

Peracarid assemblages of *Zostera* meadows in an estuarine ecosystem (O Grove inlet, NW Iberian Peninsula): spatial distribution and seasonal variation

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Abstract The Galician rias are singular and complex estuarine systems of great economic importance. Seagrasses are key elements of the ecosystem and favor the maintenance of high species diversity in benthic communities. Nevertheless, the ecological role of seagrass meadows in the Galician rias has been only partially assessed. Peracarid crustaceans are an important component of soft-bottom faunas and have great importance for the structure of benthic assemblages. In this work, species diversity, patterns of distribution and seasonal fluctuations of peracarids (Crustacea, Peracarida) are studied in estuarine sediments colonized by two species of *Zostera* (*Z. marina* and *Z. noltii*) at the O Grove inlet (Ría de Arousa, Galicia, NW Iberian Peninsula). The spatial distribution of peracarid assemblages was characterized by high numerical dominances due to a few species, particularly tanaidaceans. The temporal study at a *Z. marina* meadow showed a strongly seasonal pattern defined by great fluctuations of the amphipod population, the latter being the dominant group in abundance and number of species. The highest numbers of species and individuals were observed in September, with minimum values in March. Analyses pointed out a high correlation among the granulometric features of the studied

bottoms and the faunistic attributes. Nevertheless, the presence of the seagrasses should influence in a major way the hydrodynamic and sedimentary features of the habitat and utterly the spatial and temporal patterns observed in the peracarid assemblage in the O Grove inlet.

Keywords Peracarida · *Zostera* · Seagrass · Assemblages · Distribution · Dynamics

Introduction

The presence of seagrass meadows in estuaries favors the establishment and maintenance of high species diversity in benthic assemblages (Fredette et al. 1990; Montadoun and Sauriau 2000). This is mostly due to their role as ecosystem engineers (Jones et al. 1994; Hasegawa et al. 2008): seagrasses reduce current velocities, and thus influence sedimentation rates. They also constitute a source of organic matter, which positively affects the establishment and survival of many benthic, particularly epifaunal species (Orth et al. 1984; Böstrom et al. 2006; Hasegawa et al. 2008). Furthermore, seagrass meadows represent a nursery habitat for fishes and invertebrates and are therefore crucial for the conservation and restoration of marine environments (Heck et al. 2003).

Peracarids (Crustacea: Peracarida) are one of the dominant taxa in benthic assemblages (Cartes et al. 2001) and are considered good indicators of the environmental conditions (Chintiroglou et al. 2004; Guerra-García and García-Gómez 2004). Besides, peracarids represent an important element of the trophic system (Cartes et al. 2001). Thus, the study of this group is a useful tool to evaluate the health and state of conservation of ecosystems.

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The Galician rias (NW of Spain) are singular, complex and productive estuarine systems, which support activities of great economic importance such as littoral fishing, mussel culture and other kinds of exploitation of sea food resources (Figueiras et al. 2002). In addition, the rias house a variety of hard- and soft-bottom habitats with high numbers of species (Garmendia et al. 1998; Moreira and Troncoso 2007). Because of their social and economic importance, the rias have been the subject of several faunistic studies in the last years (e.g. Junoy and Viéitez 1988; Currás and Mora 1991; Olabarria et al. 1998; Cacabelos et al. 2008; Lourido et al. 2008; Moreira et al. 2008b). However, there is a lack of studies on the fauna inhabiting seagrass meadows along the Galician coast. The ecological role of seagrass meadows in the Galician rias has not yet been properly assessed, despite the importance of seagrasses for the functioning of the ecosystem (Heck and Thoman 1981; Orth et al. 1984; Ersoy Karaçuha et al. 2009).

The O Grove inlet is of high economic and ecological importance due to mussel culture and tourism, on the one hand, and the presence of the extensive seagrass meadows, on the other hand. In fact, *Zostera marina* L. and *Z. noltii* Hornem. meadows cover the major part of the intertidal and shallow subtidal sediments of the inlet; this contributes to habitat complexity and thus to high values of benthic biodiversity (Quintas 2005).

As a starting point for a better understanding of the role of *Zostera* meadows in the ecosystem of the Galician rias, we (1) characterized the peracarid assemblage present in the *Zostera* spp. beds of the O Grove inlet and (2) studied possible seasonal changes of this assemblage in a representative *Zostera marina* bed.

Materials and methods

Study area and sampling procedures

The Ensenada de O Grove is located in the southern part of the Ria de Arousa (Galicia, NW Iberian Peninsula), between 42°41'–42°28'N and 9°01'–8°44'W (Fig. 1). It is a sheltered inlet, influenced by high precipitations in autumn/winter and affected seasonally by freshwater input from several streams. The peracarid fauna inhabiting the *Zostera* meadows at O Grove was studied at both spatial and temporal scales. The spatial study was done in December 1996 and comprised 10 sampling sites to assure a representative coverage of the seagrass meadows, which are composed of *Z. marina*, *Z. noltii* or both of them (Fig. 1). For the temporal study, samples were taken bimonthly between May 1998 and March 1999 in site D27, a subtidal area colonized by *Z. marina*, which was assumed to be less affected by salinity fluctuations than meadows located in

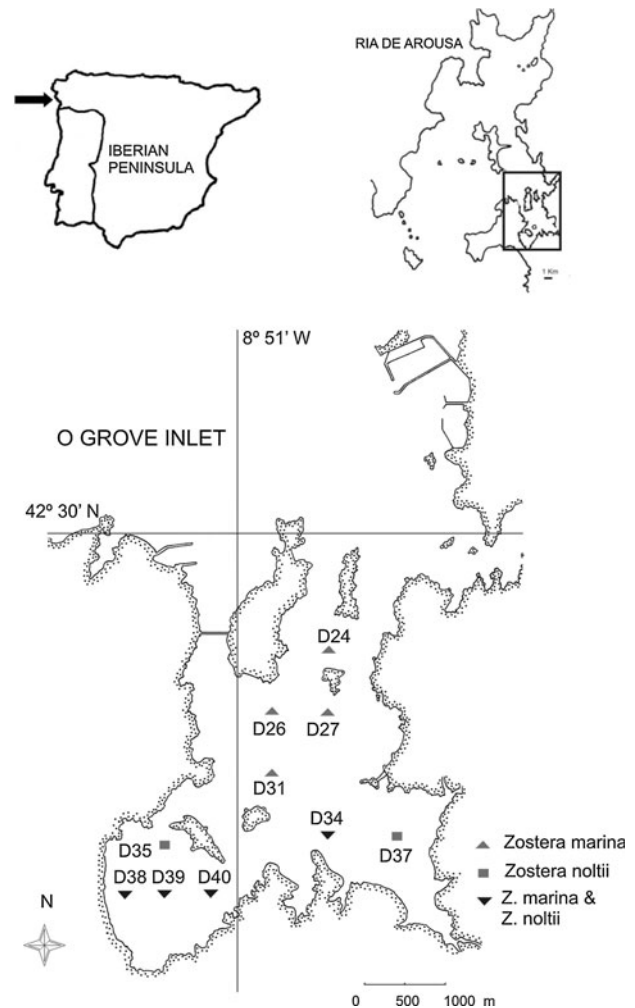


Fig. 1 Location of the O Grove inlet and sampling sites

the innermost parts of the inlet. This site was furthermore selected because of its high peracarid diversity and the good state of conservation of the meadow.

The spatial study was part of a larger project on the benthic environment of the Ria de Arousa. In order to unify the sampling procedure across different kinds of soft substrata, samples were taken by means of a Van Veen grab. Usually, studies on benthic faunas of seagrass meadows are performed by collecting samples with corers or quadrats (e.g. Blanchet et al. 2004; Fredriksen et al. 2005; González et al. 2008). Nevertheless, the grab used here was considered to take representative samples of the bottom; anyway, samples were discarded when the grab closed on *Zostera* roots and a substantial part of the sample could have been lost. Five replicate samples were taken at each site, thus covering a total area of 0.28 m² per site. Samples were sieved through a 0.5-mm mesh and fixed in 10% buffered formalin for later sorting and identification of the fauna. An additional sample was taken at each site for granulometric analyses and to determine calcium carbonate and organic

matter content. Also, a sample of the bottom water was taken by means of a Niskin bottle. The following granulometric fractions were distinguished: gravel (>2 mm), very coarse sand (1–2 mm), coarse sand (0.5–1.0 mm), medium sand (0.25–0.50 mm), fine sand (0.125–0.250 mm), very fine sand (0.063–0.125 mm) and silt/clay (<0.063 mm). Median grain size (Q_{50}) and the sorting coefficient (S_0) were also determined for each site. Calcium carbonate content (%) was estimated by treating the sample with hydrochloric acid in a Bernard Calcimeter, and the total organic matter content (TOM, %) was estimated from the weight loss of samples dried in a furnace for 4 h at 450°C. Temperature and pH of bottom seawater were measured in situ, by means of a portable microprocessor model HI9025C (Hanna instruments). Salinity was measured by means of a refractometer model S/Mill-E (Atago).

For the study of possible seasonal changes in the fauna, samples were taken at site D27 in May, July, September and November 1998, as well as in January and March 1999 by Scuba divers. At each sampling date, the seagrass cover of five replicate quadrats of 0.0625 m² each was harvested; the shoot and rhizome fractions (the latter including the sediment) were kept separately in plastic bags. An additional sample of sediment was taken for granulometric analyses and to determine calcium carbonate and organic matter content. Salinity, pH and temperature were measured in situ. Samples destined for faunal analysis were sieved through a 0.5-mm mesh and fixed in 10% buffered formalin.

Data analyses

Univariate measures were calculated for each sampling site and date: total abundance (N), number of species (S), Shannon–Wiener's diversity index (H' , as \log_2) and Pielou's evenness (J'). Peracarid assemblages (spatial study) and patterns of seasonal changes (site D27) were determined through non-parametric multivariate techniques as described by Clarke and Warwick (1994), using PRIMER 6 (Plymouth Routines in Multivariate Ecological Research) software package. The Bray–Curtis similarity index was applied on the fourth-root transformed data (to downweight the contribution of the most abundant species). Data were previously averaged through the five replicates for each site/date thus obtaining a centroid. Classification of sampling sites/dates was done by cluster analysis based on the group-average sorting algorithm and tested by Simprof test. Non-metric multidimensional scaling (nMDS) was used to produce a visual representation of the ordination of centroids. The SIMPER analysis served to identify the species that contributed most to the differentiation of the groups of samples (sampling sites/dates). The possible relationship between the peracarid assemblages

and the measured environmental variables was analyzed by the BIO-ENV procedure. All variables expressed in percentages were previously transformed by $\log(x+1)$.

Results

Spatial distribution

Environmental variables

Sediments were composed mainly of muddy sand, with relatively high percentages of fine and very fine sand (up to 64.6 and 47.9%, respectively) and silt/clay (up to 61.6% in site D37). Salinity was relatively low (maximum 33‰) especially for sites 34 and 37 (around 20‰). Content in TOM was high (up to 15.55%), whereas content in calcium carbonate was low (<10.5%). Values of the studied variables are detailed for each site in Table 1.

Fauna

A total of 15,523 individuals belonging to 113 species were identified (those with >1% of dominance are detailed in Table 2). Tanaids accounted for 52% of the specimens, with *Apseudes latreillii* (Milne-Edwards, 1828) being the numerically dominant species (40.2%). Amphipods were the group best represented in number of species (83) and constituted 35.8% of the specimens. The least represented group was cumaceans, which accounted for only 3.12% of the total abundance.

The highest number of species was found in site D27 (60); diversity (H') and evenness (J') indexes were low for this site (H' : 2.05; J' : 0.51). Both H' and J' were highest for sites D38, D39 and D40 (H' : 3.74–4.07; J' : 0.73–0.78).

The ANOSIM test showed significant differences in faunistic composition among sites (global R : 0.823, $P < 0.001$). The cluster dendrogram and the graphic representation of the nMDS analysis revealed the existence of three major groups of sites (Fig. 2). Group A (similarity level of 60%) comprised four sites located in the central part of the inlet and colonized by *Z. marina* (D24, D26, D27 and D31). The species that mostly contributed to the similarity were the tanaids, *Apseudes latreillii* and *Zeuxo holdichi* Bamber, 1990, followed by the caprellids, *Caprella acanthifera* Leach, 1814 and *Pariambus typicus* (Krøyer, 1884). Group B was composed of two sites colonized by both species of seagrasses, situated in the sheltered south-western part of the inlet (D38 and D39; similarity of 70%). *Uromunna* spp., *Microdeutopus* spp., *Gammarella fucicola* (Leach, 1814) and *Apseudes talpa* (Montagu, 1808) were the taxa determining this group. Site D35 was also included in this group (similarity of 60%),

Table 1 Spatial study: environmental variables measured in different sites

	D24	D26	D27	D31	D34	D35	D37	D38	D39	D40
T sed. (°C)	12.50	11.10	11.60	13.40	12.70	13.50	12.90	12.60	12.70	12.80
T bottom water (°C)	14.60	10.00	9.90	16.70	13.00	15.30	13.20	13.20	13.00	13.30
pH sed.	7.36	7.53	7.41	7.39	7.27	7.46	7.20	7.30	7.29	7.26
pH bottom water	7.76	7.90	7.85	7.81	7.74	7.89	7.74	7.71	7.70	7.73
Salinity (‰)	29.00	30.00	32.00	32.50	30.00	30.50	20.00	33.00	33.00	32.00
Gravel	1.87	4.44	0.38	1.95	0.23	0.68	1.03	5.77	1.05	22.38
Very coarse sand	0.50	2.38	0.21	0.57	0.14	0.53	0.36	1.09	0.37	3.95
Coarse sand	0.97	4.56	0.45	0.91	1.83	1.54	1.86	2.81	1.00	5.00
Medium sand	3.82	10.19	2.37	4.76	10.97	14.48	3.88	5.13	4.72	9.71
Fine sand	40.14	46.14	37.80	58.03	20.85	64.63	11.77	18.51	43.58	18.36
Very fine sand	40.68	25.89	47.89	23.20	33.93	11.40	19.49	29.66	31.07	13.17
Silt/clay	12.01	6.41	10.90	10.59	32.05	6.75	61.61	37.02	18.22	27.44
Q ₅₀	0.12	0.17	0.11	0.16	0.18	0.19	0.10	0.11	0.13	0.18
S ₀	1.52	1.50	1.48	1.45	1.82	1.30	2.31	1.70	1.61	1.99
TOM (%)	3.93	1.37	2.98	2.80	5.08	1.32	15.55	10.75	3.32	7.10
Carbonate content (%)	7.58	10.05	8.46	8.69	7.22	10.46	5.41	7.40	9.59	7.17

Granulometric fractions in %, *T sed* temperature of the sediment, *T bottom water* temperature of the bottom water, *pH sed* pH of the sediment, *pH bottom* pH of the bottom water, *Q₅₀* median grain size, *S₀* sorting coefficient, *TOM* total organic matter

although this was not supported by the Simprof test. Group C (similarity 50%) was formed by two sites located near the mouth of rivers in the south-east (D34, with both *Z. marina* and *noltii*; D37, only with *Z. noltii*) and another site hosting both seagrasses (D40); the latter was situated on the other side of the inlet, near site D39. The species that most contributed to the similarity of this group were the isopods, *Idotea chelipes* (Pallas, 1766) and *Idotea balthica* (Pallas, 1772), followed by the amphipods, *Corophium sextonae* Crawford, 1937 and *C. insidiosum* Crawford, 1937.

The BIO-ENV procedure revealed that the combination of salinity, gravel, fine sand and silt/clay had the highest correlation with the faunal composition, according to the values of the Spearman's rank correlation coefficient (ρ_w : 0.734). The variable that showed the best correlation was silt/clay (ρ_w : 0.603).

Seasonal changes

Environmental variables

The temperature of the bottom water reached a minimum in March (12.4°C) and a maximum in July (25.2°C). Fine and very fine sand were the dominant granulometric fractions throughout the year at site D27 (20.9–58.0% and 11.4–40.7%, respectively). Coarser granulometric fractions were present in small percentages, showing some variation over the study period. Silt/clay fraction showed more or

less constant values, reaching the maximal content in January (32.1%). Calcium carbonate and organic matter contents showed slight variations over the year, with maximal values in March (TOM, 4.6%; calcium carbonate, 9.9%). Details are shown in Table 3.

Fauna

A total of 5,768 individuals belonging to 83 species were found in the study period. Amphipods were dominant in number of the specimens (69.4% of total abundance), followed by tanaids (21.8%), isopods (8%) and cumaceans (0.8%). Amphipods were also numerically dominant at each sampling date except for July, when tanaidaceans were the dominant group (Fig. 3). The dominant species was the amphipod, *Gammarella fucicola* (23.6% of total abundance), followed by the tanaid, *Zeuxo holdichi* (18.6%), and the caprellid, *Phtisica marina* Slabber, 1769 (16.6%; Fig. 4).

The highest numbers of species and individuals were observed in September, minimal numbers in March. Diversity (H') and evenness (J') were minimal in summer–autumn, reaching the highest values in January (Table 4).

The ANOSIM test showed significant differences in faunistic composition among all sampling dates (global R : 0.634, $P < 0.001$). Cluster analysis and nMDS ordination showed two defined groups of samples (Fig. 5): spring–summer (May and July; group A) and autumn–winter (November, January and March; group B). The September

Table 2 Spatial study: list of the peracarid orders and most abundant species (>1% dominance) with abundances (individuals/0.28 m²) in the different sampling sites, total abundances and dominance (%)

	D24	D26	D27	D31	D34	D35	D37	D38	D39	D40	Total	D (%)
AMPHIPODA (total)	437	510	1,064	267	858	126	68	1,116	671	444	5,561	35.82
<i>Stenothoe monoculoides</i> (Montagu, 1815)	21	9	6	3	23	3	0	10	4	87	166	1.07
<i>Gammarus tigrinus</i> Sexton, 1939	0	1	1	0	213	0	1	10	0	1	227	1.46
<i>Gammarella fucicola</i> (Leach, 1814)	17	22	516	18	0	1	2	170	69	5	820	5.28
<i>Melita palmata</i> (Montagu, 1804)	0	0	1	0	0	6	6	0	0	157	170	1.09
<i>Perioculodes aequimanus</i> (Kossmann, 1880)	28	5	7	8	1	11	0	55	105	68	288	1.85
<i>Harpinia pectinata</i> Sars, 1891	12	55	78	16	0	11	0	33	39	0	244	1.57
<i>Dexamine spinosa</i> (Montagu, 1813)	25	5	28	12	0	0	0	74	34	0	178	1.15
Aoridae indet.	0	1	0	1	12	0	0	246	16	4	280	1.80
<i>Microdeutopus</i> spp.	13	9	17	30	60	6	3	166	81	27	412	2.65
<i>Microdeutopus versiculatus</i> (Bate, 1856)	2	64	1	0	96	0	1	0	1	0	165	1.06
<i>Siphonocetes sabatieri</i> de Rouville, 1894	0	0	0	0	0	7	0	0	149	0	156	1.00
<i>Pariambus typicus</i> (Krøyer, 1804)	22	17	178	25	0	0	0	0	1	0	243	1.56
ISOPODA (total)	14	76	100	60	55	26	449	199	94	194	1,267	8.16
<i>Cyathura carinata</i> (Krøyer, 1847)	0	74	2	0	1	6	3	15	6	68	175	1.13
<i>Uromunna</i> spp.	12	0	10	57	2	16	0	180	87	4	368	2.37
CUMACEA (total)	196	10	96	26	0	26	0	58	70	3	485	3.12
<i>Iphinoe trispinosa</i> (Goodsir, 1843)	173	2	30	8	0	5	0	9	10	3	240	1.55
TANAIDACEA (total)	1,456	1,411	2,711	1,424	0	258	0	662	248	30	8,200	52.82
<i>Apeudes latreillii</i> (Milne- Edwards, 1828)	1,394	806	2,699	1,250	0	37	0	30	24	0	6,240	40.20
<i>Apeudes talpa</i> (Montagu, 1808)	0	530	0	0	0	15	0	61	117	3	726	4.68
<i>Leptocheilia savignyi</i> (Kroyer, 1842)	0	0	0	1	0	12	0	400	51	1	465	2.99
<i>Zeuxo holdichi</i> Bamber, 1990	59	70	6	173	0	194	0	171	23	4	700	4.51
Pielou's evenness (J')	0.42	0.54	0.35	0.38	0.72	0.67	0.68	0.74	0.79	0.74		
Shannon-Wiener's diversity index (H')	2.39	3.07	2.05	2.04	3.72	3.62	2.94	4.07	4.48	3.74		

sampling appeared separated from both groups. Group A (70% similarity) was defined by *Zeuxo holdichi*, *Stenothoe monoculoides* (Montagu 1815), *Uromunna* spp. and *Microdeutopus* spp. Group B (60% similarity) was characterized by *Z. holdichi*, *S. monoculoides* and *Gammarella fucicola*. In the x-axis, the September sampling appeared to be closest to group A (70% similarity), but this was not supported by the Simprof test.

The BIO-ENV procedure revealed that the combination of pH, temperature of bottom water and content in medium sand, very fine sand and silt/clay had the highest correlation with peracarid fauna, according to the Spearman's rank correlation coefficient (ρ_w : 0.532).

Discussion

The *Zostera* meadows at the O Grove inlet have a very diverse peracarid fauna, with a total of 113 taxa identified in this study. The assemblages were numerically dominated

by tanaidaceans (53% of the total abundance) and amphipods (36%); on the other hand, amphipods were the peracarid order with the highest number of species (85). The high numerical dominance of tanaidaceans was mostly due to *Apeudes latreillii*, particularly in sites colonized by *Zostera marina*.

The species composition of the studied seagrass meadows was typical for north-east Atlantic estuarine sediments (Cunha et al. 1999; Dauvin et al. 2009). However, in other similar estuarine environments of the North Atlantic and the Mediterranean, whether colonized by seagrasses, the number of peracarid species was often smaller and tanaidaceans were very scarce or even absent (Cunha et al. 1999; Cartes et al. 2007; Dauvin et al. 2009). In seagrass meadows, the total number of species was usually high, although tanaidacean densities were much lower than in the present study (Gambi et al. 1992; Sfriso et al. 2001; Paganelli et al. 2005; Ersoy Karacüha et al. 2009). In general, amphipods were dominant in most of the studies listed above. This dominance may be explained by the fact

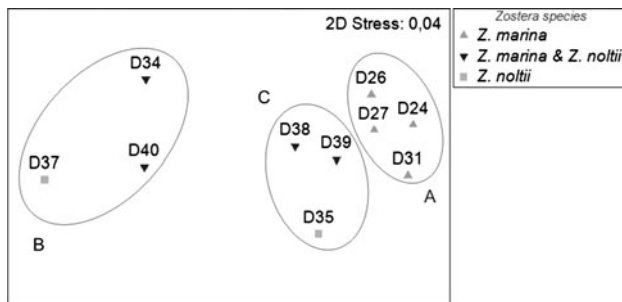


Fig. 2 nMDS ordination of sampling sites showing the groups determined by cluster analysis. The *Zostera* species present in each site are also indicated

that amphipods are highly diversified both taxonomically and in terms of niche occupation (habitat preferences, feeding habits) and life strategies (e.g. Lancellotti and Trucco 1993; Nelson et al. 1982). Seagrass meadows in turn provide a variety of microhabitats and food sources (vegetal biomass, detritic deposits, epiphytes on seagrasses) to be colonized and exploited by amphipods.

High densities of the tanaid, *Apseudes latreilli*, have recently been reported in several studies and have often been linked to organic and/or inorganic pollution (Cruz et al. 2003; Guerra-García and García-Gómez 2004; Tomasetti et al. 2009). According to Riggio (1996), *A. latreilli* is found frequently in sediments with detritic deposits. In the O Grove inlet, organic matter contents are high in general, and extensive mussel culture also

contributes to a significant detritus input. These features, together with the pollution related to intense vessel activities, may have favored the establishment of large populations of *A. latreilli* in the inlet.

Recent benthic studies of several Galician rias have pointed out a particular richness in peracarid species when compared to similar environments of the North Atlantic (Lourido et al. 2008; Moreira et al. 2008a, b). The granulometric characteristics of the sediment have been suggested the main factor in structuring those assemblages. Nevertheless, in the study area, the presence of the seagrasses undoubtedly contributes to the establishment and structure of the peracarid assemblage by providing, for example, an increased habitat complexity. Furthermore, seagrasses enhance sedimentation rates and organic matter supply and are crucial for the sedimentary features of the habitat (Böstrom et al. 2006; Hasegawa et al. 2008). As expected, the organic matter contents measured in the *Zostera* meadows at the O Grove inlet was high, and multivariate analysis indicated that peracarid assemblages were positively correlated with the granulometric composition, especially with the silt/clay fraction. This granulometric fraction is easily suspended and drifted away by hydrodynamism in spite of the presence of the seagrasses (Hasegawa et al. 2008), and then distributed irregularly across the meadows. This provides the basis for restricted distributions of infaunal species in the meadows depending on species-specific differences in granulometric preferences. Indeed, we observed that infaunal species such as

Table 3 Seasonal study: environmental variables measured in site D27 at different dates

	May	July	September	November	January	March
T sed. (°C)	19.30	18.80	19.60	16.90	21.20	12.30
T bottom water (°C)	21.50	25.20	20.10	17.20	21.20	12.40
pH sed.	7.25	7.28	7.19	7.45	7.56	6.38
pH bottom water	8.05	7.79	7.66	7.73	7.55	7.58
Salinity (‰)	32.00	34.70	40.40	40.80	32.70	41.00
Gravel	1.9	4.4	0.4	1.9	0.2	0.7
Very coarse sand	0.5	2.4	0.2	0.6	0.1	0.5
Coarse sand	1.0	4.6	0.4	0.9	1.8	1.5
Medium sand	3.8	10.2	2.4	4.8	11.0	14.5
Fine sand	40.1	46.1	37.8	58.0	20.9	64.6
Very fine sand	40.7	25.9	47.9	23.2	33.9	11.4
Silt/clay	12.0	6.4	10.9	10.6	32.1	6.7
Q ₅₀	3.050	2.950	2.183	2.283	1.283	4.600
S ₀	8.089	8.506	8.406	8.183	8.511	9.930
TOM (%)	0.1932	0.1745	0.1963	0.1725	0.2505	0.1747
Carbonate content (%)	1.339	1.470	1.345	1.689	1.567	1.597

Granulometric fractions in %, *T sed* temperature of the sediment, *T bottom water* temperature of the bottom water, *pH sed* pH of the sediment, *pH bottom* pH of the bottom water, *Q₅₀* median grain size, *S₀* sorting coefficient, *TOM* total organic matter

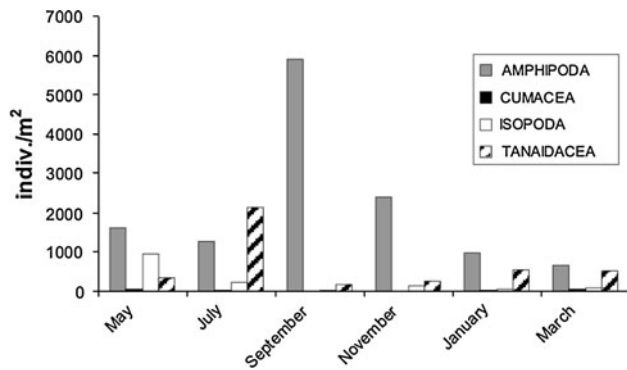


Fig. 3 Total abundance (individuals per m²) of the four peracarid orders per sampling date at site D27

Pariambus typicus and *A. latreillii*, which have been related with the silt/clay fractions (Guerra-García et al. 2003), contributed significantly to the characterization of the assemblages.

Peracarid assemblages of the *Zostera marina* meadows in the center of the inlet constituted a definite group (A) in the cluster analysis. The assemblages corresponding to the other two groups (B and C) were found in meadows composed of *Z. noltii* or a mixture of both species. Group C (sites D35 and D37) is clearly defined in the nMDS ordination and is located close to the mouth of several rivers. The differences in those peracarid assemblages might be related to the different conditions in salinity observed across the inlet. In wet climates, macrofaunal distributions in estuaries are influenced by salinity gradients (Talley et al. 2000). Indeed, salinity affects peracarids in estuarine areas more than any other environmental factor (Paganelli et al. 2005). In fact, in the sites of group C, euryhaline species such as *Idotea balthica*, *I. chelipes*, *Corophium acherusicum* Costa, 1851, *C. insidiosum*, *Gammarus tigrinus* Sexton, 1939, and *G. insensibilis* Stock, 1966, were more abundant than in the sites of the other two groups, while

species less tolerant to changes in salinity (i.e. tanaidaceans) were completely absent. In conclusion, our results suggest that the spatial variations in peracarid assemblages found at the O Grove inlet are related to three main factors: sediment characteristics, seagrass species composition and salinity conditions.

In the second part of the study (seasonal changes in the peracarid assemblage of a subtidal *Z. marina* meadow; D27), the numbers of species and total numbers of individuals were generally lower than in the samples (including those from D27) taken for the first (spatial) part of the study. This might be due to the different sampling techniques, as scuba diving (used in the seasonal study) might expose peracarids to a higher rate of disturbance than a Van Veen grab (applied in the spatial study). Indeed, some peracarid taxa tend to escape or bury into the sediment when disturbed; for example, Guerra-García and García-Gómez (2008) observed that tanaidaceans are able to bury actively to deeper levels when disturbed by a sampling device. That would explain in particular the low abundances of *Apseudes latreillii* compared to those found for the same site in the spatial scale study.

The studied peracarid assemblage showed clear seasonal changes. There was a decline in the total abundances and numbers of species from autumn through winter for all orders of peracarids, while diversity and evenness indexes increased. This seasonality in peracarid assemblages is typical of temperate latitudes (Cunha et al. 1999; Moreira et al. 2008a; Ersoy Karaçuha et al. 2009). The reasons may be diverse: Frequent rains characterize winter and autumn periods at the area of study, altering the salinity conditions in estuarine habitats, and thus leading to changes in the benthic assemblages (Szedlmayer and Able 1996; Cunha et al. 1999). Furthermore, life histories with seasonal changes in reproductive activity and dispersal may explain variations of the benthic crustacean assemblages over the annual cycle (Cunha et al. 1999; Moreira et al. 2008a).

Fig. 4 Total abundance (individuals per m²) of *Phtisica marina*, *Gammarella fucicola*, *Uromunna* spp. and *Zeuxo holdichi* per sampling date at site D27

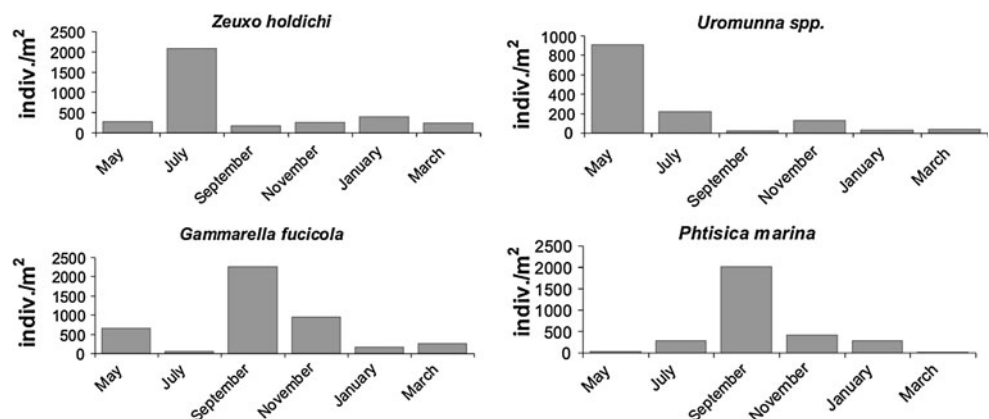
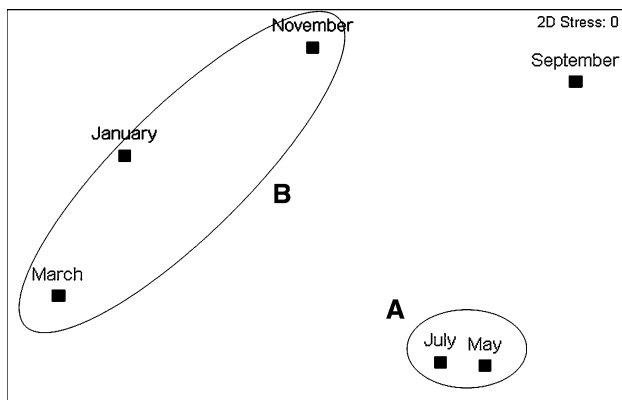


Table 4 Faunistic parameters for each sampling date at site D27

	<i>S</i>	<i>N</i>	<i>J'</i>	<i>H'</i>
May	40	925	0.64	3.39
July	33	1,146	0.52	2.63
September	42	1,911	0.52	2.82
November	38	876	0.64	3.36
January	35	499	0.70	3.59
March	33	411	0.68	3.41

S number of species; *N* total number of individuals (individuals/0.31 m²); *H'* Shannon–Wiener's diversity index; *J'* Pielou's evenness

**Fig. 5** nMDS ordination of bimonthly samples (centroids) collected at site D27 showing the groups determined by cluster analysis

In the present study, amphipods showed the highest number of species and made the greatest contribution to the total abundance. Amphipod populations also showed great fluctuations through the study period (Fig. 3). These results agree with those of other studies done in similar environments in the northern hemisphere (e.g. Gambi et al. 1992; Dias and Hassal 2005; Quiroz-Vázquez et al. 2005; Ersoy Karaçuha et al. 2009). Dias and Hassal (2005) suggested that amphipods living in seagrasses and feeding on (live or decaying) *Zostera* eat faster show higher growth rates and also may have larger broods than other groups such as isopods, which might contribute to the numerical dominance and seasonality of their populations.

The life history of the seagrasses can also affect associated organisms via seasonal fluctuations in organic matter supply and alterations of sedimentation rates (Jones et al. 1994; Quiroz-Vázquez et al. 2005; Böstrom et al. 2006; Hasegawa et al. 2008). In particular, *Zostera marina* shows

a clear seasonal dynamics, with elongation of the leaves and rhizomes in spring–summer and spreading of seeds in winter (Hasegawa et al. 2007). This may be reflected in changes of the peracarid faunas, as indicated by the present study. Indeed, some dominant species of the *Zostera* beds in the O Grove inlet (e.g. *Gammarella fucicola*, *Phtisica marina*, *Uromunna* spp. and *Aapseudes latreillii*, among others) showed great variations in density through seasons (Fig. 4). Guerra-García et al. (2001) reported similar fluctuations of densities for the caprellid, *P. marina*, influenced by the life cycle of the seaweed, which it is associated with. González et al. (2008) found a correlation between the abundance of *P. marina* and seagrass biomass in *Zostera* meadows. Likewise, high abundances of *G. fucicola* have been related to detritus accumulation in seagrass meadows right after the decay of the leaves (Lepoint et al. 2006). Furthermore, the increase in seagrass biomass favors the establishment of epiphytic algae, which bloom in August and provide additional food for secondary producers (Hasegawa et al. 2007). This leads to high rates of the secondary production, with grazers such as amphipods of the families Dexaminidae and Amphitoidae as well as most of the isopods reaching their greatest abundances after late summer (Fredette et al. 1990).

The life cycle of *Z. marina* has been reported to be coupled the breeding and development of certain peracarids. An illustrative example is given by Nakaoka (2002), who reported the tanaidacean *Zeuxo* not only feeding on *Z. marina* seeds, but also using the spathes for reproduction and nursery. Indeed, we found large numbers of *Zeuxo holdichi* in summer, just after the anthesis of the seagrass (Fig. 4).

In conclusion, peracarid assemblages in *Zostera* meadows in the O Grove inlet are rich and diversified. These findings from the subtidal benthic system of the Galician rias again demonstrate the important ecological role of the seagrasses. As the rias are strongly affected by urbanization and pollution, conservation of these peculiar habitats will be crucial for the preservation of the local biodiversity.

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Appendix

See Table 5.

Table 5 List of peracarid species found during the period of study

Order Amphipoda

Lysianassa ceratina (Walker, 1889)
Tryphosites longipes (Bate & Westwood, 1861)
 Amphipoda indet.
Ampelisca spp.
Ampelisca brevicornis (A. Costa, 1853)
Ampelisca gibba Sars, 1882
Ampelisca serraticaudata Chevreux, 1888
Ampelisca spinifer Reid, 1951
Ampelisca spinipes Boek, 1861
Ampelisca tenuicornis Liljeborg, 1855
Ampelisca typica (Bate, 1856)
Amphilochus spencebatei (Stebbing, 1876)
Peltocoxa marioni Catta, 1875
Leucothoe incise Robertson, 1892
Leucothoe lilleborgi Boek, 1861
Leucothoe spinicarpa (Abildgaard, 1879)
Stenothoe monoculoides (Montagu, 1815)
 Gammaridae indet.
Gammarus spp.
Gammarus crinicornis Stock, 1966
Gammarus insensibilis Stock, 1966
Gammarus tigrinus Sexton, 1939
Gammarella fucicola (Leach, 1814)
Abludomelita gladiosa (Bate, 1862)
Melita dentata (Kroyer, 1842)
Melita herguensis Reid, 1939
Melita palmata (Montagu, 1804)
Urothoe elegans (Bate, 1857)
Urothoe grimaldii Chevreux, 1895
Urothoe pulchela (Costa, 1853)
Periculodes aequimanus (Kossmann, 1880)
Periculodes longimanus (Bate & Westwood, 1868)
Harpinia spp.
Harpinia antennaria Meinert, 1890
Harpinia crenulata (Boeck, 1871)
Harpinia delavallei Chevreux, 1910
Harpinia laevis Sars, 1891
Harpinia pectinata Sars, 1891
Apherusa bispinosa (Bate, 1856)
Apherusa henneguyi Chevreux & Fage, 1925
Apherusa jurinei (Milne-Edwards, 1830)
Dexamine spinosa (Montagu, 1813)
Ampithoe spp.
Ampithoe gammaroides (Bate, 1856)
Ampithoe helleri Karaman, 1975
Ampithoe neglecta Lincoln, 1976
Ampithoe ramondi Audouin, 1826
Ampithoe rubricata (Montagu, 1808)
Sunamphitoe pelgica (Milne-Edwards, 1830)

Table 5 continued

Aoridae indet.
Lembos spp.
Lembos websteri Bate, 1857
Leptocheirus pilosus Zaddach, 1844
Microdeutopus spp.
Microdeutopus anomalus (Rathke, 1843)
Microdeutopus chelififer (Bate, 1862)
Microdeutopus damnoniensis (Bate, 1856)
Microdeutopus gryllotalpa Costa, 1853
Microdeutopus stationis Della Vale, 1893
Microdeutopus versiculatus (Bate, 1856)
Gammaropsis maculata (Johnston, 1827)
Gammaropsis sophiae (Boeck, 1861)
Gammaropsis palmata (Stebbing & Robertson, 1891)
Microprotopus maculatus Norman, 1867
Photis longipes (Della Valle, 1893)
Monocorophium spp.
Monocorophium ascherusicum (Costa, 1851)
Monocorophium insidiosum Crawford, 1937
Monocorophium sextoane Crawford, 1937
Siphonocetes kroyeranus Bate, 1856
Siphonocetes striatus Myers & McGrath, 1979
Siphonocetes sabatieri de Rouville, 1894
Colomastix pusilla Grube, 1861
Erichthonius punctatus (Bate, 1857)
Jassa falcata Montagu, 1808
Caprellidae indet.
Caprella sp.1
Caprella sp.2
Caprella equilibra Say, 1818
Caprella penatis Leach, 1814
Caprella acanthifera Leach, 1814
Pariambus typicus (Krøyer, 1884)
Phthisica marina Slabber, 1769
Pseudoprotella phasma Montagu, 1804
 Order Isopoda
Arcturidae indet.
Astacilla longicornis (Sowerby, 1806)
Cyathura carinata (Krøyer, 1847)
Idotea spp.
Idotea baltica (Pallas, 1772)
Idotea chelipes (Pallas, 1776)
Idotea granulosa Rathke, 1843
Idotea neglecta Sars, 1897
Jaera albifrons Leach, 1814
Janira maculosa Leach, 1814
Janiropsis sp.
Munna spp.
Uromunna spp.
Lekanesphaera levii (Argano & Ponticelli, 1981)

Table 5 continued

Order Cumacea

- Bodotria pulchella* (Sars, 1879)
Iphinoe tenella Sars, 1878
Iphinoe trispinosa (Goodsir, 1843)
Nannastacidae indet.
Nannastacus spp.
Cumella spp.
Cumella pygmaea Sars, 1865
Pseudocuma longicorne (Bate, 1858)
Pseudocuma simile G.O. Sars, 1900

Order Tanaidacea

- Apseudopsis latreilli* (Milne-Edwards, 1828)
Apseudes talpa (Montagu, 1808)
Akanthophoreus gracilis (Krøyer, 1842)
Leptocheilia savignyi (Krøyer, 1842)
Tanais dulongii (Audouin, 1826)
Zeuxo holdichi Bamber, 1990

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