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Effects of organic pollution in the distribution of annelid communities in the Estero de Urías coastal lagoon, Mexico

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SUMMARY: The Estero de Urías coastal lagoon is subjected to several anthropogenic activities and has been characterized since 1997 through the study of benthic fauna. We analyzed the spatial and temporal distribution of annelids and their relationships with environmental variables (depth, sediment temperature, grain size and organic matter) in order to determine the current degree of perturbation. Density, species richness, diversity, dominance, biomass, and the application of classification and ordination techniques allowed us to distinguish 5 zones: 1) a non-perturbed zone at the mouth of the lagoon, 2) a slightly perturbed zone surrounded by mangroves and shrimp farms, 3) a temporarily perturbed zone close to the effluent of the thermoelectric plant, 4) a perturbed zone in front of the slaughterhouse and fish factory, and 5) a very perturbed zone subjected to sewage and industrial input. Only minor changes in granulometry and faunal composition were observed in comparison with previous data from the same area, suggesting that the lagoon is still perturbed due to the effect of anthropogenic activities.

Keywords: Polychaeta, Oligochaeta, soft-bottoms, indicator species, human activities, Sinaloa.

RESUMEN: Efectos de la contaminación orgánica sobre la distribución de las comunidades de anélidos en la laguna costera "Estero de Urías" (Mexico). – La laguna costera "Estero de Urías" se encuentra sujeta al efecto de varias actividades antropogénicas y ha sido caracterizada desde 1997 a través del estudio de la fauna bentónica. Con el fin de conocer el grado de perturbación actual, se analizó la distribución espacial y temporal de los anélidos, así como su relación con las variables ambientales (profundidad, tamaño de grano, materia orgánica y temperatura del sedimento). Los valores de densidad, riqueza específica, diversidad, dominancia, biomasa y la aplicación de técnicas de clasificación y ordenación permitieron distinguir cinco zonas: 1) zona no perturbada, en la boca de la laguna; 2) zona ligeramente perturbada, bordeada por manglares y granjas camaronícolas; 3) zona temporalmente perturbada, cerca del efluente de la planta termoeléctrica; 4) zona perturbada, frente al matadero y la fábrica procesadora de pescado; 5) zona muy perturbada, sujeta al efecto de los desechos domésticos e industriales. La comparación con los datos previos registrados para la misma zona indica que la laguna ha sufrido sólo cambios ligeros en la granulometría y en la composición faunística. Esto sugiere que la laguna aún se encuentra perturbada debido al efecto que producen las actividades antropogénicas.

Palabras clave: Polychaeta, Oligochaeta, fondos blandos, especies indicadoras, actividades humanas, Sinaloa.

INTRODUCTION

Human activities in coastal areas can cause disturbances that affect shallow-water benthic communities. One of the most universal pollutants in highly polluted areas is organic matter coming from sewage outfalls, which produces organic enrichment of sediments. This may induce changes in the number of species, abundance, and biomass of benthic communities that may be the first indications of environmental impact. Some r-strategist or opportunistic species with short life cycles, high reproductive rates and high mortality are good indicators of marine pollution. The spatial distribution of these organisms along enrichment gradients may show different sensitivities, allowing us to identify different kinds of bottom subjected to different degrees of disturbance (Hily and Glémarec, 1990; Pearson and Rosenberg, 1978; Tsutsumi, 1990).

Polychaetes are excellent indicators of organic pollution due to their high abundance and sensitivity to different amounts of organic matter in sediments. They can be found at all latitudes and depths and can account for up to 40% of the number of species and individuals in soft-bottom benthic communities (Fauchald, 1977). Some detritivorous polychaetes belonging to the families Capitellidae (especially the *Capitella capitata* species complex), Spionidae and Cirratulidae have been catalogued as indicators of different degrees of pollution due to their strong dominance in perturbed environments, caused mainly by urban sewage (Hily and Glémarec, 1990; Olsgard and Somerfield, 2000; Pearson and Rosenberg, 1978).

The estuarine oligochaetes *Limnodrilus hoffmeisteri* and *Tubifex tubifex* have been described as good organic pollution indicators due to their high dominance in enriched sediments (Arimoro *et al.*, 2007; Gamito, 2008). These bottoms are covered by bacterial and fungal layers which constitute the main food source for oligochaetes (Rueda *et al.*, 2003).

The Estero de Urías coastal lagoon offers good examples of the coexistence of different sources of disturbance produced by anthropogenic activities, like shrimp farms, a thermoelectric plant, a slaughterhouse, a fish processing factory, a harbour and urban sewage. Characterizations of this ecosystem based on benthic faunal communities inhabiting soft-bottoms are scarce. Méndez (2002) characterized the lagoon through the study of annelids collected during 1997. This author confirmed the results related to organic pollution obtained by Álvarez-León (1980) with coastal vegetation and benthic flora and fauna, and by Ochoa-Izaguirre *et al.* (2002) with macroalgae. Later, other characterizations of the lagoon were performed with benthic copepods collected in 2001 and 2002 (Morales-Serna *et al.*, 2006) and 2005 (Morales-Serna, 2006). Those studies showed that the 120-ha Clementina shrimp farm had negative effects on macro and meiofauna. It is now known that this shrimp farm (currently called "Don Jorge") has been extended to about 244.3 ha and there are other smaller farms with a direct influence on the lagoon (María Ana Tovar, pers. comm.). In order to detect possible changes occurring over time due to these new anthropogenic activities, in this study Estero de Urías was characterized on the basis of the spatial and temporal variations of annelids through their relationship with environmental variables.

MATERIALS AND METHODS

Study area

Estero de Urías coastal lagoon (23º09′ and 23º12′N, and 106º18′ and 106º25′W) is located in the state of Sinaloa, along the southeast coast of the Gulf of California, near Mazatlán city. It has a permanent communication with the sea and is almost parallel to the coastline. It is a shallow and brackish lagoon with an intense vertical water mixture (Salgado-Barragán *et al.*, 2004). Its depth ranges from 1 to 3 m, except in the navigation channel, where it can reach 12 m, and it has a surface area of 18 km^2 and a length of 17 km (Montaño-Ley, 1985). The climate is tropical/subtropical, with two contrasting seasons: rainy (July-October) and dry (November-June). The average annual temperature is 25°C and the average annual rainfall 800 mm (Ochoa-Izaguirre *et al.*, 2002).

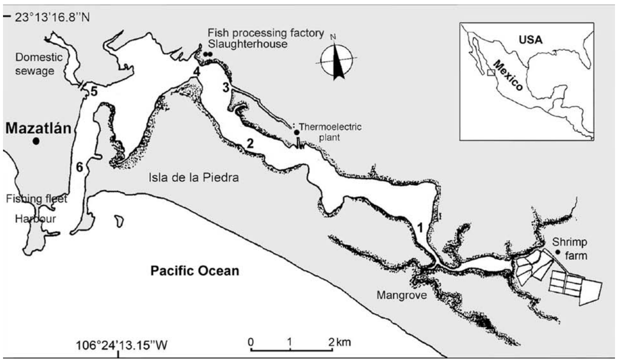

FIG. 1. – Study area showing the sampling stations.

Sampling stations were selected according to the previous characterization of annelid assemblages in the area provided by Méndez (2002). In total, six stations located close to the anthropogenic effluents were sampled along the lagoon (Fig. 1). The upper part of the lagoon is fringed by mangrove trees and receives the shrimp effluents from the Don Jorge shrimp farm (station 1) and about 13 smaller farms, of which two seem to have the greatest influence on the lagoon (station 2). The other anthropogenic influences are the José Aceves Pozos thermoelectric plant, which discharges hot water into the lagoon (station 3), a fish processing factory and a slaughterhouse (station 4), the urban sewage input of the "Infiernillo" stream (station 5), and the Mazatlán Harbour and fishing fleet, which receives the influence of marine water (station 6).

Sampling and laboratory work

Sampling was performed during the dry (February) and rainy (August) seasons in 2008. Samples of sediment were collected with a 26.5×12.5 cm van Veen grab (three replicates; 0.1 m^2 total area) and sieved through a 0.5 mm mesh. The retained material was fixed with a 4% formaldehyde solution and preserved with 70% ethanol (Hobson and Banse, 1981). Annelids were sorted, counted and identified according to Blake and Ruff (2007), Fauchald (1977), Hartman (1968, 1969), Hernández-Alcántara (1992), Kudenov (1980), Salazar-Vallejo and Londoño-Mesa (2004) and Tovar-Hernández (2007). Mean biomass per station was expressed as g dry weight/m^2, which was calculated through the wet weight multiplied by the correction factors 0.088 (February) and 0.065 (August). These factors were calculated through the weight of two ad-

Table 1. – Environmental variables measured in interstitial water and sediments in February and August 2008 (Temp: sediment temperature, OM: organic matter)

	February						August					
	1	2	3	4	5	6	1	2	3	4	5	6
Depth (m)	0.4	5.3	1.0	0.6	4.5	4.9	2.0	1.6	1.6	1.1	3.1	5.4
Temp (ºC)	21.4	22.9	24.4	21.8	20.6	18.9	29.4	30.6	31.8	30.2	30.7	30.7
Gravel (%)	0.5	30.7	2.8	1.5	0.0	0.1	9.6	66.6	0.4	1.0	0.4	0.4
Sand (%)	70.4	55.2	85.1	18.7	1.6	81.9	85.5	24.9	52.6	43.0	26.2	88.0
Mud (%)	29.1	14.1	12.1	79.9	98.4	17.9	5.0	8.5	47.0	56.0	73.5	11.6
OM (%)	6.7	3.0	2.3	12.5	15.2	4.0	1.2	10.9	8.1	12.9	8.6	1.9

ditional organism samples (wet weight) collected in the two sample periods, which were dried in the stove (60ºC for 24 h) to record the dry weight (Brown, 1991). The correction factor was calculated through the relationship between the dry and wet weights.

Additional sediment samples were collected for sediment analyses (one sample per station). Organic matter percentages in sediments were obtained following the ignition loss method (Dean, 1974). According to Folk (1965), about 200 g of sediments were sieved through a 2-mm mesh (to separate gravel from sand) and a 0.0625-mm mesh (to separate sand from mud), and grain size was expressed as percentages of each fraction. Sediment temperature was measured with a digital CE model KM43F thermometer.

Data analyses

Shannon diversity (H') (Shannon and Wiener, 1963), evenness (J') (Pielou, 1969), species richness (S), dominance (Simpson, 1949) and mean density were calculated with the PRIMER 6.0 program. Dominant taxa were obtained according to the formula $MD=(n_i/N)\times100$, where MD is the mean dominance index (Picard, 1965) for species i; n_i, the number of individuals belonging to species i; and N, the total number of individuals belonging to all the species. Taxa were considered dominant when $MD\geq1\%$. The similarities among stations were established by cluster analysis (Bray-Curtis index; group average link; PRIMER 6.0 program), using the mean densities of taxa transformed to fourth root to avoid the effect of rare or very abundant taxa (Field *et al.*, 1982). A SIMPER analysis was used to determine the contributions of each species to the Bray-Curtis similarity within each group of stations obtained in the dendrograms.

The spatial variability of the biotic variables was studied through the differences among stations (each biotic variable vs. stations) with one-way ANOVAs or Kruskal-Wallis tests, depending on normality and homoscedasticity of data (SigmaStat 3.0 program). Also, a multiple comparisons test was applied using pairs of stations (Holm-Sidak or Dunn's, when the assumptions mentioned above were fulfilled) to determine the stations that had the maximal difference for each parameter. Temporal variations of the biotic and environmental variables were determined through the *t* test using the same statistical program.

In order to determine the main factors influencing annelid assemblages, a canonical correspondence analysis was performed (MVSP 3.1 program). The biotic variables were the mean densities of the dominant taxa for each sampling period, while the environmental variables were depth, sediment temperature, organic matter content and percentages of mud, sand and gravel.

RESULTS

Results of the measured environmental variables are shown in Table 1. Sediment temperature was the only abiotic parameter that showed significant differences between February and August (t= –10,731; n=12; P<0.001).

Fifty-eight taxa (polychaetes and oligochaetes) were identified during the whole study. We counted and identified a total of 2719 individuals distributed in 50 taxa in February and 1320 individuals distributed in 35 taxa in August (Table 2). Taxonomic observations concerning Polychaeta are contained in Ferrando and Méndez (2010).

Clear associations between stations 2 and 6 and stations 1 and 4 were observed during the two sampling periods in the cluster analysis (Fig. 2). Station 5 was always completely separated from these groups, whereas only station 3 showed a different association pattern during the two sampling periods. In February, station 5 formed group A, with 59.68% of average similarity (SIMPER analysis), which was represented mainly by Oligochaeta sp.2 (contribution of 100%). The average Bray-Curtis similarity between sites of group B (stations 2 and 6) was 50.69%, and was made up mainly of contributions of *Mediomastus ambiseta* (17.54%), *Caulleriella pacifica* (15.23%), *Scoletoma luti* (12.61%), and *Aricidea catherinae* (10.21%), with a cumulative percentage of about 56% of the total similarity. For group C (stations 1, 3 and 4), the average similarity was 41.51% and the main species were *Capitella* sp. (34.58%), *Nereis procera* (11.82%), *Prionospio heterobranchia* (10.97%), *Streblospio benedicti* (10.46%), and *Mediomastus californiensis* (8.58%), with a cumulative contribution of 76.42%. In August, group D (stations 3 and 5) with 28.02% of average similarity was represented by *N. procera*, with a 100% contribution. The average similarity of group E (stations 2 and 6) was 50.53% and the typical species were *M. ambiseta* (16.59%), *C. pacifica* (16.10%), *P.*

Table 2. – Density (ind/m^2; mean values of three replicates; rounded values) of taxa found at the 6 stations in February and August 2008.

	February						August					
	1	2	3	4	5	6	1	2	3	4	5	6
POLYCHAETA												
Capitellidae												
Capitella sp.	646	30	889	1081		91	1535			162		
Heteromastus filiformis	152					30		798				
Mediomastus ambiseta		3455	61			768		1071				364
Mediomastus californiensis			333	91			525	621				414
Spionidae												
Prionospio steenstrupi	273	364					71					
Prionospio heterobranchia	364	1636	303	121		30		111				192
Prionospio lighti			30			172		30		61		455
Streblospio benedicti	636			1697			798					
Polydora websteri	348	30	40			101						
Paraprionospio pinnata					30	364	30	30			30	222
Marenzelleria viridis						30						
Spio sp.						30						
Scolelepis cf. *tridentata*						30						
Spionidae sp.				30								
Cirratulidae												
Caulleriella pacifica		1172	61	61	152	475	45	899				232
Chaetozone senticosa						30		91				
Opheliidae												
Armandia brevis	182	323	131				30	45				30
Ophelina acuminata						485						
Polyophthalmus pictus						30						
Nereididae												
Neanthes succinea		30		30		91				30		
Perinereis monterea		30										
Nereis procera	192			566			30		121	283	61	
Dorvilleidae												
Dorvillea longicornis		838	45			30		91		30		30
Ophryotrocha puerilis							364			384		61
Lumbrineridae												
Scoletoma luti	30	364				232		576	30			182
Syllidae												
Odontosyllis phosphorea		182										
Exogone molesta		101				212						808
Exogone lourei		45										
Sphaerosylis californiensis		30	30									
Paraonidae												
Aricidea catherinae		455				141		404				
Sabellidae												
Chone mollis		106										576
Megalomma pigmentum		30										
Paradialychone ecaudata			30			91	51	258				323
Amphicorina gracilis						76						
Magelonidae												
Mageloma berkeleyi						61						
Maldanidae												
Axiothella rubrocincta												30
Hesionidae												
Podarkeopsis glabrus				61			30					
Gyptis brunnea							61	136				
Phyllodocidae												
Eteone californica						61						
Polynoidae												
Lepidonotus squamatus						30						
Polynoidae sp.						91						
Pilargiidae												
Sigambra tentaculata		30		30		61		76				
Sigambra bassi				30								
Onuphidae												
Onuphis elegans	61	30						30				
Onuphis iridescens	30											
Glyceridae												
Glycera macrobranchia		30	61					30				
Chaetopteridae												
Spiochaetopterus pottsi						30						
Flabelligeridae												
Brada villosa		30				30						45
Nephtyidae												
Aglaophamus spp.						30						30

TABLE 2 (cont.). – Density (ind/m^2; mean values of three replicates; rounded values) of taxa found at the 6 stations in February and August 2008.

	February						August					
	1	2	3	4	5	6	1	2	3	4	5	6
Gonianidae												
Goniada brunnea						30						
Glycinde armigera												30
Orbiniidae												
Orbinia johnsoni							30					
Pectinaridae												
Pectinaria californiensis								61				
Poecilochaetidae												
Poecilochaetus johnsoni												30
Sigalionidae												
Sthenelais verruculosa		30										
OLIGOCHAETA												
Oligochaeta sp. 1				5475	303		121			152	30	
Oligochaeta sp. 2					748							
Oligochaeta sp. 3							111			51		

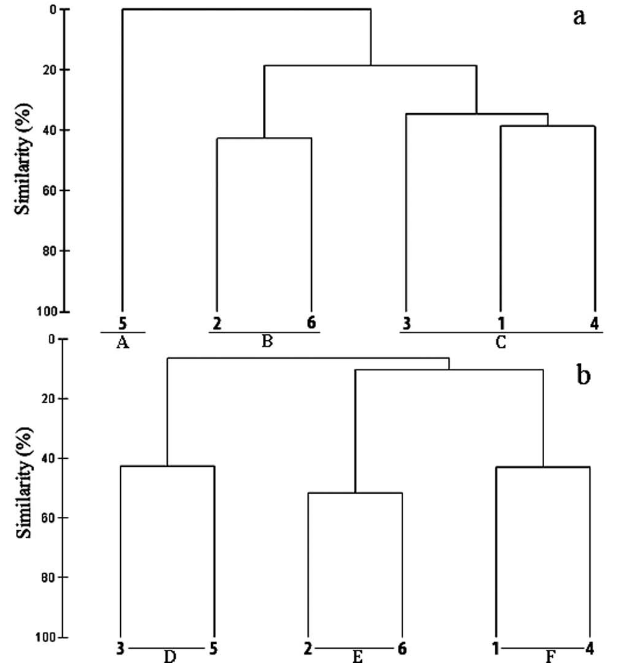

FIG. 2. – Dendrograms (Bray-Curtis index) showing the grouping of stations (a) February; (b) August.

heterobranchia (12.41%), *M. californiensis* (10.39%) and *Paradialychone ecaudata* (8.64%), with a cumulative percentage of about 64%. Stations 1 and 4 formed group F (average similarity of 54.66%), which was represented by *Ophryotrocha puerilis* (26.23%), *Capitella* sp. (22.36%), Oligochaeta sp. 3 (17.14%), *N. procera* (9.85%), and Oligochaeta sp. 1 (9.39%), with a cumulative percentage of almost 85%.

The biological parameters calculated for each station are shown in Table 3. Temporal variations tested for these parameters showed no significant differences in February compared with August, except for density (t=267,500, n=36, P=0.040). The spatial variations of each biological parameter indicated significant differences for density, species richness, diversity and biomass values at the different stations throughout the study and for dominance only in February (Table 4). Moreover, multiple comparisons tests showed that stations 2 and 5 showed the maximal differences in density in February (P<0.001) and stations 1 and 3 in August (P<0.05). Stations 4 and 5 showed the maximal differences in biomass in both sampling periods (P<0.001 and P<0.05 in February and August, respectively). Finally, stations 5 and 6 showed the maximal differences in species richness, diversity and dominance in February (P<0.05, P<0.001 and P<0.001, respectively), while stations 3 and 6 showed maximal differences in species richness and diversity in August (P<0.001 and P<0.05, respectively).

Results of the mean dominance index indicated that 20 taxa were dominant during the two sampling periods. They are listed in the Figure 3 legend, which corresponds to the canonical analysis diagram representing

TABLE 3. – Biological parameters (mean values of the three replicates) and standard deviation (between brackets) for each station in February and August 2008 (S, species richness; H'(log$_e$), Shannon diversity index; J', evenness).

	February						August					
	1	2	3	4	5	6	1	2	3	4	5	6
Density (ind/m^2)	2040.4 (1480.3)	9151.5 (814.8)	1898.1 (705.7)	9080.8 (677.8)	676.8 (201.8)	3333.3 (1508.8)	3616.2 (1340.3)	4414.1 (4109.0)	50.5 (63.1)	1070.7 (46.3)	80.8 (63.1)	3878.78 (248.0)
S	6(1.2)	17(1.5)	9(1.7)	8(1.7)	2(1.1)	18(5.0)	10(0.6)	12(3.6)	1(0.6)	6(1.7)	2(1.2)	13(2.6)
H'(log$_e$)	1.6(0.2)	1.9(0.1)	1.6(0.2)	1.0(0.3)	0.2(0.3)	2.3(0.2)	1.5(0.1)	1.8(0.2)	0(0.0)	1.4(0.4)	0.3(0.5)	2.2(0.0)
J'	0.9(0.0)	0.7(0.0)	0.7(0.1)	0.5(0.2)	0.5(0.0)	0.8(0.0)	0.6(0.0)	0.7(0.1)	0(0.0)	0.8(0.1)	0.3(0.5)	0.9(0.0)
Dominance	0.2(0.0)	0.2(0.0)	0.3(0.1)	0.5(0.2)	0.9(0.2)	0.1(0.0)	0.3(0.0)	0.2(0.1)	0.6(0.6)	0.3(0.2)	0.8(0.3)	0.1(0.0)
Biomass (g/m^2)	0.6(0.2)	1.1(0.3)	0.3(0.1)	1.8(0.4)	0.1(0.0)	0.4(0.3)	0.3(0.1)	0.8(0.5)	0.1(0.2)	0.8(0.4)	0.0(0.0)	0.4(0.1)

TABLE 4. – Results of one-way ANOVA (F) and Kruskal-Wallis test (H) to test spatial variability of the biological parameters (n=18) in February and August 2008 (NS: non-significant values).

	February	August
Density (ind m^{-2})	F=40.491; p<0.001	H=14.413; p=0,013
S	H=15.209; p=0.010	F=20.333; p<0,001
H'(log$_e$)	F=28.697; p<0.001	H=15.447; p=0,009
J'	NS; p=0.050	NS; p=0,056
Dominance	F=11.520; p<0.001	NS; p=0,113
Biomass (g m^{-2})	F=17.911; p<0.01	H=14.017; p=0,016

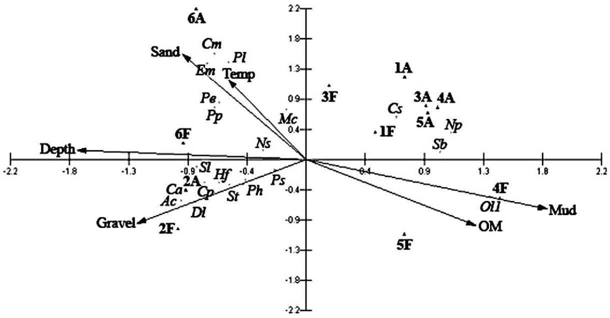

FIG. 3. – Canonical correspondence analysis ordination showing the 20 dominant taxa and stations with respect to the environmental variables, relative to axes 1 and 2 in February and August (1F- 6F, stations in February; 1A- 6A, stations in August; *Ac: Aricidea catherinae; Ca: Capitita ambiseta; Cm: Chone mollis; Cp: Caulleriella pacifica; Cs: Capitella* sp.*; Dl: Dorvillea longicornis; Em: Exogone molesta; Hf: Heteromastus filifornis; Sb: Streblospio benedicti; Mc: Mediomastus californiensis; Np: Nereis procera; Ns: Neanthes succinea; Ol1: Oligochaeta* sp. 1*; Pe: Paradialychone ecaudata; Ph: Prionospio heterobranchia; Pl: Prionospio lighti; Pp: Paraprionospio pinnata; Ps: Prionospio steenstrupi; Sl: Scoletoma luti; St: Sigambra tentaculata*; OM: organic matter percentage; Temp: sediment temperature).

the spatial distribution of taxa and stations according to the environmental variables. A total of 36.0% of the variance was explained by the first axis and 16.70% by the second one. In February, stations 4 and 5 were characterized by percentage of mud and organic matter content and by the dominance of Oligochaeta sp. 1.

DISCUSSION

Results obtained in this study allowed us to characterize the Estero de Urías coastal lagoon through the analyses of the relationships between environmental variables and annelid fauna. Five zones with different pollution degrees located close to areas with anthropogenic activities were distinguished:

1) A non-perturbed zone located close to the mouth of the lagoon (station 6), with low percentages of organic matter (1.9 and 4.0%), the highest diversity (2.2 and 2.3) and species richness recorded (13 and 18 taxa), the lowest dominance (0.1%), and intermediate biomass values (0.4 g/m^2). This zone has a strong marine influence as a result of the currents produced at the mouth, which allow the mixture of estuarine and marine species. Previous data concerning annelids in this area (Méndez, 2002) are consistent with results found here. Morales-Serna (2006) described this zone as slightly perturbed because of the presence of sandy sediments with low organic matter content, high diversity and a lack of dominant copepod species.

2) A slightly perturbed zone, mainly surrounded by mangrove trees and comprising station 1 (receiving the effluents of the Don Jorge shrimp farm) and station 2 (receiving the effluents from the Crustáceos de El Castillo S.A. de C.V. shrimp farm and the Raúl Cárdenas Velarde shrimp farm). It has intermediate organic matter contents ranging from 1.2% and 10.9%, diversity ranging from 1.5 to 1.9, biomass from 0.3 to 1.1 g/m^2, low dominance (0.2-0.3%) and 6 to 17 taxa. Comparisons with previous studies have shown that this zone has changed during the last 11 years. Taking into account data of samples collected in 1997, Méndez (2002) catalogued the zone close to the Don Jorge shrimp farm (station 1) as a polluted zone, with the dominance of *S. benedicti* and oligochaetes. However, those taxa are less dominant nowadays so this zone is now catalogued as slightly polluted.

In 1997, station 2 was catalogued as an unpolluted zone because of the high diversity of annelids and the lack of dominance of any species (Méndez, 2002). Although this station showed low dominance and a high number of taxa, diversity values and organic matter contents indicate some enrichment of sediments. This is probably due to the effect produced by the effluents from the new shrimp farms that have been set up in this area. On the other hand, the study performed by Morales-Serna (2006) with samples of copepods collected in 2005 indicated that this zone was also slightly polluted due to the intermediate organic carbon contents in the sand-muddy sediments, high diversity and lack of dominance of any copepod species.

3) A temporary perturbed zone located in front of the input of hot water from the José Aceves Pozos thermoelectric plant (station 3). In February this area was characterized as a non-perturbed zone because it showed intermediate values of the biological and environmental variables. On the other hand, the extremely low biological values in August, with the dominance of *N. procera* and *S. luti*, may be the reflection of the high temperature effect (the mixture of the seasonal effect and that produced by the plant), indicating that this is a perturbed zone. According to Pearson and Rosenberg (1978), high temperatures lead to an increase in the organic matter degradation rate, with the consumption of oxygen, thus negatively affecting the survival of most species. In addition, the differences in sediment granulometry between the two sampling periods and the higher organic matter detected in August indicate that it is a temporarily perturbed zone. Compared with previous annelid data (Méndez, 2002), this zone has changed considerably, because in 1997 organic matter ranged from 8.335 to 10.95% and *Capitella* sp. was dominant, so it was catalogued as a polluted zone. In 2001 and 2002, Morales-Serna *et al.* (2006) found sandy sediments with low organic matter content, with

the highest copepod density and only two species in August. Morales-Serna (2006) described this zone as slightly polluted because of the presence of sand-muddy sediments, with intermediate contents or organic carbon, high diversity and a lack of dominance of any copepod species. This data compilation suggests that the non-controlled input from the thermoelectric plant induces changes in the type of sediment and benthic fauna over time, indicating that this is an unstable zone.

4) A perturbed zone located in front of the slaughterhouse and the fish processing factory (station 4), with high contents of organic matter (12.5 and 12.9%) and biomass (0.8 and 1.8 g/m^2), and intermediate diversity (1.1 and 1.4), species richness (6 and 8 taxa) and dominance (0.3 and 0.5%). Dominant taxa in the study were (in decreasing order) Oligochaeta sp. 1, *O. puerilis*, *N. procera*, *S. benedicti*, *Capitella* sp., and Oligochaeta sp. 3. In 1997 this zone was described as very polluted (Méndez, 2002) due to the complete absence of macrofauna and the fact that organic matter reached 11.5%. The copepod studies indicated that in 2001, 2002 and 2005 this zone showed a similar pattern, and it was thus also classified as a very polluted zone by Morales-Serna *et al.* (2006) and Morales-Serna (2006). This is the first report of annelids in this zone, showing densities of 27 364 ind/m^2. Most of these dominant taxa have been previously described as organic matter indicators: for example *Capitella* sp. and *S. benedicti* by Pearson and Rosenberg (1978), Oligochaeta by Arimoro *et al.* (2007) and Gamito (2008), and the genus *Ophryotrocha* by Ros and Cardell (1995).

5) A very perturbed zone located in front of the Infiernillo stream with the influence of urban and industrial input (station 5), with the highest organic matter percentage (15.2%) and dominance (0.9%), and very low values of diversity (0.2 and 0.3), species richness (2) and biomass (0.1 g/m^2). Sediments with organic matter contents higher than 15% have been catalogued as typical of impacted areas (López-Jamar, 1981). The sediment enrichment process occurs because muddy sediments allow the adhesion of organic particles because of the higher surface/volume relationship (Lamberson *et al.*, 1992). This fact explains the strong enrichment in front of this stream in the study area. The dominant taxa are Oligochaeta sp. 2, *N. procera*, Oligochaeta sp. 1, *P. pinnata* y *C. pacifica*, most of them previously catalogued as typical species inhabiting polluted environments (Hily and Glémarec, 1990; Pearson and Rosenberg, 1978). In 1997 this zone was considered a polluted zone characterized by the sporadic presence of oligochaetes, with organic matter reaching 10.95% (Méndez, 2002). Results from Morales-Serna *et al.* (2006) and Morales-Serna (2006) are coincident with data reported here, since they characterized this zone as very perturbed because of the presence of muddy and enriched sediments and low values of copepod density, diversity and species richness.

The spatial and temporal distribution patterns of annelids observed in this study confirm the utility of some polychaete species and oligochaetes as indicators to characterize perturbed zones in areas subjected to anthropogenic development. The importance of polychaetes in perturbed zones has been previously demonstrated at several localities around the world by Reish (1959) in California, USA, Bellan (1967 a, b) in Marseille, France, López-Jamar (1981) in northern Spain, Hily and Glémarec (1990) in Brest, France, Tsutsumi (1990) in Japan, Ros and Cardell (1992) and Méndez *et al.* (1998) in Barcelona, Spain, Mackie *et al.* (1997) in Ireland, Borja *et al.* (2000) in several European localities, Elías *et al.* (2006) in Mar del Plata, Argentina, and Ferrando *et al.* (2010) in Patagonia, Argentina. These authors have characterized zones impacted by urban and industrial wastes through the study of indicator polychaete species.

Although few differences were observed after 11 years, this study confirms the fact that Estero de Urías lagoon, as a whole, is still perturbed due to the effect of the different industries and urban input which discharge their sewage into the lagoon. The highest impact is still located close to the factories and urban sewage, but the zone fringed by mangrove trees, which some years ago was not considerably impacted, is currently beginning to be affected, especially by the shrimp farms. Further studies in the lagoon are recommended in order to detect possible pollution sources.

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