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Wetland Loss by Erosion in Odiel Marshes (SW Spain)

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ABSTRACT

Wetland loss in many estuaries around the world, has been attributed mainly to undermining and collapse of channel banks. This study aims to quantify bank erosion and vertical erosion/accretion rates on intertidal sediments in the Odiel tidal marshes (SW Spain). Bi-monthly erosion/accretion measurements were taken on eight channels over a four year period, using markers (iron stakes) located on intertidal areas and on eroding banks. The intensity of erosion divides the Odiel marshes into two zones. The northern zone has low erosion rates (horizontal erosion c. -20 cm year^{-1} and vertical erosion / accretion between 0 and –1 cm year^{-1}), and coincides with low levels of human activities. The southern zone has higher erosion rates (horizontal erosion c. -25 cm year^{-1} and vertical erosion / accretion between 0 and –5 cm year^{-1}) and exhibits higher levels of anthropogenic pressure. The highest horizontal and vertical erosion rates (c. -80 cm year-1) were recorded on navigation channels. Horizontal and vertical erosion showed a positive linear relationship ($r^2 = 0.66$; $P< 0.01$), indicating that sediments mobilized by bank erosion are not deposited on adjacent intertidal areas. Erosion led to mature marsh habitat loss of c. 17000 m2 year^{-1} and a sediment mobilization of c. 16500 m3 year^{-1}.

ADDITIONALINDEXWORDS: *accretion, anthropogenic pressure, bank erosion, intertidal plain, Spartina maritima.*

INTRODUCTION

Wetland losses have been detected in many estuaries around the world (CHUNG, 1982; DELAUNE *et al*., 1983; BARROS, 1996; BRIVIO, 1996; PSUTNY and MOREIRA, 2000), attributing their main mechanism to erosion. Thus, erosive processes such as undermining of the drainage channel banks have been characterised (PHILLIPS, 1986; KEARNEY and STEVENSON, 1991; GABET, 1998), which result in steeped slopes between vegetated marshes and bare intertidal sediments (NYMAN *et al.*, 1994). Intertidal sediment dynamics are a key process in the evolution of eroded marshes, since they determine the height of erosive banks and affect their colonization by vegetation. In addition, the identification of the causes of erosion and its quantification are necessary in developing management strategies for eroded wetlands.

This study was carried out in the Odiel tidal marshes (SW Spain), where high bank erosion rates have been quantified in a short term study (CASTILLO *et al*., 2000a). Here, we aim to quantify bank erosion and with vertical erosion / accretion rates on intertidal areas over a four year period.

STUDYAREA

This study was carried out in the Odiel tidal salt marshes in the joint estuary of Odiel and Tinto rivers (37º15' - 37º37'N, 6º57' - 6º58'W; SW Spain) (Fig. 1). This Holocene estuary is located in a coastal area with a mesotidal semidiurnal character. Mean tidal range is 2.10 m and mean spring tidal range is 2.97 m. Water levels range between 0.40 and 3.37 m above Spanish Hydrographic Zero (SHZ) (CASTELLANOS *et al*., 1994). The estuary occupies a 25 km long stretch of an incised river valley and is underlain by Neogene sandy-silty sediments. The oldest estuarine sediments have been dated at 6.715 ± 115 yr BP. Sediment accretion rates (approximately 5 mm year-1) indicate fast infilling of the estuary during the two last millennia (LARIO, 1996). Infrastructures such as dykes, breakwaters, harbours and water reservoirs have modified the hydrodynamic and the sediment supply in the estuary of Odiel and Tinto rivers (OJEDA *et al*. 1995). On the other hand, the main channel of the estuary is dredged continuously to allow vessel traffic. The Odiel marshes, with an area of 7158 hectares, were declared a Biosphere Reserve by UNESCO in 1983, and they are located in a Mediterranean climate (NIEVA and LUQUE, 1995).

METHODS

Bank erosion by undermining and vertical erosion / accretion rates on intertidal sediments were measured on the eight main channels of the Odiel Marshes, bi-monthly from May - August 1996 to July 2000 (Fig. 1). A network of 298 markers was set up (Table 1). These consisted of iron stakes approximately 1.5 m tall and 1 cm in diameter (Fig.2). Markers were inserted to a depth of 1 m, between +1.0 m and +2.5 m over SHZ on intertidal plains and over erosive banks. The distance from the sediment surface to the top of the markers was measured to quantify vertical erosion / accretion dynamic; the distance from the edge of the bank to the marker base was measured to quantify bank horizontal erosion (Fig. 2). This method has been used by many authors (WOLMAN, 1959; RANWELL, 1964; HUBBARD and STEBBINGS, 1968; RANWELL, 1972; KING, 1975), since it allows repeated measurements of erosion and accretion at the same location. Negative values indicate erosion and positive values correspond to accretion. Mean bank height (n = 6) was measured at every channel to quantify the volume of mobilized sediment by horizontal erosion.

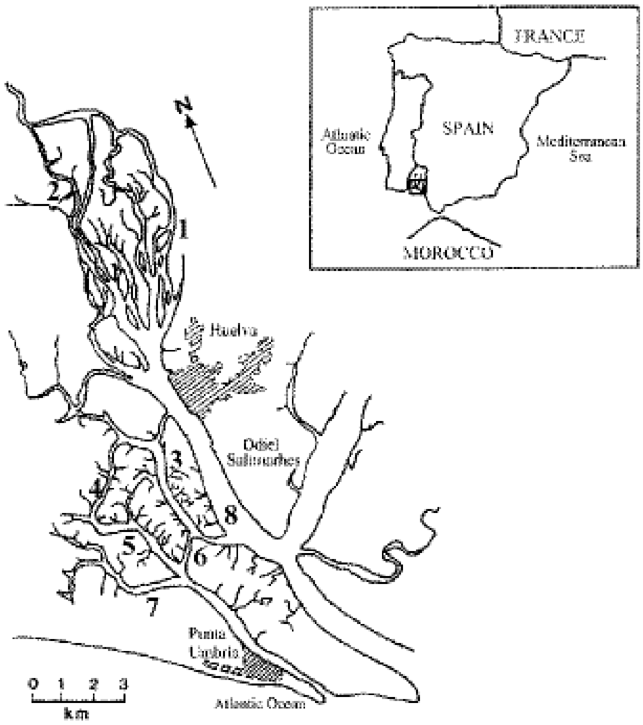

Figure 1. Location of Odiel estuary in The Iberian Peninsula and map of Odiel Marshes. Studied channels are numbered from 1 to 8.

Analysis was carried out using 'Statistica' 5.1 (Statsoft Inc.). Pearson correlation coefficients were calculated between erosion / accretion rates. Rates of erosion / accretion on different channels were compared using one-way analysis of variance. Least significant differences (LSD) between means were calculated only if the F-test was significant at the 0.05 level of probability. Data were tested for homogeneity of variance with the Levene test (P> 0.05).

Table 1. Mean ± SEM bank horizontal erosion and intertidal plain vertical erosion / accretion (cm year-1) during four years in the main channels of Odiel salt marshes (SW Spain).

Channels	Bank horizontal erosion	intertidal plain vertical erosion / accretion
1	-8 ± 2	-0.5 ± 0.5
2	-15 ± 3	-1.1 ± 1.3
3	-47 ± 12	-1.6 ± 0.3
4	-37 ± 6	-1.3 ± 0.5
5	-34 ± 7	-1.6 ± 0.7
6	-76 ± 9	-4.7 ± 0.7
7	-40 ± 6	-0.3 ± 1.0
8	-64 ± 9	-2.4 ± 0.4

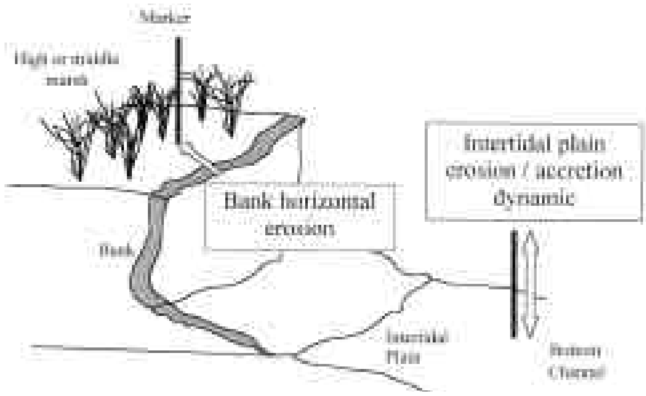

Figure 2. Diagram showing the placement of markers over a bank, to measure horizontal erosion, and on an intertidal plain, to measure erosion / accretion dynamic.

RESULTS

The intensity of bank horizontal erosion and intertidal plain vertical erosion / accretion varied significantly between channels (F = 14.66, P < 0.0001; F = 4.44, P < 0.0001, respectively) (Table 1). Erosion / accretion rates divided the Odiel marshes into two zones. In the Northern zone (channels 1 and 2) mean horizontal erosion was less than -20 cm year^{-1} and the mean vertical erosion / accretion rate was between 0 and $^{-1}$ cm year^{-1}. In the Southern zone (channels 3, 4, 5, 6, 7 and 8) mean horizontal erosion was over -25 cm year^{-1}, with a maximum close to -80 cm year^{-1}, and the vertical erosion / accretion rate was between 0 and –5 cm year^{-1} (Fig. 1).

The highest horizontal and vertical erosion rates were recorded on navigation channels –(channels 6 and 8). Both channels were located close to the estuary inlet and channel 8 was the widest channel. Horizontal and vertical erosion showed a positive and linear relationship (r^2 = 0.66; P < 0.01) at all sites (Fig. 3).

Erosion in the Odiel tidal marshes has led to a loss of mature high marsh of c. 17000 m^2 year^{-1}, provoked by bank erosion, and a sediment mobilization by bank and intertidal erosion of c. 16500 m^3 year^{-1} (Table 2). This erosion hinders the development of marshes by successional processes and limits the success of primary colonizers.

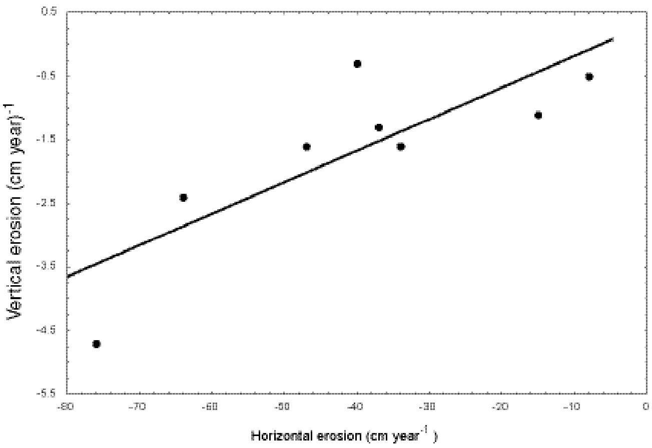

Figure 3 Correlation between horizontal and vertical erosion in eight channels in Odiel Marshes (SW, Spain). (r2 = 0.66; P< 0.01).

Table 1. Table 2. Number of markers, length (m), height of bank (cm), eroded area (m^2 year^{-1}) and mobilized sediments (m^3 year^{-1}) – considering a mean intertidal plain width of 10 m- in eight channels of Odiel Salt Marshes.

Channel	Nº of markers	Length (m)	Height (cm)	Eroded area (m^2 year^{-1})	Mobilized sediments (m3 year^{-1})
1	25	11167	37	893	892
2	19	16393	40	2459	2793
3	23	8374	51	3936	3359
4	25	5643	58	2088	1949
5	35	6351	64	2159	2403
6	53	1981	93	1506	2325
7	20	9140	59	3656	2407
8	98	600	52	384	382
∑	298	59649	-	17081	16510

DISCUSSION

Erosion / accretion dynamic divides the Odiel tidal marshes into two zones: a northern zone with low erosion rates, coinciding with low levels of human activities; and a southern zone with higher erosion rates and higher levels of anthropogenic pressures (recreational, port and industrial activities, infrastructure installation, etc.). The highest erosion rates were recorded on navigable channels, suggesting that vessel traffic may contribute to increased erosion (PEZESHKI and DELAUNE, 1996). However, human activities causing erosion are difficult to identify and quantify in this study, since more than one factor could be acting at the same time. Many infrastructures have been constructed closed to Odiel marshes that may reduce sediment supply to the estuary favouring marsh erosion, such as breakwaters, harbours and water reservoirs. OJEDA *et al.* (1995) identified anthropogenic alterations of the hydrodynamic conditions of the Odiel marshes, which may affect erosion / accretion processes through the modification of currents and sediment supply (CHMURA *et al.*, 2001). The lower rates of erosion in the upper estuary might also reflect lower wave energy, a suggestion that is also consistent with the observation of higher erosion rates adjacent to the large navigation channels. On the other hand, accelerated sea level rise could accelerate the loss of coastal wetlands by erosion (ROGERS and MCCARTY, 2000).

It is interesting to note, the positive and linear relationship between horizontal and vertical erosion which indicates that sediments mobilized by bank erosion are not deposited on adjacent intertidal area. Erosion on the Odiel marshes has led to sediment mobilization of c. 16500 m^3 $year^{-1}$. Our results suggest that some of these sediments, which are dispersed by currents and tides, could contribute to the silting of the channels of the estuary. Considerable economic expense is incurred in dredging navigable channels to enable the entrance of large ships into de Port of Huelva. Furthermore, erosion is leading to the loss of c. 17000 m^2 of marsh per year.

Although low marshes are presently forming in the southern part of the estuary, most of the lost marshes were mature ones that had taken a long time to form and were acting as exporters of organic matter (HAZELDEN and BOORMAN, 1999). The loss of these middle and high marshes reduces the habitat of certain communities, contributing to a decrease in species and habitat diversity, since they are replaced by bare intertidal areas.

Our results may contribute to the management of eroded marshes, in order to assist their restoration by administrative and constructive geo-ecological methods (CASTILLO *et al*., 2000a). These include the introduction of marsh plant species adapted to high flooding periods, such as Spartina maritima (CASTILLO *et al*., 2000b), which enhance rates of low marsh development by trapping sediments (MOELLER *et al*., 1996).

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