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Bioturbation by *Nereis* sp. and its effects on the phosphate flux across the sediment-water interface in the Palmones River estuary

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Abstract

The effects of *Nereis* sp. on the flux of dissolved phosphate across the sediment-water interface has been studied in Palmones River estuary using benthic flux-chambers and intact cores. Diffusive fluxes of phosphate were calculated from pore water gradient concentration and compared with those obtained from benthic chambers experiments. The high abundance of *Nereis* in the upper sediment layers appears to play an important part in the dissolved oxygen profiles in the overlying water, but had no effect on the redox potential. A negative relationship was found between the *Nereis* abundance and the phosphate gradient; this gradient ranged between 40 μmol l^{-1} cm^{-1} with 340 *Nereis* individuals m^{-2} and 20 μmol l^{-1} cm^{-1} with 900 *Nereis* individuals m^{-2}. The ratio of the *in situ* flux to the flux gradient concentration for dissolved phosphate increased with the abundance of *Nereis* (from 1.7 at low abundance to 5.8 at high abundance).

Introduction

The biogeochemistry of phosphorus in estuaries appears to be controlled by a combination of physical, chemical and biological processes. Previous work carried out in Palmones River estuary has shown the importance of the exchange of phosphorus between the sediments and the overlying water in the dynamics of this nutrient within the estuary. Pérez-Llorens (1987) studied the influence of the macrophyte *Zostera* in the phosphorus cycle, but other organisms and processes are involved in the dynamics of nutrients. The interchange of dissolved phosphate between sediments and the overlying water can be considerably enhanced by the presence and activity of benthic organisms (Aller, 1982; Henriksen, 1982; Aller & Yingst, 1985) and different models have been proposed to describe the effects of bioturbation (see Aller, 1980).

Sediment redox potential has been shown to effect exchange of nutrients at the sediment-water interface (Mortimer, 1941), but the most important redox reactions in aquatic environments are biologically mediated.

The aims of this paper are: (a) to calculate the phosphate fluxes using benthic chambers and intact cores; (b) to show the effect of redox conditions and dissolved oxygen in the fluxes; and (c) to assess the effect of *Nereis* abundance on these fluxes. The results of experiments carried out from June 1987 to June 1988 are reported.

Study area

The Palmones River estuary is located in Algeciras Bay (Lat. 36° 11′ N; Long. 5° 27′ 18′′ W) in southern Spain. It is a shallow estuary (maximum depth 0.9 m) with a maximum tidal range of 1 m. The salinity range was between 2,9% and 3,5% (López-Figueroa, 1984). The sediments consist of sandy muds in the surface oxidized layer and muds in the reduced layer. The benthic infauna described previously by Rodriguez (1977) is mainly composed by polychaetes of the genus *Nereis*. Densities of 340–1000 individuals m^{-2} have been recorded previously (Clavero *et al.*, 1988).

Materials and methods

In situ *Flux (J_o) and redox measurements*

The flux of dissolved phosphate, Eh and dissolved oxygen were measured in a PVC-chamber (volume 30 l; area 0.2 m^2) at low tide every 30 minutes over a period of six hours. Eh measurements were performed using a platinum electrode inserted into the chamber and placed in the water 2 cm above the sediment. The electrode was connected to a Crison model CDTM. Oxygen concentrations were monitored in the PVC chamber 2 cm above sediment using a YSI oxygen probe. Water samples (15 ml) were taken from the chamber using a syringe. The water was filtered through a Whatman GF/C filter, frozen in the field and stored for further analysis. Five replicate samples were taken on each occasion.

Sediment cores

Sediment cores, to be analysed for phosphate, organic matter and fauna, were collected by means of two PVC-cores (20 cm of internal diameter; 20 cm of length) at low tide next to the PVC chamber and frozen. In the laboratory one core was sliced into 2 cm sections. Each section was weighed and divided into two subsamples. The first subsample was centrifuged (3000 rpm, 30 minutes) to extract the pore water which was filtered through a Whatman GF/C filter. The other subsample was used to determine the sediment water content. The other core was sliced into 5 cm sections and used for density estimation. One portion was used to determine the organic matter content.

Analytical method

The overlying water and pore water samples were analyzed for phosphate using the Technicon AAII method of Fernández *et al.* (1985). Sediment water content was determined after drying at 60 °C, and organic matter was estimated in dried samples from weight loss on ignition at 450 °C for five hours.

Results

In situ *flux and redox measurements*

The dissolved phosphate flux (J_o) was determined from the following equations (Aller *et al.*, 1985):

$$J_0 = M A^{-1} T^{-1}$$

$$M = \Sigma V_t (C_t - C_{t-1})$$

where J_o is the phosphate flux (μmol m^{-2} d^{-1}); M is the total mass change of the dissolved component at time t in the chamber (μmol); V_t is the total volume of overlying water at time t in the chamber (l), A is the surface sediment exchange (m^2), and C_t and C_{t-1} are the dissolved phosphate concentrations at time t and t − 1 respectively in the water (μmol l^{-1}).

The profiles of dissolved phosphate in the sediment through the study period are shown in Fig. 1. The annual values of replicate measurements of the dissolved phosphate fluxes are shown in Fig. 2. These values oscillated from 210.2 μmol m^{-2} d^{-1} in July 1987 to 395.6 μmol m^{-2} d^{-1} in October 1987. In general, the flux appeared to be highest in winter and lowest in summer.

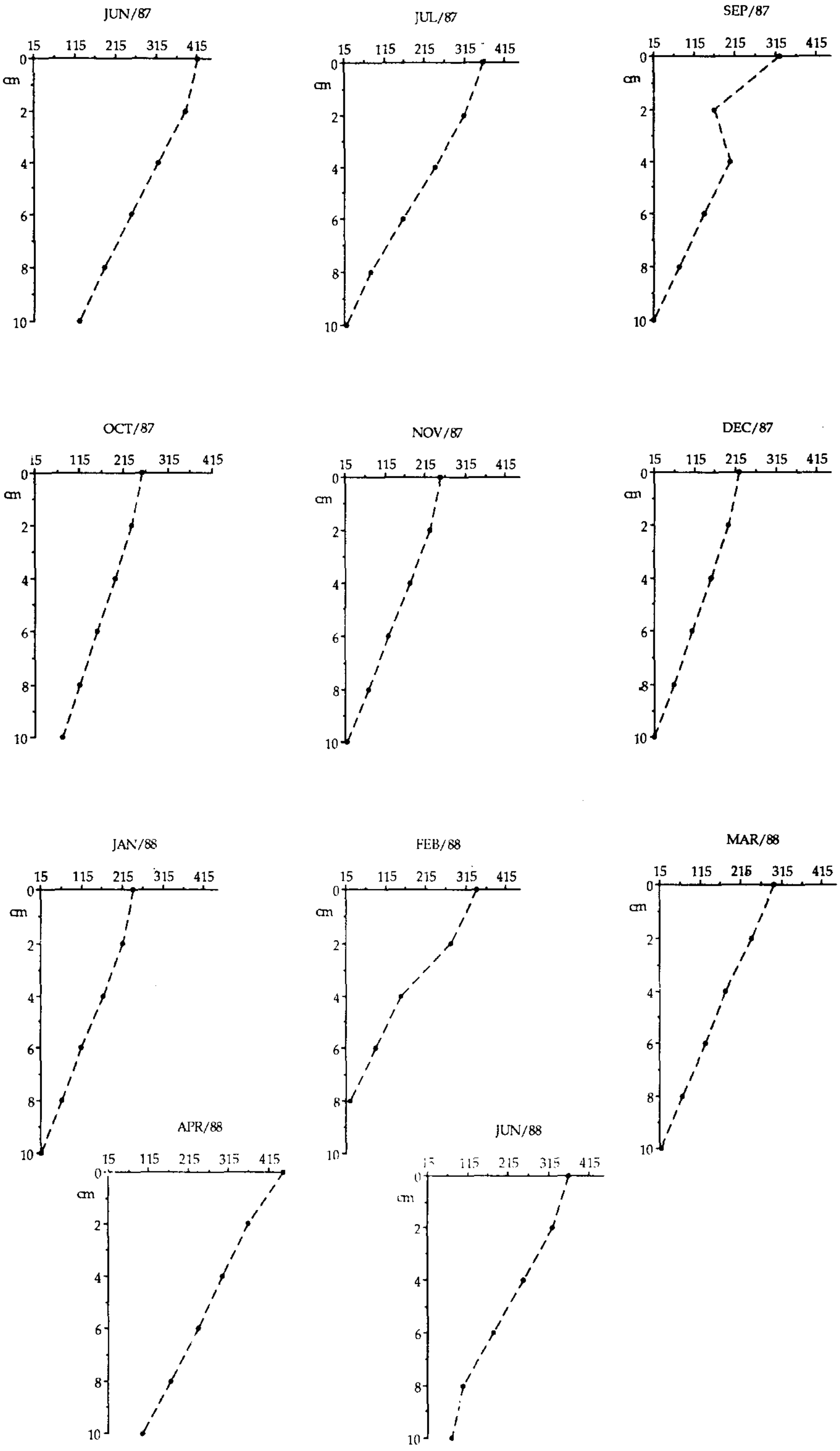

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Fig. 1. Profiles showing the concentration of dissolved phosphate (μmol l^{-1}) in sediment pore water over the study period.

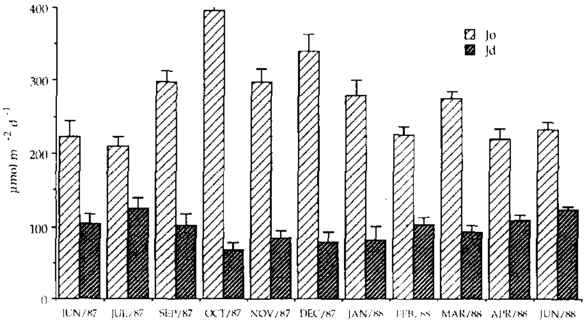

Fig. 2. Variation of the calculated phosphate flux (J_o) and the diffusive phosphate flux (J_d) obtained from the benthic chamber experiments over the study period.

The initial and final Eh values in the sediments, and the dissolved oxygen concentrations in the overlying water, are shown in Table 1. A linear decrease of dissolved oxygen coincided with an increase of J_o values.

Sediment cores

The mean organic matter contents in the sediment throughout the year are shown in Fig. 5. The diffusive fluxes are calculated using the following equation of Berner (1976):

$$J_d = \phi D_s \partial C / \partial x$$

where J_d is the diffusive flux (μmol m^{-2} d^{-1}), ϕ is the sediment porosity in the upper part (2 cm) of the sediment expressed as a percentage, ∂C / ∂x is the concentration gradient of dissolved phosphate (μmol l^{-1} cm^{-1}); D_s is the whole sediment diffusion coefficient (cm^2 s^{-1}) expressed by Krom & Berner (1980a) as: $D_s = D_o \phi_o F^{-1}$ where D_o is the diffusion coefficient for phosphate (7×10^{-6} cm^2 s^{-1}) in water at infinite dilution (Li & Gregory, 1974), and F is the modified formation factor from Archie relation (Manhein, 1970): $F = 1.28\ \phi_o^{-2}$, where ϕ_o is the average sediment porosity.

Figure 2 shows the diffusive fluxes throughout the year. The highest values were obtained in winter (124.4 μmol m^{-2} d^{-1}). The distribution of *Nereis* in the sediments are shown in Fig. 4. The maximum abundance (about 60 %) is present in the first 5 cm of the sediment in the winter (900 individuals m^{-2}).

Discussion

The correlation between oxygen consumption (Fig. 3) and phosphate fluxes (J_o) in the overlying water suggest that the exchange of phosphate is coupled with the degradation of organic matter.

Table 1. Annual variation of *Nereis* abundance (Individuals m^{-2}), mean organic matter content in the sediment (OM), water content (W), Eh measurements in chambers, initial (Eh_i) and final (Eh_f) values, phosphate concentration gradient ($\partial C/\partial X$), dissolved phosphate fluxes (J_o) and diffusive phosphate fluxes (J_d).

	Abund. (Ind. m^{-2})	O M (%)	W (%)	Eh_i (mV)	Eh_f (mV)	$\partial C/\partial X$ (μmol l^{-1} cm^{-1})	J_d (μmol m^{-2} d^{-1})	J_o (μmolm^{-2} d^{-1})
June 87	520	3.21	70	- 110	- 135	33	105	223
July 87	340	2.98	65	- 140	- 190	40	124	210
Sept. 87	639	3.06	78	- 200	- 287	31	103	298
Oct. 87	900	3.14	89	- 89	- 175	20	68	396
Nov. 87	810	3.20	85	- 110	- 176	26	86	298
Dec. 87	875	3.41	88	- 75	- 150	23	80	340
Jan. 87	750	3.61	82	- 189	- 215	25	82	279
Feb. 88	580	3.50	77	- 127	- 151	32	104	225
March 88	624	3.60	75	- 253	- 278	28	93	275
April 88	470	3.10	70	- 214	- 229	35	110	220
June 88	450	3.50	68	- 124	- 145	37	123	232

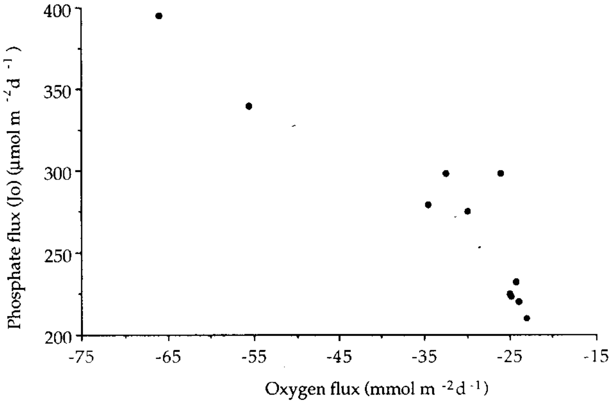

Fig. 3. Plot of calculate phosphate flux vs dissolved oxygen flux.

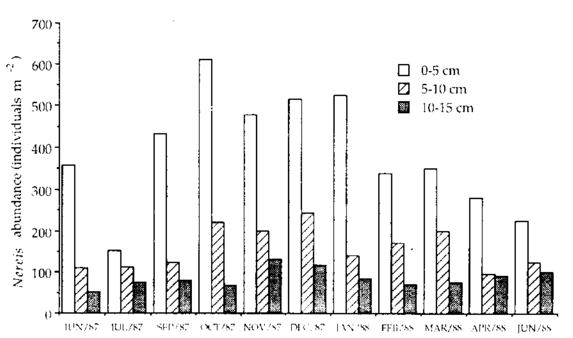

Fig. 4. Distribution of *Nereis* abundance in the sediments at three different depths.

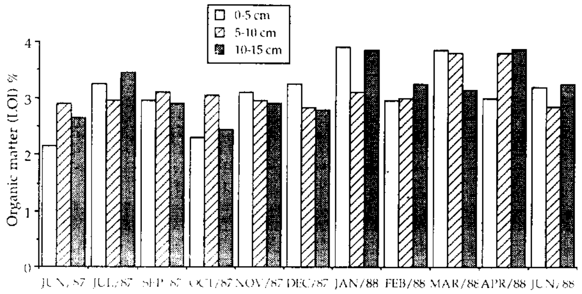

Fig. 5. Organic matter content (loss on ignition) in the sediment over the study period.

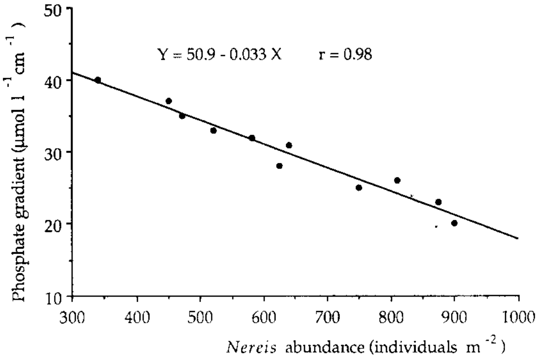

Fig. 6. Graph showing the phosphate gradient in the sediment vs *Nereis* abundance.

However, the variation in the sediment organic content (Fig. 5) does not show any significant trend over the study period. The mean annual rates of exchange across the sediment-water interface were 62900 μmol m^{-2} d^{-1} dissolved oxygen and 273 μmol m^{-2} d^{-1} for phosphate. The stoichometry of the sediment phosphate exchange was 229:1 and is similar to the 269:1 obtained by Blazer (1984) and the 221:1 obtained by Hopkinson (1987).

This relation between phosphate flux and oxygen consumption may indicate no changes in the sediment redox system (Clavero *et al.*, 1990). Table 1 shows the Eh values throughout the study period. There was little variation except in October. We believe that the release of regenerated phosphate from the sediment is driven by the concentration gradient at the sediment-water interface (Clavero *et al.*, 1991). The effects of the benthic infauna on these fluxes can be assessed by comparing the fluxes obtained *in situ* with those obtained assuming only molecular diffusion. Table 1 shows the J_o and J_d values together with the *Nereis* abundance on each sample date.

These data show that J_o increased with increased *Nereis* abundance, while the J_d values show an inverse relationship. The negative linear relationship that was found between the phosphate gradient and the *Nereis* abundance (Fig. 6), can be explained by the transport of oxygen into the sediments by the *Nereis* species. The oxygenated water would decrease the phosphate concentration in sediments. A high abundance of *Nereis* would be expected to produce increased oxygen penetration into the sediments. Since the maximum abundance of *Nereis* was found in the first 5 cm of the sediments, biological oxygenation would be greatest in this region (Fig. 4). Krezoski *et al.* (1984) found a 70% enhancement of solute diffusion from sediments because of the burrowing activity of infaunal. This enhancement can be

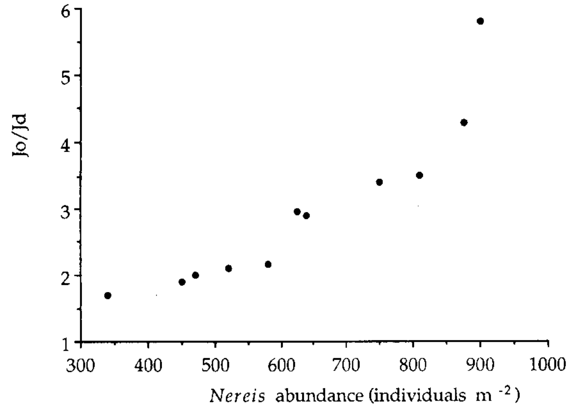

Fig. 7. Ratio of the calculated (J_o) and diffusive (J_d) phosphate fluxes vs *Nereis* abundance.

estimated by means of the J_o/J_d ratio. Kristensen & Blackburn (1987) showed that an abundant population of *Nereis* increased the solute transport in sediments by 2–3 times over that when there were no animals. Callender & Hammond (1982) obtained a J_o/J_d ratio between 1–10 assuming a one-dimensional molecular diffusion model. In our study, we found a J_o/J_d ratio between 1.7 and 5.8 and this relation increased with *Nereis* abundance (Fig. 7).

Acknowledgements

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