative importance of species diversity and functional diversity

Functional diversity performance analysis of biological response to environmental drivers has already been extensively applied to the macroinvertebrate ecosystems recent years(Baker et al., 2021). Compositions of the functional diversity are becoming more important, as revealed in many studies(Schmera et al., 2017; Zhang et al., 2019). In the meantime, studying the relationship between species diversity and functional diversity is essential to investigate the effects of biodiversity on ecosystems(Alric et al., 2022).

The low FRic value is attributed to not full utilization of the resources available in the community(Erasmus et al., 2021). Meanwhile, it means that the species utilizing the advantages of these circumstances disappear due to the environmental conditions, reducing the buffering of the environmental fluctuations and weakening the ability of the community to resist invasion(Mouton et al., 2020). Simulation data of Mouchet revealed that the FRic value rises with increase in number of species(Mouchet et al., 2010), while different conclusion was reached in this study. Because there are more macroinvertebrates with high FRic value in wet season and dry season. FEve shows an abundance distribution in the ecological niche space of the community to effectively utilize all resources(Zhang et al., 2019). A low FEve value suggests that the resource is underutilized or overutilized, which can reflect the productivity, stability, and intrusion resistance. Correlation analysis revealed that the FEve positively correlates with S , H', and d_M . Under the moderate to severe interference, the functional diversity and species diversity negatively correlate with the results above(Baker et al., 2021). FDis is the average distance between the centroid of all species and each species' traits in the multidimensional trait space, and it is a more intuitive functional diversity index, which is closely associated with RaoQ(Mason et al., 2005). Meanwhile, relationship between the functional diversity and the species diversity varied with different ecosystems. For example, Devictor found that the functional diversity decreased with increased abundance of species(Devictor et al., 2010). The analysis results told that the functional diversity showed a poor fitness with species diversity ($R^2 < 0.366$), indicating a more complex nonlinear relationship between them. Zhang believed that the nonlinear relationship between them is essential because "functional diversity can provide more special information different from species diversity"(Zhang et al., 2015).

Conclusion

In this study, it was found that the community composition of macroinvertebrates in the Jingui River strongly fluctuated from wet season to dry season. GC were highly abundant, while SH were only limitedly presented. In normal season, the special environment with high depth and velocity increased the FEve, FDis, and RaoQ values. In dry season, the high DO and NH_4^+-N upregulated the FRic value. The results in this study suggested that the seasonality and hydrologic conditions strongly influenced the FFG and functional diversity of macroinvertebrates in the Jingui River. They built a foundation for future research on resource conservation and ecological monitoring.

Acknowledgments

This research was supported by the National Natural Science of Foundation of China (32101310), Research Foundation for Introduction of Talents of Yunnan University (CZ21623201), and China Postdoctoral Science Foundation (2021M692728).

References

Allen A.P., Brown J.H., Gillooly J.F. (2002). Global biodiversity, biochemical kinetics, and the energetic-equivalence rule. Science, 297(5586), 1545-1548.

Alric B., Geffard O., Chaumot A. (2022). Metal bioavailable contamination engages richness decline, species turnover but unchanged functional diversity of stream macroinvertebrates at the scale of a French region*. Environmental Pollution, 308.

Baker N.J., Pilotto F., Haubrock P.J., Beudert B., Haase P. (2021). Multidecadal changes in functional diversity lag behind the recovery of taxonomic diversity. Ecology and Evolution, 11(23), 17471-17484.

Brown L.E., Khamis K., Wilkes M., Blaen P., Brittain J.E., Carrivick J.L., Fell S., Friberg N., Fuereder L., Gislason G.M., Hainie S., Hannah D.M., James W.H.M., Lencioni V., Olafsson J.S., Robinson C.T., Saltveit S.J., Thompson C., Milner A.M. (2018). Functional diversity and community assembly of river invertebrates show globally consistent responses to decreasing glacier cover. Nature Ecology & Evolution, 2(2), 325-333.

Casanoves F., Pla L., Di Rienzo J.A., Diaz S. (2011). FDiversity: a software package for the integrated analysis of functional diversity. Methods in Ecology and Evolution, 2(3), 233-237.

Chen H., Zhu Y., Liu G. (2020). Characteristics of zooplankton community in North Yellow Sea unveiled an indicator species for the Yellow Sea Warm Current in winter: Euchaeta plana. Journal of Oceanology and Limnology, 38(6), 1762-1770.

Chen J., Jiang W., He S., Wang H., Zhuo L., Chen Q., Wang H. (2018). Study of macroinvertebrate species and functional diversity in the New Xue River,Shandong Province,China. Acta Ecologica Sinica, 38(9), 3328-3336.

Devictor V., Mouillot D., Meynard C., Jiguet F., Thuiller W., Mouquet N. (2010). Spatial mismatch and congruence between taxonomic, phylogenetic and functional diversity: the need for integrative conservation strategies in a changing world. Ecology Letters, 13(8), 1030-1040.

Dou Q., Du X., Cong Y., Wang L., Zhao C., Song D., Liu H., Huo T. (2022). Influence of environmental variables on macroinvertebrate community structure in Lianhuan Lake. Ecology and Evolution, 12(2).

Erasmus J.H., Lorenz A.W., Zimmermann S., Wepener V., Sures B., Smit N.J., Malherbe W. (2021). A diversity and functional approach to evaluate the macroinvertebrate responses to multiple stressors in a small subtropical austral river. Ecological Indicators, 131.

Jiang W., Pan B., Jiang X., Shi P., Zhu P., Zhang L., Chen J., Wu N. (2021). A comparative study on the indicative function of species and traits structure of stream macroinvertebrates to human disturbances. Ecological Indicators, 129.

Kelly D.W., Dick J.T.A., Montgomery W.I. (2002). The functional role of Gammarus (Crustacea, Amphipoda): shredders, predators, or both? Hydrobiologia, 485(1-3), 199-203.

Lavorel S., McIntyre S., Landsberg J., Forbes T.D.A. (1997). Plant functional classifications: from general groups to specific groups based on response to disturbance. Trends in Ecology & Evolution, 12(12), 474-478.

Li Y., Ge R., Chen H., Zhuang Y., Liu G., Zheng Z. (2022). Functional diversity and groups of crustacean zooplankton in the southern Yellow Sea. Ecological Indicators, 136.

Li Z., Xing Y., Liu Z., Chen X., Jiang X., Xie Z., Heino J. (2020). Seasonal changes in metacommunity assembly mechanisms of benthic macroinvertebrates in a subtropical river basin. Science of the Total Environment, 729.

Lin C., Cao L., Xu Y., Zhang Z., Yang H., Xiang H., Li K., Gao Y., Bernhardt T.M. (2022). Spatio-temporal variability (up- and down-stream and three seasons) of response patterns of macroinvertebrates to commonly applied low-head concrete weirs under reclaimed water intervention in urban river restoration. Journal of Cleaner Production, 370.

Liu K., Lin H., He X., Huang Y., Li Z., Lin J., Mou J., Zhang S., Lin L., Wang J., Sun J. (2019). Functional trait composition and diversity patterns of marine macrobenthos across the Arctic Bering Sea. Ecological Indicators, 102, 673-685.

Liu X., Zhao R., Hua E., Lu L., Zhang Z. (2014). Macrofaunal community structure in the Laizhou Bay in summer and the comparison with historical data. Marine Science Bulletin, 33(3), 281-290.

Magni P., Draredja B., Melouah K., Como S. (2015). Patterns of seasonal variation in lagoonal macrozoobenthic assemblages (Mellah lagoon, Algeria). Marine Environmental Research, 109, 168-176.

Margalef R. (1978). LIFE-FORMS OF PHYTOPLANKTON AS SURVIVAL ALTERNATIVES IN AN UNSTABLE ENVIRONMENT. Oceanologica Acta, 1(4), 493-509.

Mason N.W.H., Mouillot D., Lee W.G., Wilson J.B. (2005). Functional richness, functional evenness and functional divergence: the primary components of functional diversity. Oikos, 111(1), 112-118.

Mouchet M.A., Villeger S., Mason N.W.H., Mouillot D. (2010). Functional diversity measures: an overview of their redundancy and their ability to discriminate community assembly rules. Functional Ecology, 24(4), 867-876.

Mouton T.L., Tonkin J.D., Stephenson F., Verburg P., Floury M. (2020). Increasing climate-driven taxonomic homogenization but functional differentiation among river macroinvertebrate assemblages. Global Change Biology, 26(12), 6904-6915.

Ochieng H., Okot-Okumu J., Odong R. (2019). Taxonomic challenges associated with identification guides of benthic macroinvertebrates for biomonitoring freshwater bodies in East Africa: A review. African Journal of Aquatic Science, 44(2), 113-126.

Pielou E.C. (1966). Species-diversity and pattern-diversity in the study of ecological succession. Journal of theoretical biology, 10(2), 370-383.

Schmera D., Heino J., Podani J., Eros T., Doledec S. (2017). Functional diversity: a review of methodology and current knowledge in freshwater macroinvertebrate research. Hydrobiologia, 787(1), 27-44.

Shannon C.E. (1997). The mathematical theory of communication (Reprinted). M D Computing, 14(4), 306-317.

Simpson I.J., Edwards G.C., Thurtell G.W., den Hartog G., Neumann H.H., Staebler R.M. (1997). Micrometeorological measurements of methane and nitrous oxide exchange above a boreal aspen forest. Journal of Geophysical Research-Atmospheres, 102(D24), 29331-29341.

Sterling J.L., Rosemond A.D., Wenger S.J. (2016). Watershed urbanization affects macroinvertebrate community structure and reduces biomass through similar pathways in Piedmont streams, Georgia, USA. Freshwater Science, 35(2), 676-688.

Talley T.S., Dayton P.K., Ibarra-Obando S.E. (2000). Tidal flat macrofaunal communities and their associated environments in estuaries of southern California and northern Baja California, Mexico. Estuaries, 23(1), 97-114.

Tews J., Brose U., Grimm V., Tielborger K., Wichmann M.C., Schwager M., Jeltsch F. (2004). Animal species diversity driven by habitat heterogeneity/diversity: the importance of keystone structures. Journal of Biogeography, 31(1), 79-92.

Thrush S.F., Hewitt J.E., Gibbs M., Lundquist C., Norkko A. (2006). Functional role of large organisms in intertidal communities: Community effects and ecosystem function. Ecosystems, 9(6), 1029-1040.

Tomanova S., Goitia E., Helesic J. (2006). Trophic levels and functional feeding groups of macroinvertebrates in neotropical streams. Hydrobiologia, 556, 251-264.

Villeger S., Mason N.W.H., Mouillot D. (2008). New multidimensional functional diversity indices for a multifaceted framework in functional ecology. Ecology, 89(8), 2290-2301.

Wang L., Gao Y., Han B., Fan H., Yang H. (2019). The impacts of agriculture on macroinvertebrate communities: From structural changes to functional changes in Asia's cold region streams. Science of the Total Environment, 676, 155-164.

Xiang H., Zhang Y., Atkinson D., Sekar R. (2022). Anthropogenic Carrion Subsidy and Herbicide Glyphosate Depressed Leaf-Litter Breakdown: Effects on Environmental Health in Streams. Frontiers in Environmental Science, 10.

Yan J., Xu Y., Sui J., Li X., Wang H., Zhang B. (2017). Long-term variation of the macrobenthic community and its relationship with environmental factors in the Yangtze River estuary and its adjacent area. Marine Pollution Bulletin, 123(1-2), 339-348.

Yang W., Li X., Sun T., Pei J., Li M. (2017). Macrobenthos functional groups as indicators of ecological restoration in the northern part of China's Yellow River Delta Wetlands. Ecological Indicators, 82, 381-391.

Zhang J., Xiao J., Li L. (2015). Variation of plant functional diversity along a disturbance gradient in mountain meadows of the Donglingshan reserve, Beijing, China. Russian Journal of Ecology, 46(2), 157-166.

Zhang Y., Cheng L., Li K., Zhang L., Cai Y., Wang X., Heino J. (2019). Nutrient enrichment homogenizes taxonomic and functional diversity of benthic macroinvertebrate assemblages in shallow lakes. Limnology and Oceanography, 64(3), 1047-1058.

Zhong X., Qiu B., Liu X. (2020). Functional diversity patterns of macrofauna in the adjacent waters of the Yangtze River Estuary. Marine Pollution Bulletin, 154, 111032.

Zhu P., Pan B., Li Z., Yuan J., Jiang X., Jiang W., Lu Y. (2020). Responses of macroinvertebrate functional traits to riverbed structure of typical debris flow gullies in the upper reaches of the Yangtze River, China. Science of the Total Environment, 738.