



## The role of salt marshes in the Mira estuary (Portugal)

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### Abstract

The Mira estuary is a narrow entrenched pristine estuary of the Ria type, about 30 km long. It comprises an area of 285 ha of salt marsh, of which 250 ha have been proposed for reclamation for aquaculture. Dredging, village and recreation development menace the yet undisturbed estuarine ecosystem. To assess the biological importance of this wetland, a multidisciplinary study was conducted in a part of the salt marsh, considered as being representative of the whole area. Halophytic vegetation covering 75% of the total salt marsh site is dominated by *Spartina maritima* (28% of total vegetation area). Total primary production attains 63.766 kg/yr (dw). A net export of 1541 kg/yr of COM to the relatively oligotrophic adjacent waters was also found.

Insects and birds are described for the first time in the saltmarsh. Macrobenthic communities are dominated by *Hediste diversicolor*, *Nephtys caeca* and *Scrobicularia plana*. The fiddler crab *Uca tangeri* attains here its north distribution limit. The mud flats and creeks associated with the salt marsh act as a nursery for 40.8% of the fish species present.

The food web is dominated by detritivorous species like the grey mullets. The results obtained in this study support the need for an effective conservation of this area.

### Introduction

Salt marshes are generally considered as being among the most productive ecosystems in the world (Mitsch and Gosselink, 1993). Their high primary production has been, from the beginning, presumed to be exported to adjacent estuarine and coastal waters.

According to Teal (1962) '... at the same time the tides remove 45% of the production before the marsh consumers have a chance to use it and, in so doing permit the estuaries to support an abundance of animals'. The concept of salt marshes as 'exporting ecosystems' in the early 1960's rapidly became an accepted idea (Nixon, 1980). Odum (1980) argued that salt marshes produce more material than can be stored within the system and the excess is exported to coastal waters where it supports oceanic productivity, the 'outwelling hypothesis'.

These outstanding functional properties have been repeatedly used as an argument to preserve estuarine marshes. These views, however, became controversial, as some European and American researchers found salt marshes to be net importers instead of net exporters of organic matter and, eventually, nutrients (Vegter, 1975; Hackney, 1977; Haines et al., 1977; Lammens and Van Eeden, 1977; Woodwell et al., 1977; Wolff, 1977; Wolff et al., 1979; Dankers et al., 1984).

In 1984, a proposal was submitted to the Portuguese Department of Environment, to reclaim about 250 ha, (80%) of the existing 285 ha of salt marshes formations in the Mira estuary in order to install aquaculture tanks (Bettencourt, 1985). At that time there was little information on the fauna and flora of the estuary as well as on its ecology. The first systematic scientific report appearing only in 1986 (Andrade). Therefore, in view of the drastic implications of the aquaculture project for the ecological

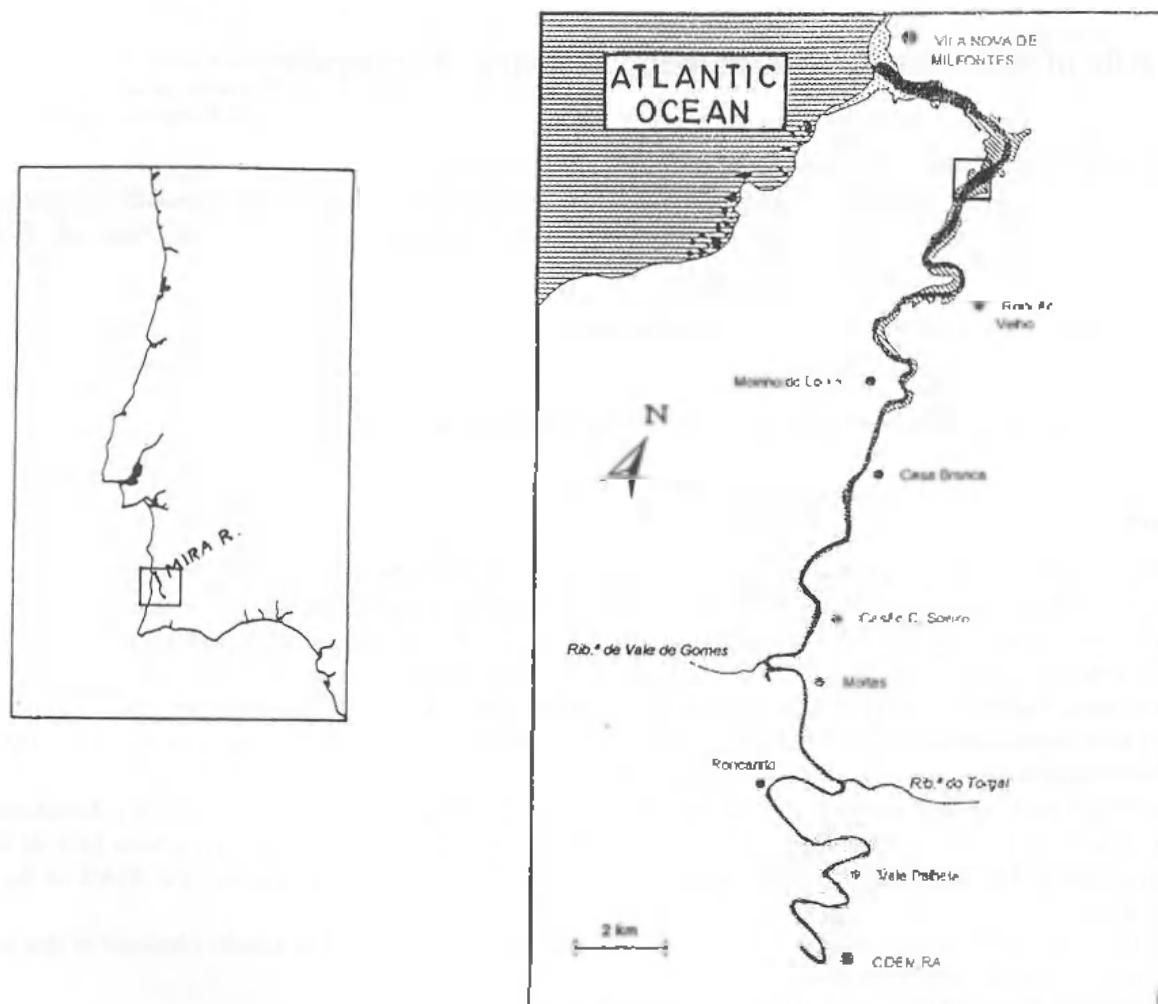


Figure 1. The Mira estuary. ▨ Salt-marsh.

processes within the estuary and the controversy about the outwelling theory, it was decided to postpone any decision on aquaculture projects until the necessary research has been carried out.

With this goal, some preliminary work was done in the following years (Costa, 1988). An adequate framework favouring a multidisciplinary approach was only found, however, within the EEC Project 'Comparative Studies of Salt Marsh Processes', which ran from 1990 to 1992 and aimed at comparing the functional behaviour of salt marshes along the European coast, from the Wadden Zee to the Portuguese south coast.

We present here results on vegetation, fauna and organic matter and nutrient budgets obtained within that Project, and subsequent diversification, for a plot of the Mira salt marshes which aid in the understanding of the structure and functional role of these partic-

ular ecosystems in order to support a decision on their conservation from present and future anthropogenic impacts, such as the aquaculture projects.

### Study site

The Mira in the southwest Portugal is a narrow incised estuary about 30 km long, 150 m wide in the lower part and 100 m in the upper reaches (Figure 1). The salt-wedge reaches Odemira in summer and the dynamic tide goes up in the estuary for more than 15 km upstream of this city (Bettencourt and Matos, 1988). In the selected saltmarsh site (Figures 1 and 2) the mean tide range is 2.4 m and salinity varies between 15‰ and 35‰. The marsh, depicted in Figure 2, corresponds on the whole to a mature marsh, its elevation

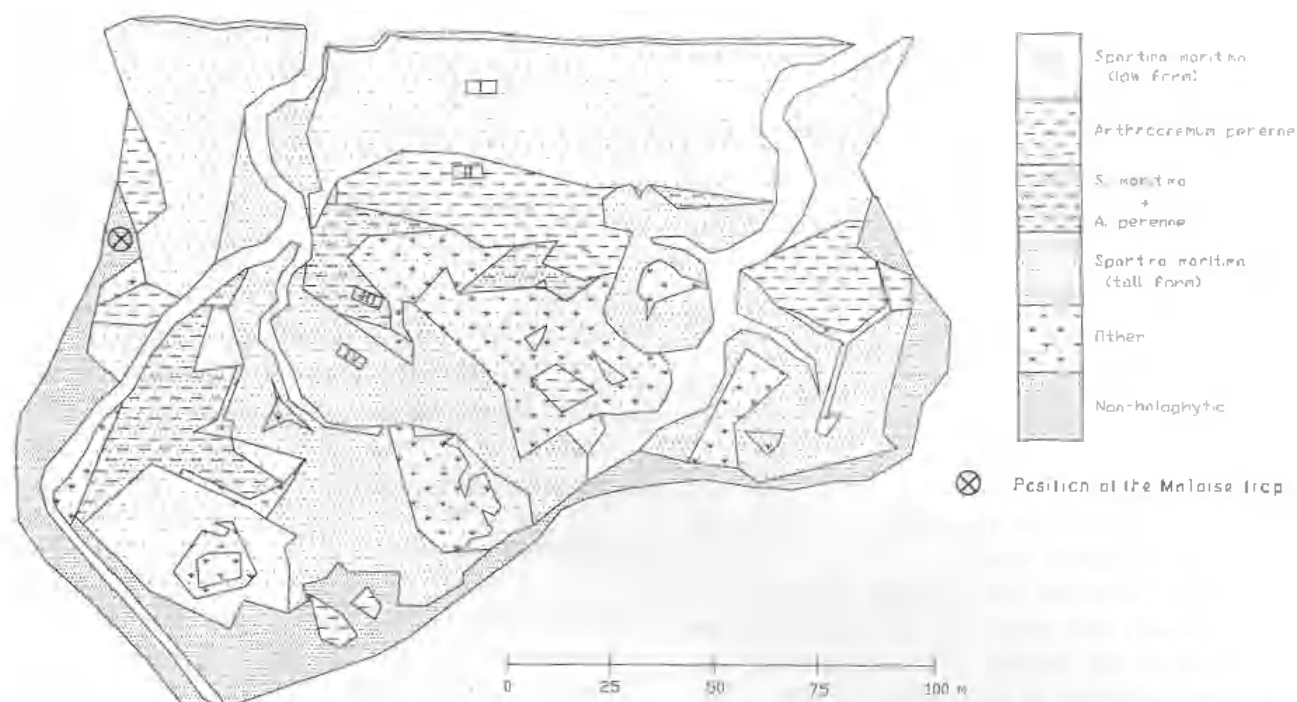


Figure 2. The vegetation of Mira salt marsh.

varying between  $-0.20$  m and  $+0.70$  m over mean high water level (MHWL). The mean depth is about 6 m with a maximum of 13 meters. Mean freshwater inflow in 1992 was  $7.13 \text{ m}^3 \text{ s}^{-1}$ , but in dry years it can be close to zero.

It is a Ria Type estuary (Fairbridge, 1980) bordered by 285 ha of salt-marsh. The temperature of water varies between  $8^\circ \text{C}$  and  $11^\circ \text{C}$  (winter) and  $20$ – $21^\circ \text{C}$  (summer). The insolation is about 2950 hours per year (I.F.N. 1972). With the exception of a dam constructed some 50 years ago, 50 km upstream of the river mouth, the estuary is relatively undisturbed and free from industrial pollution. The mouth is affected, mainly during the summer tourist season, by the domestic pollution coming from Vila Nova de Milfontes, a very popular holiday village.

In order to understand the structure and functioning of the salt-marsh we chose a study site located 4 km from the mouth of the estuary. The site was chosen for its accessibility, confinement characteristics and representativeness of higher vegetation (Bettencourt et al., 1992a).

## Methods

From December 1990 to May 1992, 27 tidal cycles were surveyed in the Mira salt marsh site to establish carbon, suspended matter and nutrient budgets. This covers a wide range of tides including 10 spring, 7 average and 8 neap tides. A significant part of these surveyed cycles were consecutive to allow for the eventual asymmetry of the tide.

Samples for ammonia, nitrate, nitrite, Kjeldahl nitrogen, silicate, total and dissolved phosphorous, coarse organic matter and suspended solids were taken by standard procedures, every half-hour along the tidal cycle, preserved and analysed by standard procedures (Bettencourt et al., 1992b).

Tidal cycles were integrated by the trapezoidal rule, the concentration of the different parameters having been previously interpolated to provide for a time interval of  $\Delta t = 15$  minutes. A rough annual budget was computed for each parameter according to the following equation:

$$\frac{\text{net budget found}}{\text{number of cycles surveyed}} \times 706 \text{ tidal cycles} = \text{annual budget}$$

Table 1. Distribution of the main plant formations in the studied salt marsh (Adapted from Bettencourt et al., 1992a).

Formation	Area	
	m <sup>2</sup>	% halophytic
<i>S. maritima</i> (low form)	7456	37.8
<i>A. perenne</i>	2308	11.7
<i>S. maritima</i> + <i>A. perenne</i>	1720	8.7
<i>S. maritima</i> (tall form)	5726	29.0
Others (halophytic)	2529	12.8
Total halophytic	19738	100.0
Non-halophytic	6256	
Total mapped	25994	

For some parameters that presented a good seasonal coverage net-weighted seasonal and annual budgets were further computed averaging the net budgets of spring, ordinary and neap tides for each season and multiplying by the number of spring, ordinary and neap tides occurring in each season (Dame et al., 1986). The annual budget was obtained by the summation of the seasonal budgets.

For vegetation analysis (Figure 2), four sampling sites were selected according to the vegetation zonation:

- Site I: *Spartina maritima* (Low form)
- Site II: *Arthrocnemum perenne*
- Site III: *S. maritima* mixed with *A. perenne*
- Site IV: *S. maritima* (Tall form)

In all sectors, 0.25 × 0.25 m (1/16 m<sup>2</sup>) quadrats were used. In order to calculate the primary production paired plots were clipped according to the Wiegert and Evans technique (1964). Harvesting and processing of vegetation was carried out following Kirby and Goselink (1976). Tissues of *Arthrocnemum perenne* were separated into succulent and non succulent parts. The benthic communities were studied taking four replicates from three different sites at depth of 20 cm using a cylindrical corer 12 cm in diameter. Insects were caught by hand with a sweep net and a Malaise trap (200mm in height) for a period of 6 days in spring. All captured animals were identified to order level and, in the case of Coleoptera and Hymenoptera to family or subfamily level. The fish were caught monthly over 2 years in eight sampling sites in the zone bordering the salt marsh including those close to the creek. A beam-

trawl (1.7 m wide; 10 mm mesh size; 15 minutes per tow) was used to cover an area of 1000 m<sup>2</sup> at each site. Bird-watching transects were also done. In order to study the food web, the stomach contents of the animals caught were analysed. In the case of benthic species, we made only a qualitative analysis.

## Results and discussion

### Vegetation

The salt marsh occupies, in the whole estuary, an area of 285 ha estimated from aerial photographs. Table 1 shows the distribution of the main plant formations by studied salt marsh area. In Figures 3 and 4 we can see the monthly variation of standing living and dead biomass in 1990-91 for *Arthrocnemum perenne* and *Spartina maritima*.

*S. maritima*, in contrast to northern salt marshes, does not display a well defined seasonal pattern, which suggests the continuous growth all year round. This can be explained mainly by the role of temperature in the processes of production and decomposition. In fact, in the Mira salt marshes, the temperature during winter does not fall to values limiting growth.

The variation pattern between sectors of *Arthrocnemum perenne*, was very stable with great differences in biomass (attaining 2,500 g m<sup>-2</sup> in sector II against 500 g m<sup>-2</sup> in sector III).

Net aerial primary production (NAPP) for *Spartina maritima* in three different sectors shows the occurrence of high productivity values (2698.2 gm<sup>-2</sup> yr<sup>-1</sup> for sector I; 3915.1 for sector III and 5915.3 for sector IV).

These data are of the same order of magnitude of those obtained by different authors in other species of *Spartina* in U.S.A. (Table 2).

### Import/Export

The 'outwelling hypothesis' developed by American ecologists has been generally accepted for a while. It states that salt marshes produce more than they can consume, exporting organic matter and nutrients to adjacent coastal waters. Despite the limitations of this type of approach (Bettencourt et al., 1994a), some trends may be detected in terms of exchange of carbon suspended matter and nutrients in the Mira salt marsh site (Table 3). The above mentioned trends, on an annual base, are as follows. There is import of oxidized forms of nitrogen (NO<sub>3</sub> + NO<sub>2</sub>), suspended sediment

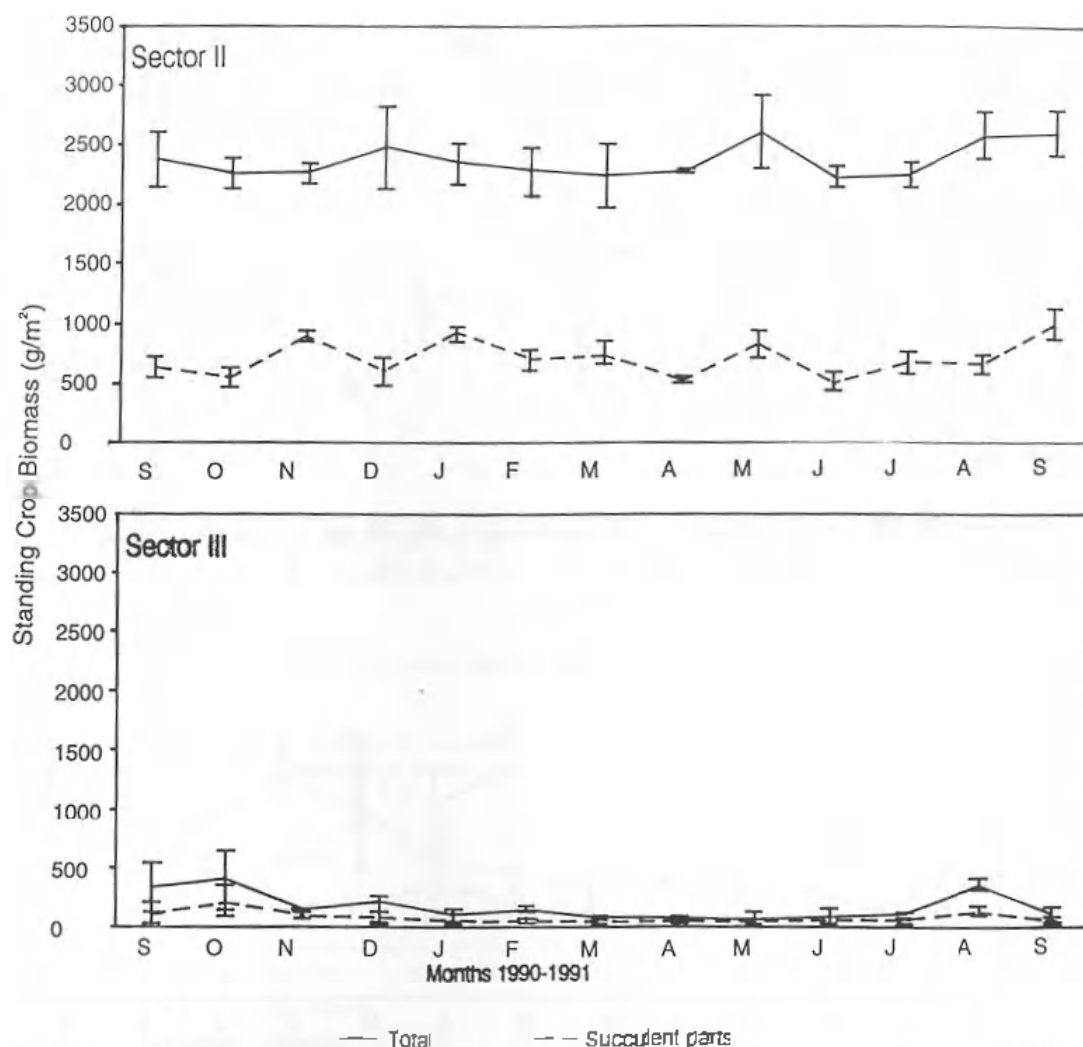


Figure 3. Monthly variation of standing living and dead biomass for *Arthrocnemum perenne*. (Bars represent standard deviation).

(SS), particulate organic matter (POM), particulate phosphorous (PP), total dissolved phosphorous (TDP), total phosphorous (TP) and possibly orthophosphate ( $\text{PO}_4$ ). There is export of dissolved organic nitrogen (DON), coarse organic matter (COM) and possibly dissolved organic carbon (DOC). A relative equilibrium ( $<10\%$  net) is found for ammonia, total nitrogen and silicate. Particularly interesting is the fact that exports of DON match the imports of  $\text{NO}_3 + \text{NO}_2$ . Some further seasonal trends may be detected (Table 3 and 4): there is export of  $\text{NO}_3$  in spring and import during the rest of the year. The same happens with  $\text{NH}_4$ . Total nitrogen as well as silicate are exported in winter and spring and imported in summer and fall, which suggests assimilation by primary producers (Serôdio

et al., 1992).  $\text{PO}_4$  is exported in winter and imported in summer with relative equilibrium in spring and fall. TDP and TP are exported in winter and imported in all other seasons, suggesting that the contributions of PP and TDP smooth out, to a certain extent, the pattern observed for  $\text{PO}_4$ .

In Figure 5, the concentration of COM in flood and ebb at several tides during the year is presented. A clear correlation was found between the transport of COM and tidal range ( $r = 0.61$ ) (Figure 6) but despite that correlation other factors, eventually seasonally determined, seem to have more influence on that transport (Dame and Stillwell, 1984; Bettencourt et al., 1992h).

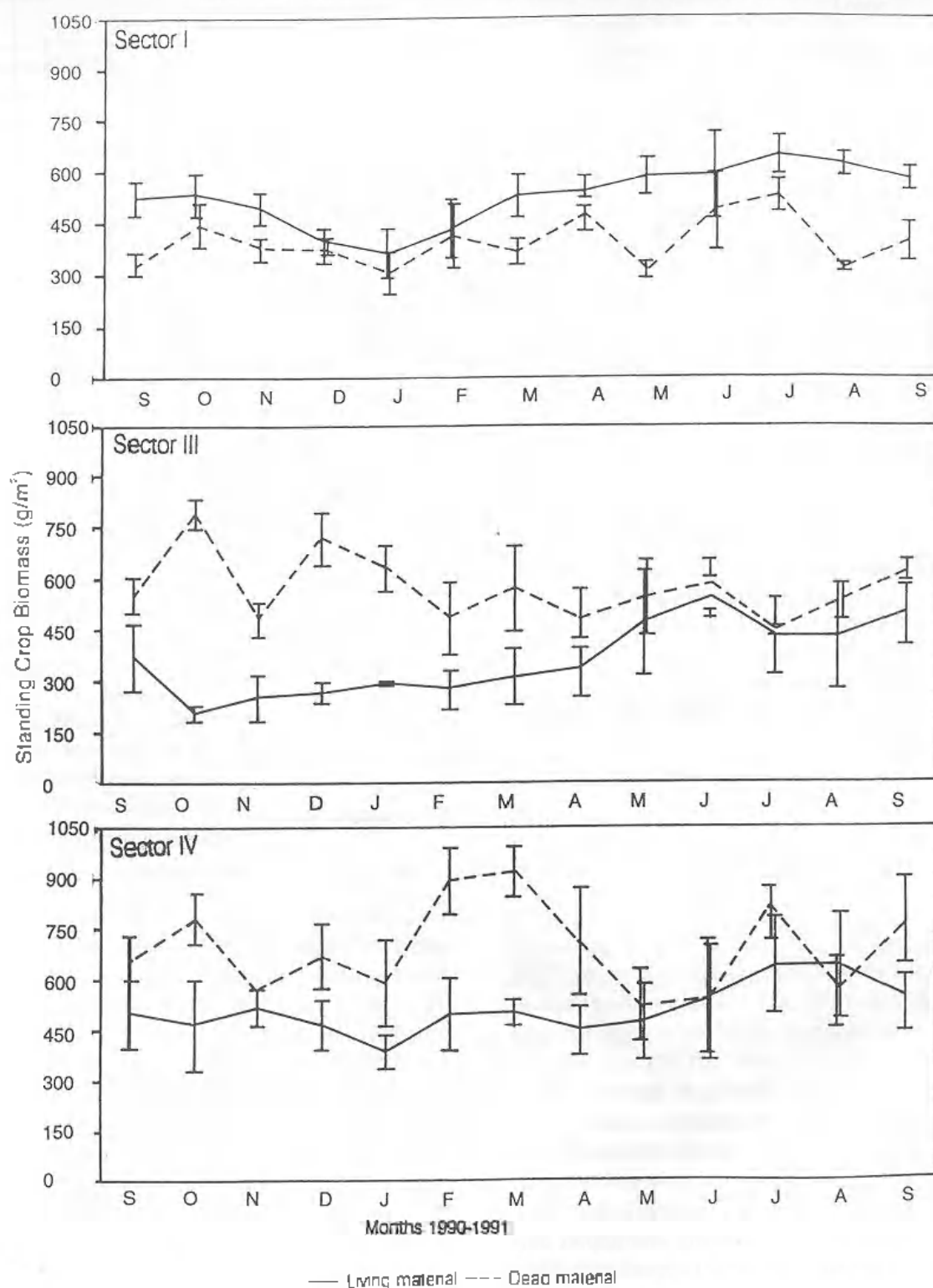


Figure 4. Monthly variation of standing living and dead biomass for *Spartina maritima*. (Bars represent standard deviation).

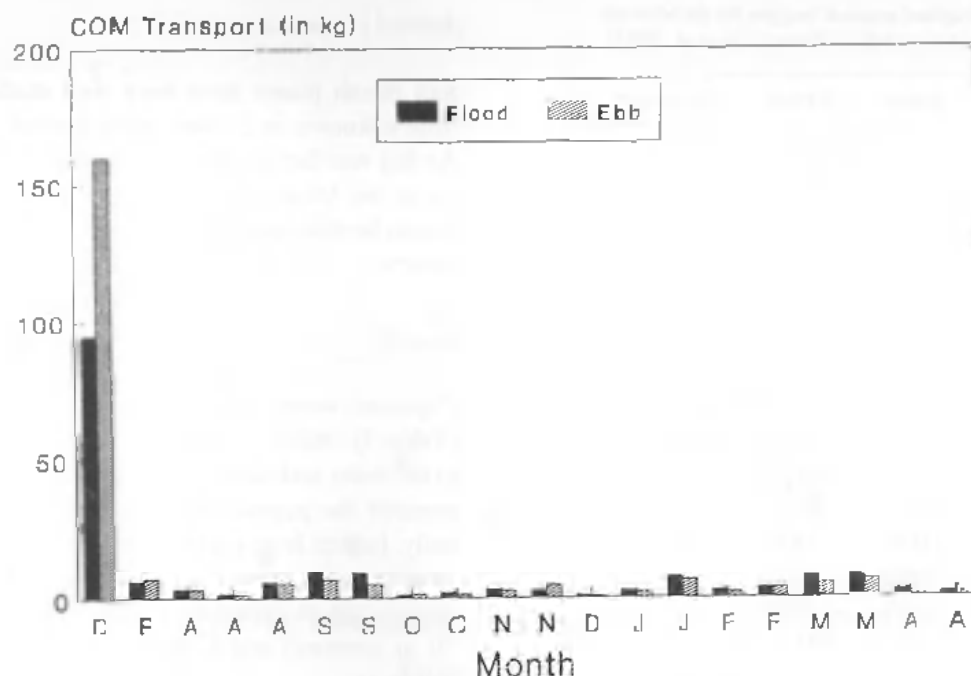


Figure 5. Concentration of Coarse Organic Matter (COM) in flood and ebb at several tides.

Table 2. Comparison of NAPP estimates obtained in the present study with those of published studies. (adapted from Bellecourt et al., 1992a).

Source	Location	Species	NAPP estimates $\text{gm}^{-2}\text{yr}^{-1}$
Kirby and Gosselink (1976)	Louisiana, USA	<i>Spartina alterniflora</i>	1323–2654
Hopkinson et al. (1980)	Louisiana, USA	<i>Spartina patens</i>	5812
Hopkinson et al. (1980)	Louisiana, USA	<i>Spartina alterniflora</i>	2100
Dickerman et al. (1986)	Michigan, USA	<i>Typha latifolia</i>	2766–2762
This study	Mira Est., Portugal	<i>Spartina maritima</i>	2698–5915

POM attains concentrations between 5.8 and 45  $\text{mg l}^{-1}$ . For the entire set of observations from December 1990 till May 1992, in 15 out of 21 tides, there is import of POM with some export in spring and fall, and a net import of 213 Kg of POM representing 14% of the material transported in the flood (1490 Kg). The different pattern of COM and POM can be explained by the different sedimentary behaviour of the two fractions. DOC was measured on only one

Table 3. Annual budgets of nutrients.

	Annual budgets				
	Simple		Weighted seasonal		
	Net (g)	% Flood	Net (g)	% Flood	$\text{g/m}^2/\text{yr}$
$\text{NO}_3$	54362	35	242281	22	1.6
$\text{NO}_2$	3978	26	2339	25	0.16
$\text{NH}_4$	7738	3	3227	1	0.22
DON	-46878	72	/	/	-3.1
TDN	-5154	2	/	/	-0.3
PON	62340	44	/	/	4.1
TN	19285	2	28416	4	1.9
$\text{PO}_4$	-1130	3	2901	9	0.19
TDP	7554	9	10136	13	0.68
PP	74428	33	25174	33	1.7
TP	260065	19	29025	21	1.9
$\text{SiO}_4$	-2118	0.3	-16017	2	1.1
SS	46483	25	50537	31	3.400
COM	-1541	24	/	/	0.1
DOC	-2824	70	/	/	-188

occasion. It ranged between 97 and 170  $\mu\text{mol l}^{-1}$ , concentrations being higher in the ebb than in the flood, which led to an export of 0.4 Kg of DOC.

Table 4. Weighted seasonal budgets for the Mira salt marsh site. (Adapted from Bertness et al., 1994).

Season	Import	Export	Net budget
<b>NO<sub>3</sub> (g)</b>			
Winter	30466	-25867	4599
Spring	17913	-21372	-3459
Summer	28248	-16852	11396
Autumn	35563	-23818	11745
<b>NO<sub>2</sub> (g)</b>			
Winter	2784	-1860	924
Spring	1369	-1350	19
Summer	1892	-1254	638
Autumn	3351	-2593	758
<b>NH<sub>4</sub> (g)</b>			
Winter	8542	-8372	165
Spring	11180	-14087	-2907
Summer	246972	-245388	21584
Autumn	45281	-40886	4395
<b>PO<sub>4</sub> (g)</b>			
Winter	5587	-9312	-3725
Spring	2505	-2502	0
Summer	15400	-8976	6424
Autumn	7374	-7172	202
<b>TDP (g)</b>			
Winter	17776	-21297	-3521
Spring	22058	-18589	3469
Summer	26708	-18612	8096
Autumn	14678	-12586	2092
<b>TP (g)</b>			
Winter	22589	-23445	-856
Spring	31976	-24412	7564
Summer	53856	-39688	14168
Autumn	27500	-19351	8149
<b>PP (g)</b>			
Winter	15165	-11411	3754
Spring	19580	-11528	8052
Summer	28160	-21076	7084
Autumn	13944	-7660	6284
<b>SS (Kg)</b>			
Winter	50918	-41923	8995
Spring	33180	-26661	6519
Summer	51392	-21208	30184
Autumn	25434	-20595	4839
<b>SiO<sub>4</sub> (g)</b>			
Winter	25187	-278780	-28593
Spring	136863	-141810	-4947
Summer	195800	-194920	880
Autumn	185789	-171248	10643
<b>TN (g)</b>			
Winter	124690	-145428	-20738
Spring	61907	-75703	-13796
Summer	59840	-9504	50336
Autumn	487374	-474760	12614

## Animal communities

Salt marsh plants have been well studied, however, little is known in Europe, about animal communities. As this was the first attempt to study these communities in the Mira salt marshes, we began by making a macro benthic and fish study, and an inventory of the insects.

### Insects

Captures were made during spring and summer (Table 5). After capture, all animals were identified to the order and family or subfamily when possible. In summer the population of insects increased significantly. Insects from eight orders were caught. The most representative orders were Diptera (169 individuals in spring, 216 in summer), Hymenoptera (28 in spring, 70 in summer) and Coleoptera (12 in spring, 61 in summer).

Insects play an important role in salt marsh ecosystem, by grazing or sucking on vascular plants. Many of the Coleoptera families need a habitat whose characteristics are particularly well represented in the salt marsh. The majority of the species live as larvae and/or adults in dead and wet decomposing material of plants or animals. Hymenoptera families caught in the salt marsh comprise mainly parasites, a few predators and almost no gatherers. Lepidoptera and Thysanoptera suck mainly nectar or cell sap.

### Benthic fauna

Mudflats adjacent to salt marshes are dominated by *Hedise diversicolor* and *Nephtys caeca* populations and in lower parts by *Scrobicularia plana*. This bivalve was observed both in the mudflats and salt marsh creeks. In the salt marsh and adjacent mudflats there are 3 species of crabs: *Carcinus maenas*, *Pachygrapsus marmoratus* and *Uca tangeri*, which attains here in the Mira estuary the northern limit of its distribution.

Bertness (1992) found interactions between another species of fiddler crab *Uca puynax* and the growth of *Spartina alterniflora*. He noticed that *U. puynax* is most abundant in stands of the tall form of *S. alterniflora* where the substrate is sufficiently cohesive for burrows to be maintained, but where root density is lower than in stands of the short form of this plant. Assessment of sediment properties showed that crab burrows increased soil drainage, soil oxidation



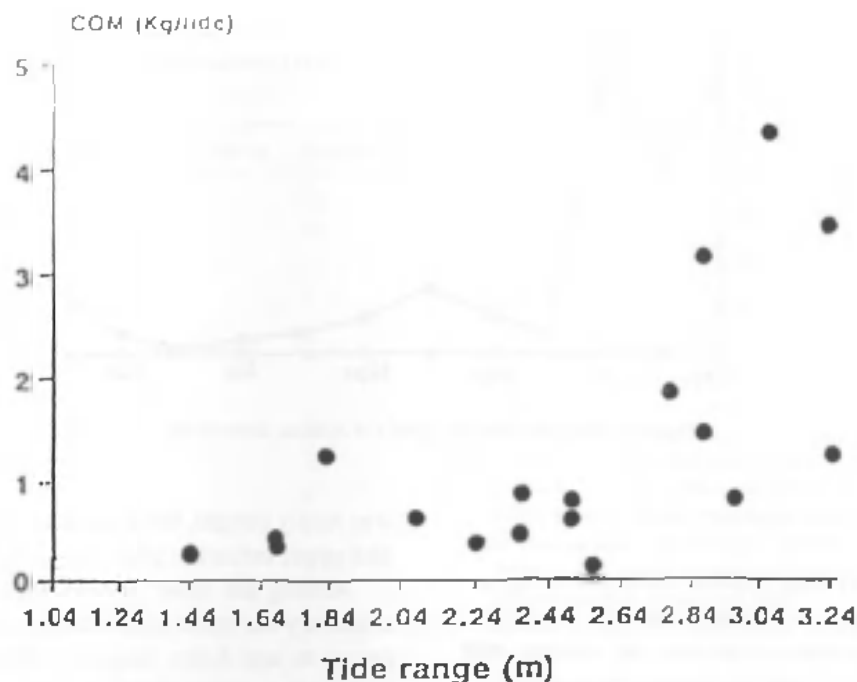


Figure 6. Correlation between tidal range and COM transport in the Mira.

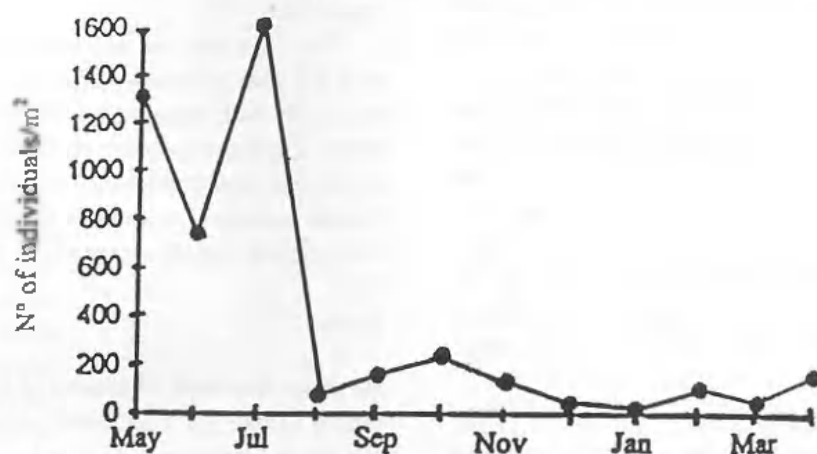


Figure 7. Monthly density (N° of individuals/m<sup>2</sup>) of *Hediste diversicolor*.

and the decomposition of below-ground debris. Bertness (1992) suggested the existence of a facultative mutualism: in soft sediments where burrows could not otherwise be maintained, the invasion of *S. alterniflora* and the presence of roots and rhizomes increases sediment fitness and allows the crabs to burrow. At higher elevations, burrowing activity creates soils conditions favouring plant productivity and prevents the establishment of a root mat. In elevated but poorly drained sites, the dense root mat in short-form *Spartina* stands, precludes crab burrowing. *Uca tangeri* in the Mira has the same pattern of distribution and we suppose it has a similar role in environmental interaction.

The density and biomass of the ragworm *H. diversicolor* is shown in Figures 7 and 8. Both presented similar pattern of variation with a minimum in February and a maximum in June. Monthly average biomass of 1.99 g m<sup>-2</sup> (0.1 to 6.4 g m<sup>-2</sup>) is much lower than that obtained by other authors: Essex – 13.1 g m<sup>-2</sup> (Humphreys, 1985), Loire – 16.0 g m<sup>-2</sup> (Gillet, 1990), Cantabric Sea – 4.28 to 11.61 g m<sup>-2</sup> (Sola and Ibañez, 1990). These low values are probably due to a high mortality in July, as most animals die in the end at the reproductive period, together with an exceptionally dry year.

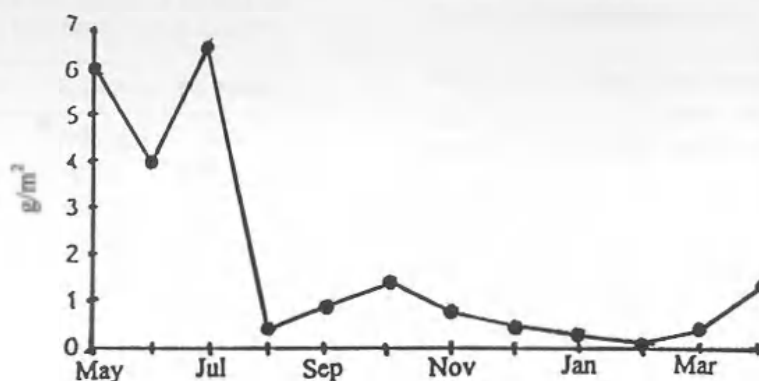


Figure 8. Monthly biomass ( $\text{g/m}^2$ ) of *Hediste diversicolor*.

### Fish

The fish community was studied throughout the estuary, because juveniles of most commercial species inhabiting adjacent waters can use the estuary, salt marshes and adjacent mudflats as nursery grounds.

Fishes caught in this zone are shown in Table 6. They were divided in resident species that accomplish all the life cycle in the estuary (R); fishes that use the estuary as a nursery (N); anadromous migrants (AM); catadromous migrants (CM); marine occasional migrants (OM) and freshwater occasional migrants (OF). From the 49 species existing in the estuary 14 are resident and 20 use the estuary as a nursery. The most abundant species (total number of individuals) is the resident toadfish *Halobatrachus didactylus* (Schneider) a benthic fish inhabiting coastal and estuarine shallow waters with a distribution range from Portugal to the coast of Ghana.

In spite of economical value and abundance of the toadfish in south eastern latitudes, very few studies of this species exist. (Cardenas, 1977; Costa, 1993). It is a sensitive species which numbers have decreased gradually in the Mira. The toadfish has two different patterns in the estuary: juveniles (<120 mm) were much more abundant in upper middle estuary and adults in the lower middle estuary. The salt marsh site is visited by both, with a density of 1796 ( $\pm 74$  SE) ind/ha for adults and 74 ( $\pm 34$  SE) ind/ha for juveniles (these densities were calculated directly from captures as catches per hectare).

Grey mullet are represented in the Mira estuary by five species. *Liza aurata* (Risso) appears near the river mouth. *Chelon labrosus* (Risso) is present in the four estuarine areas. *L. saltiens* (Risso) occurs only in relation to salt marsh areas and *L. ramada* (Risso) clearly prefers the upper estuary. *Mugil cephalus* (L.)

was rarely caught, but it seems to prefer the salt marsh and upper estuarine sites (Almeida, 1996).

Among the other species that use the estuary as a nursery the most important in the salt marsh is the common sole *Solea vulgaris* (Quensel), which attains very high population densities during spring and summer when large numbers of small individuals were captured.

The juveniles of sea-bass *Dicentrarchus labrax* (L.) are also common in the estuary, in late summer and early fall. Sparids are represented by the sea-bream *Diplodus vulgaris* (E.G. Saint-Hilaire), and the white sea-bream *Diplodus sargus* (L.). The gilt-head *Sparus aurata* (L.) and the salema *Sarpa salpa* also visit the salt marsh, especially in the winter.

### Birds

We have observed 10 species of birds visiting the salt marsh (Table 7). This small number compared with the other European salt marshes must be related to the physiography of the estuary and the salt marsh. In fact the salt marsh is rather small and borders the river banks in a narrow valley with steep margins.

### Nursery grounds

One of the most important role of estuaries is to act as a nursery area for many species. The youngest life stages of some marine fishes use the shallow and warm waters of estuaries for initial growth. There they find safety and good feeding conditions, which contribute to the important role that estuaries play in preserving stocks of some marine species. What is not yet clear is the role played by salt marshes as nurseries. Most of the work on this subject has been done in the USA, the study of the role of salt marshes having nevertheless

Table 5. Insects captured during spring and summer at Mira site (n° of individuals).

Order	Family/subfamily	Spring	Summer
Psephenoptera			32
Hemiptera		1	46
Thysanoptera		13	17
Neuroptera			4
Coleoptera	Nilionidae	4	
	Chrysomelidae	2	2
	Cantharidae	4	
	Rhipiphoridae		18
	Malachidae	2	16
	Erotylidae		9
	Curculionidae		6
	Anthicidae		3
	Scolytidae		2
	Ruprescidae		2
	Cerambycidae		1
	Staphylinidae		1
	Nitidulidae		1
Diptera		169	214
	Syrphidae		2
Lepidoptera		17	57
Hymenoptera	Ichneumonidae		3
	Bracnidae	2	3
	Cynipidae		2
	Torymidae		2
	Pteromalidae	1	4
	Eucyrtidae		1
	Eulophidae	7	3
	Aphelinidae	1	1
	Mymaridae		19
	Diapriidae		3
	Scelionidae	4	4
	Platygastridae	4	4
	Ceraphronidae		10
	Tiptidae/Tiphidae	1	1
	Formicidae/Formicinae	7	4
	Sphecidae/Larrinae		2
	Sphecidae/Sphecinae		1
	Sphecidae/Philanthinae		1
	Megachilidae	1	1
	Apidae		1

Table 6. Fish species observed at Mira Estuary. (AM – Anadromous migrants; CM – Catadromous migrants; N – Nursery; OM – Occasional migrants; OF – Occasional freshwater; R – Residents).

Species	Phenology
<i>Torpedo torpedo</i> (Linnaeus) (electric ray)	CM □
<i>Raja undulata</i> Lacépède (undulated ray)	OM □
<i>Alasa fallax</i> Lacépède (rwsite shad)	AM □
<i>Engraulis encrasicolus</i> (Linnaeus) (anchovy)	R △
<i>Anguilla anguilla</i> (Linnaeus) (European eel)	MC □
<i>Conger conger</i> (Linnaeus) (conger eel)	N □
<i>Hippocampus hippocampus</i> (Linnaeus) (sea-horse)	R □
<i>Hippocampus ramulosus</i> Leach, (sea-horse)	R □
<i>Nemphitis ophidion</i> (Linnaeus) (straight-nosed pipefish)	R □
<i>Syngnathus acus</i> Linnaeus (great pipefish)	R □
<i>Syngnathus typhle</i> Risso (deep-snouted pipefish)	R □
<i>Cyrtus mustela</i> (Linnaeus) (five-beard rockling)	N □
<i>Serranus hepatus</i> (Linnaeus) (rown comber)	N □
<i>Dicentrarchus labrax</i> (Linnaeus) (sea-bass)	N □
<i>Mullus surmuletus</i> Linnaeus (red mullet)	N □
<i>Diplodus annularis</i> (Linnaeus) (annular sea bream)	N □
<i>Diplodus sargus</i> (Linnaeus) (white sea bream)	N △
<i>Diplodus vulgaris</i> (E.G. Saint-Hilaire) (two-handed sea bream)	N △
<i>Diplodus cervinus</i> (Lowe) (zebra sea bream)	OM □
<i>Diplodus puntazzo</i> (Cetti) (sharp-snout sea bream)	OM □
<i>Pagrus pagrus</i> (Linnaeus) (common sea bream)	N □
<i>Sarpa salpa</i> (Linnaeus) (salema)	N □
<i>Sparus aurata</i> Linnaeus (gilthead)	N □
<i>Spondylosoma cantharus</i> (Linnaeus) (black sea bream)	N □
<i>Symphodus bailloni</i> (Valenciennes) (wrasse)	R □
<i>Echichthys vipera</i> (Cuvier) (lesser weaver)	OM □
<i>Gobius auratus</i> Risso (golden goby)	R □
<i>Gobius niger</i> (Linnaeus) (black goby)	R △
<i>Gobius paganellus</i> Linnaeus (rock goby)	R □
<i>Pomatoschistus knerii</i> (Steindachner) (kner's goby)	R □
<i>Pomatoschistus microps</i> (Kroyer) (common goby)	R △
<i>Pomatoschistus minutus</i> (Pallas) (sand goby)	R △
<i>Pomatoschistus pictus</i> (Malm) (painted goby)	R □
<i>Callionymus lyra</i> Linnaeus (dragonet)	R △
<i>Chelon labrosus</i> (Risso) (thick-lipped grey mullet)	N □
<i>Liza aurata</i> (Risso) (golden grey mullet)	N △
<i>Liza ramada</i> (Risso) (thinlip grey mullet)	MC □
<i>Liza saliens</i> (Risso) (leaping mullet)	N □
<i>Mugil cephalus</i> Linnaeus (flat head grey mullet)	N □
<i>Cyprinus carpio</i> Linnaeus (carp)	OF □
<i>Atherina presbyter</i> Cuvier (sand smelt)	OM □
<i>Trigla lucerna</i> Linnaeus (rub gumard)	N □
<i>Lepidorhombus whiffiagonis</i> (Walbaum) (melgrim)	OM □
<i>Psetta maxima</i> (Linnaeus) (turbot)	OM □
<i>Platichthys flesus</i> (Linnaeus) (flounder)	N □
<i>Microchirus azevia</i> (Capello) (bastard sole)	OM □
<i>Solea senegalensis</i> Kaup (senegal sole)	N □
<i>Solea vulgaris</i> Quensel (common sole)	N △
<i>Habibatrachus didactylus</i> (Schneider) (madfish)	R △

□ Rate < 1 ind/1000 m<sup>2</sup>.△ Common < 10 and ≥ 1 ind/m<sup>2</sup>.○ Very Common ≥ 10 ind/1000 m<sup>2</sup>.

Table 7. Birds observed in Mira estuary.

<i>Ardea cinerea</i>	(grey heron)
<i>Egretta garzetta</i>	(little egret)
<i>Anas platyrhynchos</i>	(mallard)
<i>Gallinula chloropus</i>	(moorhen)
<i>Charadrius dubius</i>	(little ringed plover)
<i>Pluvialis squatarola</i>	(grey plover)
<i>Limosa lapponica</i>	(bar-tailed godwit)
<i>Tringa totanus</i>	(redshank)
<i>Larus melanocephalus</i>	(mediterranean gull)
<i>Larus ridibundus</i>	(black-headed gull)

recently been started in Europe (Cattrijsse et al., 1994; Costa et al., 1994; Kneib, 1997). In Mira it was noticed, comparing different habitats in the estuary, that salt marshes act preferentially as nursery for most fish species (Costa et al., 1994).

#### Food Web

For food web design we divided the marsh into three major habitats according to Montague and Wiegert (1990) and Mitsch and Gosselink (1993): The **aerial habitat** which is seldom flooded, a **benthic habitat** the marsh surface together with lower portions of the living plants, and an **aquatic habitat** – the marsh pools and creeks.

#### Aerial habitat

The plants of the aerial habitat (mainly *S. maritima*) are grazed by herbivorous insects. They are also frequented by Lepidoptera and Thysanoptera which suck mainly nectar or cell sap. In this habitat we can also find Hymenoptera which are generally parasites or predators on other insects. Some beetles are usually seen hunting prey on the marsh surface. Spiders also inhabit the salt marsh and are predators on insects. Finally, a small number of birds graze the vegetation or feed on fishes or crustaceans, and also the micro and meiofauna.

#### Benthic habitat

When plants, mainly *S. maritima*, die, they decompose and enter the detritus pathway. Microbial fungi and bacteria are primary consumers which are preyed on by meiofauna, including small crustaceans. As an example of deposit feeders we can find populations of *H. diversicolor* which feed mainly on inorganic and

decomposed organic matter. They also ingest microalgae, copepods and amphipods. There is also some evidence of cannibalism. This species seems to adopt an omnivorous diet with detritivorous predominance. Populations of *Nephtys caeca*, with similar food items also exist in smaller densities.

In the mudflats, there are large populations of *Scrobicularia plana*, the peppery furrow shell, a detritus feeder. It sucks detritus from the mud surface using the inhalant siphon. Among deposit detritus feeders, we also have a small population of *Uca tangeri*. Another crab *Carcinus maenas*, feed mainly on shrimps, isopods and amphipods, *H. diversicolor* other crabs and *Pomatoschistus* spp.

#### Aquatic habitat

As pointed out by Mitsch and Gosselink (1993), the animals classified as aquatic overlap with those in the benthic fauna.

Crustaceans existing in this area are mainly shrimps *Palaemon serratus*, *P. adspersus*, *P. longirostris*, *P. elegans* and *Crangon crangon* which use the salt marsh and adjacent mud flats to feed. The most important food items of these shrimps are polychaetes (mainly *H. diversicolor*), meiofauna and detritus.

Fishes are represented by residents such as *Halobatrachus didactylus* which is an opportunistic predator on almost all aquatic fauna. The most important food items of this species in the Mira are crabs, isopods and amphipods, shrimps, polychaetes, bivalves and gastropods, algae, detritus and fish. Some cases of cannibalism were observed (Costa, pers. com.). Small gobies (*Pomatoschistus* spp.) are also resident and feed mainly on small crustacean and shrimps.

The juveniles of the common sole *Solea vulgaris* use the mudflats adjacent to salt marshes to feed. They eat mainly bivalves, polychaetes, small crustaceans and fish. In addition, juveniles of the sea bass (*Dicentrarchus labrax*) use the salt marsh and creeks as feeding ground but their diet is mainly small crustaceans, shrimps, crabs, polychaetes and fish, including *H. didactylus*.

Sparids have a wide diet range, presenting diversified food items, especially barnacles and cockles from adjacent oysterbeds, small crustaceans, *H. diversicolor* and macroalgae.

Grey mullet (*Liza aurata*, *L. saliens*, *L. ramada*, *Mugil cephalus* and *Chelon labrosus*) are illophagous or detritus feeders. Their stomach contents showed the presence of Bacillariophyceae, Cyanophyceae, Fu-

clorophyceae, Zygothryx, Foraminifera and a large amount of detritus.

## Conclusions

In the budgets of organic matter and nutrients the most striking feature of the Mira salt marsh seems to be a net export of COM ( $-1542 \text{ Kg yr}^{-1}$ ) and an import of nutrients. This suggests that the Mira salt marsh site is closer to the marshes that have inspired the early versions of the 'outwelling theory' than to those European salt marshes that were found to be importers of organic matter and nutrients (Vegter, 1975; Wolff, 1977; Wolff et al., 1979; Lammens and van Eeden, 1977; Woodwell et al., 1977; Haines et al., 1977; Hackney, 1977; Dankers et al., 1984; Danais, 1985; Wolaver and Spurrier, 1988; Dame and Lefeuve, 1994). In addition aerial net primary productivity of the halophytic vegetation is very high (Boorman et al., 1994). The oligotrophy of estuarine waters can be explained by the low nutrient conditions of marine waters along the southern coast of Portugal and the low level of agricultural fertilisers used in the watershed.

All this suggests a food web that we may consider as being detritus-based, with species feeding directly on the detritus, bacteria fungi and microalgae (surface microlayer). This is the case with grey mullet. The toadfish, a resident fish species, also uses the salt marsh as feeding ground in both its juvenile and adult stages. The salt marsh acts as a nursery for commercial fish species. In the Mira estuary, the fisheries, although small, represent an important asset to the local subsistence economy. This ecological and economical value of the Mira salt marsh, together with the apparent confirmation of the 'outwelling hypothesis' for an European estuary stresses the importance of this ecosystem and strongly argues in favour of its preservation.

We hope that these results will show that it is critical that decisions about salt marshes should be supported by a sound scientific understanding of their functioning and behaviour, and that in Europe, as in USA will become the 'cause célèbre' for conservation-minded people and organisations, as Mitsch and Gosselink (1993), have pointed out.

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