Research Journal of

Environmental Sciences

ISSN 1819-3412

Academic
Journals Inc.

www.academicjournals.com

Research Journal of Environmental Sciences 8 (4): 193-204, 2014
ISSN 1819-3412 / DOI: 10.3923/rjes.2014.193.204

Grey Relational Analysis Between Plankton Diversity and Major Water Environmental Factors in Yongjiang River

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ABSTRACT

In order to elaborate the relationship between the plankton community and the water environment factors in Yongjiang River, the gray correlation analysis on the plankton community structure and the main water environmental factors was conducted. The results showed that Total Nitrogen (TN) had the maximum effect on phytoplankton abundance; Dissolve Oxygen (DO) has the minimum effect. The impacts from COD_{Cr} and BOD_5 to all groups of plankton abundance were also significant. In addition, the study showed that TN and BOD_5 were the main factors to affect the plankton community diversity index in Yongjiang River. By means of the grey relational grades, sequences and the measured data analysis, it is determined that TN and BOD_5 were the two factors with more obvious effects on the plankton community in the Yongjiang River. Their variation resulted in significant changes in the plankton community structure.

Key words: Water environmental factors, plankton, grey relational analysis, Yongjiang River

INTRODUCTION

Species diversity is an important indicator for describing the biological community structure. In general, in a bio-community, the more species it has and the more uniform and stable individual distribution it presents, the higher the biological diversity is. However, under natural conditions, any biological community structure can be disturbed by biotic and abiotic factors. Consequently, these effects of these factors are reflected on the biodiversity of a community. In terms of aquatic community, we know that a variety of physical and chemical factors in water do affect the aquatic community's structure; but how much the impact from different single factors or combined factors on the whole community can only be studied by statistical methods (Liu, 1990).

Planktons (including phytoplankton and zooplankton), are small size organisms in aquatic ecosystems. As the primary producer, phytoplankton is either the direct or indirect food foundation for the fish and other larger animals in water ecosystems. As an important part of the food chain, zooplankton is the connection between the producers and the upper level consumers. Therefore, some planktonic community structural parameters, such as the species composition, biomass and diversity indexes are important indicators for evaluating the fishery production (Liu, 1990; Guo and Shen, 2003; Lampert and Sommer, 2007; Li *et al.*, 2010; Zhang *et al.*, 2011). Due to their high sensitivity to the environmental changes and their short life cycles, many types of plankton can quickly reflect the changes in the ecosystems indicated by their density and diversity variations.

For these reasons, the planktons are considered to be the right bio-indicators for the assessment of water quality and the ecosystem health (Beisner, 2001; Bianchi *et al.*, 2003; Ternjej and Tomec, 2005). With a large number of individuals and the complexity of the species composition, planktons play crucial roles on material transformation, energy flow and information transmission process in aquatic ecosystems. They are important objects not only in theoretical but also experimental ecological studies (Scheffer *et al.*, 2003).

Grey Relational Analysis (GRA), as one of the most important contents of the Grey theory. The principle of GRA is to estimate the similarity and the degree of the compactness among factors based on the geometric shape of the different sequences (Deng, 2002; Shen and Yang, 2002). Since the inception of the analytical method, it has been applied by the researchers in the fields of environmental science and ecology (Lin *et al.*, 2005; Li *et al.*, 2012; Chen *et al.*, 2012; Zhu *et al.*, 2012; Wang *et al.*, 2011; Li *et al.*, 2011; Bao *et al.*, 2011; Yang *et al.*, 2011; Yu *et al.*, 2011; Bian *et al.*, 2012; Zhang, 2011; Yan, 2011; Noorul Haq *et al.*, 2008).

In freshwater, zooplanktons is consisted of free-living protozoa, rotifers, cladocerans and copepods. There are a few reports for the gray relational analysis between plankton community and environmental factors. However, only part of the plankton species were considered in these studies (Lin *et al.*, 2005; Li *et al.*, 2012; Yu *et al.*, 2011; Bian *et al.*, 2012; Zhang, 2011; Yan, 2011). In our study, using the annual data of various groups of planktons in the Yongjiang River, the Grey relational analysis between the species abundance and environmental factors were conducted. Similar GRA was also used to analyze the community diversity index and environmental factors. The purpose of this study is to reveal the major roles of the water environmental factors that affect the various groups of planktons in the Yongjiang River. It is hoped that the results will serve as a base for the formulation and adjustment of the environmental protection program in Yongjiang River.

MATERIALS AND METHODS

Sampling selections: Yongjiang River is one of the seven major river systems in Zhejiang province, China (Feng and Bao, 2004). There are two larger tributaries, Fenghua River and Yaojiang River, in the river system. Yaojiang River with total length of 105 km and the basin area of 1934 km^2, originates from Xiajialing, Siming Mountain. Fenghua River with 98 km long and a valley area of 2223 km^2, rises in Xiujian Hill, Siming Mountain. The water from Fenghua River and Yaojiang River converges in the centre of Ningbo City and flows into the East China Sea. Traditionally, the section of Yongjiang River system that is formed after the convergence of the Fenghua and Yongjiang branches is called Yongjiang River and has a total length of 26 km, the basin area of 361 km^2. Just before Yaojiang River connects to Fenghua River, a dam was built in 1959. Since then, Yaojiang River has become a relatively static reservoir. For most of the year, Yaojiang River is closed or allows only a small amount of water to flow, du to the dam (Feng and Bao, 2004). Therefore, the study area in this work included 124 km length and 2584 km^2 basin area.

The main functions of water from Yongjiang River system include drinking, agricultural irrigation, aquaculture, ship transportation and landscape.

Thirteen sampling sections have been set (Fig. 1) by this study in Yongjiang River. The locations and other basic information were listed in Table 1.

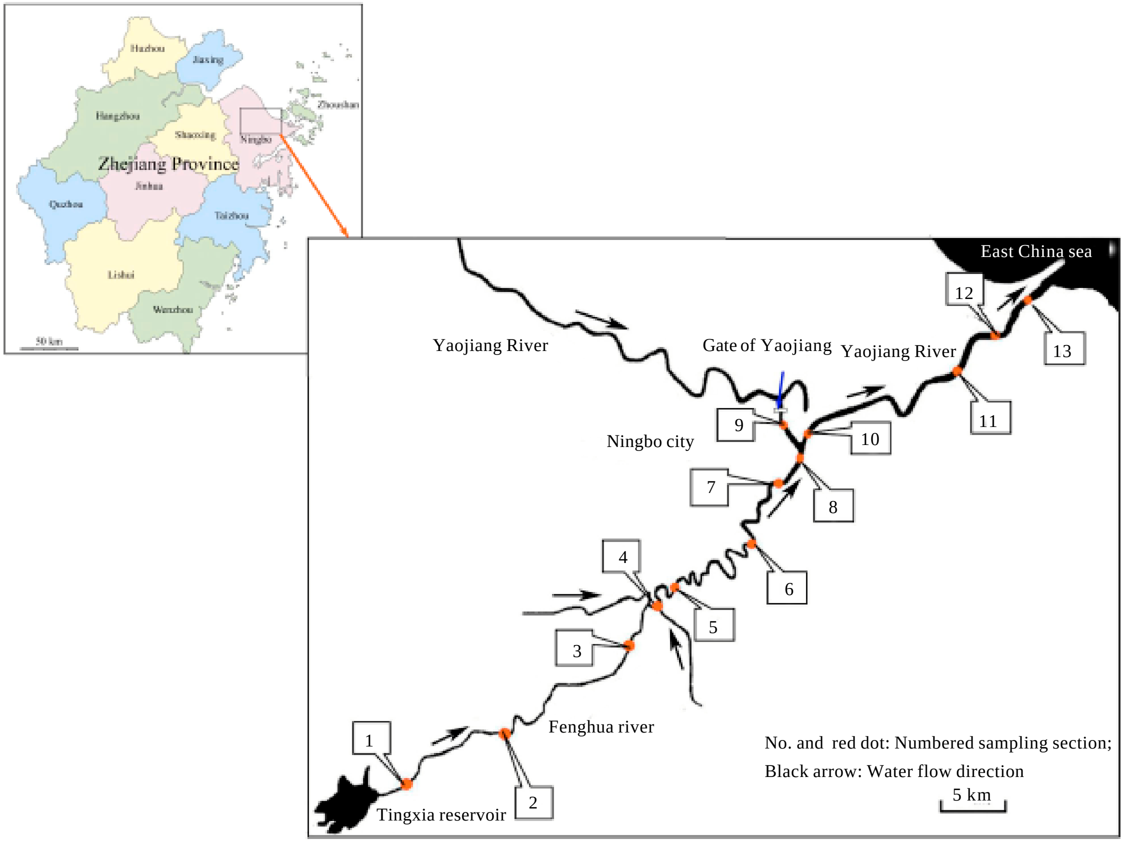

Fig. 1: Sketch map of sampling sites in Yongjiang River

Table 1: Introductions of sampling sections

Sampling section	Coordinate (Latitude and Longitude)	Description
1	29°39'16"N, 121°14'25"E	Shallow water, narrow river course, clear water, visible bottom
2	29°38'23"N, 121°19'50"E	Shallow water, narrow river course, clear water, visible bottom
3	29°43'42"N, 121°24'37"E	Widen river course, muddy water
4	29°45'27"N, 121°25'58"E	Muddy water, many floaters
5	29°45'32"N, 121°27'50"E	Muddy water, some floaters
6	29°48'20"N, 121°31'00"E	Muddy water, large amount of silt
7	29°52'13"N, 121°34'50"E	Muddy water, small amount of silt
8	29°52'24"N, 121°33'31"E	Muddy water, small amount of silt
9	29°53'32"N, 121°32'52"E	Clearer water, slow flow velocity
10	29°52'29"N, 121°33'44"E	Wide river course, some silt
11	29°53'41"N, 121°35'26"E	Wide river course, some silt
12	29°56'43"N, 121°43'14"E	Wide river course, large amount of silt
13	29°47'26"N, 121°44'56"E	Wide river course, larger amount of silt

Water sampling and determination: With the monthly frequency, the field sampling was carried out from March 201 to February 2012 along the river sections from upstream to downstream.

One semi-automatic plastic water sampler with 2.5 L volume, was used for the rotifers quantitative samples. Each sample was 5 L volume taken twice at one sampling section, from the surface and the bottom of the river, respectively and then mixed on sites. All samples were fixed with formaldehyde (final concentration of 4-5%). An identical water sample was collected at each section by the same way at the same times and used for analyzing physical and chemical factors.

Physical and chemical factors were analyzed according to national standards and the American Water Works Association (AWWA, 1999). Water temperature (Tem.), transparency, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD_{Cr}), Total Nitrogen (TN), Total Phosphorus (TP), chlorophyll-*a* (Chl-*a*) and salinity (Sal.) were determined.

Water samples were taken back to the lab and concentrated by precipitation to 50 mL for plankton identification. Under the microscope (200-400×), the plankton counting chamber was used for the plankton species identification and number counting. The different plankton groups were identified based on the descriptions from the references (Zhang and Huang, 1991; Jin *et al.*, 1965; Hu and Wei, 2006; Guo and Qian, 2003; Li and Qi, 2010; Lin, 2009; Qi *et al.*, 2004; Shen *et al.*, 1990; Yang and Dong, 2006; Wang, 2007; Wang, 2004; Wei, 2003; Shi, 1999; Foissner *et al.*, 1999). In order to ensure the accuracy of the rotifer count, each water sample was counted twice and the average is used.

In this study, the free-living protozoa (especially sarcodinas and ciliates) contributed much more to the composition and abundances of the zooplankton community in the Yongjiang River. In order to accurately determine the impacts of multicellular zooplankton on the zooplankton community, the data of sarcodinas and ciliates were displayed separately. So, the data for zooplankton in this study is the total of rotifers, cladocerans and copepods.

Diversity index calculation: Diversity index (H') was calculated by using the Shannon-Wiener diversity index (Eq. 1):

$$H' = -\sum_{i=1}^{s} p_i \log_2 p_i \quad (1)$$

where, S is the total number of species; p_i is the relative abundance of the i species calculated as the proportion of individuals of a given species to the total number of individuals of all species in the community.

Grey relational analysis: Grey relational grade was calculated with the Eq. 2 as suggested by Deng (2002):

$$\zeta_i(k) = \frac{\left|\min_i \min_k\right| \left|x_0(k) - x_i(k)\right| + \rho \bullet \max_i \max_i \left|x_0(k) x_i(k)\right|}{\left|x_0(k) - x_i(k)\right| + \rho \bullet \max_i \max_i \left|x_0(k) - x_i(k)\right|} \quad (2)$$

$$(k = 1, \ldots, m;\ i = 1, 2, \ldots, n)$$

$\zeta_i(k)$ is grey relational grade; $x_0(k)$ is an element in indicator sequence; $x_i(k)$ is an element in reference sequence; ρ ($0 < \rho \leq 1$) is a distinguishing coefficient to adjust the range of the comparison environment which was selected as 0.1 in this study.

In this study, the diversity index (H') of phytoplankton and zooplankton were selected as elements in indicator sequence, respectively. The elements in reference sequence were DO{X_1}, BOD_5{X_2}, COD_{Cr}{X_3}, TN{X_4}, TP{X_5} and Chl-α{X_6}.

Statistical methods: The statistical analysis was performed with SPSS 11.0 version. Matlab R14 was used to program and perform GRA data statistic analysis.

RESULTS

The annual average of DO, BOD_5, COD_{Cr}, TP, TN and chlorophyll-α contents at different sections in Yongjiang River is shown in Table 2.

In Table 2, except for Section 9, the DO contents in water showed a decrease trend from the upstream sections to the urban sections with the lowest value at the urban sections. On the other hand, the DO contents increased from the urban sections to downstream sections.

In contrast, BOD_5, COD_{Cr} and TN values increased from the upstream sections to the urban sections. The highest value occurred at the urban sections (except for Section 9); but these values decreased from urban areas to the sea.

TP was very low at Section 1 and 2 and it was extremely high at Section 3. This is caused by the many industrial plants along both sides of the river near Section 3. All of the plants were township or village-owned enterprises that lacks pollution control and management facilities.

It is easy to understand why the highest Chl-α content appeared at Section 9 based on the analysis mentioned above. The lower Chl-α content happened at both the upstream sections and the downstream sections with different reasons. The lower Chl-α content at the upstream sections is because that these sections have less nutrients and organic materials, even though they have higher transparency. In reverse, even though the downstream sections have higher nutrients and organic materials, they have worse transparency due to a large amount of suspended solid in the water. The difficulty of the photosynthesis process for algae resulted in the lower Chl-α content.

Statistical analysis showed that there was a significant negative correlation between DO concentration and BOD_5, COD_{Cr}, TN and TP contents, respectively. The correlation coefficient (R) were -0.8693, -0.9232, -0.9226 and -0.6392, respectively ($p<0.05$).

Table 2: Annual average of major water environmental factors in Yongjiang Rriver

Sampling sections	DO (mg L^{-1})	BOD_5 (mg L^{-1})	COD_{Cr} (mg L^{-1})	TN (mg L^{-1})	TP (mg L^{-1})	Chl-α (μgL^{-1})
1	9.171	1.001	2.333	1.835	0.022	2.592
2	8.099	1.098	5.671	2.549	0.060	4.038
3	5.414	2.172	12.748	4.464	1.691	5.956
4	3.622	2.879	18.383	5.794	0.882	10.738
5	3.168	2.836	22.933	6.293	0.679	9.193
6	2.328	4.057	25.528	5.863	1.052	5.291
7	2.636	4.929	25.967	6.555	1.027	5.550
8	2.616	5.327	22.930	6.380	0.810	6.559
9	5.158	3.643	14.908	5.517	0.262	14.369
10	2.585	5.125	29.217	5.624	0.980	5.898
11	4.845	2.783	8.538	3.587	0.630	3.338
12	5.218	1.944	8.278	3.572	0.538	1.990
13	6.210	1.844	8.099	3.014	0.505	2.215

Table 3: Annual average of abundances from different groups of planktons in Yongjiang River (ind./L)

Sampling sections	Phytoplankton	Rotifera	Sarcodina	Ciliate	Zooplankton*
1	237.4×10^3	36	1.75×10^3	2.23×10^3	55
2	118.6×10^3	129	0.67×10^3	1.66×10^3	140
3	211.5×10^3	358	0.41×10^3	8.42×10^3	595
4	439.1×10^3	869	0.61×10^3	20.46×10^3	1017
5	411.4×10^3	1023	2.26×10^3	23.74×10^3	1219
6	307.4×10^3	1033	6.09×10^3	14.95×10^3	1189
7	344.8×10^3	1012	9.21×10^3	14.97×10^3	1235
8	299.0×10^3	942	5.58×10^3	17.29×10^3	1222
9	1375.3×10^3	502	3.57×10^3	11.45×10^3	741
10	270.7×10^3	636	9.42×10^3	14.03×10^3	740
11	232.4×10^3	223	7.40×10^3	7.66×10^3	328
12	132.7×10^3	71	8.47×10^3	7.63×10^3	123
13	71.8×10^3	147	9.78×10^3	3.14×10^3	189

*Including rotifers, cladoceras and copepodas

Table 4: Annual average of Shannon-Wiener indexes (H') from different groups of planktons in Yongjiang River

Sampling sections	Phytoplankton	Rotifera	Sarcodina	Ciliate	Zooplankton*
1	1.786	0.912	0.397	1.6945	1.483
2	2.885	1.582	0.451	1.5980	1.723
3	2.883	1.800	0.148	2.1670	1.868
4	2.565	1.782	0.071	2.0270	2.043
5	2.504	1.743	0.349	2.1710	1.970
6	2.468	1.498	0.557	1.6760	1.710
7	2.169	1.795	1.038	1.9910	2.080
8	2.359	1.748	0.618	1.6580	2.090
9	2.690	1.602	0.508	1.4810	1.840
10	1.960	1.828	1.074	1.9510	2.078
11	1.556	1.448	1.191	1.5770	1.905
12	1.492	1.178	1.083	1.7970	1.680
13	1.695	1.638	1.421	0.7530	1.918

*Including rotifers, cladoceras and copepodas

The annual average of abundances and biodiversity indexes from different groups of planktons are listed in Table 3 and 4.

From Table 4, the H' values of different groups of planktons from different sections were displayed, the numbers vary significantly. Especially, the H' value of Sarcodina is significantly lower than the others.

The results of equalization of the abundances and H' values from the different groups of planktons and major environmental factors (DO, BOD_5, COD_{Cr}, TN, TP and Chl-α) in various section of Yongjiang River are listed in Table 5.

The grey relational grades (GRA) and sequences (GRS) of abundances and H' values from various groups of planktons and water environmental factors are listed in Table 6 and 7.

From Table 6, it can be found that, when compared with other environmental factors, TN has a maximum affect on the phytoplankton abundances. Meanwhile, DO has the minimum influence to the phytoplankton abundances. Among the main environmental factors, COD_{Cr} and BOD_5 have obvious influences on the abundances of various groups of planktons while DO has less impact on

Table 5: Equalizations of the abundances and H' values from the different groups of planktons and water main factors

		Sampling sections												
Sequence	Elements	1	2	3	4	5	6	7	8	9	10	11	12	13
X_0	AP	0.6931	0.3464	0.6175	1.2821	1.2012	0.8977	1.0067	0.8731	4.0159	0.7906	0.6785	0.3875	0.2095
	HP	0.8003	1.2927	1.2918	1.1494	1.1220	1.1059	0.9719	1.0570	1.2054	0.8783	0.6973	0.6686	0.7595
	AR	0.0670	0.2402	0.6667	1.6183	1.9050	1.9237	1.8845	1.7542	0.9348	1.1844	0.4153	0.1322	0.2737
	HR	0.5768	1.0006	1.1385	1.1271	1.1024	0.9475	1.1353	1.1056	1.0132	1.1562	0.9158	0.7451	1.0360
	AS	0.3496	0.1326	0.0809	0.1214	0.4495	1.2144	1.8364	1.1113	0.7120	1.8768	1.4757	1.6890	1.9503
	HS	0.5795	0.6583	0.2160	0.1037	0.5094	0.8130	1.5152	0.9021	0.7415	1.5678	1.7385	1.5808	2.0742
	AC	0.1967	0.1464	0.7413	1.8012	2.0906	1.3168	1.3184	1.5228	1.0079	1.2355	0.6747	0.6714	0.2763
	HC	0.9772	0.9216	1.2497	1.1690	1.2520	0.9666	1.1482	0.9562	0.8541	1.1252	0.9095	1.0364	0.4343
	HZ	0.0813	0.2070	0.8797	1.5036	1.8022	1.7579	1.8259	1.8067	1.0955	1.0941	0.4849	0.1818	0.2794
	HZ	0.7905	0.9184	0.9957	1.0890	1.0501	0.9115	1.1087	1.1141	0.9808	1.1077	1.0155	0.8955	1.0224
X_1	DO	1.9522	1.7240	1.1525	0.7710	0.6744	0.4956	0.5611	0.5569	1.0980	0.5503	1.0314	1.1108	1.3219
X_2	BOD_5	0.3283	0.3601	0.7123	0.9442	0.9301	1.3306	1.6166	1.7471	1.1948	1.6808	0.9127	0.6376	0.6048
X_3	COD_{Cr}	0.1476	0.3587	0.8063	1.1627	1.4505	1.6147	1.6424	1.4503	0.9429	1.8480	0.5400	0.5236	0.5123
X_4	TN	0.3908	0.5428	0.9506	1.2338	1.3401	1.2485	1.3959	1.3586	1.1748	1.1976	0.7639	0.7607	0.6418
X_5	TP	0.0313	0.0854	2.4057	1.2548	0.9660	1.4966	1.4610	1.1523	0.3727	1.3942	0.8963	0.7654	0.7184
X_6	Chl-*a*	0.4335	0.6754	0.9962	1.7960	1.5375	0.8849	0.9283	1.0970	2.4032	0.9864	0.5583	0.3328	0.3705

AP: Abundance of phytoplankton; HP: H' index of phytoplankton; AR: Abundance of rotifer; HR: H' index of rotifer; AS: Abundance of sarcodina; HS: H' index of sarcodina; AC: Abundance of ciliate; HC: H' index of ciliate; AZ: Abundance of zooplankton; HZ: H' index of zooplankton

Table 6: Grey relational grades and sequences of abundances from various groups of planktons and water environmental factors (ρ = 0.1)

Environmental factors	Phytoplankton		Rotifera		Sarcodina		Ciliate		Zooplankton*	
	GRA	GRS	GRA	GRS	GRA	GRS	GRA	GRS	GRA	GRS
DO	0.3918	5	0.1987	6	0.2714	6	0.2288	6	0.2462	6
BOD_5	0.5217	3	0.4341	2	0.4225	1	0.4989	3	0.4151	3
COD_{Cr}	0.5425	2	0.4967	1	0.3978	3	0.5001	2	0.5025	1
TN	0.5641	1	0.3867	3	0.3831	4	0.5213	1	0.4174	2
TP	0.4799	4	0.3498	5	0.3991	2	0.4133	5	0.3537	5
Chl-α	-	-	0.3765	4	0.3184	5	0.4203	4	0.4142	4

*Including rotifers, cladoceras and copepodas

Table 7: Grey relational grades and sequences of H' values from various groups of planktons and water environmental factors (ρ = 0.1)

Environmental factors	Phytoplankton		Rotifera		Sarcodina		Ciliate		Zooplankton*	
	GRA	GRS	GRA	GRS	GRA	GRS	GRA	GRS	GRA	GRS
DO	0.2739	5	0.3363	5	0.3014	6	0.3240	6	0.3359	4
BOD_5	0.3804	2	0.3742	4	0.3684	1	0.3410	5	0.3282	5
COD_{Cr}	0.3230	4	0.3280	6	0.3259	5	0.3696	3	0.3152	6
TN	0.4458	1	0.4647	1	0.3592	3	0.4327	1	0.4088	2
TP	0.3583	3	0.4175	2	0.3429	4	0.3657	4	0.3598	3
Chl-α	-	-	0.3916	3	0.3648	2	0.3882	2	0.4220	1

*Rotifers, cladoceras and copepodas

these abundances. Also, TP has little influence on abundance of the planktons. It can be derived that TN was the most correlative impact factor and TP was the least correlative impact factor for planktons among the 6 environmental factors in Yongjiang River.

Similar to abundance, Table 7 shows that the water environmental factors have influence on the H' of the various groups of planktons; but the GRA and GRS of the water environmental factors on the plankton H' are different from the abundance. Relatively, TN and BOD_5 are the most correlative impact factors on the plankton H' index followed by COD_{Cr}. DO is the least correlative impact factor and TP is not a main factor on various groups of planktons as well.

Through the aforementioned sorting and combining with the measured data of the water environmental factors it could be estimated that, in the Yongjiang River, TN and BOD_5 are the two major impacting factors on the plankton community. Their changes causes the obvious plankton community structure changes. COD_{Cr} also has fairly obvious impacts on the plankton community obviously. DO and TP affected the plankton community less.

DISCUSSION

Not only the number of species and the abundances are dominant in the water ecological systems but also the planktons are the energy and material basis for the other aquatic animals surviving in the systems. From the perspective of ecosystem, the planktons are involved in multiple trophic levels in the aquatic ecosystem. Due to the different ecological roles played by the various groups of planktons, they are important links between the predator-prey and detritus food chains in the water. Therefore, they play significant roles in the food web structure and function in the whole water system. As a result, many studies on the freshwater planktons in different types of water bodies have been published (Wang *et al.*, 2002; Gu and You, 2008; Zhang *et al.*, 2009; Chen *et al.*, 2009; Huang *et al.*, 2009; Mieczan, 2007; Dembowska, 2009; Yu *et al.*, 2012; Wang *et al.*, 2008). At the same time, because of the interactions between the various environmental factors and planktons at the population and community levels, the structures and functions of the plankton community features have also been used to evaluate the water environments. (Fisher *et al.*, 1992; Shen *et al.*, 2009; Mieczan, 2007; Yu *et al.*, 2011; Beisner, 2001; Ternjej and Tomec, 2005; Scheffer *et al.*, 2003).

Because of the complexity of the species compositions, different plankton groups have different nutrition patterns and needs, so the effects from the different environmental factors on the different plankton groups are inevitably different. Although in different studies, the relationships between planktons and their environmental factors and the mechanism behind the relationships have been reported and discussed, these researches often considered single environmental factors. In reality, the complexity of the water and the environmental factors are not alone in a plankton taxa, their roles must be comprehensively studied. The characteristics of the plankton community structure are also a result of the integrated effects of various environmental factors. In this study, 6 environmental factors were used in GRA to explore their integrated effects on the planktons and the most and the least correlative impact factors in Yongjiang River were discovered.

As one of the analytical tools for ecological research, GRA has been used in the study of both water and aquatic environmental biology; it has become a useful data analysis tool. With this analysis, the relationships between the biological communities and the environmental factors and the impacts of the various environmental factors on the biological communities were revealed. A previous study on the algae in Shengjinhu lake of Anhui, China, showed that the water temperature was the main factor limiting the growth of algae during winter (Shen *et al.*, 2009). In the Hongze Lake Basin Rivers, BOD_5 and COD_{Cr} were the water quality index for the wide area (Zhang *et al.*, 2012). In Hailang River, TN content was the largest environmental factor for the phytoplankton abundance (Yu *et al.*, 2011) which is the same as this study in Yongjiang River. In Taoshan reservoir, the maximum correlation between the environmental factor and the phytoplankton abundance was COD_{Cr} (Bian *et al.*, 2012). COD_{Cr} also affected phytoplankton abundance obviously in Yongjiang (GRS is 2).

This study found that the correlations between the water environmental factors and the plankton structure characteristics can be revealed more intuitively by the means of the grey relational analysis. According to Table 7, when combining with the measured data of water environmental factors it is determined that, in the Yongjiang River, TN and BOD_5 are the two factors with more obvious effects on the plankton community; their changes result in the obvious changes of plankton communities in this river. Meanwhile, COD_{Cr} also has relatively obvious impact on the rotifer community structure.

ACKNOWLEDGMENTS

This work is funded by the Project of Science and Technology Plans in Ningbo (No. 2010A80002). The authors are grateful to Mr. Jiang Lu, Ms. Xiaoxi Fu and Ms. Xihan Wang for their help in sampling and data processing. The authors also wish to thank Mr. Dapeng Tan for his valuable advice. Thanks are given to Mr. Thomas Bennett and Dr. Jean Huang for reviewing this manuscript.

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