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Full Length Research Paper

Dynamics of macrozoobenthos assemblages in the Fubao Bay of Lake Dianchi and their relation to organic pollutants

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A two-year-long investigation on the dynamics of the structure and biodiversity of macrozoobenthos was conducted in the Fubao Bay of Dianchi Lake, Southwest China. A high level of organic pollution has been detected in this Bay for the last 10 years. In all, 31 benthic taxa belonging to eight families and 20 genera were identified. Oligochaeta dominated this ecosystem, comprising 53 to 99% of the total abundance and 75 to 99% of the total wet biomass. The standing crop of the solely dominant species *Limnodrilus hoffmeisteri* rose sharply in the two-year period: It increased from 46% of the total abundance to 73% and from 73% of the wet biomass to 99% in second year. One-way analysis of variance (ANOVA) revealed that there was no significant difference ($p > 0.05$) in the richness value for all and the most predominant groups between the two years. However, significant differences were detected between the total and oligochaete abundances ($p < 0.05$). The standing crop was the lowest (188.72 ind/m^2 and 0.20 g/m^2) in October, 2006 and the highest (14931.7 ind/m^2 and 39.33 g/m^2) in January, 2008. The annual mean standing crop increased nearly 10 times in density and eight times in wet biomass between the two years, and this increase was mainly contributed by oligochaetes. Analyses of three diversity indices and the K-dominance curve revealed that there was a significant difference between the two years. Multiple regression analysis indicated that the dynamics of the biomass of macrozoobenthos could be largely attributed to nitrate nitrogen.

Key words: Macrozoobenthos, structure, biodiversity, Dianchi Lake, organic pollution.

INTRODUCTION

Economic development in China is associated with an increase in the pollution levels. The inflow of effluents of different kinds due to anthropogenic activities has become a major threat to the quality of water, particularly in urban lakes (Liang, 2007; Jing et al., 2006). These activities cause a diverse range of stresses to lake ecosystems and affect biota at different temporal and spatial scales. The effects of damage to these lake ecosystems are typically seen in the form of the disappearance of vegetation, a sharp increase in the amount of organic matter, and frequent occurrence of algal bloom.

In most cases, macrozoobenthos fauna have been successfully used as indicators of biological integrity, environmental degradation, and water quality (Brinkhurst and Jamieson, 1971; Aston, 1973; Roy et al., 2003; Ndaruga et al., 2004). The sensitivity and tolerance to pollution exhibited by different members of this group vary considerably from species to species. The composition of a macrozoobenthos community at any given point in a

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Abbreviations: T, Temperature; **SD,** secchi depth; **DO,** dissolved oxygen; **TN,** total nitrogen; **TP,** total phosphorus; **NH_4-N,** ammonium nitrogen; **NO_3-N,** nitrate nitrogen; **NO_2-N,** nitrite nitrogen; **SS,** suspended substance; **COD,** chemical oxygen demand; **BOD,** biochemical oxygen demand.

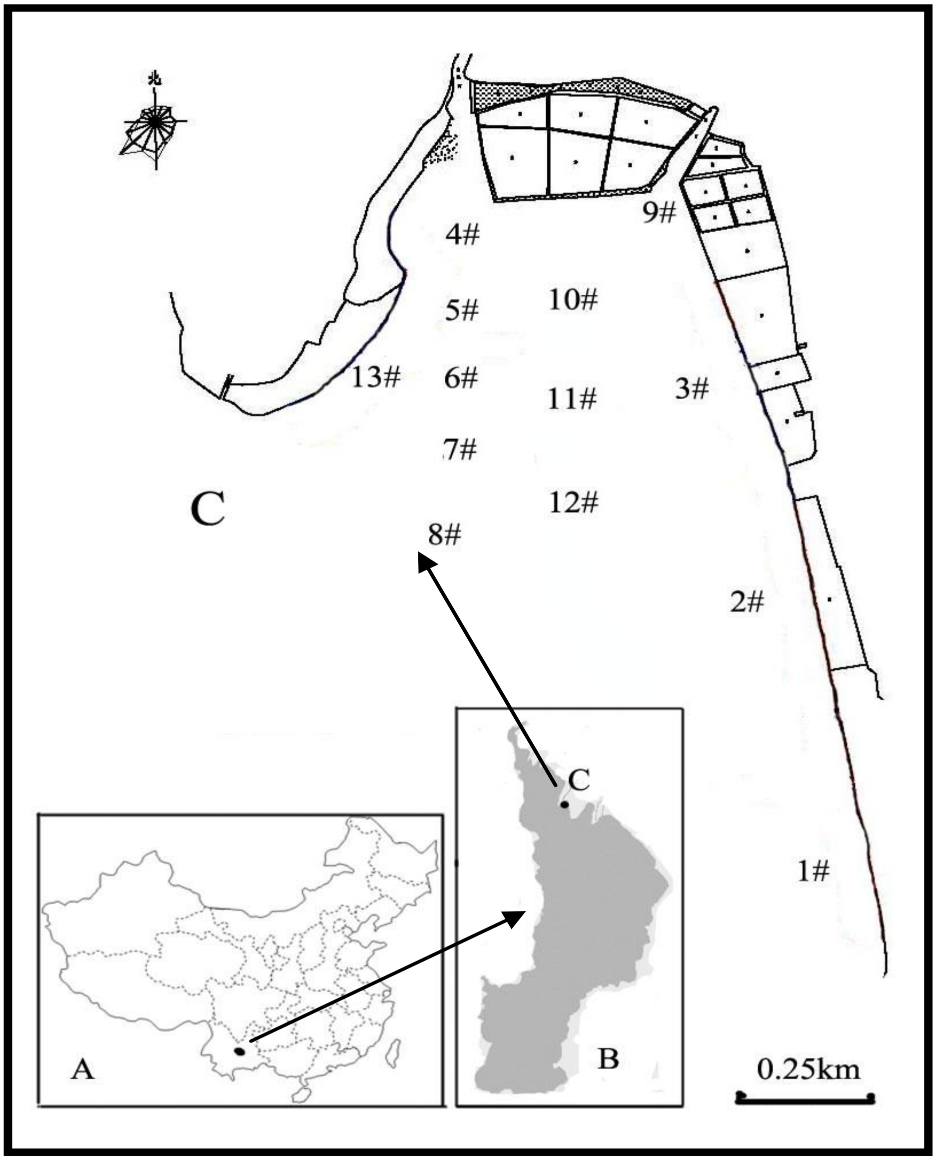

Figure 1. Sampling sites in the Fubao Bay (C) in Lake Dianchi (B) and its location in China (A).

lake, therefore, reflects the average water quality at that particular point (Roy et al., 2003). Due to this specificity, examining the nature of macrozoobenthos is a valuable tool in water quality assessment.

Lake Dianchi, which is one of the largest shallow lakes in Yunnan Province of Southwest China, is bordered by the south of Kunming City and has, therefore, become highly polluted with industrial and agricultural pollutants and domestic waste. Since the 1960s, Lake Dianchi has shown very rapid eutrophication, and a recent study on the trophic state of Lake Dianchi revealed that the total phosphorus and total nitrogen concentrations are much higher than former levels (Fang et al., 2004; Guo, 2002). Others variables such as the nature of zoobenthos and the frequent occurrence of cyanobacterial blooms during the year confirmed the high degree of eutrophication in this lake (Wang, 1985; Wang et al., 2002, 2003).

Our work attempts to elucidate the dynamics of the community structure and biodiversity of macrozoobenthos in a hypereutrophic Bay of Lake Dianchi. Furthermore, we seek to determine whether there is any relationship between the macrozoobenthic community and environmental variables.

MATERIALS AND METHODS

The Fubao Bay, where this study was carried out, is located at the north of Lake Dianchi (102°41'E, 24°56'N) (Figure 1). Quarterly

Table 1. Major physicochemical variables influencing water quality in the Fubao Bay of Lake Dianchi (mean ± SE; from April, 2006 to January, 2008).

Parameter	2006 – 2007	2007 – 2008
Temperature (T, °C)	18.55 ± 2.97	17.88 ± 2.56
pH	8.40 ± 0.30	8.55 ± 0.23
Secchi depth (SD, cm)	15.48 ± 2.54	28.23 ± 5.63
Dissolved oxygen (DO, mg/L)	5.93 ± 1.26	5.53 ± 1.82
Total nitrogen (TN, mg/L)	8.35 ± 2.17	6.05 ± 0.67
Total phosphorus (TP, µg/L)	0.60 ± 0.07	0.70 ± 0.13
Ammonium nitrogen (NH_4-N, mg/L)	2.03 ± 0.79	2.10 ± 0.18
Nitrate nitrogen (NO_3-N, mg/l)	0.20 ± 0.11	0.53 ± 0.30
Nitrite nitrogen (NO_2-N, mg/l)	0.08 ± 0.03	0.05 ± 0.03
Suspended substance (SS, mg/l)	122.58 ± 45.61	55.53 ± 18.30
Chemical oxygen demand (COD, µg/L)	40.10 ± 14.90	26.48 ± 4.38
Biochemical oxygen demand (BOD, µg/L)	15.78 ± 1.91	15.60 ± 4.02

samplings were carried out between April, 2006 and January, 2008 using a weighted Peterson grab. Quantitative samples were obtained for each station at each sampling time. All samples were sieved with a 450-µm sieve. The specimens were manually sorted out from the sediment on a white porcelain plate and preserved in 10% formalin. In the laboratory, the animals were identified to the lowest possible taxon, on the basis of keys developed by Morse and Yang (1994), Epler (2001), Brinkhurst (1986), and Liu et al. (1979). Physicochemical variables determining the water quality, including water temperature (T), pH, secchi depth (SD), dissolved oxygen (DO), total nitrogen (TN), total phosphorus (TP), ammonium nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), suspended substance (SS), chemical oxygen demand (COD) and biochemical oxygen demand (BOD) are listed in Table 1 according to the Chinese standard method for the assessment of water quality in lakes (Huang et al., 1999).

We evaluated the variation in the properties of macrozoobenthos (density, biomass, and biodiversity) using one-way analysis of variance (ANOVA). A logarithmic transformation (log(x+1)) was used to normalize the variance of the density and biomass of macrozoobenthos. The biodiversity of macrozoobenthos was assessed using K-dominance curves (Platt et al., 1984) and three indices (Margalef, Simpson, and Shannon-Wiener). The relationship between the characteristics of macrozoobenthos (density and biomass) and environmental variables were analyzed using multivariate regression analyses with stepwise selection. All statistical analyses were carried out on SPSS 13.0 for Windows.

RESULTS

In total, 31 benthic taxa belonging to eight families and 20 genera were identified using quantitative samples collected over two years (Table 2). The numerically dominant taxa were Oligochaeta (13 taxa) and Chironomidae (8 taxa), comprising 58.8% and 29.4% of all the species, respectively. Although the total richness value and those for the most predominant groups were relatively higher in the first year than in the second, the differences between the values for the two years were not significant (Table 4).

Oligochaetes were the most predominant groups in the Bay. The two-year average standing stock was 4435.8 ind/m^2 and 8.89 g/m^2 in wet biomass, comprising 99.38% and 97.20% in total abundance, respectively (Table 3). The standing crop was the lowest (188.7 ind/m^2 and 0.20 g/m^2) in October, 2006 and the highest (14931.7 ind/m^2 and 39.33 g/m^2) in January, 2008. In the two years, the annual mean standing crop increased by nearly 10 times in density and 8 times in wet biomass, and this increase was mainly contributed by oligochaetes (Table 3). ANOVA revealed a significant difference between the total and oligochaete abundances ($p < 0.05$) (Table 4).

Limnodrilus hoffmeisteri was the absolutely dominant species in Fubao Bay, and contributed to up to 46% and 99% of the total abundance and 73% and 99% of the total wet biomass in the two years. One-way ANOVA revealed that there was a significant difference in the density ($F = 9.258$, $p = 0.023$) and biomass ($F = 8.516$, $p = 0.027$) of *L. hoffmeisteri* between 2006 and 2008 (Table 4, Figure 2).

A comparison of the K-dominance curves of macroinvertebrate assemblages for the two years revealed that the diversity of macroinvertebrates in first year was higher than that in second year (Figure 3). A similar trend was observed in the values of the three indices determined for the two years (Table 4, Table 5)).

A significant correlation was observed between the biomass of macrozoobenthos and the concentrations of NO_3-N, NO_2-N, SS and BOD in the Fubao Bay (Table 6). Stepwise multiple regressions revealed that NO_3-N concentration was a significant factor that influenced community biomass variance and could be attributed to 49.5%, 51.0%, and 44.9% of the total variation in the total biomass and in the biomasses of oligochaetes and chironomids, respectively (Table 7).

DISCUSSION

Eutrophication affects the richness and diversity of the

Table 2. Macrozoobenthos species found in the Fubao Bay of Lake Dianchi.

Species	2006 – 2007	2007 – 2008	Species	2006 – 2007	2007 – 2008
Annelida			Arthropoda		
Oligochaeta			Crustacea		
Naididae			Amphipoda		
Chaetogaster limnaei	+		Gammaridae		
Dero digitata	+	+	*Gammarus* sp.	+	
Dero obtusa	+		Insecta		
Branchiodrilus hortensis	+		Diptera		
Nais pardalis		+	Chironomidae		
Haemonais waldvogeli	+		*Chironomus riparius*	+	
Stephensoniana trivandrana		+			
Tubificidae			*Chironomus* sp.	+	+
Limnodrilus hoffmeisteri	+	+	*Orthocladius* sp.	+	
Limnodrilus claparedianus	+	+	*Pseudochironomus* sp.	+	+
Limnodrilus grandisetosus	+	+	*Polypedilum* sp.	+	
Tubifex sp1	+	+	*Einfeldia insolita*	+	+
Tubifex sp2	+				
Tubifex tubifex	+	+	*Tanypus* sp	+	
Bothrioneurum vejdovskyanum	+		*Clinotanypus* sp.		+
Branchiura sowerbyi	+	+	Psychodidae	+	
Aulodrilus pluriseta		+	Mollusca		
Aulodrilus sp.		+	Gastropoda		
Ilyodrilus templetoni		+	Lymnaea		
Lumbriculus variagatus	+		*Radix swinhoei*	+	
Hirudinea					
Hirudinea	+	+			

Table 3. Abundance of macroinvertebrates in the Fubao Bay of Lake Dianchi.

Macroinvertebrate		2006 – 2007				2007 – 2008			
		April	July	October	January	April	July	October	January
Oligochaeta	D	306.5	1371.1	100.9	1466.5	2769.9	12311.4	2276.3	14883.7
	B	0.77	1.75	0.15	5.28	9.56	10.66	3.95	38.98
Chironomidae	D	8.6	4.9	87.8	2.5	3.1	12.3	6.2	48.0
	B	0.05	0.02	0.05	0.00	0.02	0.01	0.01	0.35
Others	D	12.3	0.0	0.0	11.1	0.00	1.2	24.2	0.0
	B	0.10	0.00	0.00	0.20	0.00	0.00	1.23	0.00
Total	D	327.4	1376.0	188.7	1480.0	2772.9	12324.9	2306.7	14931.7
	B	0.9	1.77	0.20	5.48	9.58	10.68	5.18	39.33

D, Density (ind/m^2); B, wet biomass (g/m^2).

macroinvertebrate community (Heip, 1995). It is argued that the increase of organic matter in the sediment associated with the decrease of dissolved oxygen are the deterministic factors determining the elimination or replacement of species (Heip, 1995; Grall and Chauvaud, 2002). However, an increased sedimentation of organic matter is harmful to some benthic species due to siltation, habitat modification, and oxygen depletion, which are caused by high decomposition rates (Grall and Chauvaud, 2002). The macrobenthic succession in the Fubao Bay is clearly influenced by changes in the physicochemical characteristics of the water column and sediment. The

Table 4. Summary of one-way analysis of variance of richness, density, and biomass of macrozoobenthos determined for a period between 2006 and 2008.

Parameter	F	*p*
Taxa richness		
Oligochaetes	1.412	0.280
Chironomids	0.200	0.670
Total richness	0.860	0.390
Density		
Oligochaetes	9.243	0.023*
Chironomids	0.001	0.982
L. hoffmeisteri	9.258	0.023*
Total density	10.343	0.018*
Biomass		
Oligochaetes	8.392	0.027*
Chironomids	0.583	0.474
L. hoffmeisteri	8.516	0.027*
Total biomass	9.596	0.021*
Biodiversity	1.997	0.207

*, At the 0.05 level.

Table 5. Values of the biodiversity of macrozoobenthos in the Fubao Bay by month.

Biodiversity	2006 – 2007				2007 – 2008			
	April	July	October	January	April	July	October	January
Shannon-Wiener	0.75	0.45	1.02	0.06	0.05	0.48	0.28	0.20
Margalef	0.84	0.77	0.53	0.19	0.35	0.74	0.54	0.58
Evenness	0.36	0.20	0.63	0.05	0.03	0.20	0.15	0.09
Richness	8	9	5	3	5	11	7	9

amount and accumulation rate of organic matter in the sediments are key factors determining the succession pattern. A model of the changes in the structure of the zoobenthic community due to organic enrichment was presented by Pearson and Rosenberg (1978). This model indicates that the early stages of eutrophication and organic matter enrichment are often followed by increase in the abundance and number of species. If enrichment continues, the macrofauna disappears, and the sediment eventually becomes azoic. Although the model was developed and used for the analyses of marine systems that have experienced long-term eutrophication (Heip, 1995; Grall and Chauvaud, 2002), it explains the temporal pattern recorded in the Fubao Bay very well.

Many studies have documented that the amount of zoobenthos increased with the accumulation of organic matter in sediments (Gong and Xie, 2001; Lang, 1997; Lang and Reymond, 1996). These findings are consistent with our results. The sharp increase in the standing crops of macrozoobenthos in the Fubao Bay was mainly attributable to oligochaetes, especially *Limnodrilus hoffmeisteri*. Oligochaete communities respond to the increase in the black layer and an increase in the organic sedimentation in similar fashions (Lang and Hutter, 1981; Zhong et al., 2008). This results in an increase in the nutrition available for tolerant species, but a decrease in the amount of oxygen available for those intolerant. Therefore, the abundance of mesotrophic and eutrophic species increases, while that of oligotrophic species decreases.

The decomposition of organic matter led to oxygen depletion in the sediment and, in turn, to its enrichment with nutrients. This enrichment is known to generate an increase in the levels of NO_3-N in the interstitial water (Hansen et al., 1998). Due to their toxicity, NO_3-N at high concentrations are considered to be key factors in the succession of benthic macroinvertebrates (Wilson et al., 1995; Frazier et al., 1996; Sparks and Sandusky, 1981).

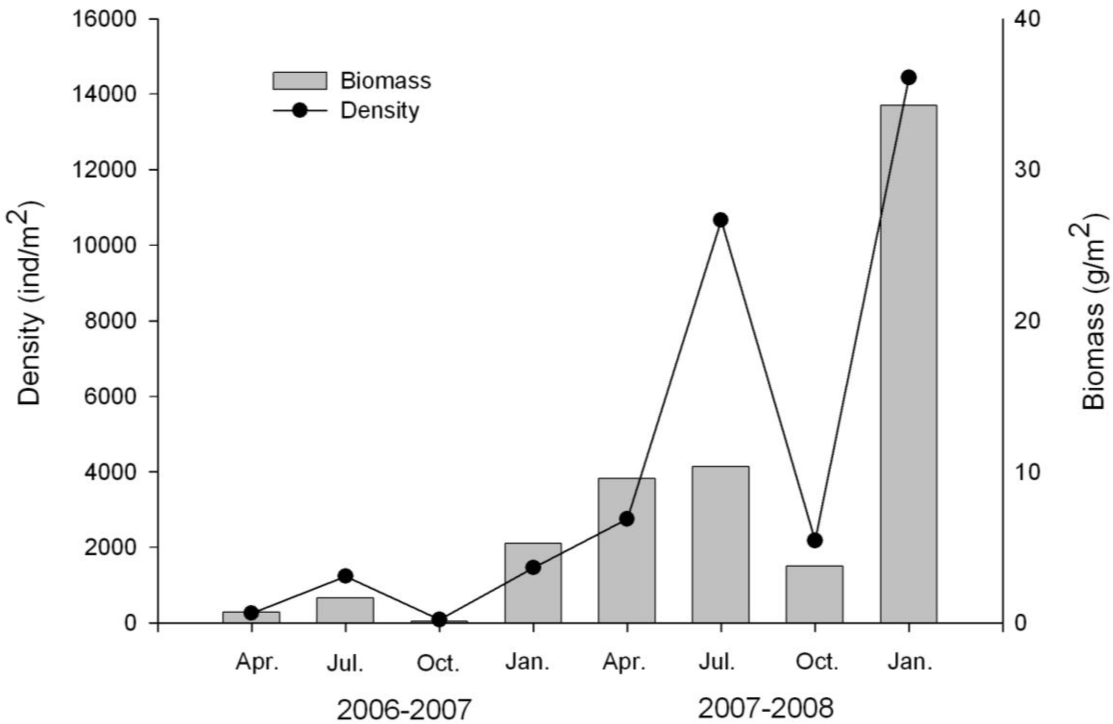

Figure 2. Seasonal variation of L. *hoffmeisteri* abundance in Fubao Bay.

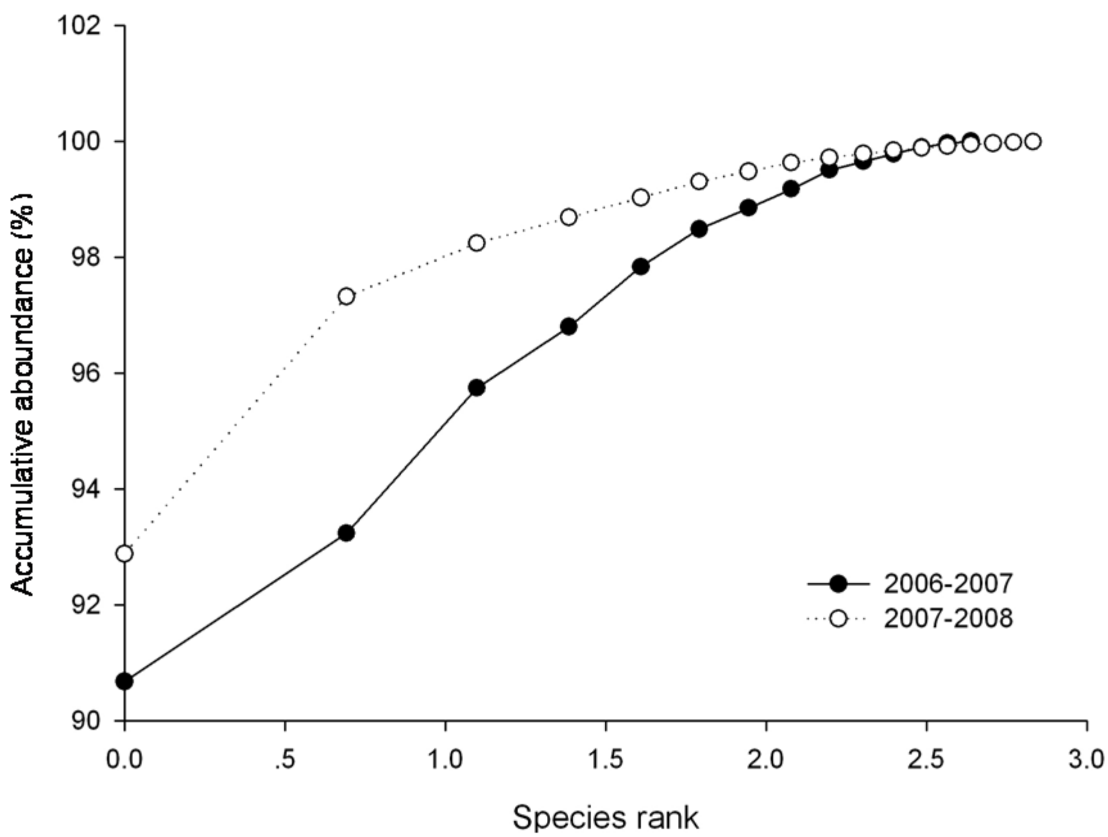

Figure 3. K-dominant curve of macrozoobenthos between 2006 and 2008 in Fubao Bay.

Table 6. Correlation coefficients between the environmental variables and the macrozoobenthic parameters (density and richness) of the Fubao Bay during the survey.

Parameter	TP	TN	NH_4-N	NO_3-N	NO_2-N	SS	COD	BOD	T	DO	pH	SD
Ro	0.456	0.274	0.090	-0.197	-0.207	0.113	0.537	-0.025	0.556	-0.609	0.091	0.000
Rc	-0.543	0.019	0.030	0.395	0.454	-0.343	0.109	-0.642	-0.210	-0.090	-0.309	0.347
Rt	0.325	0.212	0.153	-0.143	-0.128	0.024	0.480	-0.181	0.422	-0.644	-0.098	0.027
Do	0.199	-0.313	-0.101	0.516	0.413	-0.233	0.016	0.044	-0.210	-0.400	-0.206	0.229
Dc	-0.442	-0.331	0.108	-0.007	-0.130	-0.364	-0.307	-0.551	-0.023	0.125	0.166	0.293
Dt	0.171	-0.355	-0.112	0.509	0.385	-0.251	-0.022	0.025	-0.203	-0.377	-0.157	0.244
Bo	-0.106	-0.523	-0.015	0.761*	0.626*	-0.479	-0.199	-0.055	-0.458	-0.124	-0.235	0.430
Bc	-0.538	-0.391	0.090	0.727*	0.671*	-0.664*	-0.216	-0.642*	-0.507	-0.046	-0.371	0.607
Bt	-0.073	-0.526	-0.008	0.753*	0.617	-0.501	-0.231	-0.093	-0.472	-0.148	-0.255	0.453

Ro, Oligochaete richness; Rc, chironomid richness; Rt, total richness; Do, oligochaete density (ind/m^2); Dc, chironomid density (ind/m^2); Dt, total density (ind/m^2); Bo, oligochaete biomass (g/m^2); Bc, chironomid biomass (g/m^2); Bt, total biomass (g/m^2). **, Correlation is significant at the 0.01 level; *, at the 0.05 level.

Table 7. Stepwise multiple regression analyses determining the environmental variables affecting the biomass of macrozoobenthos of the Fubao Bay during the 2 year period.

Parameter	Model	β	Adjusted R^2	t	*p*
Bt	constant				
	NO_3-N	0.753	0.495	2.803	0.031
Bo	constant				
	NO_3-N	0.761	0.510	2.878	0.028
Bc	constant				
	NO_3-N	0.727	0.449	2.591	0.041

Bo, Oligochaete biomass (g/m^2); Bc, chironomid biomass (g/m^2); Bt, total biomass (g/m^2).

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