RAPPORTO STM CNR (2015)

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Dipartimento di afferenza: **Scienze del sistema terra e tecnologia per lôambiente**

Titolo del programma: **Valutazione dello biodiversità e dello stato ecologico della laguna costiera di Yundang (Xiamen, Cina)**

[*Assessment of the biodiversity and the ecological status of the Yundang lagoon (Xiamen, China)*]

Periodo del soggiorno: **16 novembre ï 8 dicembre 2015**

Attività

Lôattività svolta dallo scrivente tra il 16 novembre e lô8 dicembre 2015 presso il Dipartimento di Ecological Science and Engineering, dellôUniversità di Xiamen, Cina, ha compreso lôanalisi ed una prima interpretazione dei dati ambientali e biologici ottenuti in una precedente campagna di monitoraggio condotta nella laguna di Yundang (Xiamen), secondo quanto indicato nel programma di ricerca. Le analisi univariate e multivariate dei dati chimico-fisici della colonna dôacqua (nutrienti, BOD_5, COD_{Mn}, clorofilla-a, solidi sospesi), dei sedimenti superficiali (granulometria, carbonio organico totale, azoto totale) e delle comunità macrozoobentoniche (es. ricchezza specifica, abbondanze, dominanze, indici derivati di diversità) hanno permesso di fornire una valutazione integrata dello stato ecologico e della biodiversità della laguna di Yundang e di identificare le aree maggiormente soggette al rischio di eventi anossici e/o distrofici.

Nel complesso, si è riscontrata una situazione di forte degrado ambientale della laguna di Yundang, con valori molti elevati di azoto e fosforo nei campioni di acqua e comunità macrozoobentoniche con ridotte abbondanze, una bassa ricchezza specifica e la dominanza di un mollusco bivalve invasivo proveniente dal Sud America, *Mytilopsis sallei*, causa di depauperamento delle comunità autoctone. In particolare, la situazione di maggior degrado è stata evidenziata al sito *F* (vd. Fig. 1 riportata in Annex 1) dove si sono riscontrati valori molto elevati di sostanza organica nei sedimenti (6% di carbonio organico totale) ed una comunità macrozoobentonica fortemente ridotta in termini di abbondanze e numero di taxa. Si ritiene che questa situazione sia il risultato di una forte pressione antropica dovuta agli scarichi urbani di natura domestica ed industriale provenienti dalle aree circostanti la laguna. Unôaltra area critica della laguna è risultata il sito *B* che, per quanto meno arricchito in sostanza organica rispetto al sito *F*, ha pure mostrato valori di abbondanze e ricchezza specifica molto bassi, probabilmente legato ad un elevato grado di confinamento (scarsa circolazione) ed una maggiore profondità. Il sito *A* è risultato relativamente più ricco, dominato peraltro dal mitilo invasivo *M. sallei* proveniente. Nel complesso, i risultati di questa ricerca hanno permesso di fornire unôapprofondita conoscenza scientifica sullo stato di salute della laguna di Yundang a supporto delle amministrazioni locali per lôadozione di strategie utili ad una corretta gestione di questo ambiente ed un suo possibile recupero. Durante la permanenza presso lôUniversità di Xiamen, lo scrivente ha iniziato altresì la stesura di un manoscritto, di cui se ne riporta una bozza (vd. Annex 1), che sarà completato ed

inviato per pubblicazione a rivista scientifica internazionale, rispettando appieno gli obiettivi del programma di ricerca presentato.

La presente STM ha rappresentato un'importante opportunità scientifica e di collaborazione internazione con la Cina per lo studio degli ambienti di transizione che oltre a permettere la preparazione di un lavoro scientifico comune tra il CNR-IAMC e l'Università di Xiamen, darà nuovo impulso al reperimento di fondi sia su scala nazionale che internazionale. In questo ambito, è intenzione dello scrivente di presentare un nuovo programma di ricerca per invitare il collega cinese, Prof. Lingfeng Huang, responsabile ospitante per la mia STM e direttore del Dipartimento di Ecological Science and Engineering, presso il CNR-IAMC di Oristano.

ANNEX 1. DRAFT MANUSCRIPT FOR SUBMISSION TO AN INTERNATIONAL PEER-REVIEWED JOURNAL

Assessment of the biodiversity and the ecological status of the Yundang lagoon (Xiamen, China)

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1. Introduction

Coastal lagoons and the adjacent marine areas form unique transitional systems where the inlet plays a key role. Inlets are critical in the interaction between lagoons and the coastal marine ecosystem as they influence the exchange of water masses with different physical and chemical characteristics and ensure the renewal of the water within the lagoon (Magni et al., 2008). However, in the last few decades major man-made interventions affecting the morphology of inlets, such as the installation of artificial structures and barriers, are profoundly impairing the trophic status and functioning of these systems worldwide (Como et al., 2007; Magni et al., 2008).

The Yundang lagoon (China) is a typical example of such coastal lagoons characterized by a high ecological and economic potential, but increasingly stressed by various human pressures. The Yundang Lagoon is a typical urban water body in modern cities. The main source of pollutants is domestic wastes, which contains high concentrations of nutrients and organic matter (Zheng et al., 2008). The main concerns of people and the government on the Yundang lagoon are its service in social aspects, e.g. scenery, flood prevention capacity and values for travel, entertainments, recreations and dwelling. Thus, it is of vital importance to provide science-sound knowledge in order to support local administrations in decision making with regard to the management of these transitional systems.

The aims of this study were: (1) to study the spatial variability in benthic assemblages and sediment characteristics along an environmental gradient; (2) to assess the benthic biodiversity of Yundang lagoon; and (3) to assess most degraded areas or areas at major risk of environmental damage. Within this framework, we hypothesized that are differences in the

spatial distribution of macrobenthic assemblages and sediment characteristics in relation to environmental gradients (e.g. organic enrichment, confinement).

2. Materials and methods

2.1 Study area

The study was conducted in the Yundang lagoon, a subtropical lagoon in Xiamen City, southeast China, which connects to the Western Sea of Xiamen Island through a small canal controlled by a sluice (Fig. 1). The Yundang lagoon used to be a natural bay called Yundang Harbor. The harbor covered an area of about 10 km^2 (6.3 km long and 1.6 km wide). A great number of land reclamation projects were carried out in the early 1970s and the Yundang Harbor gradually became a dead lagoon unable to exchange water with the sea. The lagoon area was reduced from the original 10 km^2 to only 2.2 km^2 (1988 data, including marshes of 1.0 km^2). Now, the total water area of the Yundang lagoon is approximately 1.5 km^2, with a maximum depth of around 5 m and a drainage area of 37 km^2, making up 30% of Xiamen Island. The lagoon is separated into several parts, including a diversion canal, main canal, inner lagoon, and outer lagoon (Fig. 1). Water exchange between the lagoon and inshore water is limited and the retention time of lagoon water is approximately 3d. Given the massive domestic sewage discharge in the area, eutrophication has become an extremely serious threat in the lagoon water (Weidong et al., 2010; Huang et al., 2013). High levels of estrogenic compounds have also been found in sediments, pore-water and biota originated mainly from municipal wastewaters (Zhang et al., 2009, 2011).

2.2 Experimental design and sampling activities

Samplings were conducted on day 13 (sediment samples) and day 14 (water samples) of November 2012 at six different sites (A to F) covering all different sectors of the lagoon (Fig. 1). At each site, three replicate sediment samples were collected 3-5 m apart, at three stations 50-100 m apart, using a van Veen grab (30 x 20 cm, penetration depth 18 cm). Each sediment sample was sieved on a mesh size of 0.5 mm and the residue was fixed in a 5% formalin buffered solution for macrozoobenthos determination. Prior to sieving, a subsample of the topmost cm of the sediment from each grab was collected for grain size and chemical analysis (total organic carbon and total nitrogen) using an acrylic core tube (3 cm i.d.) gently pushed by hand into the sediment.

At each site and station, water salinity, temperature and dissolved oxygen (DO) concentrations were measured using a portable CTD cast (YSI 6600) and near-bottom water

samples for chemical (nutrients, BOD_5, COD_{Mn} and Chl-*a*) analysis and suspended solid determination were collected using a 2-liter Niskin bottle.

2.3 Sample treatment and analysis

In the laboratory, water samples were firstly filtered by using a 0.45 μm filter. Nutrients (ammonia, nitrate, nitrite and reactive phosphorus), BOD_5, COD_{Mn} and SS were measured by applying standard analytical methods (Table 1) according to the National standard GB17378.4 (2007). Chl *a* was measured by fluorometric analysis using a Turner Designs Fluorometer (Mode 10-AU).

For the measurements of sediment particle size, diluted hydrochloric acid and hydrogen peroxide were added to the evenly mixed sample to remove carbonates and organic matter. After being washed to remove the acid to attain neutrality, Na-Hexametaphosphate 0.6% solution was added to avoid particle flocculation, and the samples stood still for 24 h. Subsequently, the particle size was measured with a Malvern Mastersize 2000 laser particle size analyzer, and the measurement data were outputted at 1/4 ū intervals. The moment method was used to calculate the grain-size parameters of the sediments (McManus, 1988).

The water content of the sediment was obtained after drying a sediment subsample at 70 ºC for 24 h. For the analysis of the total organic carbon (TOC) and total nitrogen (TN) content of the sediment, the sediment sample was once freeze-dried, and powdered. After removal of carbonate from the sample with 2 N HCl, it was vacuum-dried. TOC content of the dried sediment sample was measured using an Elemental vario EL-III element analyzer. Replicate analyses of standards of acetanilide yielded a mean precision of about 0.3% for organic carbon and nitrogen.

The macrozoobenthos from each grab sample were sorted, identified to the species level, when possible, counted under a stereo-microscope and preserved in 75% ethanol. After counting, individuals of the same species in each sample were weighed as a wet weight.

2.4. Data analyses

2.4.1 Univariate analyses

Near-bottom water variables included temperature, salinity, ammonium, nitrate, nitrite, dissolved inorganic nitrogen (DIN = sum of ammonium, nitrate and nitrite), reactive phosphorous (DIP), N/P ratio, DO, BOD_5, COD_{Mn}, chlorophyll-a (Chl-a) and suspended solids (SS). For these variables there was one measurement per station, thus data were

analyzed using a 1-way ANOVA with Sites (6 levels; random) as factor and 3 stations as replicates.

Sediment variables included three grain size fractions, i.e. sand (<63 µm), silt (63-8 µm) and clay (<8 µm) and the median particle size (Md). For sediment variables, TOC, TN and the abundances and biomass there were 3 replicates per station, thus data were analyzed using a 2-way ANOVA with Sites (6 levels; random) and Stations (3 levels; random and nested in sites) as factors and 3 stations as replicates.

2.4.2. Multivariate analyses

Multivariate analyses were done using the mean of sedimentary variables (grain size fractions, Md, TOC and TN) and the sum of fauna replicates. Near-bottom water variables and sediment fractions were analyzed using principal component analyses (PCA) ordination model.

The variables used in the analysis included: ammonium, nitrate, nitrite, DIN, N/P, DO, BOD_5, COD_{Mn}, SS, Md. DIP, Chl-a, sand, silt, clay, TOC and TN were excluded from the multivariate analyses as they were correlated to the other variables (at R>0.90). Analyses was done on standardized and normalized data.

Macrozoobenthos were examined by means of nonmetric multidimensional scaling (nMDS) based on the Brayï Curtis similarity matrix with different degrees of data transformation (none, square root, and fourth root). The results did not differ regardless of the level of data transformation, so only results on square root data are presented here. Differences among sites were investigated using the ANOSIM routine in PRIMER v6 (Clarke and Warwick, 2001).

2.4.3. Relationships between environmental variables and macrozoobenthic assemblages

Spearmanôs rank correlation coefficients were used to determine the relationship between the environmental variables and the spatial variations in macrozoobenthic assemblages. Only the selected environmental variables were included. Separate analyses were done using DO % and DO mg/l. Similar results were obtained, so only results on DO as % of saturation are presented here. BIO-ENV was conducted using the PRIMER v6 package (Clarke and Warwick, 2001).

Correlation coefficients, *R*, were calculated using Statistica (StatSoft 6.1, 1994) to analyse further the relationships between the univariate environmental and benthic variables. To account for multiple simultaneous correlations, the level of significance was adjusted for

each environmental variable within each of the macrofaunal groups with the sequential Bonferroni technique (Rice, 1989) using Statistica (StatSoft 6.1, 1994).

For correlation analyses, the mean values of sediment grain variables per station were used. For the macrozoobenthos, the sum of the three replicate samples per station was used as the sum included the spatial variations).

3. Results and Discussion (in progress)

3.1. Univariate analyses

3.1.1. Near-bottom water variables

Near-bottom water temperature and salinity were rather homogeneous throughout the lagoon averaging 22.6 ± 0.3 °C and 29.9 ± 0.6 (± standard deviation), respectively (data not shown). Separation among sites was found for all the other variables examined (Table 2 and Fig. 2). Ammonium was highest at site F, while nitrite was lowest at site A. Nitrate tended to be lower at both sites A and F, but the SNK test failed to discriminate alternative hypothesis. DIN was lowest at site A and DIP was highest at site F. Consequently, the N/P ratio tended to be lower at sites A and F but the SNK test failed to discriminate alternative hypothesis. Dissolved oxygen (%) tended to be lower at site F, but the SNK test failed to discriminate alternative hypothesis. Similar result was obtained using DO expressed as mg l^{-1} ($P<0.05$; data not shown). Marked spatial differences were found for BOD_5, COD_{Mn} and Chl-a which were highest at site F. Finally, suspended solid was lowest at sites A and B and highest at sites D, E and F. Overall, the near-bottom water variables indicated site F as the most degraded site, as indicated by the highest BOD_5 and COD_{Mn} values and relatively lower DO concentrations.

3.1.2. Sediment grain size, TOC and TN

Sediments were muddy at all sites, with a prevalence of silt (Fig. 3). This fraction was up to about 80% at sites D and E, while the sand tended to be relatively higher at sites A and B. The median particle diameter ($\bar{u}$) varied little from 4.6 (site A) and 6.9 (sites C and D), while the TOC and TN content showed marked differences being highest at site F with mean of 5% and 0.7%, respectively. Separation among sites was found for all sediment variable, but only for TOC and TN the SNK test discriminated alternative hypothesis (Table 3). Similarly to what found for the near-bottom water variables site F appeared the most degraded one as indicated by organic over-enrichment.

3.1.3. Macrozoobenthic assemblages

Overall, 43 taxa were found. The invasive bivalve *Mytilopsis sallei* was the most common benthic species, accounting for 75% of the total individuals. Several other less abundant species included *Stenothyra glabra*, *Pseudopythina tsurumaru*, *Rissolina plicatula*, *Corophium* sp., *Corophium uenoi* and *Cossurella dimorpha*. It is worth noting that *Stenothyra glabra* is considered a threatened species according to the IUCN (www.iucnredlist.org). *M. sallei* accounted for 88% of the total biomass followed by another invasive species the ascidian *Styela plicata* (8.4%). *S. plicata* occurred in some replicates of site C (ANOVA did not revealed differences in both abundances and biomass so data are not shown).

There were differences among sites for all benthic variables (Table 4, Fig. 4). The total number of species and individuals were highest at site A. H' tended to be higher in site D but SNK test failed to discriminate alternative hypotheses.

The analyses revealed differences among sites for the abundance of the dominant taxa, with the exception of *Pseudopythina tsurumaru*. The abundances of *Mytilopsis sallei*, *Stenothyra glabra*, *Rissolina plicatula*, *Corophium* sp. and *Corophium uenoi* were higher in the site A than in all other sites (Table 5, Fig. 5). However, SNK test failed to discriminate alternative hypotheses for *Stenothyra glabra*. Conversely, *Cossurella dimorpha* was the most abundant in the site.

The total biomass and the biomass of *Mytilopsis sallei* were higher in site a than in all other sites, but SNK test discriminates alternative hypotheses only for the biomass of *M. sallei* (Table 6, Fig. 6).

3.2. Multivariate analyses

Separation of Sites was revealed by the PCA (Fig. 7a). Site F separated from the other sites (along the Y axis). Along the X axis there was a separation between site A and the inner sites (sites C, D and E) with the site B (deeper) in the middle. Nitrite, nitrate, DIN, N/P , COD_{Mn} and Md explained the most the separation along the X axis, while DO, ammonium, SS, BOD_5 and COD_{Mn} explained the most the separation along the Y axis (Table 6).

Separation of Sites was revealed by the ANOSIM ($R=0.40$, $P<0.01$) (MDS in Fig. 7b). The lowest variability within sites was found at sites A and C and highest at site F (Table 8).

3.3. Relationships between environmental variables and fauna

The Spearman rank correlation coefficients from BIO-ENV revealed modest agreement between the environmental variables and the macrofaunal assemblage (0.24 and 0.29 weighted and unweighted Spearman coefficients, respectively; only weighted Spearman

coefficient is significant at $P<0.05$). The combination of environmental variables that produced the strongest correlation (significant weighted Spearman coefficients) was ammonium and nitrite.

Linear correlation between all environmental variables and macrofaunal variables (including univariate indices, abundances and biomass of fauna) are reported in Table 9.

Acknowledgments

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Table 1. Methods used for seawater analysis in Yundang lagoon. All methods are according to the National standard GB17378.4 (2007).

Variable	Method	Lower Detection Limit (mg l^{-1})
Ammonia	Indophenol-blue colorimetric method	0.012
Nitrite	N(1-naphty1)-ethylenediamine dihydrochloride spectrophotometric method	0.0005
Nitrate	Cadmium column reduction method	0.012
Phosphate	Phosphomolybdenum blue spectrophotometric method	-
Biological Oxygen Demand (BOD_5)	Five-days biochemical culture method	2
Chemical Oxygen Demand (COD_{Mn})	Potassium iodide-alkaline potassium permanganate determination method	0.5
Suspended solids (SS)	Weighting	0.1

Table 2. Results of one-way ANOVA testing differences among sites for near-bottom water variables. Results of SNK test are also indicated.

		Ammonium (μM)			Nitrite (μM)			Nitrate (μM)		
Source	df	MS	F	P	MS	F	P	MS	F	P
Sites	5	754.46	81.99	0.00	215.74	4.36	0.02	1507.10	8.49	0.00
residuals	12	9.20			49.48			177.53		
total	17									
Transformation		None			None			None		
Cochran's Test		0.34 (P>0.05)			0.51 (P>0.05)			0.53 (P>0.05)		
SNK test		A=B=C=D=E<F			A<B=C=D=E=F			nah		

		DIN (μM)			DIP (μM)			N/P ratio		
Source	df	MS	F	P	MS	F	P	MS	F	P
Sites	5	1.13	10.65	0.00	0.59	36.19	0.00	582.93	10.28	0.00
residuals	12	0.11			0.02			56.73		
total	17									
Transformation		Ln(X+1)			None			None		
Cochran's Test		0.54 (P>0.05)			0.33 (P>0.05)			0.52 (P>0.05)		
SNK test		A<B=C=D=E=F			A=B=C=D=E<F			nah		

		DO (%)			BOD_5 (mg l^{-1})			COD_{Mn} (mg l^{-1})		
Source	df	MS	F	P	MS	F	P	MS	F	P
Sites	5	235.54	26.04	0.00	0.66	6.55	0.00	0.14	10.54	0.00
residuals	12	9.05			0.10			0.01		
total	17									
Transformation		None			None			None		
Cochran's Test		0.66 (P>0.05)			0.50 (P>0.05)			0.37 (P>0.05)		
SNK test		nah			A=B=C=D=E<F			A=B=C=D=E<F		

		Chl-a			SS (mg l^{-1})		
Source	df	MS	F	P	MS	F	P
Sites	5	1.80	446.51	0.00	0.62	19.68	0.00
residuals	12	0.00			0.03		
total	17						
Transformation		Ln(X+1)			Ln(X+1)		
Cochran's Test		0.39 (P>0.05)			0.39 (P>0.05)		
SNK test		A=B=C=D=E<F			A=B<C<D=E=F		

Table 3. Results of two-way ANOVA testing differences among sites for the proportion of sediment fractions (i.e., sand, silt and clay) and results of one-way ANOVA testing differences among sites for the proportion of TON and TN. Results of SNK test are also indicated.

		Sand (>63 µm)			Silt (63-8 µm)			Clay (< 8 µm)			Md (ū)		
Source	df	MS	F	P	MS	F	P	MS	F	P	MS	F	P
Sites	5	15.09	104.22	0.00	1234.10	61.08	0.00	1.14	48.33	0.00	8.10	101.12	0.00
Stations(Sites)	12	0.14	0.75	0.69	20.20	0.50	0.90	0.02	0.77	0.68	0.08	0.43	0.94
residual	36	0.19			40.54			0.03			0.18		
total	53												
Transformation		Ln(X+1)			None			Ln(X+1)			Ln(X+1)		
Cochran's Test		0.30 (P > 0.05)			0.28 (P > 0.05)			0.24 (P > 0.05)			0.29 (P > 0.05)		
SNK test		nah			nah			nah			nah		

		TOC			TN		
Source	DF	MS	F	P	MS	F	P
Sites	5	4.95	63607.96	0.00	0.13	2284.18	0.00
residuals	12	0.00			0.00		
total	17						
Transformation		None			None		
Cochran's Test		0.50 (P>0.05)			0.30 (P>0.05)		
SNK test		A=B=C=D=E<F			A=B=C=D=E<F		

Table 4. Results of two-way ANOVA testing differences among sites for S, N and Hô. Results of SNK test are also indicated.

		N				S				H		
Source	DF	MS	F	P		MS	F	P		MS	F	P
Sites	5	14.91	5.71	0.01		28.91	12.80	0.00		1.35	5.96	0.01
Stations(Sites)	12	2.61	5.51	0.00		2.26	1.05	0.43		0.23	1.03	0.45
residual	36	0.47				2.15				0.22		
total	53											
Transformation		Ln(X+1)				none				none		
Cochran's Test		0.13 (P>0.05)				0.23 (P>0.05)				0.16 (P>0.05)		
SNK		A>B=C=D=E=F				A>B=C=D=E=F				nah		

Table 5. Results of two-way ANOVA testing differences among sites for the abundances of the dominant taxa (*Mytilopsis sallei, Stenothyra glabra, Pseudopythina tsurumaru, Rissolina plicatula, Corophium* sp., *Corophium uenoi* and *Cossurella dimorpha*). Results of SNK test are also indicated.

		Mytilopsis sallei				*Stenothyra glabra*				*Pseudopythina tsurumaru*						
Source	DF	MS	F	P		MS	F	P		MS	F	P				
Sites	5	74.79	8.76	0.00		2.11	3.56	0.03		0.64	2.09	0.14				
Stations(Sites)	12	8.54	2.66	0.01		0.59	2.35	0.02		0.31	1.64	0.12				
residual	36	3.21				0.25				0.19						
total	53															
Transform:		Sqrt(X+1)				Ln(X+1)				Ln(X+1)						
Cochran's Test		0.24 (P>0.05)				0.30 (P>0.05)				0.28 (P>0.05)						
SNK		A>B=C=D=E=F				nah										
		Rissolina plicatula				*Corophium* sp.				*Corophium uenoi*				*Cossurella dimorpha*		
Source	DF	MS	F	P		MS	F	P		MS	F	P		MS	F	P
Sites	5	23.66	12.05	0.00		12.04	6.85	0.00		12.52	35.58	0.00		1.10	5.21	0.01
Stations(Sites)	12	1.96	1.45	0.19		1.76	0.93	0.53		0.35	0.18	1.00		0.21	0.75	0.69
residual	36	1.35				1.89				1.96				0.28		
total	53															
Transformation		none				None				None				Ln(X+1)		
Cochran's Test		0.38 (P>0.05)				0.48 (P < 0.01)				0.63 (P < 0.01)				0.33 (P < 0.01)		
SNK		A>B=C=D=E=F				A>B=C=D=E=F				A>B=C=D=E=F				D>A=B=C =E=F		

Table 6. Results of two-way ANOVA testing differences among sites for the total biomass and the biomass of *Mytilopsis sallei*. Results of SNK test are also indicated.

		Biomass				*Mytilopsis sallei*		
Source	DF	MS	F	P		MS	F	P
Sites	5	2078.72	8.25	0.00		1709.7	6.0	0.0
Stations(Sites)	12	252.11	1.07	0.41		285.5	1.9	0.1
RES	36	235.10				153.0		
TOT	53							
Transform:		none				None		
Cochran's Test		0.37 (P<0.05)				0.31 (P<0.05)		
SNK		nah				A>B=C=D=E=F		

Table 7. Coefficients in the linear correlation of the environmental variables with PC axes.

Variable	PC1	PC2
Ammonium	-0.16	**-0.92**
Nitrite	**0.97**	-0.05
Nitrate	**0.93**	0.12
DIN	**0.90**	-0.35
N/P	**0.96**	-0.09
DO	0.24	**0.60**
BOD_5	-0.13	**-0.85**
COD_{Mn}	**-0.57**	**-0.56**
SS	0.38	**-0.63**
Md	**0.80**	-0.20

Table 8. Mean Bray Curtis dissimilarity values calculated within each site and between sites.

Variability within sites			Variability among sites					
A	28.8		A vs. B	92.6		B vs. C	94.2	
B	80.8		A vs. C	56.6		B vs. D	81.1	
C	39.1		A vs. D	87.4		B vs. E	77.7	
D	63.9		A vs. E	92.1		B vs. F	96.2	
E	71.7		A vs. F	83.2				
F	95.3					C vs. D	86.1	
						C vs. E	91.2	
						C vs. F	83.9	
						D vs. E	65.6	
						D vs. F	86.2	
						E vs. F	91.1	

Table 9. Correlation coefficients, *R*, between environmental variables and univariate benthic variables including abundance and biomass of all taxa. Only those variables that shown at least a significant correlation were reported. Significant correlations after sequential Bonferroni correction (Rice, 1989) are in bold.

	Ammonium	Nitrite	Nitrate	DIN	DIP	N/P	DO	BOD_5	COD_{Mn}	Chl-a	SS	sand	silt	clay	Md	TOC	TN
S	**-0.57**	-0.49	-0.13	-0.51	-0.52	-0.32	**0.67**	**-0.64**	-0.15	**-0.51**	-0.31	0.31	-0.44	0.03	-0.20	**-0.60**	**-0.70**
N	-0.19	**-0.77**	-0.56	**-0.73**	-0.11	**-0.68**	0.18	-0.13	0.31	-0.06	-0.48	**0.65**	**-0.69**	-0.43	-0.61	-0.14	-0.29
H'(loge)	-0.50	-0.14	0.23	-0.11	-0.52	0.08	**0.75**	**-0.70**	-0.36	**-0.53**	0.02	-0.16	0.02	0.41	0.27	**-0.61**	**-0.64**
Taxa abundance																	
Corophium sp.	-0.28	**-0.69**	-0.53	**-0.72**	-0.21	**-0.67**	0.15	-0.22	0.18	-0.23	**-0.55**	**0.73**	**-0.75**	-0.55	**-0.67**	-0.25	-0.34
Corophium uenoi	-0.29	**-0.68**	-0.51	**-0.71**	-0.22	**-0.66**	0.23	-0.24	0.22	-0.23	-0.47	**0.76**	**-0.79**	-0.54	**-0.70**	-0.26	-0.39
Gammaropsis sp.	-0.25	-0.62	-0.52	**-0.68**	-0.16	**-0.64**	-0.02	-0.43	0.06	-0.20	-0.51	0.60	-0.60	-0.49	-0.54	-0.19	-0.22
Mytilopsis sallei	-0.13	**-0.76**	**-0.58**	**-0.71**	-0.04	**-0.68**	0.11	-0.03	0.37	0.02	-0.47	**0.64**	**-0.67**	-0.45	-0.61	-0.06	-0.21
Rissolina plicatula	-0.39	-0.54	-0.39	-0.63	-0.28	-0.55	0.27	-0.46	0.17	-0.28	-0.43	0.60	**-0.67**	-0.33	-0.52	-0.32	-0.46
Taxa biomass																	
Corophium sp.	-0.30	**-0.74**	**-0.58**	**-0.78**	-0.22	**-0.73**	0.15	-0.26	0.19	-0.24	**-0.58**	**0.79**	**-0.81**	**-0.59**	**-0.73**	-0.26	-0.35
Corophium uenoi	-0.30	**-0.68**	-0.51	**-0.72**	-0.21	**-0.67**	0.23	-0.27	0.21	-0.23	-0.47	**0.75**	**-0.78**	-0.53	**-0.70**	-0.26	-0.39
Gammaropsis sp.	-0.26	-0.62	-0.50	**-0.67**	-0.16	-0.63	0.03	-0.45	0.08	-0.20	-0.48	0.61	-0.61	-0.49	-0.55	-0.20	-0.26
Mytilopsis sallei	-0.15	**-0.67**	-0.49	-0.63	-0.06	-0.57	0.13	-0.06	0.35	0.03	-0.45	0.52	-0.56	-0.32	-0.48	-0.06	-0.20
Neanthes sp.	-0.13	0.26	0.33	0.26	-0.05	0.25	0.13	-0.19	-0.27	-0.20	0.27	-0.39	0.27	**0.56**	0.45	-0.22	-0.22
Praxillella sp.	0.53	0.23	0.10	0.39	**0.57**	0.10	-0.41	0.30	0.45	0.44	0.15	-0.05	0.05	0.04	0.04	0.48	0.43
Rissolina plicatula	-0.38	-0.56	-0.41	**-0.64**	-0.27	-0.57	0.26	-0.46	0.17	-0.27	-0.43	0.62	**-0.69**	-0.34	-0.54	-0.32	-0.45

Figures caption

Figure 1. Map of the Yundang lagoon, Xiamen island, and location of sampling sites (sites A to F).

Figure 2. Mean values (n = 3; ± SE, Standard Error) of the near-bottom water variables: ammonium, nitrate, nitrite, dissolved inorganic nitrogen (DIN), reactive phosphorous (DIP), N/P, dissolved oxygen (DO), biological oxygen demand (BOD_5), chemical oxygen demand (COD_{Mn}), chlorophyll-a (Chl-a) and suspended solids (SS).

Figure 3. Mean percentage (n = 9; ± SE, Standard Error) of sand, silt and clay content, and mean (n = 3; ± SE, Standard Error) of sediment median particle diameter (Md), total organic carbon (TOC) and total nitrogen (TN) content at each site.

Figure 4. Mean values (n = 9; ± SE, Standard Error) of the total number of species (S), total number of individuals (N) and Shannon index (H') at each site.

Figure 5. Mean values (n = 9; ± SE, Standard Error) of the abundance of the dominant taxa, *Mytilopsis sallei*, *Stenothyra glabra*, *Pseudopythina tsurumaru*, *Rissolina plicatula*, *Corophium* sp., *Corophium uenoi* and *Cossurella dimorpha* at each site.

Figure 6. Mean values (n = 9; ± SE, Standard Error) of the total biomass and the biomass of *Mytilopsis sallei* at each site.

Figure 7. (a) PCA environmental variables (near-bottom water and sediment variables). 85% of variance explained by PC1 and PC1; (b) nMDS ordination model of square root transformed abundance data. Each symbol represent a sampling station at each site obtained as sum of the three replicates; Symbols: white square = site A; white triangle = site B; white circle = site C; grey square = site D; grey triangle = site E; black circle = site F.

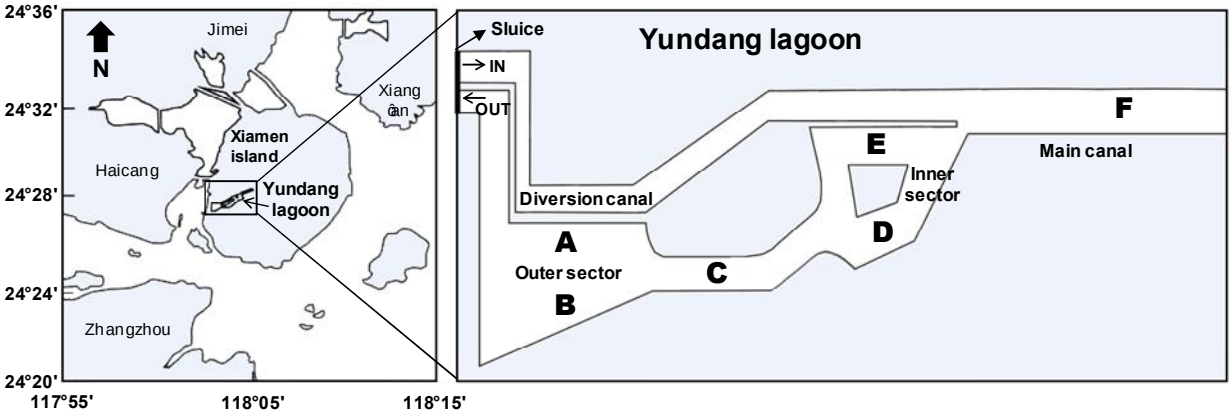
24°36'
24°32'
24°28'
24°24'
24°20'
117°55'
118°05'
118°15'
N
Jimei
Xiang an
Haicang
Xiamen island
Yundang lagoon
Zhangzhou
Sluice
IN
OUT
Yundang lagoon
F
Main canal
E
Inner sector
Diversion canal
D
A
Outer sector
C
B

Figure 1.

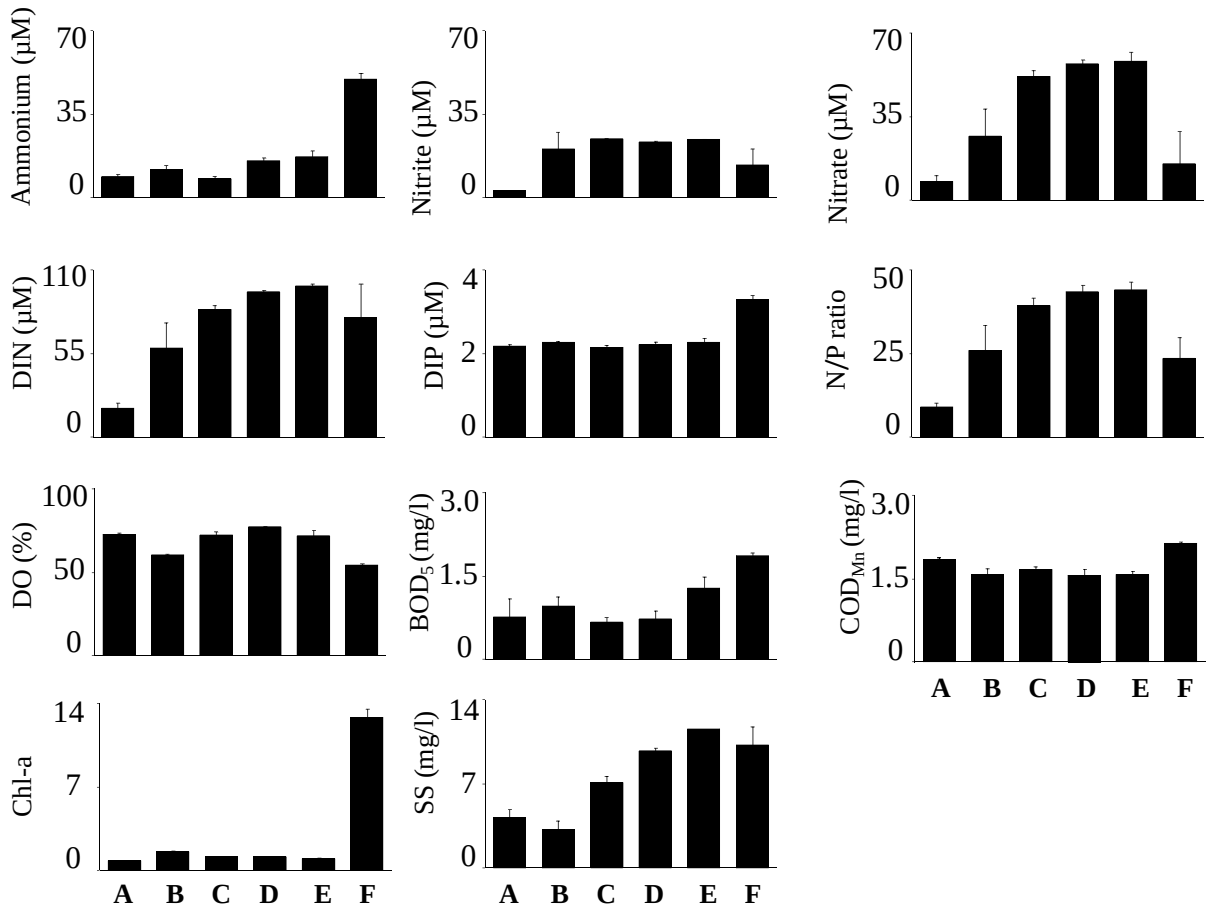
Ammonium (μM)
70
35
0
Nitrite (μM)
70
35
0
Nitrate (μM)
70
35
0
DIN (μM)
110
55
0
DIP (μM)
4
2
0
N/P ratio
50
25
0
DO (%)
100
50
0
BOD5 (mg/l)
3.0
1.5
0
CODMn (mg/l)
3.0
1.5
0
A B C D E F
Chl-a
14
7
0
SS (mg/l)
14
7
0
A B C D E F

Figure 2.

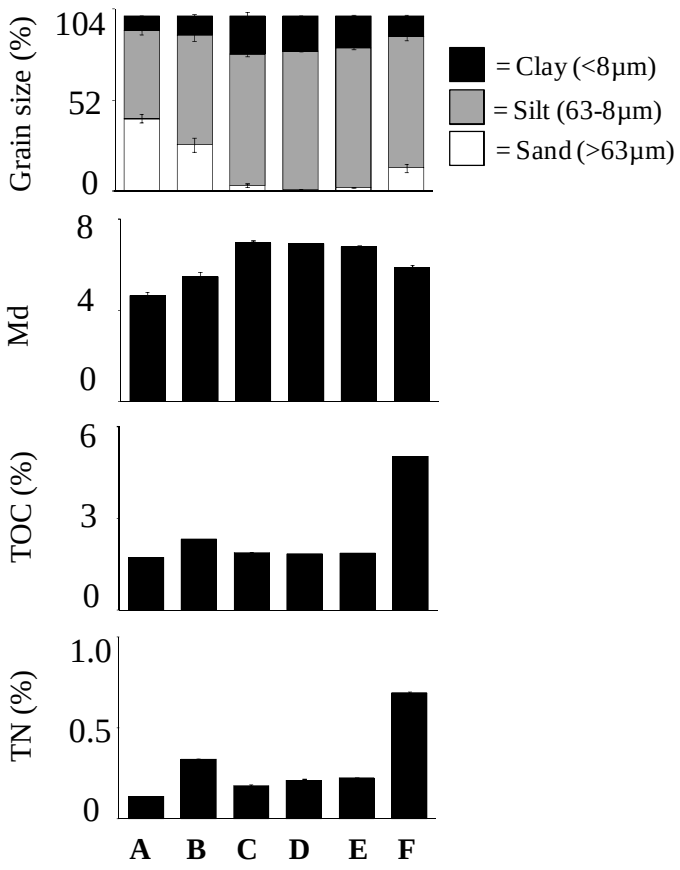
Grain size (%)
104
52
0
= Clay (<8µm)
= Silt (63-8µm)
= Sand (>63µm)
Md
8
4
0
TOC (%)
6
3
0
TN (%)
1.0
0.5
0
A
B
C
D
E
F

Figure 3.

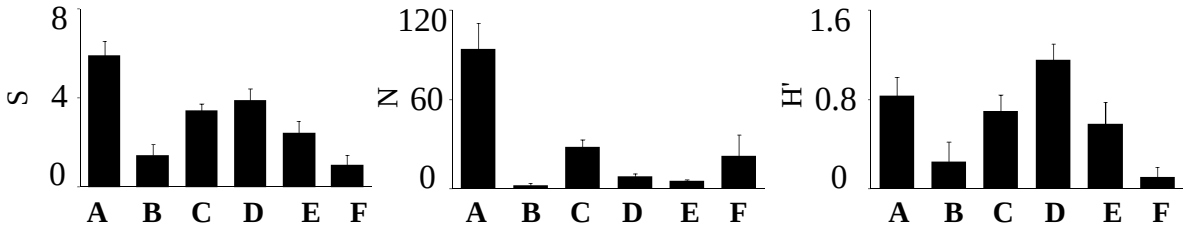

Figure 4.

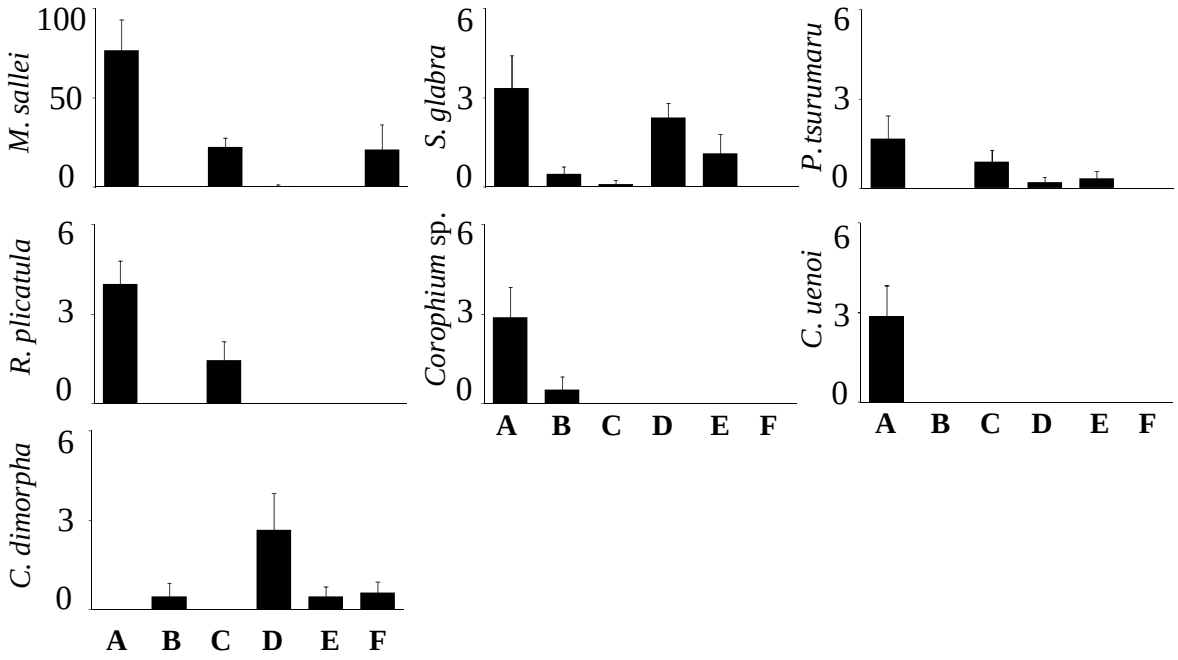
M. sallei
100
50
0
S. glabra
6
3
0
P. tsurumaru
6
3
0
R. plicatula
6
3
0
Corophium sp.
6
3
0
C. uenoi
6
3
0
C. dimorpha
6
3
0
A B C D E F
A B C D E F
A B C D E F

Figure 5.

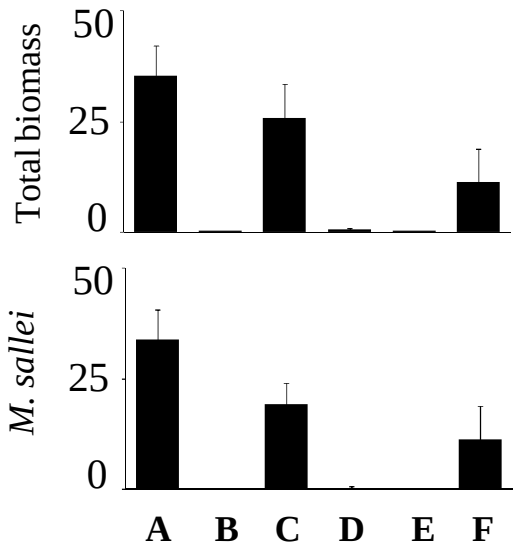

Figure 6.

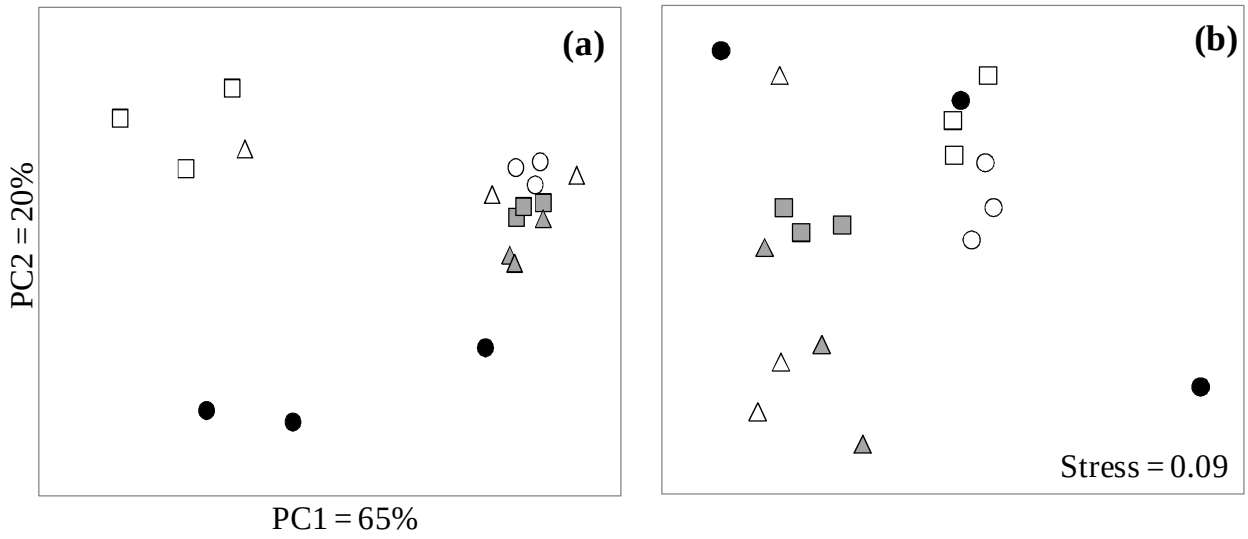

Figure 7.