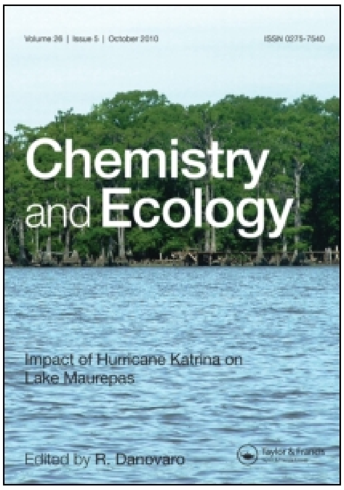

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SEDIMENTARY PIGMENTS AND ORGANIC MATTER IN RELATION TO BENTHIC FAUNA IN THE TAN-SHUI ESTUARY, TAIWAN

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The benthic ecological structure of the Tan-Shui estuary, Taiwan is changed due to long term effects of dumping of urban wastewater and of engineering actions. To monitor these changes, we sampled and analyzed benthos and sediment from 12 stations on the estuary.

The composition of the dominant species of benthos varied seasonally, with molluscan and crustacean species having greater numbers and higher frequencies of occurrence than other species. The dominant taxa during winter were *Nassarius* sp. and Maldanidae at two stations. Analysis using Simpson's index and Shannon's index showed the benthic community varied more in coastal areas than in offshore areas.

Physicochemical analysis showed that most of the Tan-Shui estuary consisted of sandy sediment. The variations in concentrations of organic carbon and total nitrogen at each station were small. Although the concentrations of chlorophyll-a and carotenoid at all stations were generally low, the two stations had the highest concentrations, and we concluded that the concentration of pigments in these sediments was related to the abundance of benthos. The community structure of the benthos reflected the characteristics of the sediments, and benthic species exhibited selection of and adaptation to specific sedimentary environments.

Keywords: Sediment; organic matter; benthos; Taiwan

INTRODUCTION

The estuary of the Tan-Shui River is situated between Tan-Shui town and Pali village (121°21′E, 25°11′N). According to Chinese Navy

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Survey Bureau (R.O.C)(1975) investigations, the depth gradient of the northern part of the estuary is 19 m per nautical mile, which is greater than the southern part at 9 m per nautical mile. Over 90% of the sediment is sand. The ocean current mainly is tidal, and tidal range is 1.5 ~ 2.5 m depth.

At flood tide, the salinity of sea water around the estuary is over 30‰; at ebb tide, the salinity of sea water becomes 15 ~ 20‰. This change is strongly affected by the exchange of river water and sea water during high-flow and low-flow periods.

The estuarine community consists of local species, oceanic species and freshwater species with osmotic regulation ability. Strongly affected by human activity and owing to river and sea water exchange, estuarine circulation results in high sedimentation rates of nutrients and pollutants (Rhoads *et al.*, 1978). Sanders (1968) believed that physical influences such as climate, and pollutants have caused communities in estuaries to stay in an unstable state, especially benthos, due to its lower mobility. Physical and chemical disturbances strongly affect the distribution of benthos (Hargrave and Thiel, 1983). Odum (1985) suggested using P/R doing series of tests on the succession processes of ecosystems.

Margalef (1963) suggested that pigments extracted from plankton populations and analyzed for absorption ratios (D430/D665) would express the stage of succession process of the ecosystem.

Burford *et al.* (1994) considered sediment pigment and macrobenthos to be related to environmental quality. Sediment pigments originate from microalgae, algae, fungi, bacteria, zooplankton, and benthos, so the types and quantities of pigments differ as environment, season and species composition of benthos change (Billett *et al.*, 1983). Many studies point out that the chlorophyll concentration in the water column has a relationship with the community and quantity of phytoplankton (Head and Harris, 1992; Garrison and Hurley, 1993; Williams, 1991).

Claustre and Harve (1994) suggested that chlorophyll-a and other pigments are in flux in the water column. The carotenoids are distributed in both photosynthetic and non-photosynthetic organisms (Ropeta and Gagosian, 1982). The chlorophyll-a is a pigment of photosynthesis.

In this paper, we report the concentrations of organic carbon, chlorophyll-a and carotenoid of pigment in sediments of the Tan-

Shui estuary to determine their relationship with the abundance of benthos.

MATERIALS AND METHODS

Survey trips were made to 12 stations located on the Tan-Shui estuary of the north shore of Taiwan from June 1995 to January 1996. For sampling offshore, samples were taken on board by a 10 min haul with a $50 \times 20\,cm^2$ rectangular dredge; net bag length of 80 cm with 3 mm diameter mesh, so that a sample of small-sized benthos was obtained. The benthic fauna from the dredge samples was rinsed and screened through a 5 mm pore sieve followed by a 1 mm pore sieve. Samples were preserved in 5% neutral formalin. Total community diversity was estimated using the Shannon-Wiener index (Ludwig and Reynolds, 1988). By this index, species diversity is:

$$H' = -\sum_{i=1}^{S} P_i \times \ln P_i,$$

where $P_i = n_i/N$, in which n_i is the number of individuals of the species, N the total number of individuals, and S the total number of species. The literature suggests that such indices can be used to assess environmental quality (Wilhm and Dorris, 1968; Sanders, 1968; Headrich, 1975; Washington, 1984).

An additional grab sample was collected at each station for sediment analysis. Samples taken from the top of the sediment surface were analyzed for pH, redox potential (Eh), grain size, organic carbon, and pigments.

The pH and redox potential (Eh) were determined by portable pH/Eh meter (model PHM210, Radiation Analytical S.A.), organic carbon was determined according to the Gerchaov and Hatcher (1972) method. Sediment organic content was determined by ignition loss from dry sediment placed in a muffle furnace at 550°C for 2–8 hr. The samples of sediment were analyzed for chlorophyll-a and carotenoids. The technique was a modification of that outlined in Strickland and Parsons (1972), where the pigments were extracted with 90% acetone. After centrifugation, the supernatant was examined in a spectrophotometer (Perkin Elmer Lambda 3B).

RESULTS

Benthos samples at nearshore stations (*c*1 to *c*12, Tab. I).

TABLE I Species of macrobenthos and their abundance (in $10\,m^2$) at sampling stations in the Tan-Shui River Estuary, June 1995

	*c*1	*c*2	*c*3	*c*4	*c*5	*c*6	*c*7	*c*8	*c*9	*c*10	*c*11	*c*12
Coelenterata												
Medusae								2				
Sertularella sp.						1						
Mollusca												
Anomalocardia squamosa												
Casmaria sp.									2		1	
Crassostrea gigas												
Cyclina sinensis			3						4		3	
Drupella concatenata							2					
Gomphina aequilatera					6	9	2			12	4	
Laternula anatina												
Liolophura sp.												
Mactrinula sp.												
Mitridae										5		
Terebridae									1			
Thais clavigera												
Annelida												
Marphysa sp.					1							
Arthropoda												
Alpheus sp.												
Balanus albicostatus												
Calcinus												
Callianassa petalura												
Clibanarius sp.					1							
Harrovia elegans					1							
Hippa pacifica			1							2		
Matuta lunaris		5	9		4					1		
Metapenaeus sp.												
Ocypodidae												
Paguristes sp.												
Penaeus sp.		9	24		10	6		5	1		2	
Portunus haanii												
Processa sp.					1		1					
Rivulogammarus nipponensis												
Rocinela sp.												
Scopimera globosa	1											
Enchinodermata												
Ophiomyxa sp.									1			
Pisces												
Saurida gracilis												
Number of individuals		14	37		24	17	5	7	9	20	10	
Number of species		2	4		7	4	3	2	5	4	4	

Fauna

Seventeen species of macrobenthos were identified from the summer sampling (Tab. I), mostly mollusca and arthropoda. Stations *c*1 to *c*5 located near the coast did not have any benthos other than *Cyclina sinensis* at *c*3. Arthropoda mostly were *Penaeus* sp., as a bottom dredge only sampled smaller sized and slower moving benthic animals.

Winter sampling produced 41 species of macrobenthos (Tab. II), mostly mollusca, followed by arthropoda and polychaetes. Mollusca, which consisted of 13 bivalve species, 8 species of Prosobranchia, 6 species of Opisthobranchia. Polychaetes consisted of Goniadidae, Maldanidae, and Onuphidae, and were particularly obvious at stations *c*3 and *c*7. The benthic composition exhibited obvious seasonal differences (Tab. III). There were more species in winter than in summer.

Community Structure

Comparing the value of Shannon's index and Simpson's index at each station (Tab. IV) showed the relation of species and individuals in the community. In winter, Simpson's index at *c*1, *c*3 and *c*7 was higher than at other stations, and showed that polychaetes predominated. Shannon's index at *c*4 and *c*9 was higher than at other stations. If the value of Shannon's index is low, it was noted that environmental stress has changed the biological community (Sanders, 1968).

Relation of Sediment Character and Benthos Abundance

Organic carbon in sediment at station *c*1 was lowest at 2.7–8.0 mg g^{-1} with total organic nitrogen at 3.3–29.7 mg g^{-1}, and Eh at 187–210 mv (Tab. V). Basford and Eleftheriou (1988) thought this was the proper oxidation state. Because of the physical and chemical peculiarity of sediment, moreover (Tab. VI), our sampling area was sandy sediment where water action was strong. All these results showed no major difference in organic content, total nitrogen and Eh among stations. Highest concentrations of chlorophyll-a (0.433 mg g^{-1} and 0.382 mg g^{-1}) and carotenoid (0.498 mg g^{-1} and 0.460 mg g^{-1}) in the sediment occurred at stations *c*3 and *c*7, where there was a great abundance of polychaetes and mollusca.

TABLE II Species of macrobenthos and their abundance in (10 m^2) at sampling stations in the Tan-Shui River Estuary, January 1996

	c 1	*c* 2	*c* 3	*c* 4	*c* 5	*c* 6	*c* 7	*c* 8	*c* 9	*c* 10	*c* 11	*c* 12
Phylum Protozoa												
Globigerina sp.									1			
Phylum Coelenterata												
Gorgonacea								7				
Phylum Ectoprocta												
Vesculariidae									1			
Phylum Mollusca												
Monilea sp.				1								
Umbonium vestiarum		9		1	2	5	1					2
Liotina sp.				1								
Glassaulax didyma			1									
Nassarius sp.			23	1		1	40	11			1	
Babylonia areolata			1									
Thais clavigera				1				1				
Mastonia peanites						2	1					
Colsyrnola brunnea			1				1					
Pyrgulina casta									4			
Solidula strigosa							4					
Decorifer insignis									3			
Scaphandridae						1						
Creseis acicula											2	3
Barbatia sp.				1		1		1				
Crassostrea gigas				9								
Anomia chinensis.				6								
Gomphina aequilatera		1										
Meretrix sp.	23	28	26	1	3		9	1				17
Placamer tiara			4									
Dosinia troschelis							5					
Chama sp.								3				
Tentidonax kiusiuensis	1											
Veremolpa minuta			2									
Nitidotellina iridella						3				6	1	3
Slique sp.			1									
Corbula formosae							9					
Siphonodentaliidae			1				1					
Phylum Annelida												
Goniadidae					2			1		3		
Maldanidae			684			1	1775	1	3			1
Onuphidae								1				
Phylum Arthropoda												
Homolidae									1			
Penaeus sp.			2		3	92			4	10	6	34
Digenidae		1		3	1				2			
Dynoides dentisinus										4		13
Phylum Echinodermata												
Ophiomyxa sp.						1		1	3		1	2
Dendrasteridae				1		1			1			
Phylum Chordata												
Saurida gracilis											3	
Number of individuals	24	39	746	26	11	108	1846	28	23	23	14	75
Number of species	2	4	11	11	5	10	10	10	10	4	6	8

TABLE III Percent occurrence of benthic macrofauna taken in the Tan-Shui River Estuary, 1994–1996

	Dec. (1994)		*Jun.* (1995)		*Jan.* (1996)	
	Species No.	***%***	***Species No.***	***%***	***Species No.***	***%***
Mollusca	10	0.55	17	0.35	28	0.68
Arthropoda	5	0.27	7	0.41	4	0.10
Polychaeta	1	0.06	1	0.06	3	0.07
Echinodermata	1	0.06	1	0.06	2	0.05
Pisces	1	0.06			1	0.02
Other species	0		2	0.12	3	0.07
Total	18	100	17	100	41	100

DISCUSSION

When an environment suffers stress or disturbance, the number of organisms and variety of species of the ecosystem differ from the normal succession process. Our summer sampling produced 17 species of benthos, mostly Mollusca and Crustacea, with Veneridae predominating. The Veneridae are among the most recent and numerous colonizers of the shallow water, being especially common on soft shores, having almost lost horizontal movement ability. Therefore, they are strongly affected by water quality and sediment. Their low mobility precludes escape from environmental stress. When turbidity is too high, death probably results. Distribution of benthos is related to habitat specialization. Numbers of *Crassostrea gigas* and the concentration of suspending solids in the water column at station *c*4 were not high. Many studies suggest that benthos exhibits habitat specialization (Rhoads and Young, 1970; Richter 1985) and this is supported by our results.

In winter, a total of 41 species of benthos were identified from the grab sampling, the fauna consisting mainly of sedentary and burrowing forms of *Nassarius* sp., *Metetrix* sp., Maldanidae, Gorgonacea and *Crassostrea gigas*, mostly Mollusca. The stations with more benthos species were located around the estuary at stations *c*3, *c*4, and *c*1, with less near the Tan-Shui River estuary. According to species diversity indices, stations along the coast varied greatly, while stations nearshore were more stable.

The traditional way of using diversity indices and similarity indices is to show a community's stability (Washington, 1984). Goodman

TABLE IV Indices of benthic macrofaunal analysis in the Tan-Shui River Estuary, 1995 and 1996

	Station	*c* 1	*c* 2	*c* 3	*c* 4	*c* 5	*c* 6	*c* 7	*c* 8	*c* 9	*c* 10	*c* 11	*c* 12
Jun.	No. of Species		2	4		7	4	3	2	5	4	4	
95'	Simpon's index (λ)		0.505	0.472		0.239	0.375	0.20	0.524	0.194	0.405	0.222	
	Shannon's index (H')		0.652	0.926		1.54	1.037	1.055	0.598	1.427	1.033	1.280	
Jan.	No. of Species	2	4	11	11	5	10	10	10	10	4	6	8
96'	Simpon's index (λ)	0.920	0.559	0.843	0.166	0.145	0.727	0.925	0.209	0.087	0.273	0.209	0.282
	Shannon's index (H')	0.173	0.764	0.408	1.957	1.547	0.712	0.218	1.786	2.163	1.283	1.537	1.507

TABLE V Physicochemical parameters of sediment in the Tan-Shui River Estuary, 1996

	c 1	*c* 3	*c* 4	*c* 5	*c* 6	*c* 7	*c* 9	*c* 10	*c* 11	*c*12
TOC ($mg\,g^{-1}$)	2.7	6.6	8.0	7.6	6.2	6.4	3.2	5.7	4.7	5.5
TON ($\mu g\,g^{-1}$)	8.94	3.59	13.27	7.69	4.22	3.3	8.67	8.22	7.28	29.7
pH	7.77	7.59	7.27	7.44	7.62	7.32	8.11	7.89	7.53	7.06
Eh (mv)	191	196	187	195	193	194	205	210	203	189
Organic content (%)	2.3	3.05	3.19	2.31	2.24	2.66	3.14	3.03	3.43	2.45
Water content (%)	26.3	27.4	30.3	25.4	29.3	30.1	30.2	28.4	29.4	28.7
Sand (%)	88.6	88.1	87.4	85	87.91	88.18	87.01	87.7	87.6	86.2
Clay (%)	11.4	11.7	12.5	14.9	12.08	11.02	12.96	12.1	12.3	13.6
Silt (%)	0	0.2	0.1	0.1	0.01	0.8	0.05	0.2	0.1	0.2
chl.a ($\mu g\,g^{-1}$)	0.142	0.433	0.089	0.165	0.151	0.382	0.142	0.144	0.140	0.135
carotenoid ($\mu g\,g^{-1}$)	0.071	0.497	0.136	0.139	0.086	0.460	0.054	0.070	0.069	0.069

TABLE VI Concentrations of pigments and suspended solids in the water column of the Tan-Shui River Estuary, 1996

	Chlorophyll-a (μg)	*carotenoid* (μg)	*Suspended Solid* ($mg\ L)^{-1}$
*c*1U	0.039	0.063	17.64
*c*1L	0.024	0.043	22.68
*c*2U	0.008	0.010	13.08
*c*2L	0.008	0.008	34.36
*c*3U	0.021	0.019	49.44
*c*3L	0.023	0.023	20.00
*c*4U	0.021	0.018	27.00
*c*4L	0.021	0.020	9.76
*c*5U	0.007	0.007	19.04
*c*5L	0.009	0.010	12.60
*c*6U	0.021	0.031	6.76
*c*6L	0.008	0.008	40.88
*c*7U	0.008	0.007	48.72
*c*7L	0.013	0.022	54.24
*c*8U	0.005	0.004	49.56
*c*8L	0.004	0.003	37.44
*c*9U	0.005	0.006	35.88
*c*9L	0.011	0.018	44.36
*c*10U	0.010	0.008	8.28
*c*10L	0.009	0.008	13.44
*c*11U	0.006	0.005	4.68
*c*11L	0.007	0.007	7.52
*c*12U	0.005	0.005	3.84
*c*12L	0.004	0.003	23.64

U: upper layer of water column;
L: low layer of water column.

(1975) and Gray (1979) considered it difficult to correctly indicate the change of community structure with diversity indices. Therefore, to further understand community structure change, we should study its relation to the food chain, and sediment characteristics.

Stations *c*3 and *c*7 exhibited high abundance of polychaetes and molluscans. The distribution of the main feeding types was found to be closely associated with the particle size and the amount of organic carbon in the sediment, polychaetes and bivalves being very important environmental indicators (Pocklington and Wells, 1992; Wolfe, 1992). At these two stations chlorophyll-a and carotenoid concentrations were higher than at other stations. Burford *et al.* (1994) believed pigment concentration, benthos and environmental parameters are related. We have shown that sediment pigment concentration is related to species diversity and abundance of benthos and that benthos with different feeding adaptations has certain habitat selection and adaptation abilities.

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