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Incidence of Urban Sewage Disposal in the Salt-ponds Areas of the South of the Bay of Cadiz

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The highest pollution indices in the marsh and tide-lands situated to the south of the Bay of Cadiz have been evaluated. At the present, the salt industry of this area is being transformed into mariculture installations. This study consisted of the systematic evaluation of different parameters at 26 sampling stations during the period 1976–1981. The results suggest that extensive zones are too seriously affected to make use of them as marine piscifactories.

This report shows the results obtained in various studies undertaken in the years 1977 to 1981 at the Faculty of Sciences, University of Cadiz, Spain. The purpose was to determine general levels of contamination affecting the area of saline and marshland which surrounds the Sancti Petri channel and the various secondary channels which flow from it, given the present tendency to transform the salt industry into marine piscifactories.

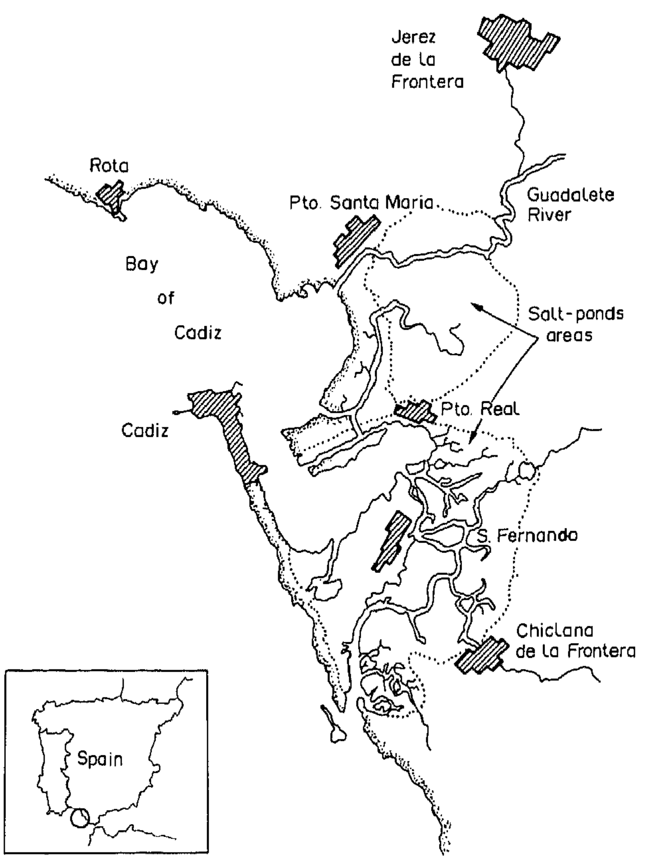

Fig. 1 Situation of the salt-ponds areas studied.

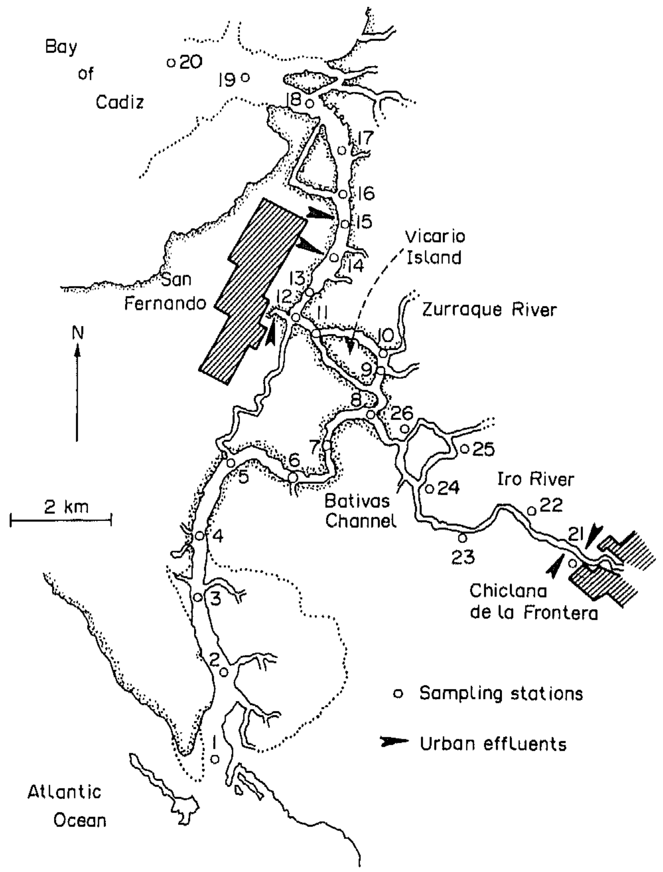

Fig. 2 Location of sampling stations.

The area studied is situated to the east and south of the Bay of Cadiz, in the municipal jurisdiction of San Fernando, Chiclana and Cadiz city, with a population of about 400 000. This area (Fig. 1) has been built up by alluvia from the river Guadalete, along with lesser contributions from other rivers in the area, such as the Zurraque and the Iro. It owes its present configuration to the balance between fluvial deposits and the dredging action of the tidal currents which affect the bay (Rodriguez, 1952).

This salt-pond area is an expanse of about 90 km^2 of muddy terrain, mostly intertidal, where approximately one hundred salines have been created from the middle of the last century until the present day. As a result of this, the area of free circulation of water has become restricted to the Sancti Petri channel and others adjacent to it (Fig. 2). These provide the water for the salines established in the area.

Water enters to the Sancti Petri channel with the rising tide, by way of its two mouths, on the Atlantic and on the Bay of Cadiz, with a time-difference of about 20 min. This determines the meeting-point of the waters, which is normally in a 1–2 km stretch to the north of Vicario island (Flores *et al.*, 1979a).

It is in the area of the meeting of tides, where the waters are at their most stagnant or renewal is at its least, that undepurated urban sewage enters from San Fernando by way of outlets located between sampling stations 12 and 15 (Fig. 2), and from Chiclana de la Frontera by way of outlets of the river Iro and Batívas channel.

TABLE 1

	Date	Tide	Parameters analysed	
Sancti Petri channel	Apr./77	Low		
	May/77	Low		
	Jun./77	High		
	Jan./78	Flood	Tw	
	Feb./78	Flood	pH	
	Mar./78	High	D.O.	
	Mar./78	Ebb	NO_2	
	Apr./78	Low	MnO_4^-	
	Apr./78	Flood	S	
	Apr./78	High		
	Apr./78	Ebb		
	May/78	Low		
	May/78	Flood		
River Iro	Sep./81	Flood	Tw	NO_2^-
			pH	
	Oct./81	High	S	NH_4^+
			S.S.	T.N.
	Oct./81	Flood	D.O.	PO_4^{3-}
			B.O.D.	A.S.
	Oct./81	High		

Materials and Methods

At the initial stage, the quality of the water was examined throughout the length of the Sancti Petri channel by means of systematic testing at twenty sampling stations whose location is shown in Fig. 2, and the assessment of six physical and chemical parameters at different stages of the tide (Table 1).

Later, in 1981, given values arrived at for the different parameters determined at sampling station 8, the confluence of the river Iro and Sancti Petri channel, and also given the special nature of the sewage from the town of Chiclana de la Frontera, we went on to study the quality of the waters along the river Iro, using six sampling stations (21 to 26 in Fig. 2). Study was restricted to the moments of high tide, which is when water enters the

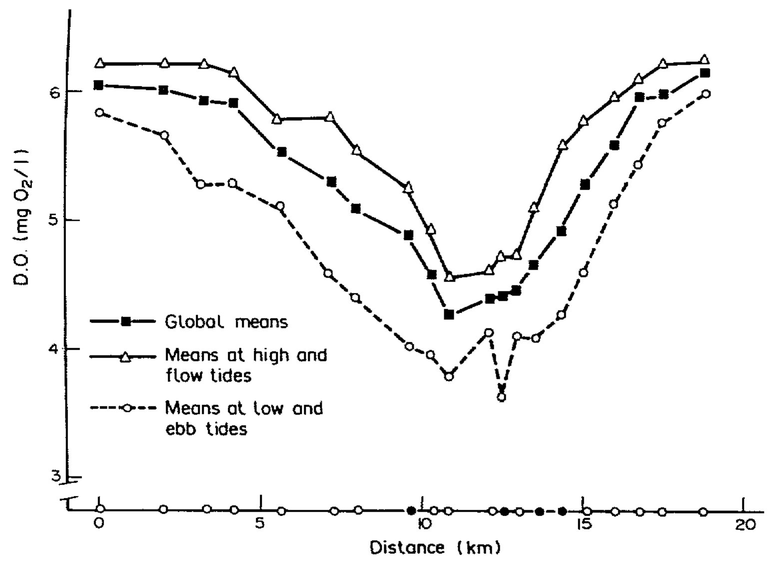

Fig. 3 Dissolved oxygen versus location of the different sampling stations along Sancti Petri channel.

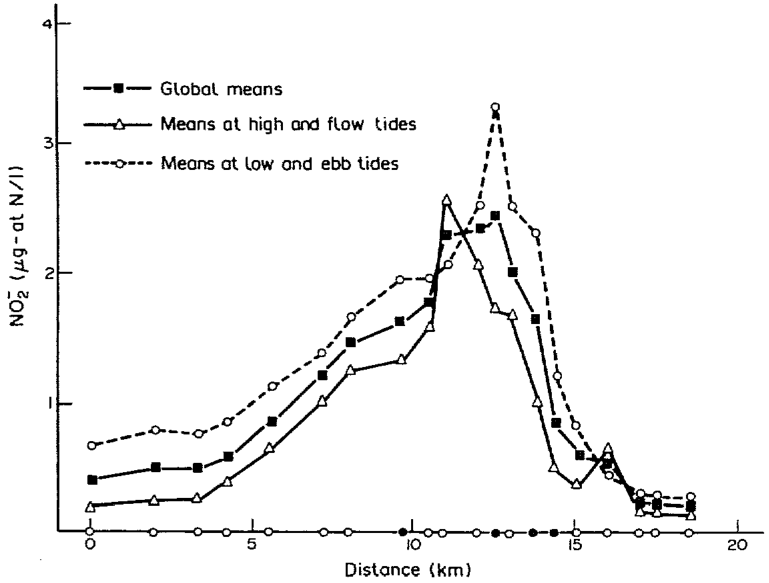

Fig. 4 Nitrites versus location of the different sampling stations along Sancti Petri channel.

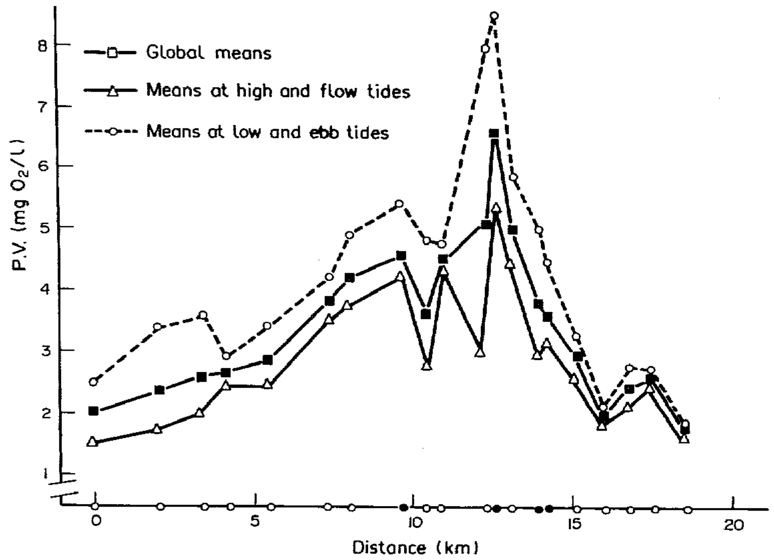

Fig. 5 Permanganate values versus location of the different sampling stations along Sancti Petri channel.

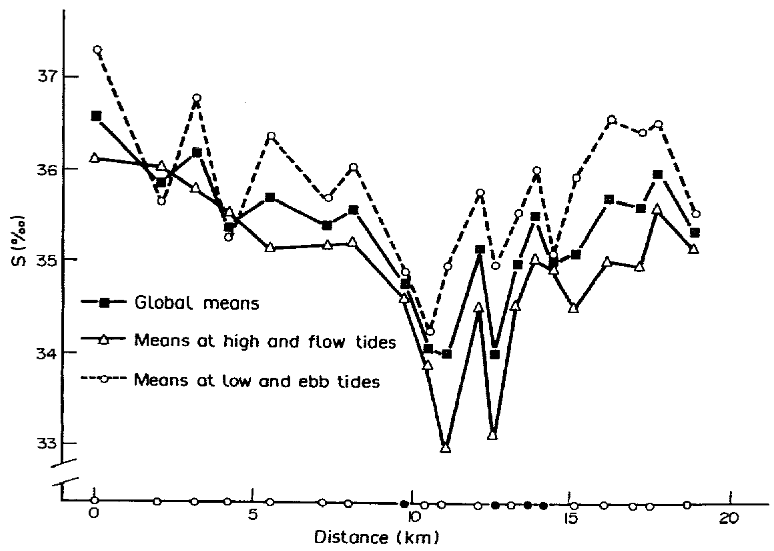

Fig. 6 Salinity versus location of the different sampling stations along Sancti Petri channel.

TABLE 2

Maximum, minimum and mean values of the different parameters analysed along Sancti Petri channel.

	Tw	S	pH	D.O.	NO_2^-	P.V.
References		*		*	*	†
Units	°C	‰		mg O_2 l^{-1}	μat-g N l^{-1}	mg MnO_4 K l^{-1}
Range	19.3–11.0	42.157–31.077	8.5–7.8	705–2.50	5.40–0.05	15.8–0.1
Mean	16.9	35.291	8.1	5.27	1.15	3.00
Standard deviation	0.3	0.690	0.1	0.62	0.74	1.23

*Strickland & Parsons (1968).
†Seki & Taga (1973).

TABLE 3

Maximum, minimum and mean values of the different parameters analysed along river Iro.

	Tw	pH	S	S.S.	D.O.	B.O.D.	NO_2^-	NH_4^+	T.N.	PO_4^{3-}	A.S.
References			*	†	*	*	*	†	†	‡	§
Units	°C		‰	mg l^{-1}	mg O_2 l^{-1}	μatgN l^{-1}	mg N l^{-1}	mg N l^{-1}	μatgP l^{-1}	μgDSNa l^{-1}	
Range	18.5–20.0	7.92–8.17	28.6–35.8	29–387	0.11–6.03	10–3125	0.00–2.72	0.7–32.9	24.3–44.9	26–242	23–9950
Mean	18.9	8.07	33.9	117	3.30	837	1.49	10.4	32.8	113	3344
Standard deviation	0.5	0.09	2.7	135	2.71	1308	1.19	13.1	7.6	93	4841

*Strickland & Parsons (1968); †APHA, AWWA, WPCT (1976); ‡Murphy & Riley (1962); §Abbot (1962).

salines, and the number and significance of the parameters determined was greatly increased (Table 1). The analytical methods used for the determination of the different parameters analysed have been described in previous papers (Flores *et al.,* 1979b, 1980), and the bibliographic references appear in Tables 2 and 3.

Results and Discussion

Table 2 shows the maximum, minimum and mean values obtained from the sampling undertaken along Sancti Petri channel. Values obtained for water temperature (Tw) at the various sampling stations, taking into account the dependence of temperature on the hour at which the sampling was done, did not permit the demarcation of zones with different thermal characteristics. Little variation was observed in the pH values obtained, which remained within the limits normally to be found in seawater (Hörne, 1979).

Special mention must be made of the variations found for the determination of dissolved oxygen (D.O.) along the watercourse. Fig. 3 shows the mean values for the ten samplings, and also for the samplings done at high and flood tides on the one hand, and at low and ebb tides on the other. Black points on the *x* axis of the graph represent the locations of the urban effluents mentioned above. From the graph, we can deduce the existence of three clearly differentiated zones: a central zone deficient in oxygen, with values normally below 60% of saturation, and two others, near either entrance, in which the dissolved oxygen content is similar to that found in off-shore waters.

The variation observed in the mean values for nitrites (NO_2^-) (Fig. 4) bears a strong resemblance to that of dissolved oxygen, while there were notably high nitrite levels in the central zone.

Figure 5 shows the mean values in permanganate (P.V.) obtained for the different sampling stations; this parameter estimates easily oxidized organic materials. With the analytical method followed (Seki & Taga, 1973), we have tried to obviate the interference represented by the high chloride content of the samples analysed. In any case, the variation of values in permanganate is analogous to that found for nitrites. Fluctuations to be seen in Fig. 6 of the variations of salinity (S) may be due to the highly saline drainage from the salines along the channel. The minimal concentrations to be

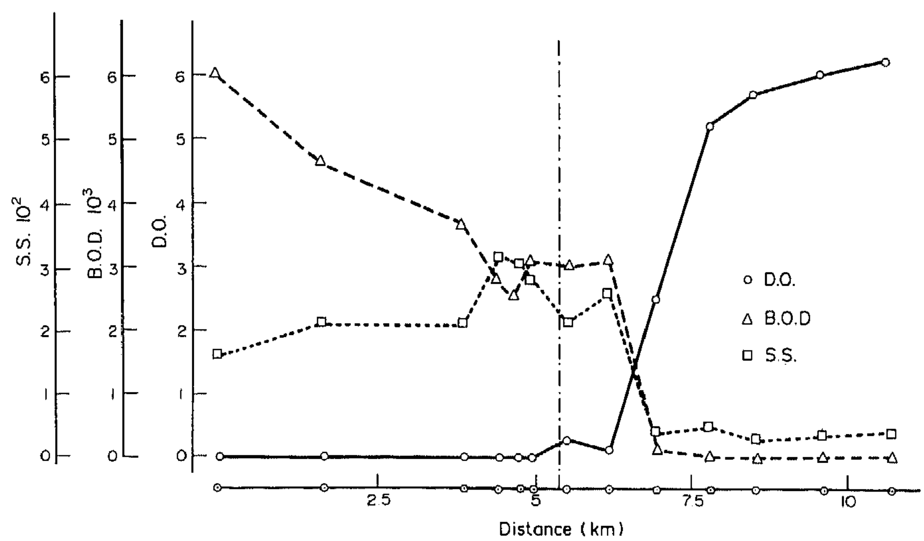

Fig. 7 Dissolved oxygen, biochemical oxygen demand and suspended solids versus location of the different sampling stations along river Iro.

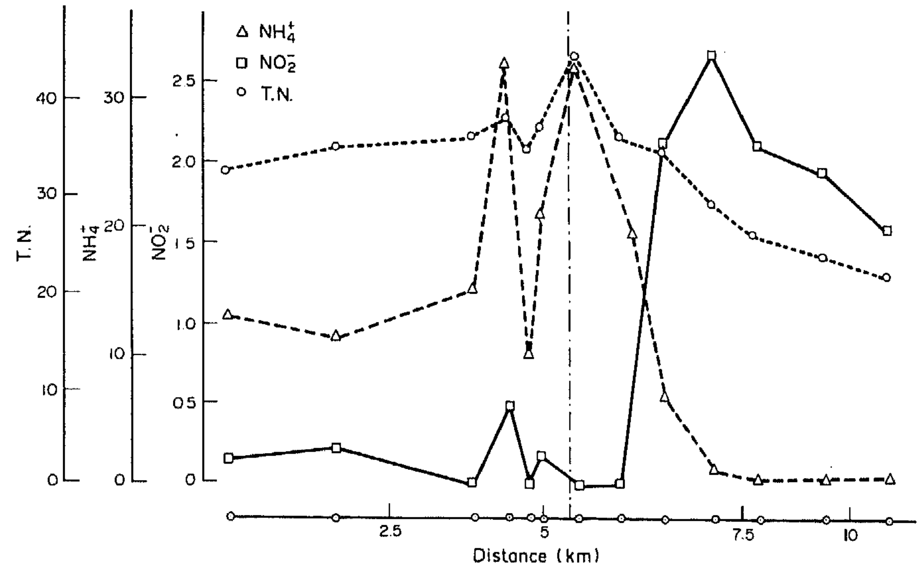

Fig. 8 Total nitrogen, ammonia and nitrites versus location of the different sampling stations along river Iro.

found in the central area can be explained by the entry of non-saline waters from the river Zurraque and the urban sewage effluents.

The analysis effected in the river Iro are summarized in Table 3, which shows the variations at mean values in the most significant parameters.

Figure 7 shows the variations found for dissolved oxygen (D.O.), biochemical oxygen demand (B.O.D.) and suspended solids (S.S.) along the course of the river Iro, taking as arbitrary zero a point situated 3 km upstream from Chiclana. This graph is divided into two parts: the left-hand part corresponds to the variations of these parameters before and during their passage through Chiclana town; these are not included in the table of mean values, but at least they give an idea of the bad quality of these waters, and of their recovery along the watercourse. We can detect a transitional area between stations 21 and 23, where the contamination levels are alarming, given the persisting influence of the river waters in their passage through Chiclana town.

A similar situation is reflected in Fig. 8, which shows the variations in total nitrogen (T.N.), ammonia (NH_4^+) and nitrites (NO_2^-); we can detect the intermediate area referred to above, and the slow recovery of the water along its course. We have not included the results obtained from analysis of total coliforms, but a qualitative analysis of them indicates a slow recovery of the river from station 21 to its mouth in the Sancti Petri channel. Values were found running from 200–300 colonies per 100 ml water at stations 24 and 25, down to 30–60 colonies per 100 ml at station 8. Likewise, the values of phosphates (PO_4^{3-}) and anionic surfactants (A.S.) found, expressed as μg of natrium dodecylsulphate, confirm previous results.

Conclusions

In conclusion, we may state:

(a) The quality of the water in the channels studied is badly affected by urban sewage disposal, the levels of contamination being highest around the outlets.

(b) The diluting effect of tide water on the sewage diminishes noticeably and progressively towards the central zone of the area under study. There are wide differences both in general levels of contamination and in the distribution of the values of the parameters analysed at various stages of the tide.

(c) Along the river Iro, there is an appreciable recovery of the watercourse as a consequence of the action of the tides and a certain amount of self-purification in the course itself.

(d) It is considered especially deleterious that the sewage effluents from the above-named towns should be situated in the area of least renewal of water, coinciding as they do with the meeting-point of the two tidal waves affecting the Sancti Petri channel.

On the basis of the foregoing, we can establish different zones in the channels studied, as far as levels of quality are concerned (Fig. 9):

(i) A first zone from the Atlantic entrance to the Sancti Petri channel up to 8 km (between sampling stations 6 and 7). This zone displays low contamination levels with reference to the parameters analysed. This zone affects approximately twenty-two salines in an area of about 21 km².

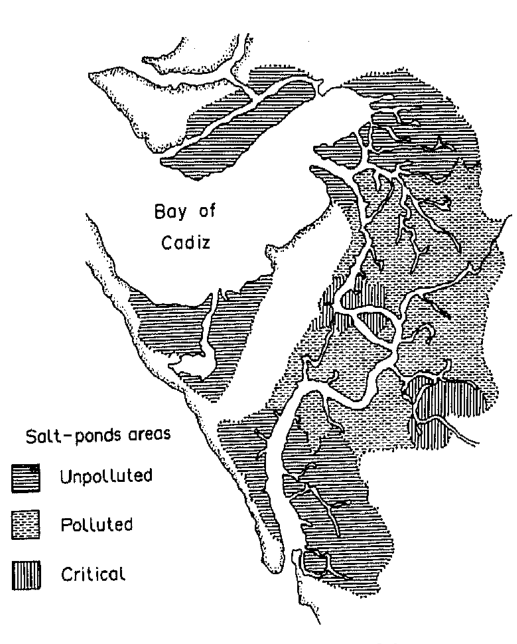

Fig. 9 Zones with different quality of the waters.

(ii) A second zone including the area near the Bay entrance to the channels derived from the Bay, with characteristics similar to those of the first, although with slightly higher contamination levels due to its nearness to the urban effluents. This zone supplies water to about twenty-four salines in an area of 13 km^2.

(iii) A third zone including all the central area of the Sancti Petri channel and the course of the river Iro and Zurraque channel. In this zone the contamination levels were found to be noticeably higher than in the other zones. It is roughly 35 km^2 in area, and supplies about fifty-one salines. Within this zone, two small areas stand out because of their high contamination levels: the first area goes along the area of the sewage effluents between sampling stations 9 to 13, in an area of about 6.5 km^2, supplying thirteen salines; the second area is in the first stretch of the river Iro after its passage through Chiclana, and is seriously affected by the urban sewage disposal of the town; this last area covers around 2.9 km^2 and supplies four salines.

To sum up, we can affirm that the extensive salt-ponds areas situated in the South of the Bay of Cadiz are seriously affected by urban sewage from the littoral towns. This situation is specially damaging at the present time in which the strong salt-industry existing in the area is beginning to be transformed into marine piscifactories, whose development is very important for the local economy given the serious crisis that the fishery sector is going through now.

As a solution to the problem mentioned above, we suggest the prior depuration of the urban sewage. In addition, the principal channels of the zone ought to be dredged, especially in the central zones, in such a way that the rate of renovation of their waters is increased.

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Clam Burrowing Behaviour: Inhibition by Copper-enriched Sediment

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Burrowing behaviour is adaptive and allows clams to escape predation; yet the effects of potentially toxic metals on such behaviour have not been adequately investigated. In natural marine sediment contaminated with copper the time for littleneck clams (*Protothaca staminea*) to achieve complete burial was recorded. Above a threshold of 5.8 $\mu g\ g^{-1}$ Cu added to dry sediment, the time for 50% of the clams to burrow (ET_{50}) increased logarithmically with increasing sediment copper concentration according to:

$$\log ET_{50} = 0.15(\mathrm{Cu}) - 1.37 \quad (n = 4, r^2 = 0.98)$$

where ET_{50} = time in hours for 50% of clams to burrow and Cu = $\mu g\ g^{-1}$ Cu in dry sediment. Previously exposed clams had both a lower threshold to Cu and a longer reburrowing time (ET_{50}). Clams exposed to sediment mixed with Chelex-100®-sorbed copper showed no significant change in burrowing time. Bioassays based on claim burrowing behaviour can measure both bioeffectiveness of sediment-sorbed metals and a sublethal effect with ecological meaning.

Copper is one of the metals most toxic to marine life, but when it enters coastal waters the majority is sorbed by organic suspended material and transferred to sediments (EPA, 1982; Helz *et al.*, 1981). This sorption decreases the cupric ion activity in water and reduces its bioavailability and toxicity to neritic life (Sunda & Guillard, 1976; Crecelius *et al.*, 1982). Once this sorbed copper accumulates on the sediment surface, little is known of its effects on infaunal benthos such as clams. Behavioural modification is one of the most sensitive indicators of environmental stress (Eisler, 1979; Olla *et al.*, 1980) and may directly affect survival. For example, Pearson *et al.* (1981) have shown that oiled sediment inhibits burrowing speed in the littleneck clam, *Protothaca staminea*, leading to increased predation by the Dungeness crab (*Cancer magister*). McGreer (1979) reported a correlation between the levels of mercury and cadmium in sediments and decreased burrowing speed in the estuarine clam *Macoma balthica*. The purpose of our study was to examine the effects of sediment-sorbed copper on the burrowing speed and reburial ability of *P. staminea*.