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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*, *Nepthys 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

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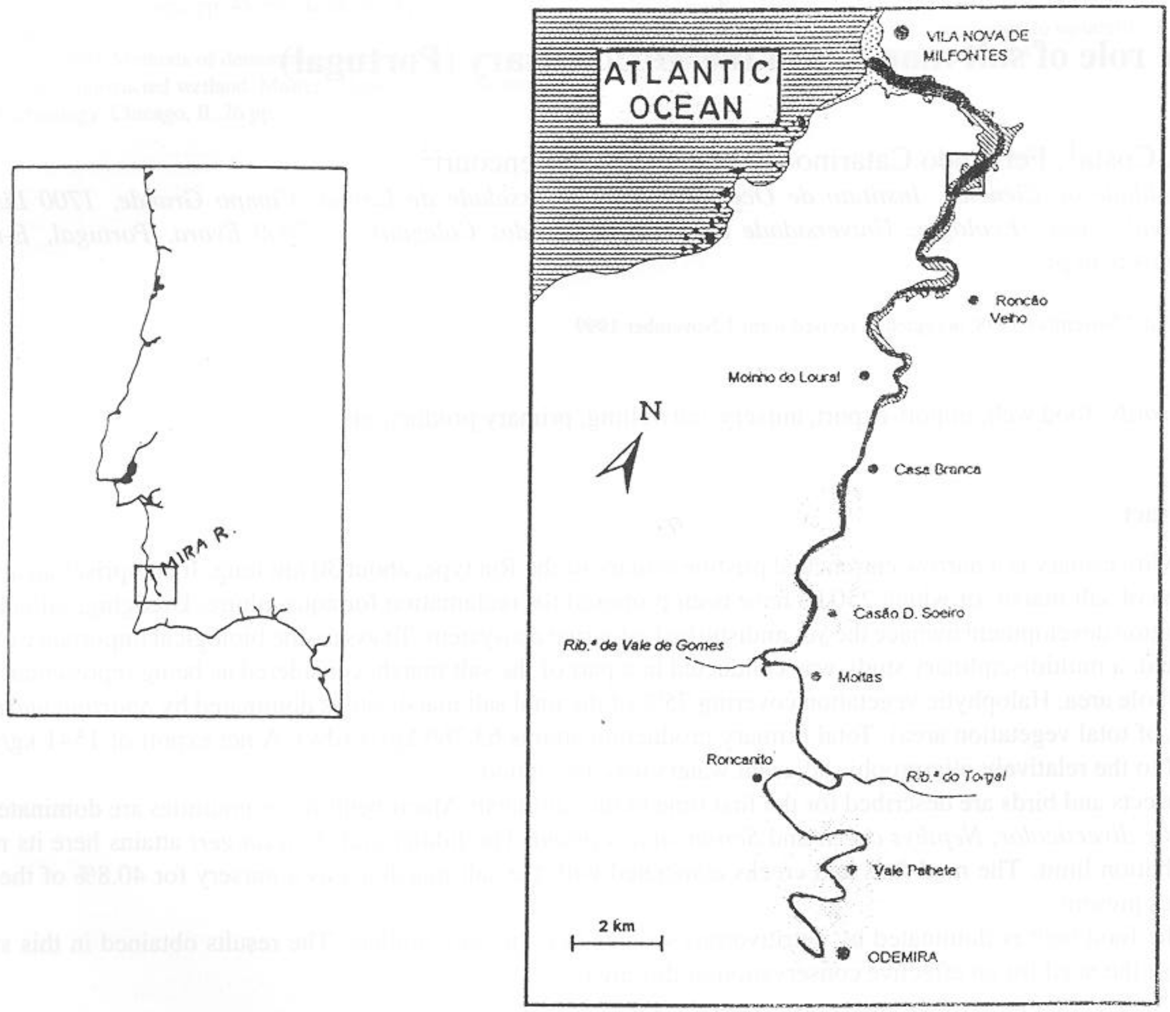

Figure 1. The Mira estuary. ▧ Salt-marsh.

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 particular 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

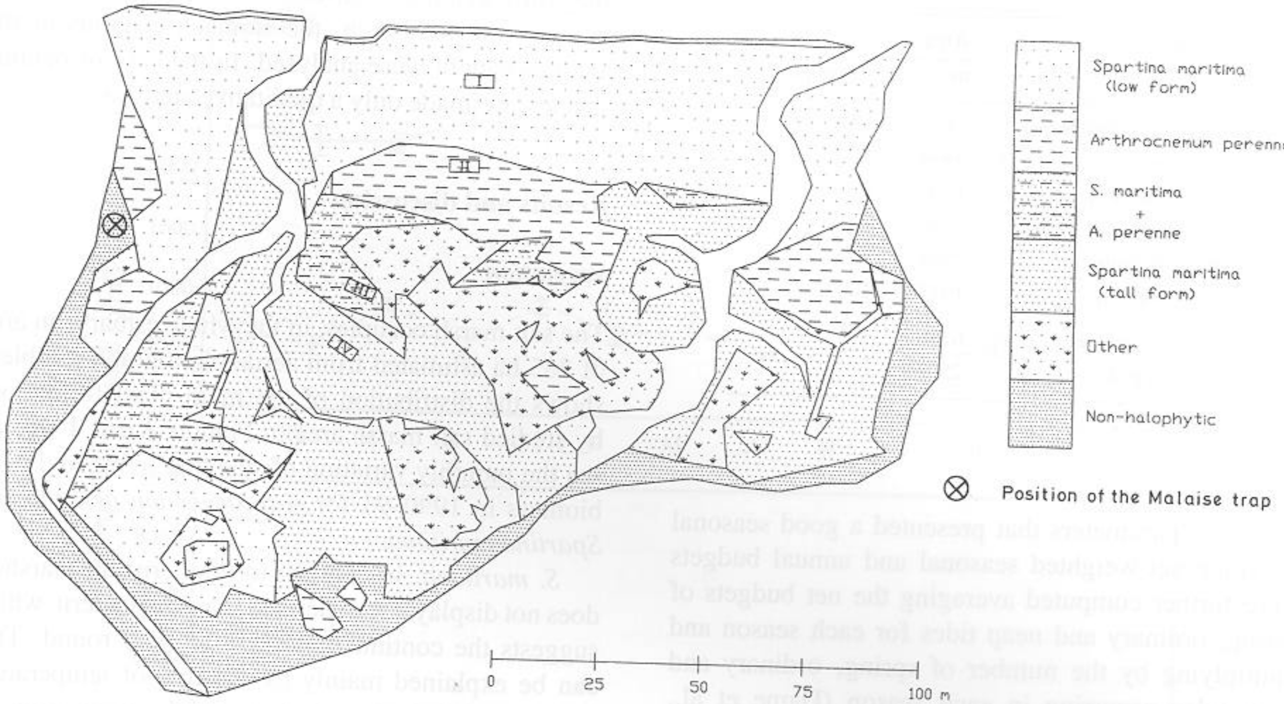

Figure 2. The vegetation of Mira salt marsh.

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 m^3s^{-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 °C and 11 °C (winter) and 20–21 °C (summer). The insolation is about 2950 hours per year (J.E.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 standards 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 Dt = 15 minutes. A rough annual budget was computed for each parameter according to the following equation:

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

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

Formation	Area	
	m^2	% halophytic
S. maritima (low form)	7456	37.8
A. perenne	2308	11.7
S. maritima + A. perenne	1720	8.7
S. maritima (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^2) 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 Gosselink (1976). Tissues of *Arthrocnemum perenne* were separated into succulent and non succulent parts. The benthic communities were studied taking four replicates from three diferent 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^2 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^{-2} in sector II against 500 g m^{-2} 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^{-2} yr^{-1} 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 that 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 ($NO_3 + NO_2$), suspended sediment

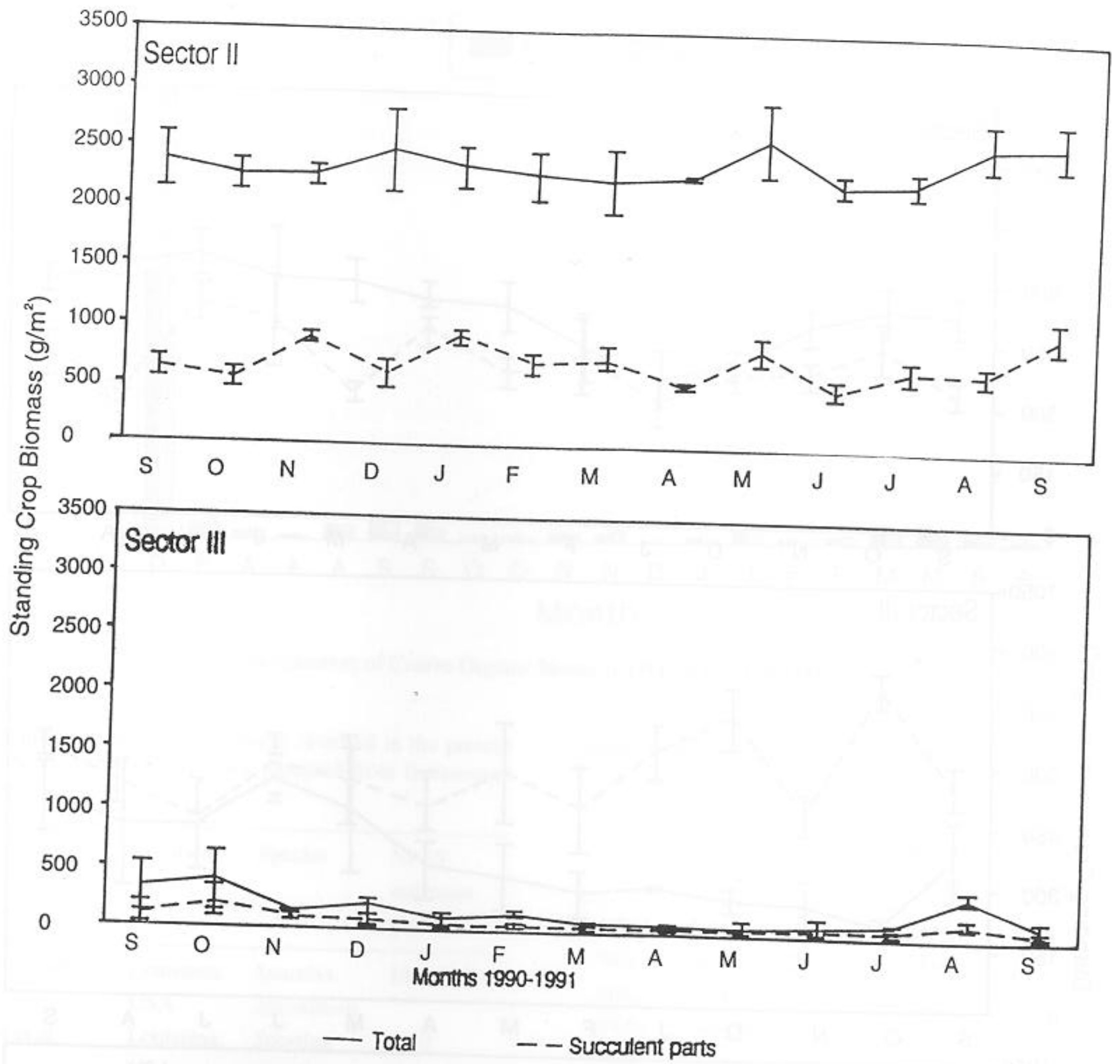

Figure 3. Monthly variation of standing living and dead biomass for *Arthrocnemum perenne*. (Bars represent standard deviation).

(SS), particulate organic matter (POM), particulate phosphorous (PP), total dissolved phosphorous (TDP), total phosphorous (TP) and possibly orthophosphate (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 $NO_3 + NO_2$. Some further seasonal trends may be detected (Table 3 and 4): there is export of NO_3 in spring and import during the rest of the year. The same happens with 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). 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 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., 1992b).

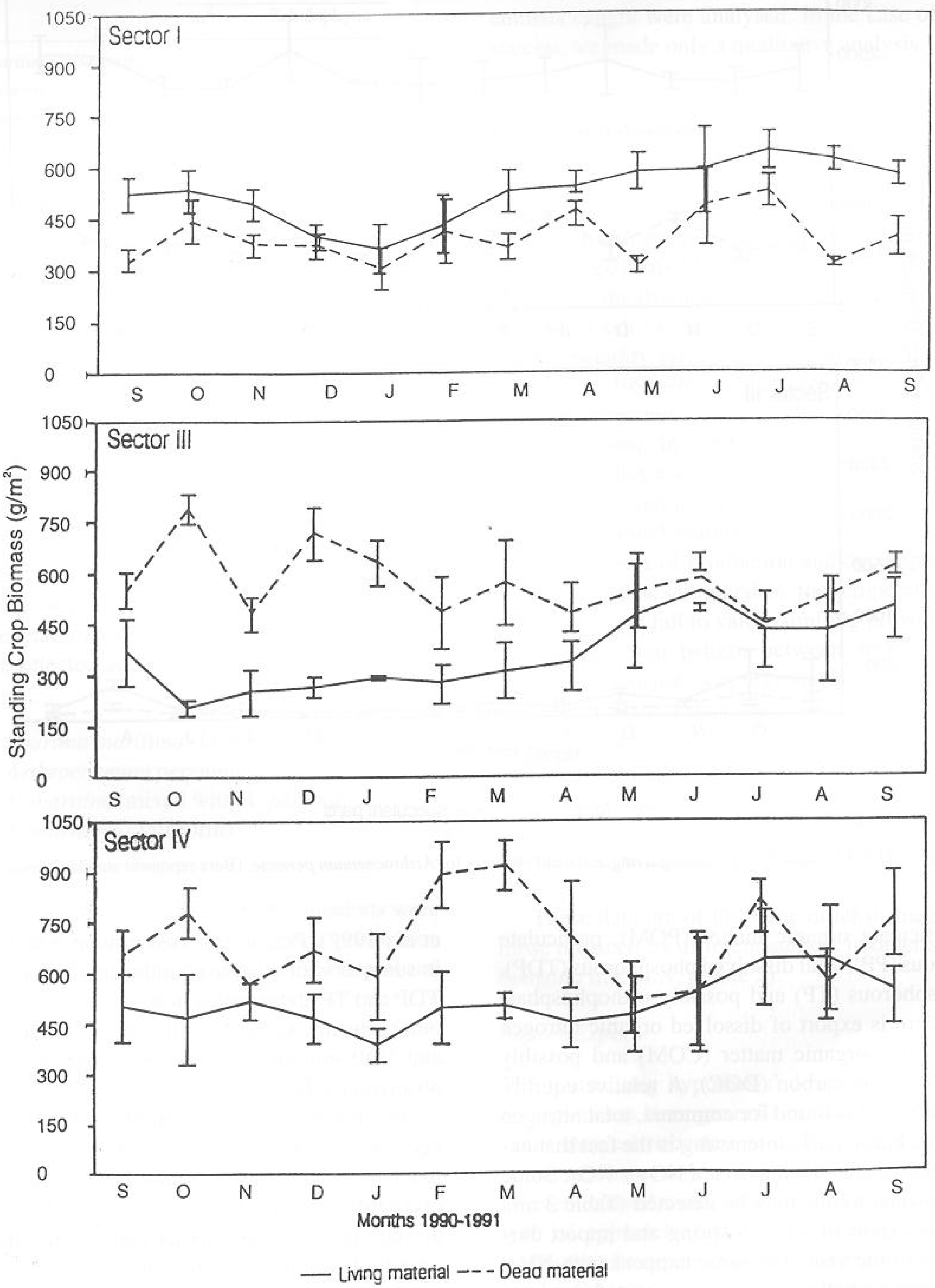

Figure 4. Monthly variation of standing living and dead biomass for *Spartina maritima*. (Bars represent standard deviation).

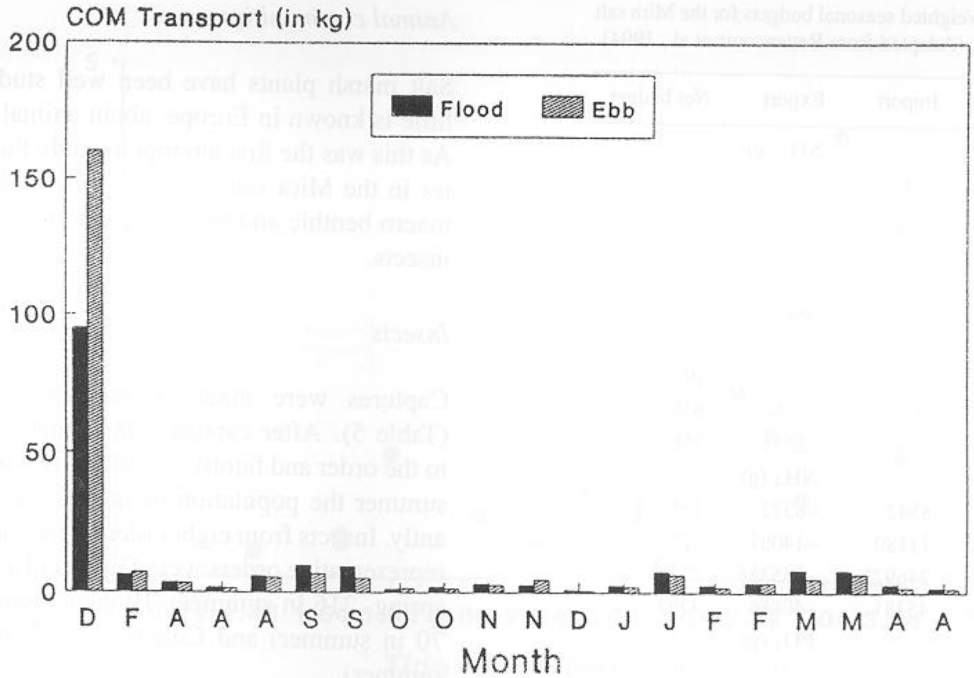

Figure 5. Concentration of Coarse Organic Matter (COM) in flood and ebb at several tides.

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

Source	Location	Species	NAPP estimates $gm^{-2}yr^{-1}$
Kirby and Gosselink (1976)	Louisiana, USA	*Spartina alterniflora*	1323–2654
Hopkinson et al. (1980)	Louisiana, USA	*Spartina patens*	5812
Hopkinson et al. (1980)	Louisiana, USA	*Spartina alterniflora*	2100
Dickerman et al. (1986)	Michigan, USA	*Typha latifolia*	2266–2762
This study	Mira Est., Portugal	*Spartina maritima*	2698–5915

Table 3. Annual budgets of nutrients.

	Annual budgets				
	Simple		Weighted seasonal		
	Net (g)	% Flood	Net (g)	% Flood	$g/m^2/yr$
NO_3	54362	35	242281	22	1.6
NO_2	3978	26	2339	25	0.16
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
PO_4	–1130	3	2901	9	0.19
TDP	7554	9	10136	13	0.68
PP	24428	33	25174	33	1.7
TP	260065	19	29025	21	1.9
SiO_4	–2118	0.3	–16017	2	1.1
SS	46483	25	50537	31	3400
COM	–1541	24	/	/	0.1
DOC	–2824	70	/	/	–188

POM attains concentrations between 5.8 and 45 mgl^{-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 occasion. It ranged between 97 and 170 μmol^{-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 Bettencourt et al., 1994).

Season	Import	Export	Net budget
		NO_3 (g)	
Winter	30466	–25867	4599
Spring	17913	–21372	–3459
Summer	28248	–16852	11396
Autumn	35563	–23818	11745
		NO_2 (g)	
Winter	2784	–1860	924
Spring	1369	–1350	19
Summer	1892	–1254	638
Autumn	3351	–2593	758
		NH_4 (g)	
Winter	8542	–8372	165
Spring	11180	–14087	–2907
Summer	246972	–245388	21584
Autumn	45281	–40886	4395
		PO_4 (g)	
Winter	5587	–9312	–3725
Spring	2505	–2502	0
Summer	15400	–8976	6424
Autumn	7374	–7172	202
		TDP (g)	
Winter	17776	–21297	–3521
Spring	22058	–18589	3469
Summer	26708	–18612	8096
Autumn	14678	–12586	2092
		TP (g)	
Winter	22589	–23445	–856
Spring	31976	–24412	7564
Summer	53856	–39688	14168
Autumn	27500	–19351	8149
		PP (g)	
Winter	15165	–11411	3754
Spring	19580	–11528	8052
Summer	28160	–21076	7084
Autumn	13944	–7660	6284
		SS (Kg)	
Winter	50918	–41923	8995
Spring	33180	–26661	6519
Summer	51392	–21208	30184
Autumn	25434	–20595	4839
		SiO_4 (g)	
Winter	25187	–278780	–28593
Spring	136863	–141810	–4947
Summer	195800	–194920	880
Autumn	1857891	–171248	10643
		TN (g)	
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 *Hediste diversicolor* and *Nepthys 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

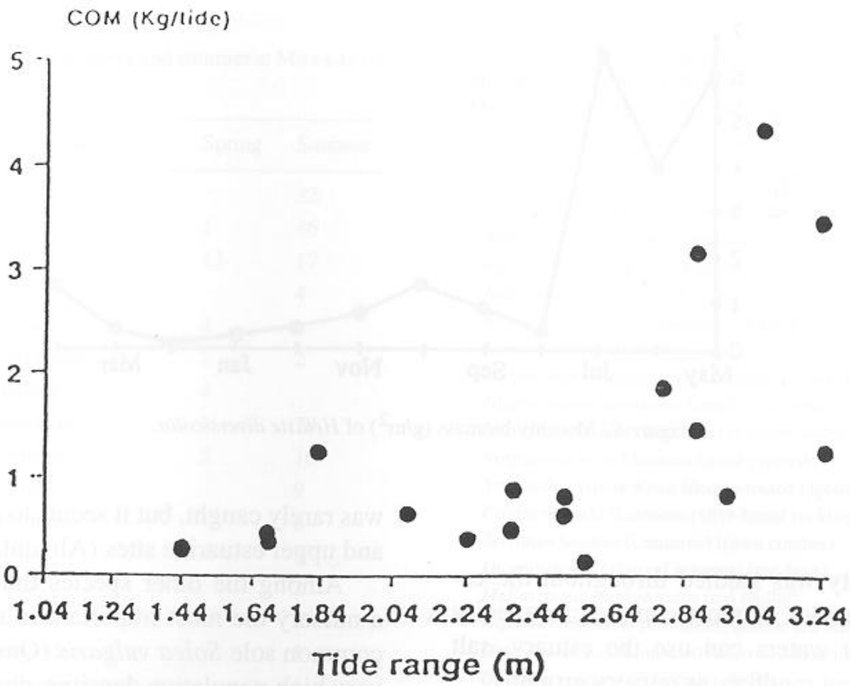

Figure 6. Correlation between tidal range and COM transport in the Mira.

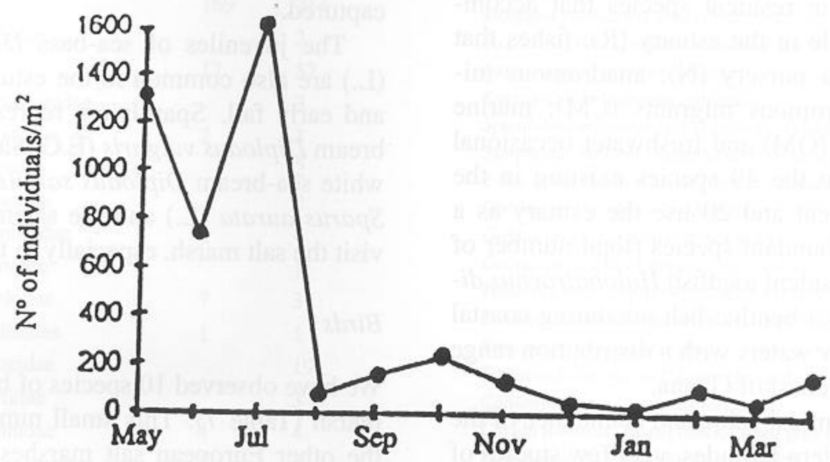

Figure 7. Monthly density (N° of individuals/m^2) of *Hediste diversicolor*.

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^{-2} (0.1 to 6.4 g m^{-2}) is much lower than that obtained by other authors: Essex – 13.1 g m^{-2}(Humphreys, 1985), Loire – 16.0 g m^{-2} (Gillet, 1990), Cantabric Sea – 4.28 to 11.61 g m^{-2} (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.

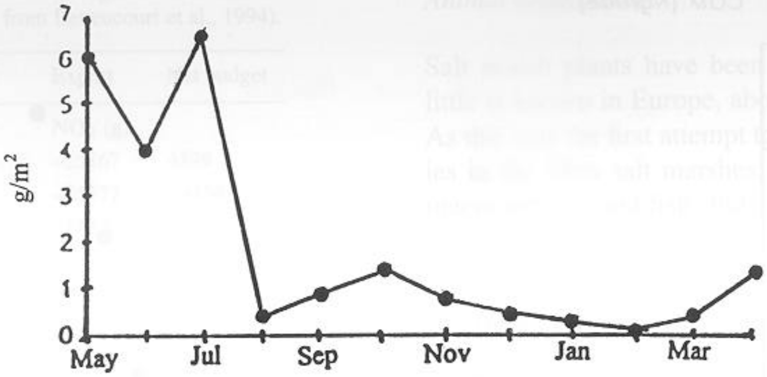

Figure 8. Monthly biomass (g/m^2) of *Hediste diversicolor*.

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. saliens* (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

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

Order	Family/subfamily	Spring	Summer
Psocoptera			32
Hemiptera		1	46
Thysanoptera		13	17
Neuroptera			4
Coleoptera	Nilionidae	4	
	Chrysomelidae	2	2
	Cantharidae	4	
	Rhipiphoridae		18
	Malachiidae	2	16
	Erotylidae		9
	Curculionidae		6
	Anthicidae		3
	Scolytidae		2
	Buprestidae		2
	Cerambycidae		1
	Staphylinidae		1
	Nitidulidae		1
Diptera		169	214
	Syrphidae		2
Lepidoptera		17	57
Hymenoptera	Ichneumonidae		3
	Braconidae	2	3
	Cynipidae		2
	Torymidae		2
	Pteromalidae	1	4
	Encyrtidae		1
	Eulophidae	7	3
	Aphelinidae	1	1
	Mymaridae		19
	Diapriidae		3
	Scelionidae	4	4
	Platygasteridae	4	4
	Ceraphronidae		10
	Tiphiidae/Tiphiinae	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	
Torpedo torpedo (Linnaeus)(electric ray)	OM	□
Raja undulata Lacepède (undulated ray)	OM	□
Alosa fallax Lacepède (twaite shad)	AM	□
Engraulis encrasicolus (Linnaeus) (anchovy)	R	△
Anguilla anguilla (Linnaeus) (european eel)	MC	□
Conger conger (Linnaeus) (conger eel)	N	□
Hippocampus hippocampus (Linnaeus) (sea-horse)	R	□
Hippocampus ramulosus Leach, (sea-horse)	R	□
Nerophis ophidion (Linnaeus) (straight-nosed pipefish)	R	□
Syngnathus acus Linnaeus (great pipefish)	R	□
Syngnathus typhle Risso (deep-snouted pipefish)	R	□
Ciliata mustela (Linnaeus) (five-beard rockling)	N	□
Serranus hepatus (Linnaeus) (rown comber)	N	□
Dicentrarchus labrax (Linnaeus) (sea-bass)	N	□
Mullus sumuletus Linnaeus (red mullet)	N	□
Diplodus annularis (Linnaeus) (anular sea bream)	N	□
Diplodus sargus (Linnaeus) (white sea bream)	N	△
Diplodus vulgaris (E.G. Saint-Hilaire) (two-banded sea bream)	N	△
Diplodus cervinus (Lowe) (zebra sea bream)	OM	□
Diplodus puntazzo (Cetti) (sharpsnout sea bream)	OM	□
Pagrus pagrus (Linnaeus) (common sea bream)	N	□
Sarpa salpa (Linnaeus) (salema)	N	□
Sparus aurata Linnaeus (gilthead)	N	□
Spondyliosoma cantharus (Linnaeus) (black sea bream)	N	□
Symphodus bailloni (Valenciennes) (wrasse)	R	□
Echiichthys vipera (Cuvier) (lesser weaver)	OM	□
Gobius auratus Risso (golden goby)	R	□
Gobius niger (Linnaeus) (black goby)	R	△
Gobius paganellus Linnaeus (rock goby)	R	□
Pomatoschistus knerii (Steindachner) (kner's goby)	R	□
Pomatoschistus microps (Krøyer) (common goby)	R	△
Pomatoschistus minutus (Pallas) (sand goby)	R	△
Pomatoschistus pictus (Malm) (painted goby)	R	□
Callionymus lyra Linnaeus (dragonet)	R	△
Chelon labrosus (Risso) (thick-lipped grey mullet)	N	○
Liza aurata (Risso) (golden grey mullet)	N	△
Liza ramada (Risso) (thinlip grey mullet)	MC	□
Liza saliens (Risso) (leaping mullet)	N	□
Mugil cephalus Linnaeus (flat head grey mullet)	N	□
Cyprinus carpio Linnaeus (carp)	OF	□
Atherina presbyter Cuvier (sand smelt)	OM	○
Trigla lucerna Linnaeus (tub gurnard)	N	□
Lepidorhombus whiffiagonis (Walbaum) (melgrin)	OM	□
Psetta maxima (Linnaeus) (turbot)	OM	□
Platichthys flesus (Linnaeus) (flounder)	N	□
Microchirus azevia (Capello) (bastard sole)	OM	□
Solea senegalensis Kaup (senegal sole)	N	□
Solea vulgaris Quensel (common sole)	N	△
Halobatrachus didactylus (Schneider) (toadfish)	R	△

□ Rare < 1 ind/1000 m^2.
△ Common < 10 and ⩾ 1 ind/m^2.
○ Very Common ≥ 10 ind/1000 m^2.

Table 7. Birds observed in Mira estuary.

Ardea cinerea	(grey heron)
Egretta garzetta	(little egret)
Anas platyrhynchos	(mallard)
Gallimula chloropus	(moorhen)
Charadrius dubius	(little ringed plover)
Pluvialis squatarola	(grey plover)
Limosa laponnica	(bar – tailed godwit)
Tringa totamus	(redshank)
Larus melanocephalus	(mediterranean gull)
Larus ridibundus	(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 *Nepthys 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 macroalge.

Grey mullet (*Liza aurata, L. saliens, L. ramada, Mugil cephalus* and *Chelon labrosus*) are iliophagous or detritus feeders. Their stomach contents showed the presence of Bacilliarophycea, Cyanophycea, Euclorphycea, Zygophycea, 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 Kg yr^{-1}) and an import of nutrients. This suggest 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 Lefeuvre, 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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References

Almeida, P.M.R. 1996. Biologia e ecologia da *Liza ramada* (Risso, 1826) e *Chelon labrosus* (Risso, 1826) (Pisces, Mugilidae) no estuário do Mira (Portugal). Inter-relações com o sistema estuarino. Ph.D. Thesis. Fac. Ciências Universidade Lisboa.

Andrade, F.A.L. 1986. O Estuário do rio Mira: Caracterização geral e análise quantitativa da estrutura dos macropovoamentos bentónicos. Ph.D. Thesis. Fac. Ciências Universidade Lisboa.

Bertness, M.D. 1992. The ecology of a New England salt marsh. American Scientist 80: 260–268.

Bettencourt, A.M.M. 1985. Programa de trabalhos e parecer sobre o estabelecimento de instalações de piscicultura no estuário do rio Mira: DGO, MQV.

Bettencourt, A.M.M. de, Abreu, M.C. de, Revez, M.A., Leitão, A.B.C., Catarino, F.M. Serôdio, J., Neves, R.J.J., Baptista, P.O, Lança, M.J., Alves, M.J., Costa, M.J., Raposo, P. and Costa, J.L. 1992a. Final report on the Mira estuary studies. Comparative studies of salt marsh processes. ECE-DG XII-Lisbon.

Bettencourt, A.M., Gomes, M.L.R., Vilas-Boas, L.F. and Cauwet, G. 1992b. Refractory dissolved organic carbon (RDOC) over an estuarine tidal cycle – implications for carbon budgets in Natural Water and Water Technology: Organic Matter in Natural Waters and Water Technology, European Science Foundation. Res. Conf. Espinho.

Bettencourt, A.M.M. de and Matos, J.S. 1988. Hidrologia e Qualidade da Água, Plano Director Municipal de Odemira, EGF.

Bettencourt, A.M.M. de, Neves, R.J.J., Lança, M.J., Batista. P.J. and Alves M.J. 1994. Uncertainties in import/export studies and the outwelling theory. An analysis with the support of hydrodynamic modelling *In:* Mitsch, W.J. (ed.), Global Wetlands: Old World and New. pp. 235–256. Elsevier: Amsterdam.

Boorman, L.A., Hazelden, J., Loveland. P.J. and Wells, J.G. 1994. Comparative relationships between primary productivity and organic and nutrient fluxes in four salt marshes. *In:* Mitsch, W.J. (ed.), Global Wetlands: Old World and New. pp. 181–199. Elsevier: Amsterdam.

Cardenas, S. 1977. Régimen alimenticio del sapo Halobatrachus didactylus (Shneider, 1801) (Pisces: Batrochoididae), en la bahía de Cádiz (España Sodoccidental). Vie et Milieu 28: 111–129.

Cattrijsse, A., Makawaia, E.S., Dankwa, H.R., Hemminga, M. and Hamerlynck, O. 1994. Nekton communities of an intertidal creek of a European estuarine brackish marsh. Marine Ecology Progress Series 109: 195–208.

Costa, J.L. 1993. Abundance and distribution of the toadfish Halobatrachus didactylus in the Mira estuary: seasonal variations and ruling factors. Journal of Fish Biology 43 (Sup. A): 330.

Costa, M.J. 1988. The Tagus and Mira estuaries (Portugal) and their role as spawning and nursery areas. Journal of Fish Biology 33 (Sup. A): 249–250.

Costa, M.J., Almeida, P.R., Costa, J.L. and Assis, C.A. 1994. Do eel grass beds and salt marsh borders act as preferential nurseries and spawning grounds for fish? – An example of the Mira estuary in Portugal. Ecological Engineering 3: 187–195.

Dame, R. T., Chrzanowski, T., Bildstein, K., Kjerfve, B., Mc Kellar, D., Nelson, Spurrier, J., Stancyk, S., Stevenson, SH., Vernberg, J. and Zingmark, R. 1986. The outwelling hypothesis and North

eel grass beds and salt marsh borders act as preferential nurseries

Inlet, South Carolina. Marine Ecology. Progress Series 33: 217–229.

Dame, R.F. and Lefeuvre, J.C. 1994. Tidal exchange: import-export of nutrients and organic matter in new and old world salt marshes: conclusions. *In:* Mitsch, W.J. (ed.), Global Wetlands: Old World and New. pp. 303–305.Elsevier: Amsterdam.

Dame, R.F. and Stillwell, O. 1984. The influence of environmental factors on floating macrodetritus flux in the North Inlet Ecosystem. Estuarine Coastal and Shelf Science 18: 721–726.

Danais, M. 1985. Production primaire du schorre et transports de matiérie organique flottante en baie du Mont Saint Michel. Rapport, fonctionnement des systèmes ecologiques en baie du Mont Saint Michel. CEE Environment et IRIEC.

Dankers, N., Binsbengen, K., Zegers, Laane, R. and Van der Loeff, M.R. 1984. Transportation of water, particulate and dissolved organic and inorganic matter between a salt marsh and the Ems – Dollard estuary, the Netherlands. Estuarine Coastal and Shelf Science 19: 143–165.

Dickerman, J.A. Stewart, A.J. and Wetal, R.G. 1986. Estimates of net annual above ground production: sensitivity to sampling frequency. Ecology 67: 650–659.

Fairbridge, R.W. 1980. The estuary: its definition and geodynamic cycle. *In:* Olausson, E. and Cato, I. (eds.), Chemistry and Biogeochemistry of Estuaries. John Wiley.

Gillet, P. 1990. Biomass, production et dynamique des populations de *Nereis diversicolor* in upper estuarine creek. Journal of Biological Education 19: 141–146.

Hackney, C.T. 1977. Energy flux in a tidal creek draining an irregularly flooded Juncus Marsh. Ph.D. Thesis, Mississippi State University.

Haines, E.B., Chalmers, R.B., Hanson, R B. and Sherr, B. 1977. Nitrogen pools and fluxes in a Georgia salt marsh. *In:* Wiley, M. (ed.), Estuarine Processes 2. pp. 241–254. Academic Press: New York.

Hopkinson, C.S., Gosselink, J.G. and Parrando, R. T. 1980. Production of coastal Louisiana marsh plants calculated from phenometric techniques. Ecology 61: 1091–1098.

Humpreys, T.J. 1985. Production of *Nereis diversicolor* in an upper estuarine creek. Journal of Biological Education 19: 141–146.

J.E.N. 1972 'Necessidades da água – estudos e análise'. DGCRNI, Jen Lisboa.

Kneib, RT. 1997. The role of tidal marshes in the ecology of estuarine nekton. Oceanographic Marine Annual Revue 35: 163–230.

Kirby, C.J. and Gosselink, J.G. 1976. Primary production in Louisiana gulf coast *Spartina alterniflora* marsh. Ecology 57: 1052–1059.

Lammens, E.J. and Van Eeden, M.J. 1977. Waardebepaling van een schor langs de Oosterschelde met betrekking tot zijn moglijke voor voedsel bijdrage tot het estuarium in de vorm van detritus. Studentenverslag D1-1977. Delta Instituut voor Hydrobiologische Onderzoek, Yerseke. 41 pp.

Mitsch, J.W. and Gosselink, J.G. 1993. Wetlands. Van Nostrand Reinhold: New York.

Montague, C.L. and Wiegert, R.G. 1990. Salt marshes. *In:* Meyers, R.L. and Ewel, J.J. (eds.), Ecosystems of Florida. pp. 481–516. University of Central Florida Press: Orlando.

Nixon, S.W. 1980. Between coastal marshes and coastal waters – a review of twenty years of speculation and research on the role of salt marshes in estuarine productivity and water chemistry. *In:* Hamilton, P. and MacDonald, K.B. (eds.), Estuarine and Wetland Processes. pp. 437–525. Phenum: New York.

Odum, E.P. 1980. The status of three ecosystem-level hypothesis regarding salt marsh estuaries: tidal, subsidy, outwelling and detritus based food chains. *In:* Kennedy, V.S. (ed.), Estuarine perspectives. pp. 485–495. Academic Press: New York.

Serôdio, J., Cabrita, T. and Catarino, F. 1992. The role of epiphytic algal mats in the tidal exchange of suspended matter between salt marshes and estuaries: the case of the Mira Estuary, Portugal. Poster INTECOL's IV International Wetlands Conference, Columbus, USA, 13–18 September 1992.

Sola, J.C. and Ibanez, M. 1990. Contribucion al estudio de los ciclos de vida de las especies *Scrobicularia plana* (Dacosta) y *Nereis diversicolor* (O.F. Müller) en el estuario del Bidasoa. *In:* Benthos 6. Act. VI Simposio Iberico Est. Bentos Marino. Palma de Maiorca: 69–79.

Teal, J.M. 1962. Energy flow in the salt marsh ecosystem of Georgia. Ecology 43: 614–624.

Vegter, F. 1975. Phytoplankton production in the Grevelingen estuary in relation to nutrient cycles. 10th European Symposium on Marine Biology, Ostende.

Wiegert, R.G. and Evans, F.C. 1964. Primary production and the disappearence of dead vegetation on an old fields in the southeastern Michigan. Ecology 45: 49–63.

Wolff, W.J. 1977. A benthic food bridget for the Grevelinger estuary, the Netherlands, and a conservation of the mechanisms causing high benthic secondary production in estuaries. *In:* Cool, J.C. The Ecology of Marine Benthos. University of South Carolina Press.

Wolff, W.J., Van Deen, M.J. and Lammers, E. 1979. Primary production and import of particulate organic matter on a salt marsh in the Netherlands. Netherlands Journal of Sea Research 13: 242–255.

Wolaver, T.G. and Spurrier, J.D. 1988. The exchange of phosphorus between a eurihaline vegetated marsh and the adjacent tidal creek. Estuarine Coastal and Shelf Science 26: 203–214.

Woodwell, G.M., Whitney, D.E., Hall, C.A.S. and Hourghton, R.A. 1977. The Flax Pond ecosystem study: exchanges of carbon in water between a salt marsh and Long Island Sound. Limnology and Oceanography 22: 833–838.