ABSTRACT

The aim of this work was to analyze spatial and temporal variations in composition and abundance of benthic species assemblages in an intertidal environment of the Río Gallegos Estuary, Patagonia, Argentina (51° 35' S 69° W). Species distribution and its temporal fluctuations were analyzed using multivariate statistical methods. Different species assemblages were observed, their distribution being related to the tidal level and type of intertidal sediment. The polychaete Scolecolepides uncinatus was dominant in a species assemblage restricted to the high intertidal levels, which are characterized by silty clay sediments. At the intermediate intertidal level, the number of species and total macrofauna abundance increased; at this level, the clam Darina solenoides and the mussel Mytilus edulis platensis were dominant. At the low levels, which are composed of fine sediments, the polychaete Clymenella minor and the bivalve Mysella sp. were dominant. Temporal variations detected in species abundance were mainly due to the incorporation of recruits in the population, especially of the most abundant species.

INTRODUCTION

Distribution, diversity, and abundance of benthic organisms inhabiting intertidal environments have been associated with variations of several factors, such as depth, tidal height, time of exposure, and type of sediment (Dahl, 1952; Beukema, 1976; Mc Lachlan, 1983; Day et al., 1989; Brown & Mc Lachlan, 1990; Zaixso et al., 1998; Dittmann, 2000; Lizarralde, 2002; Veloso et al., 2003). Food availability, larval dispersal and settlement, intra and interspecific competition, and the effects of predation also influence community structure. Some experimental studies have demonstrated that biological interactions, such as predation and competition, affect the benthic community structure by acting on recruitment, survival, or migration of organisms (Woddin, 1974; Peterson & Andre, 1980; Brenchley, 1982; Thrush et al., 1992; Knox, 2000).

Benthic communities may fluctuate in a cyclic pattern over time, because of the characteristics of the life cycle of the species, as well as of the influence of temporal fluctuations of abiotic factors, such as environmental temperature or salinity (Day et al., 1989; Souza & Gianuca, 1995; Veloso et al., 1997; Das Neves et al., 2008).
Soft-bottom intertidal benthic communities from the southern portion of Argentine Patagonia have been poorly studied. The few studies conducted in the region have provided information on communities from shallow subtidal environments (Lopez Gappa & Cruz Sueiro, 2006, Martin & Bastida, 2008). There are also reports from the Chilean portion of the Strait of Magellan that contribute to the knowledge of those organisms in the region and that allow us to make comparisons at a regional scale (Espoz et al., 2008).

The Río Gallegos estuary is located in the province of Santa Cruz, southern Patagonia. Its northern shore is high, with cliffs and gravel beach plains, whereas the southern shore is dominated by vast muddy intertidal flats, saltmarshes, and complex channels (Perillo et al., 1996). It is a Western Hemisphere Shorebird Reserve Network (WHSRN) Site of international importance because it provides habitat and food for a high number of Nearctic migratory shorebirds that visit the area during summer, such as the White-rumped Sandpiper (*Calidris fuscicollis*), the Red Knot (*Calidris canutus*), and the Hudsonian Godwit (*Limosa haemastica*). These species arrive from the Northern Hemisphere and use the estuary as a migration stopover site during the non-breeding season; the estuary also provides shelter to some species endemic to southern Patagonia, such as the Magellanic Plover (*Pluvianellus socialis*) and the Magellanic Oystercatcher (*Haematopus leucopodus*) (Ferrari et al. 2002, 2007, 2008, Albrieu et al. 2004). Small-scale artisanal fisheries are conducted at the estuary, one of the target species being the Patagonian blenny *Eleginops maclovinus* (Caille et. al., 1995), which also feeds on benthic organisms (Martin & Bastida, 2008).

Despite the ecological importance of the estuary, no systematic studies of benthic organisms inhabiting the variety of intertidal environments have been conducted; therefore, it is necessary to generate baseline information that contributes to the management of the coastal area, which is permanently influenced by anthropogenic activities (recreation, sport and commercial fisheries, urban development).
because of its proximity to the city of Río Gallegos. The aim of this work was to analyze the composition, abundance, and distribution of benthic species assemblages, as well as the temporal variations of species abundance throughout a year of study at the Río Gallegos Estuary.

MATERIALS AND METHODS

The Río Gallegos Estuary is located in southeastern continental Patagonia, Argentina (51° 35’ S 69° W). The tidal regime is semi-diurnal with a mean tidal range of 10.8 m on spring tides and 2.9 m on neaps. The cool coastal climate has a mean annual temperature of 7.2 °C and west winds blowing at an average speed of 35 km/h. The city of Río Gallegos, with a population of some 90,000 inhabitants, is located on the southern shore of the estuary.

The benthic macrofauna was sampled monthly during 12 months (December 2005 to November 2006) in an extensive tidal flat located on the southern shore of the estuary (Fig. 1). Samples were collected with a corer (15 cm diameter, 20 cm deep) at five tidal levels along a transect perpendicular to the waterline. Six biological samples were monthly collected per level (levels 1 to 5). Level 1 was located on the uppermost intertidal flat region and Level 5 on the lowest one. Samples were sieved with a 0.5 mm mesh and frozen. In the laboratory, organisms were identified to the smallest possible taxonomic level under a stereoscopic microscope and quantified.

Sediment samples were taken in December 2005 from each of the five levels. Sediment grain size was analyzed through sieving and expressed as proportions. On the same date another sampling was conducted to determine total organic matter content (combustion at 550 °C for 5 h).

To analyze distribution and temporal variation of the benthic macrofauna a nonmetric multidimensional scaling ordination technique (MDS) was applied employing the Bray-Curtis similarity index (calculated on square-root transformed species abundance). The analysis was performed using PRIMER v5 (Clarke & Warwick, 1994; Clarke & Gorley, 2001). A similarity analysis (ANOSIM; \( \alpha = 0.05 \)) was performed to evaluate differences between sample levels and between seasons. Similarity percentage analysis (SIMPER) was used to explore the species contribution to similarity between the groups formed (Clarke, 1993).

To analyze temporal variation of the benthic macrofauna, monthly mean of species abundance was calculated with the aim of removing the effect of inter-level variability.

![Figure 2: Grain size composition of sediment.](image)

![Figure 3: Total organic matter content in sediments.](image)
To investigate the vertical distribution patterns from high to low levels, the data from December 2005 were subjected to a Canonical Correspondence Analysis (CCA) (Ter Braak, 1985), which included tidal level (levels 1 to 5), sediment (gravel, coarse, medium, fine, very fine sand; and mud) and total organic matter content as environmental variables. Forward selection of environmental and biotic variables and Monte Carlo permutations were used to identify a subset of the measured variables that exert significant and independent influence on the benthic macrofauna distribution.

Number of species (S), total macrobenthos abundance (A), and Shannon-Wiener diversity index (H') were also determined for each tidal level (Magurran 1989).

Small individuals of *Darina solenoides* (≤ 5 mm) and *M. e. platensis* (≤ 5 mm) were considered recruits and were counted under a micrometric eyeglass.

RESULTS

Environmental variables

The sediment type of levels 1 and 2 consisted mainly of mud (more than 50%) and very fine sand (30%). Sediment of Level 3 was classified as fine sand (41%), very fine sand (22%), and mud (16%); Level 4 consisted mainly of fine sand (33%) and gravel (31%); and Level 5 was composed of very fine sand (35%) and mud (26%) (Fig. 2). Total organic matter content decreased from Level 1 (2.5%) to Level 5 (1.1%) (Fig. 3).

Benthic macrofauna

A total of 24 taxa were collected (Table 1). Polychaeta was the most diverse taxa, followed by Mollusca and Crustacea. Based on mean abundance of each species in the pooled samples collected, *Darina solenoides* and *Mytilus edulis platensis* contributed with 59% of the total number of individuals. Species richness and diversity index values are shown in Table 1. Levels 3 and 4 exhibited the highest number of taxa and diversity index.

Spatial distribution

Results of MDS analysis showed a clear pattern of macrofauna distribution (Fig. 4). Samples were separated into three groups, indicating differences in abundance and composition among faunal assemblages. ANOSIM revealed significant differences among groups (Table 2). One group comprised levels 1 and 2, with dominance of the polychaete *Scolecolepides uncinatus*; the second group was composed of samples obtained from levels 3 and 4, characterized by *Darina solenoides* and *Mytilus edulis platensis*; and the third group included samples from Level 5, characterized by *Climenella mirror* and *Mysella* sp. (Table 3).

According to results of CCA between benthos species and environmental variables, the most important variable was tidal level, followed by fine sand and mud (Fig. 5). The variables coarse, medium, and very fine sand, and organic matter were not selected by the CCA. Axes 1 and 2 explained 85% of the variance of the species-environment relationship (Table 4). The ordination showed that tidal level, fine sand, and mud were related to axis 1 and that gravel was related to axis 2 (Table 5).
DISTRIBUTION AND TEMPORAL VARIATION OF THE BENTHIC FAUNA IN A TIDAL FLAT OF THE RIO GALLEGOS ESTUARY, PATAGONIA, ARGENTINA

Solecolepides uncinatus and Eteone sculp-ta were related to high tidal levels and muddy sediments. Darina solenoides, Kimbergonuphis dorsalis, Lumbrinereis cingulata, Glycinde armata, Aglaophamus praetiosus, Notocirrus lorum, Hemipodus patagonicus and Monoculopsis vallentinia assemblage was associated with intermediate levels and fine sand; Clymenella minor and Mysella sp., were associated with fine sand and lower levels, and Mytilus edulis platensis-Edotia tuberculata, with intermediate tidal levels and gravel sediments (Fig. 5).

Temporal variation

Darina solenoides and M. e. platensis were the most abundant species throughout the study period (Fig. 6). Darina solenoides presented highest abundance values in fall (April-May), with 35% of recruits in April, and at the end of spring (November) with 25%; recruitment of Mytilus edulis platensis was most intense in summer (41% in January) (Fig. 7). Abundance of polychaete and crustaceans together remained stable throughout the year evaluated (Fig. 6).

The MDS analysis of temporal variation indicated a tendency to the formation of two groups: one group included samples obtained in spring (September to November) and summer (December to February) months; the other group was composed of samples from fall (March to May) and winter (June to August) (Fig. 8). ANOSIM tests showed significant differences between groups (Table 6). The SIMPER analysis showed that Darina solenoides and M.e.platensis were the organisms that mostly contributed to formation of the fall-winter and summer-spring groups, respectively (Table 7).
DISCUSSION

The present study is the first description of benthic organism assemblages inhabiting the intertidal flat in an area located on the southern shore of the estuary, near the city of Río Gallegos. The sediment is characterized by the presence of high percentages of silt and clay at the high levels of the intertidal, and of sand at the intermediate and low levels. Organic matter content in sediments also differed among tidal levels, the highest values being recorded at high levels.

The benthic community was characterized by low species richness but great abundance of individuals, mainly the bivalve Darina solenoides and M. e. platensis. This feature has been mentioned for different estuarine areas of the South Atlantic, especially in comparison with the adjacent marine ecosystems (Ieno & Bastida, 1998; Lopez Gappa et al., 2001; Passadore et al., 2007).

In most tidal flats macrofauna distribution patterns vary with environmental conditions following an intertidal gradient (Whitlatch, 1977; Junoy & Vieitez, 1990); species diversity is in general greatest at the intermediate levels (Beukema, 1976; Armonies & Hellwig-Armonies, 1987). This pattern has been observed in our study, since distribution of species in the different habitats remained constant throughout the study period (12 months). The high tidal flat (levels 1 and 2) characterized by silty clay sediments, was dominated by the polychaete Scolecolepides uncinatus; two other polychaete species were also present but in low numbers. At the intermediate levels (3 and 4), the number of species and total fauna abundance increased. A group of species associated with sandy sediments, dominated by the clam Darina solenoides and the polychaete Kinbergonuphis dorsalis inhabits these levels. The mussel M.e.platensis was also recorded at levels 3 and 4, but in sediments with intermediate
proportions of gravel, because the species requires coarse sedimentary substrates to settle. The great abundance of juveniles of both the clam and the mussel that recruited at the intermediate level also indicates that this region provides good conditions as nursery grounds for these species. By contrast, the low levels seem to favour mainly the polychaete Clymenella minor and a bivalve, Mysella sp., both of which are dominant in very fine sands with intermediate proportions of mud.

In general terms, intertidal zoobenthic assemblages at the Río Gallegos estuary are notably similar in composition to those described by Espoz...
et al. (2008) for Bahía Loma in the Chilean portion of the Strait of Magellan. These authors described a community dominated by *Darina solenoides*, polychaete and crustaceans; however, we did not record the polychaete *Aricidea* sp., which has been mentioned as the most abundant polychaete species. On the other hand, no similarities were observed between the species assemblage found in the estuary and that described by Lopez Gappa & Cruz Suiero (2006) for a coastal area of the South Atlantic in Tierra del Fuego (Bahía San Sebastián).

During our study we did not observe temporal variability of species composition. Temporal fluctuations recorded were related to changes in species abundance, which were strongly influenced by the incorporation of recruits to the populations. Settlement of the clam *D. solenoides* presented two peaks: one at the start of fall and the other in late spring-early summer. The mussel *M. e. platensis*,

Table 3:
Results of SIMPER analysis. Main species that contributed (%) to the differences observed among groups.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Level 1-2</th>
<th>Level 3-4</th>
<th>Level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scolecolepides uncinatus</td>
<td>94.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kinbergonuphis dorsalis</td>
<td>24.46</td>
<td>20.71</td>
<td></td>
</tr>
<tr>
<td>Clymenella minor</td>
<td></td>
<td>34.62</td>
<td></td>
</tr>
<tr>
<td>Darina solenoides</td>
<td></td>
<td>33.46</td>
<td></td>
</tr>
<tr>
<td>Mytilus edulis platensis</td>
<td></td>
<td>20.10</td>
<td></td>
</tr>
<tr>
<td>Mysella sp.</td>
<td></td>
<td></td>
<td>31.50</td>
</tr>
</tbody>
</table>

Table 4:
Summary of CCA ordination.

<table>
<thead>
<tr>
<th>Axis</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eigenvalues</td>
<td>0.90</td>
<td>0.27</td>
<td>0.134</td>
<td>1.54</td>
</tr>
<tr>
<td>species-environment correlations</td>
<td>0.86</td>
<td>0.80</td>
<td>0.67</td>
<td></td>
</tr>
<tr>
<td>Cumulative percentage variance</td>
<td>25.8</td>
<td>26.2</td>
<td>24.9</td>
<td></td>
</tr>
<tr>
<td>Species data</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Species-environment relationship</td>
<td>45.9</td>
<td>85.0</td>
<td>92.5</td>
<td></td>
</tr>
</tbody>
</table>

Table 5:
CCA. Weighted correlation matrix of environmental variables with the species axis.

<table>
<thead>
<tr>
<th>Name</th>
<th>Axis 1</th>
<th>Axis 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal Level</td>
<td>0.85</td>
<td>0.39</td>
</tr>
<tr>
<td>Fine sand</td>
<td>-0.78</td>
<td>-0.15</td>
</tr>
<tr>
<td>Mud</td>
<td>0.72</td>
<td>-0.01</td>
</tr>
<tr>
<td>Gravel</td>
<td>-0.02</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Table 6:
Analysis of similarity (ANOSIM) between seasons.
Global R: 0.852, P= 0.1%.

<table>
<thead>
<tr>
<th>Groups</th>
<th>R</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer vs Fall</td>
<td>1.0</td>
<td>0.1</td>
</tr>
<tr>
<td>Summer vs Winter</td>
<td>1.0</td>
<td>0.1</td>
</tr>
<tr>
<td>Summer vs Spring</td>
<td>0.793</td>
<td>0.1</td>
</tr>
<tr>
<td>Fall vs Winter</td>
<td>0.385</td>
<td>0.1</td>
</tr>
<tr>
<td>Fall vs Spring</td>
<td>1.0</td>
<td>0.1</td>
</tr>
<tr>
<td>Winter vs Spring</td>
<td>1.0</td>
<td>0.1</td>
</tr>
</tbody>
</table>
however, exhibited the highest proportion of recruits in summer. Several authors have mentioned that recruitment of benthic species affects abundance of macrofaunal communities (Colling et al., 2007; Das Neves et al., 2008). But other factors may also be responsible for changes in the number of individuals, such as predation pressure exerted by crustacean, fish, and bird species throughout the year or when these species are present in coastal environments during migration (Gianuca 1983; Jaramillo et al., 1996; Iribarne & Martinez, 1999; Ferreira et al., 2005). The arrival of flocks of some bird species on their migration flight agrees with the peak of macrofauna abundance in southern Brazil (Vooren, 1998).

The Río Gallegos estuary has been mentioned as an important wetland for the Red knot Calidris canutus and the Hudsonian Godwit Limosa haemastica (Ferrari et al., 2002, 2007; Albrieu et al., 2004). These species are of conservation concern because of the reduction observed in their populations at the global scale (Baker et al., 2004; González et al., 2004; Morrison et al., 2004, 2006); they use the estuary as feeding and roosting sites during their transcontinental migrations. Darina solenoides has been mentioned as the main prey item in the diet of the Hudsonian godwit and the Red knot in several intertidal sectors in southern Patagonia, both in Argentina and Chile. The mussel and several polychaete species are also secondary prey for those bird species (Espoz et al., 2008; Hernández et al., 2004, 2008; Lizarralde et al., 2010).

A monitoring program to study different sites of the estuary along a salinity gradient needs to be developed, since salinity, which has not been considered in the present work, has been mentioned as a determining factor in the species distribution of estuarine environments (Dittmann, 2000). Thus, a more detailed record of the number of benthic species present at the estuary could be obtained and the species contribution to energy flow and especially to the diet of birds and fishes could be elucidated. Moreover, long-term studies will help us understand whether changes detected in benthic communities are naturally induced or are a consequence of urban development and plan management strategies for the area accordingly.

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DISTRIBUTION AND TEMPORAL VARIATION OF THE BENTHIC FAUNA IN A TIDAL FLAT OF THE RIO GALLEGOS ESTUARY, PATAGONIA, ARGENTINA


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