PANAMJAS
Pan-American Journal of Aquatic Sciences

Spatial and temporal variations in biodiversity of polychaetes (Annelida, Polychaeta) along a multipurpose coastline

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Abstract. This study describes the spatial and temporal variations in the biodiversity of polychaetes in an area subjected to different anthropogenic activities (fishing, tourism and oil refinery activities). It involved the evaluation of sediment data and biological assessment of these invertebrates in 20 stations distributed along the coast line of the "Península de Paraguaná", being sampled in 10 occasions, between july-2008 and September-2010. Sediment analyses showed a northern zone dominated by the sand fraction, and a southern zone with a large content of mud and a high percentage of organic matter. A total of 18 taxonomic groups were recorded, where 7368 individuals of the polychaete group were identified, belonging to 35 families, with Capitellidae (35%) and Spionidae (21%) as the most abundant. The family richness oscillated between 1,6 nFam/Cam (S19) and 6,8 nFam/Cam (S16), while the higher densities were reported in the 18 and 19 stations, reaching the maximum value of 1789,73 ± 3152,86 ind/m^2 (S18). These high values belonged to capitellids and spionids (> 6000 ind/m^2), and suggested the existence of a local disturbance event that is associated with the oil refinery activities. This study showed how the analyses of biological data can be useful for detecting the influence of anthropogenic impact events when chemical information is not available.

Key words: environmental impact, biodiversity, community assemblage, oil industry, environmental monitoring

Resumen.Variaciones espaciales y temporales de la biodiversidad de poliquetos (Annelida, Polychaeta) en una costa de usos múltiples. Este estudio describe las variaciones espacio-temporales de poliquetos en una región bajo influencia antropogénica (actividades de pesca, turismo y refinerías de petróleo). El trabajo involucró la evaluación del sedimento y el análisis de estos invertebrados en 20 estaciones distribuidas a lo largo de la costa de la Península de Paraguaná en el periodo comprendido entre julio2008-septiembre2010. Los resultados del análisis de sedimentos revelaron que la zona norte estaba dominada por la fracción arenosa, mientras que en la zona sur prevaleció la fracción fangosa, con un mayor porcentaje de materia orgánica. Se identificaron18 grupos taxonómicos, cuantificando 7368 poliquetos que comprendieron un total de 35 familias, siendo Capitellidae (35%) y Spionidae (21%) las más abundantes. La riqueza de familias osciló entre 1,6 nFam/Cam (E19) y 6,8 nFam/Cam (E16); las mayores densidades fueron registradas en las estaciones 18 y 19, alcanzando los valores máximos de 1789,73 ± 3152,86 ind/m^2 (E18). Estos altos valores corresponden a capitelidos y a espionidos (> 6000 ind/m^2), y sugieren la existencia de un disturbio local asociado con las actividades de la refinería. Este estudio mostró la utilidad de analizar datos biológicos para detectar influencias antropogénicas cuando no está disponible la información química.

Palabras claves: impacto ambiental, biodiversidad, estructura comunitaria, refinería petrolera, seguimiento ambiental

Introduction

Coastal areas are directly affected by anthropogenic impacts mainly derived from industrial and urban activities. Urban runoff, sewage disposal, industrial effluents, oil production and transportation are some of the most important sources of anthropogenic impacts (Alongi 1998, Venturini *et al*. 2008, Begon *et al*. 2006). For this reason, human disturbances, whether temporary or permanent, are important components that might cause abrupt changes in benthic marine communities, altering their background conditions, and shifting them to produce different patterns (Chollett & Bone 2007). These communities also provide valuable information about the degree of environmental degradation, being used as bioindicators in monitoring studies (Gadzala-Kopciuch 2004, Guzman-Alvis & Ardila 2004). Within the macrofauna, polychaetes are one of the dominant groups in most marine habitats, showing patterns that often reflect the overall macrofauna distribution (Hernández-Alcantara & Solís-Weiss 2005). Particularly, polychaetes have been identified by several authors as a group of marine invertebrates that quickly respond to environmental disturbances, being frequently found in soft-bottom habitats and usually representing more than 50% of the total abundance of the macrofauna (Chollett & Bone 2007). Adittionally, current evidence suggests that the family level is a sufficient taxonomic rank for monitoring pollution effects in soft-bottom environments (Somerfield & Clarke 1995, Muniz & Pires-Vannin 2005, Bacci *et al*. 2009, Musco *et al*. 2009).

Based in the "taxonomic sufficiency" concept proposed by Ellis (1985), some authors suggest that the data analysis at higher levels than those of species have been proposed as a surrogate for the typical analysis of species-abundance data, especially, under conditions involving prominent pollution gradients. In these studies a slight information loss was detected when organisms were identified at higher levels than species (e.g., genera, families). Studies dealing with contamination gradients found that the family level produced similar results to those generated by species level (Gomez *et al*. 2003, Terlitzzi *et al*. 2003, Muniz & Pires-Vannin 2005, and literature therein).

Although several coast line areas in Venezuela are heavily influenced by man-made activities, only a few studies have been done with the same aim proposed in our assessment (Jaffe *et al*. 1995, Bastidas & García 1997, García *et al*. 2008). The "Península de Paraguaná" is an important example of a shoreline area influenced by human disturbances, being located in the west coast of the country, which is an important region for commercial exchange, tourism and oil industry activities. Since 2008, environmental and ecological evaluations have been done in the west coast of the peninsula to understand how the polychaete biodiversity are expected to vary along a contamination gradient. These evaluations have prompted valuable information on sediment and benthic macrofauna in this region. Therefore, the aim of this study was to analyze such data to study the condition of soft-bottom habitats by describing their sediment characteristics and biodiversity of polychaetes in a family level, evaluating possible associations between these variables that could suggest the influence of human-kind activities.

Materials and Methods

Study area

This study was conducted in the "Península de Paraguaná", which is located in the northwest region of Venezuela (Fig. 1a). The surveys were performed in a coastal area of approximately 30 km long, where a total of 20 stations (sampling sites) were established, from "El Pico" (Station 1), located in the north, to "Punta La Barra" (Station 20), located in the south (Fig. 1b). The sampling stations were usually shallow (<10 m depth) with different levels of intervention associated to human activities. Unpublished data indicate that those stations located towards the northern zone (1-10) had low levels of intervention, whereas the southern stations (11-20) were associated mainly to oil refineries (Paraguaná Refining Complex – Cardón).

Sampling

All 20 stations were sampled every 3 months, between 2008 and 2010, for a total of 10 field surveys. The samples for sediment analyses (2 replicates) and macrofauna composition (3 replicates) were collected using a Van Veen grab (0,0036 m^2). The sediment samples were refrigerated and macrofaunal samples were preserved in 10% formalin and transported to the laboratory. Sediment granulometric analysis was done by standard gravimetric methods (Folk & Ward 1957), to determine sediment fractions (i.e., the percentages of gravel, sand, mud), organic carbon (OC, by oxidation in the presence of chromic acid, Jackson 1970) and organic matter content (OM, by measuring the loss of weight following the ignition method, Holme & McIntyre 1984). The macrofauna samples were sieved on 1mm mesh and stained with rose Bengal. All benthic organisms were sorted and counted under a stereo microscope, and identified to the lowest possible taxonomic level (Phylum, Class or Order) while the polychaetes were separated by families, which is an adequate taxonomic level to detect changes at a significant statistical resolution (Gray *et al*. 1988, Warwick 1988a, b, Dauvin *et al*. 2003).

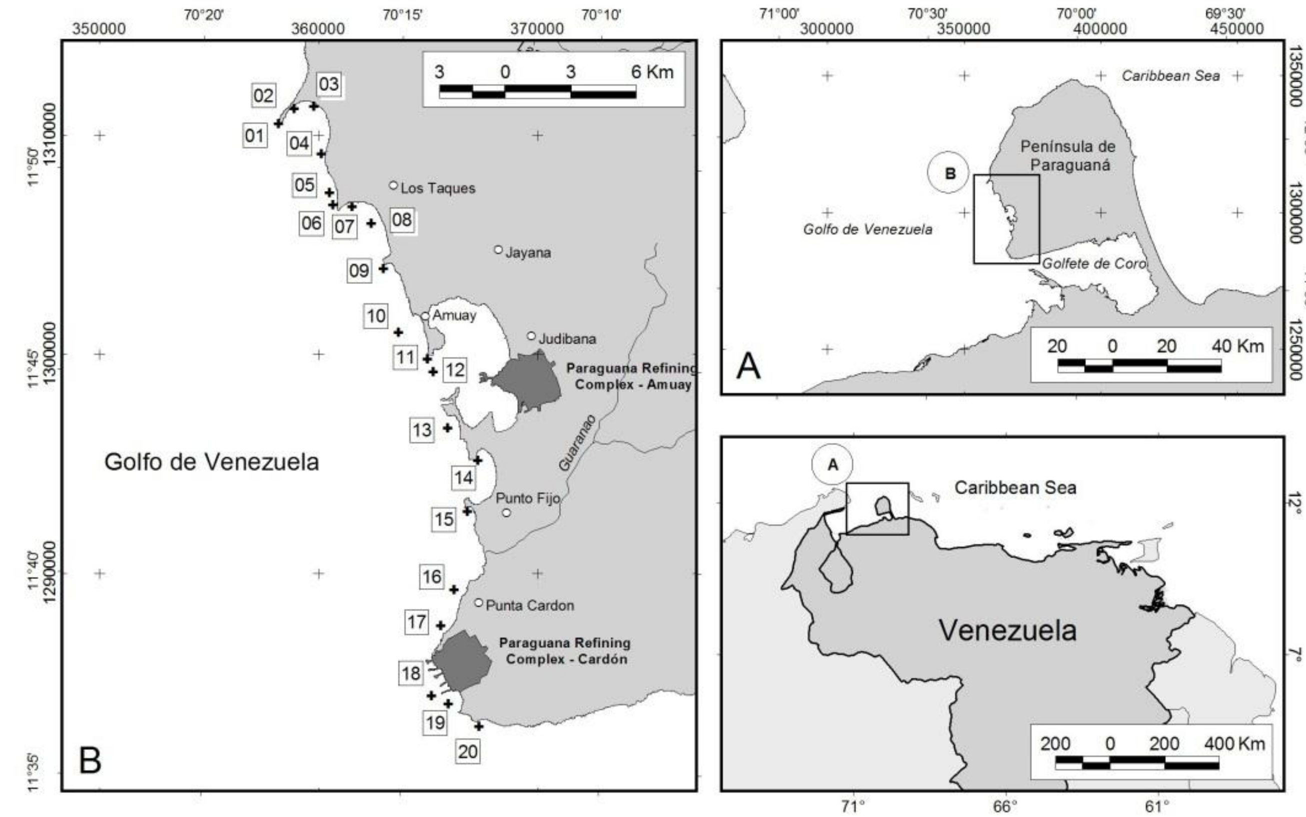

Figure 1. Map of the study area showing the survey locations (A) and the sampling sites distribution (B). The location of the oil refineries is also indicated.

Data Analysis

A Principal Component Analysis (PCA) was performed to identify any spatial patterns in the sediment samples. Additionally, differences between stations were tested with a one-way analysis of similarities ANOSIM. Temporal and spatial variations of the polychaete assemblage were analyzed in detail, using the richness and density data. Richness was expressed as the average number of families present per station or per sampling date, whereas density values were expressed as the number of individuals per square meter (ind/m^2). The relative changes between sampling dates and stations were evaluated using the Bray–Curtis similarity index applied to the abundance data, which were graphically represented using multi-dimensional scaling (nMDS) ordinations. SIMPER analysis was done to evaluate the contribution of each family to the differences between stations. Variations in families composition between stations and sampling dates were tested using a permutational multivariate analysis of variance (PERMANOVA) (Anderson 2001, 2004), based on the Bray–Curtis similarity measure on untransformed data. Each term of the analysis was tested using 4999 random permutations of appropriate units, with station (20 levels) and sampling (10 levels) as fixed factors. All analyses were performed using PRIMER (Clarke 1993, Clarke & Gorley 2001, 2006)

Results

Sediment analysis

Based on sediment composition, the coastal zone was separated in two groups of station: the ones located to the north (stations 3 to 9) with a higher proportion of sand (>70%), and the ones located to the south (stations 10 to 20) with higher silt-clay content (60%). The gravel fraction was very low (<15%) for most of the stations (Fig. 2a). The percentage of Organic Carbon (OC) ranged between 0,52% and 1,71%, with no particular spatial pattern that could separate them. On the other hand, the percentage of Organic Matter (OM) was greater in the southern stations (ranging from 5,62% to 13,54%), compared to the northern ones (3,88% - 7,71%, Fig. 2b).

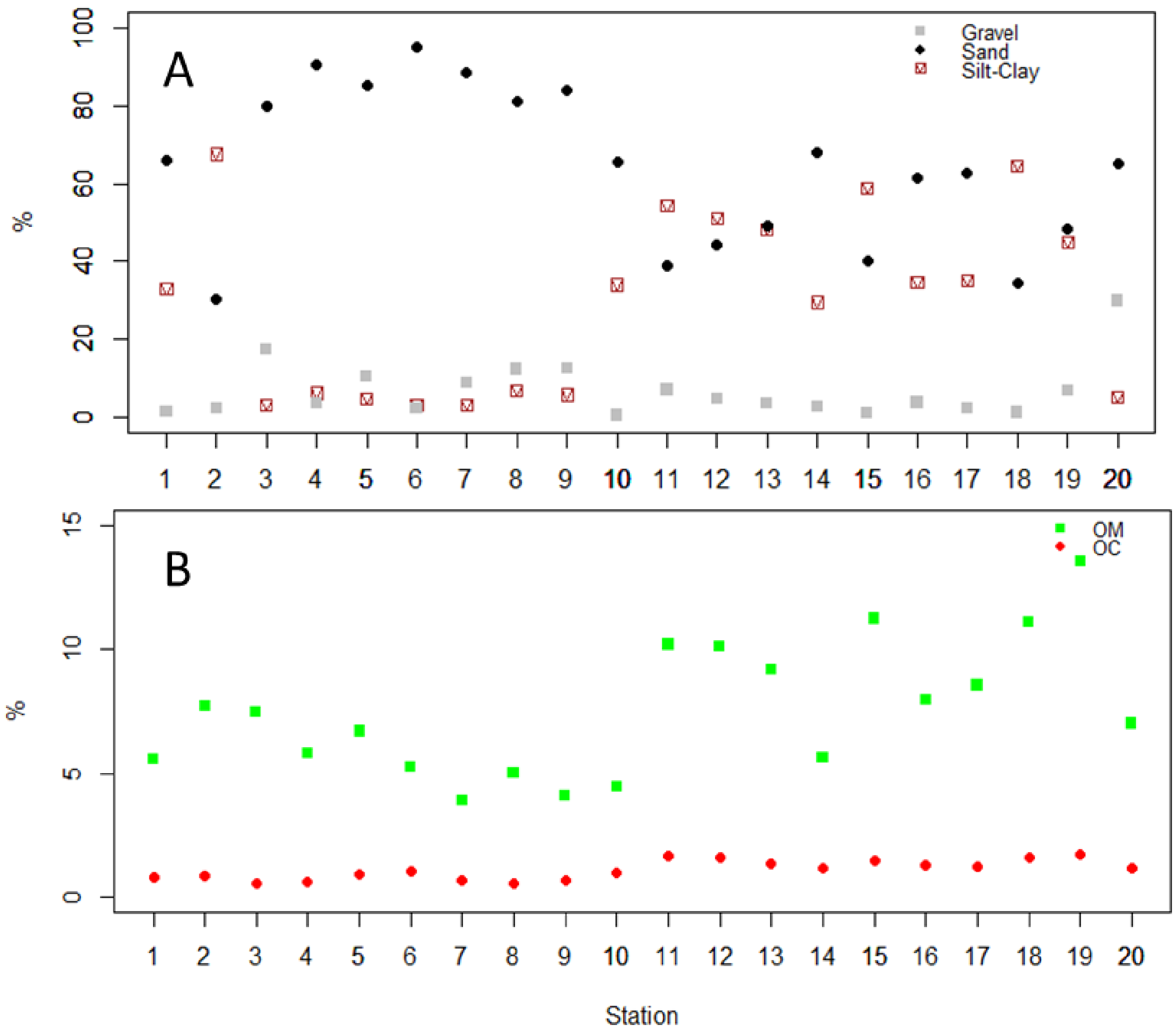

Figure 2. Percentages of sediment variables shown by stations. A) Sediment fractions: Silt-Clay, Sand, Gravel and B) Organic Carbon (OC) and Organic Matter (OM).

The results of the Principal Component Analysis showed that the first axis explained 54,5% of the total variability, being positively correlated with the percentages of silt-clay (0,57) and OM (0,43), and negatively correlated with the percentages of gravel (-0,27). The second axis explained 18,9% of the variability, and it was negatively correlated with the percentage of gravel (-0,88) (Fig. 3). The Analysis of Similarity revealed that there was a significant difference between stations, according to their sediment fraction composition (ANOSIM, global R = 0,284, with a significance of 0,1%), with the northern stations being separated from the southern sites.

Community structure

The macrofauna was composed by a total of 18 taxonomic groups, where annelids (polychaetes and oligochaetes), nematodes, crustaceans (peracarids, decapods, ostracods), molluscs (bivalves, gastropods, scaphopods), sipunculids, nemerteans, priapulids, echinoderms (holothurids, echiurids) and lancelets, in addition to fishes were all present in the study. From these, the polychaetes were the most abundant group, representing the 68,5% of all the specimens collected. Within this group, a total of 7368 individuals were recorded, belonging to 35 families, where Capitellidae (35%), Spionidae (21%), Sabellidae (8%), Lumbrineridae and Nereididae (7%) were the most abundant. These five families represented 71% of the total polychaete fauna. The 30 remaining families represented less than 29% altogether.

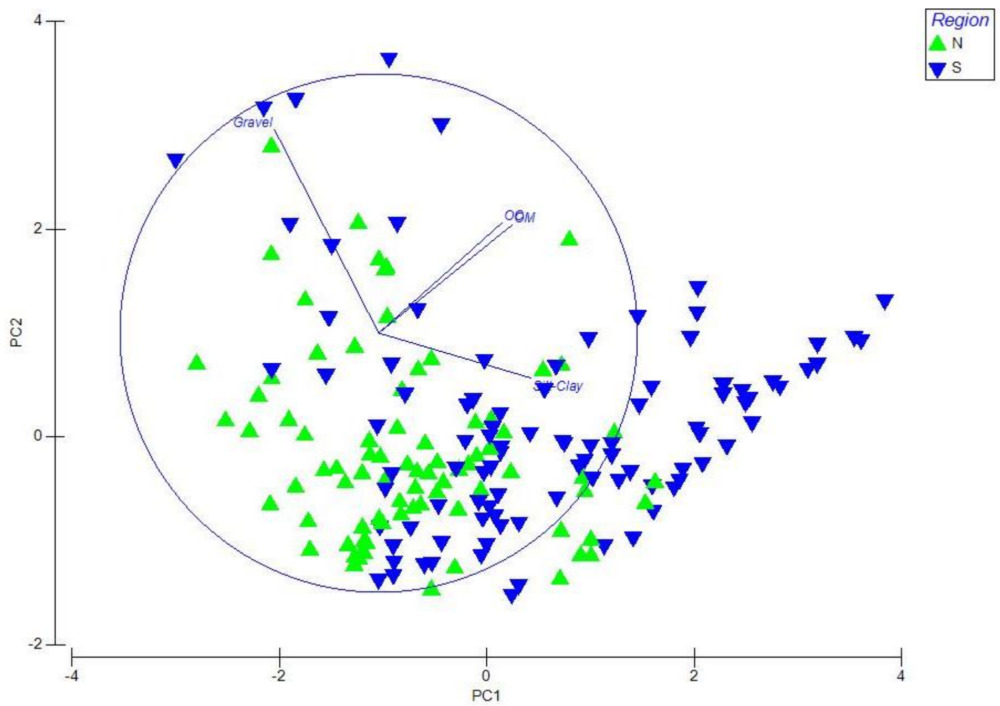

Figure 3. PCA ordination for sediment data. North region (N) is the area from station 1 to station 10, and South region (S) is that from Station 11 to station 20.

Spatial and temporal variation of polychaetes

Richness data showed the lowest mean value in station 19, with 1.6±1.4 nFam/sampling, while the highest richness was obtained in station 16, with 6.8±3.7 nFam/sampling. Figure 4A revealed the existence of 3 groups of stations with some particular richness variations, as we go from north to south: a group of increasing values between stations 1-6, a second group between stations 7-15 with a bell-shape figure around the stations 11 and 12, and another group with a decreasing trend located to the south (from stations 16 to 20, Fig. 4A), specially in station 19. On the other hand, the density analyses showed a regular spatial distribution for most of the stations, with values lower than 500 ind/m^2, except for the stations 5, 18 and 19. Density values in these stations exceeded this threshold, with a maximum peak of 1789,73 ±3152,86 ind/m^2 in station 18. The differentiation into groups was not so evident in this case, where some stations, such as 18 and 19, differ greatly from the rest. This result suggests the presence of some stations with average values ranging between 100 and 500 ind/m^2, and those exceeding this average threshold (Fig. 4B). This trend is better depicted in Figure 4C, where the inverse relation between both variables can be observed; that is**,** largest density values and a concomitant decrease of richness in stations 18 and 19, compared to the rest.

Comparisons between sampling dates showed that the family richness varied between 1.85±1.66 nFam/Sta in Mar-10, and 7.25±3.37 nFam/Sta in Jul-08, but most of the values were found ranging between 3 and 5 nFam/Sta (Fig. 5A). The mean density per sampling date varied between 893,17±1447,61 ind/m^2 in Jul-08 and 111,7±140,62 ind/m^2 during Dec-09 (Fig. 5B). In general, richness and density data showed a similar trend regardless time; that is, a decreasing over time during all the sampled period, except for Mar-10, where an opposite relation could be seen, in which the density increases and is followed by a decrease of the richness values (Fig. 5C).

The nMDS plots did not show a clear separation for the majority of the samples between stations and sampling dates. However some stations (18 and 19) and sampling dates (campaign 1:Jul-08, campaign 6: Sep-09 and campaign 8: Mar-10) were separated in small groups (Fig. 6). The PERMANOVA analysis showed significant differences between stations and sampling dates ($p < 0,005$), indicating spatial and temporal changes in polychaete assemblages. The significant interaction (time x station) showed that the short-term temporal changes varied from station to station, suggesting the occurrence of site-specific events.

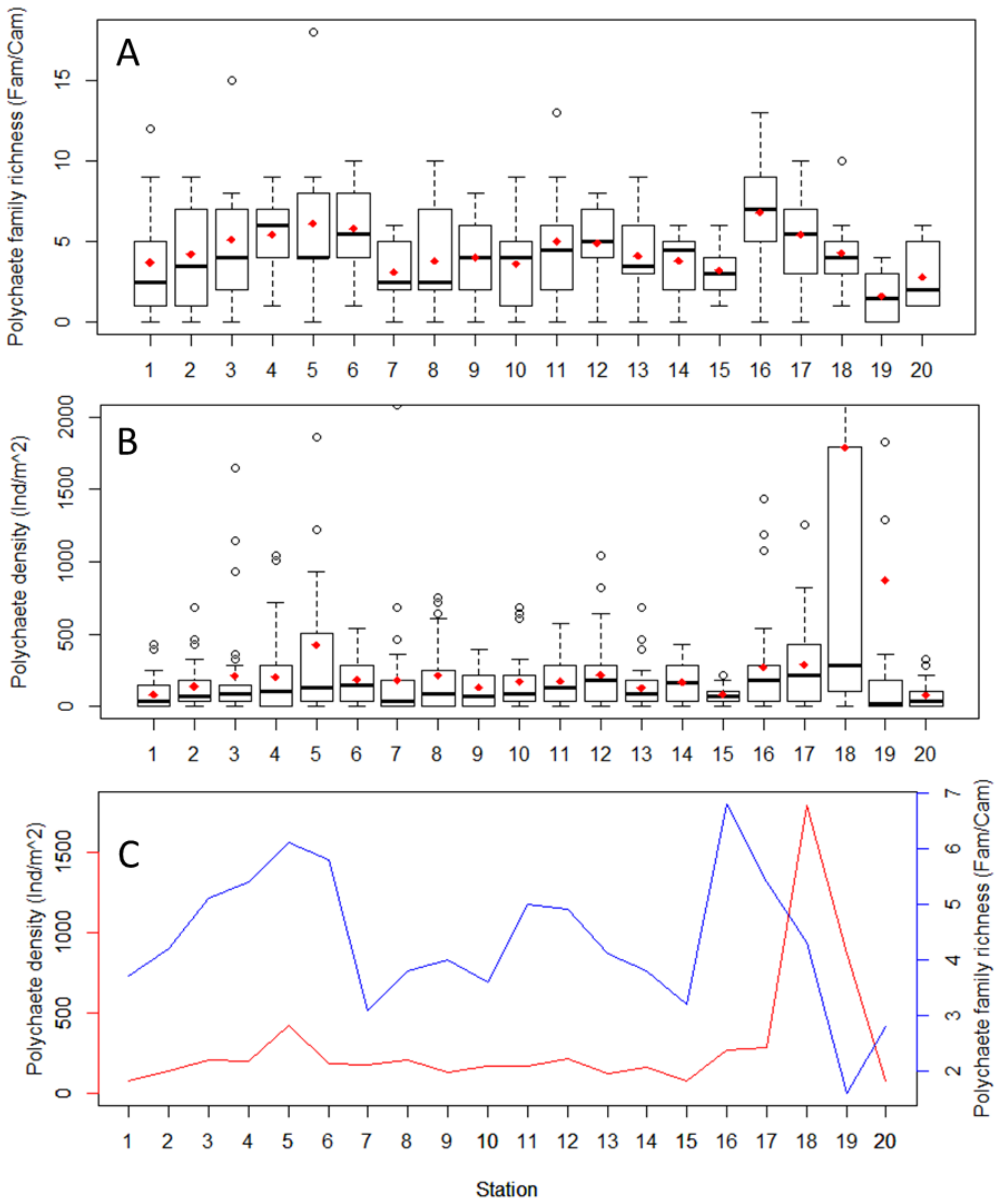

Figure 4. Spatial variation of the polychaeta variables: Richness (A) and Density (B) boxplots, and trend comparison between both variables (C, richness: blue line, density: red line).

The SIMPER analysis indicated that the polychaete families that contributed the most to differences between the pairs of stations were Spionidae, Lumbrineridae, Nereididae, Sabellidae and Capitellidae. The five most relevant families showed three main spatial patterns (Fig. 7): 1) Spionidae and Capitellidae families that showed high densities in stations located in the south zone (e.g., Capitellidae, Fig. 7A), 2) a family of preferential distribution in some of the stations in the northern zone (Fig. 7B, Sabellidae), 3) Nereididae and Lumbrineridae families with a wider geographic distribution along the coastal zone, covering a wider range of stations (e.g., Nereididae, Fig. 7C). Although Spionidae was present in almost all stations and sampling dates, they were more abundant in Jul-08, particularly at station 19, with densities superior to 578 ind/m^2; whereas capitellids were almost exclusive in stations 18 and 19 during Sep-09 and Apr-10.

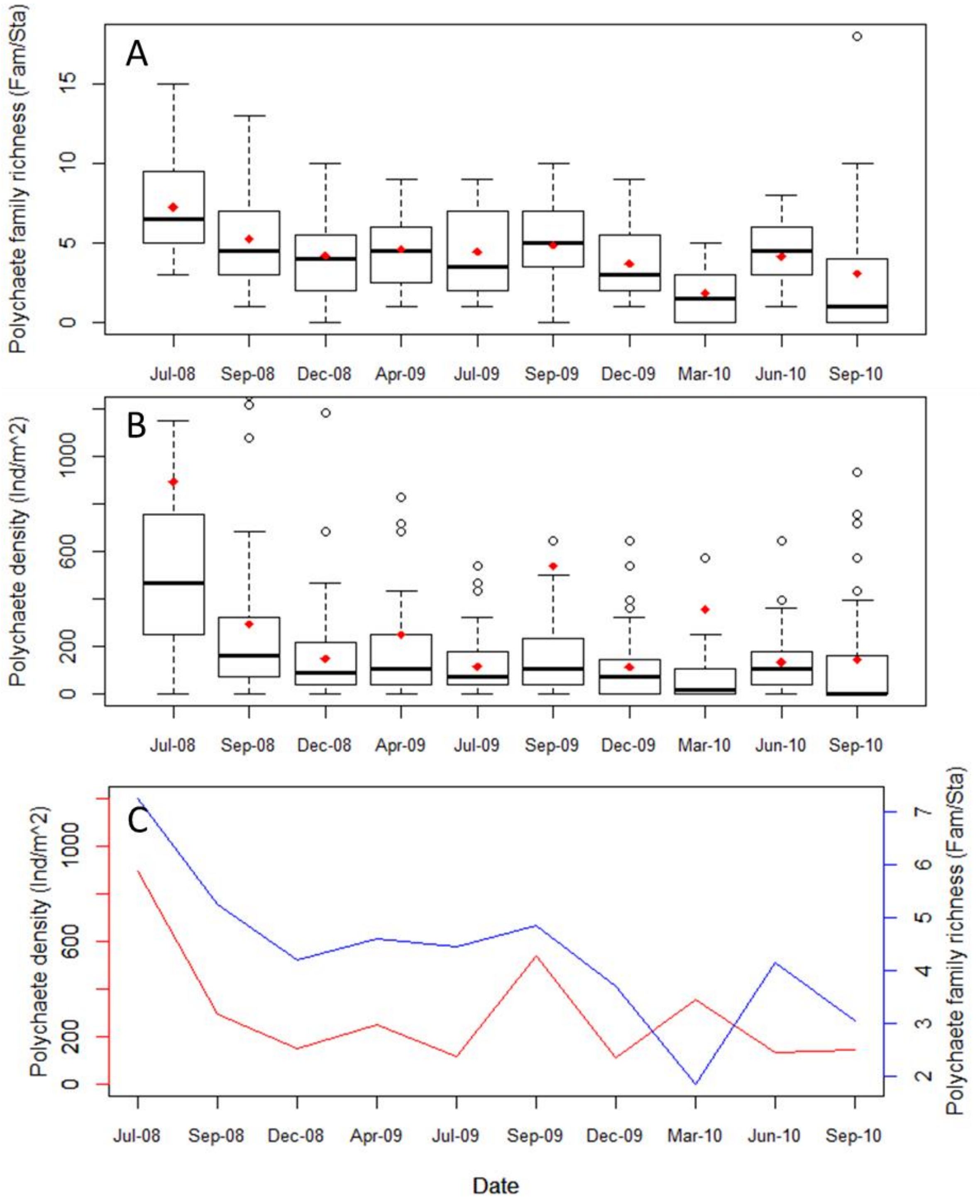

Figure 5. Temporal variation of polychaeta: Richness (A) and Density (B) boxplots, and trend comparison between both variables (C, richness: blue line, density: red line).

Discussion

This study provides the first characterization of marine benthic macrofauna for the western coast of Venezuela, spanning a coastline extension of approximately 30 km. It also represents the largest temporal monitoring study, with over 2½ years of continuous surveys. This study showed that the macrofauna biodiversity associated to this region was represented by 18 invertebrate groups, dominated by polychaetes, which were also represented by a high diversity of polychaete families (35 families). Higher diversity results were reported by Bone *et al.* (2011) for the east coast of the country, where 43 polychaete families were found in the continental shelf off the Orinoco river delta. Nonetheless, these authors also reported very low density values for this region.

The sediment results showed that the study site was separated in two different zones: one at the north, with high percentages of sand and low organic matter content, including some beaches for touristic activities and few or no human intervention, and the other at the south, characterized by high silt-clay content and larger proportion of organic matter. The most southern stations are associated to a great degree of man-kind intervention (fishing settlements, and refineries), constituting the deeper sites (>10m), as they are close to the refinery piers of the Paraguaná Refining Complex - Cardón. Therefore, deposition of the finer particles is favored, holding great quantities of organic matter and organic carbon compared with the coarser sediment zones (Schnitzer & Khan 1975, Jimenez & Lal 2006).

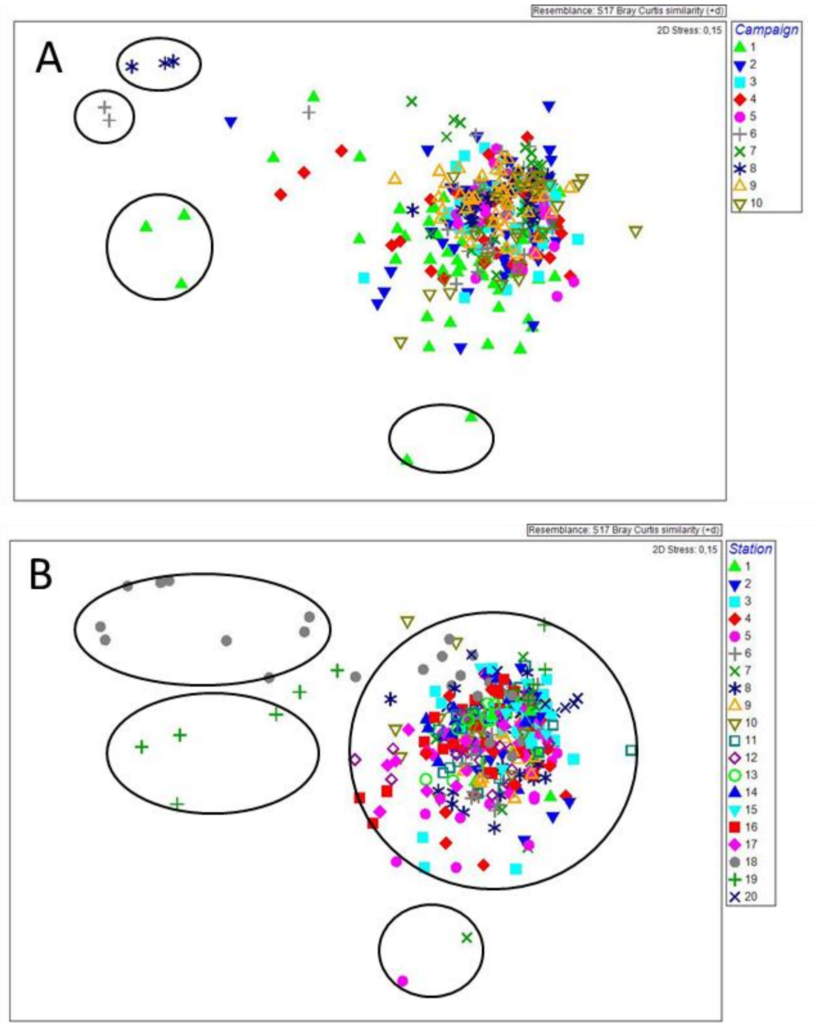

Figure 6. nMDS ordination for the 10 sampling dates (A) and the 20 stations (B) based on the polychaeta abundance

Benthic community was represented by a rich macrofauna, with polychaetes being the dominant group, which is common in these soft bottom seabeds (Cruz & Bone 1997, Hernández-Alcantara & Solís-Weiss, 2005, Dean 2008, Bone *et al*. 2011). Nonetheless, biodiversity was variable in space and time, being very low at some stations and sampling dates. Polychaete densities did not show the existence of spatial gradients along the study area and a high temporal variability was observed, but no seasonality. The lack of seasonality suggests that it is not a determinant process in the population dynamics in this area. Some studies indicate that in certain regions, especially in temperate zones, the seasonality plays a determining role over the benthic fauna (Sanders 1968, Brazeiro & Defeo 1996, Hernández-Alcantara & Solís-Weiss 2005). This study area corresponds to a tropical region, where it is very likely that variations in climatic conditions are not abrupt enough to generate strong changes in the composition of the benthic community. However, some studies have shown that other variables could be important factors in generate community variations. For instance, Chollet & Bone (2007) reported two species of spionids that responded with high abundance peaks during dramatic decreases in salinity values, as a result of a torrential rain event affecting a shallow marine coastal region. Bone *et al.* (2011) found that the discharges of the Orinoco river on the continental shelf, significantly affected the salinity and the organic matter content of the marine recipient waters, conditioning the composition and abundance of the polychaete community.

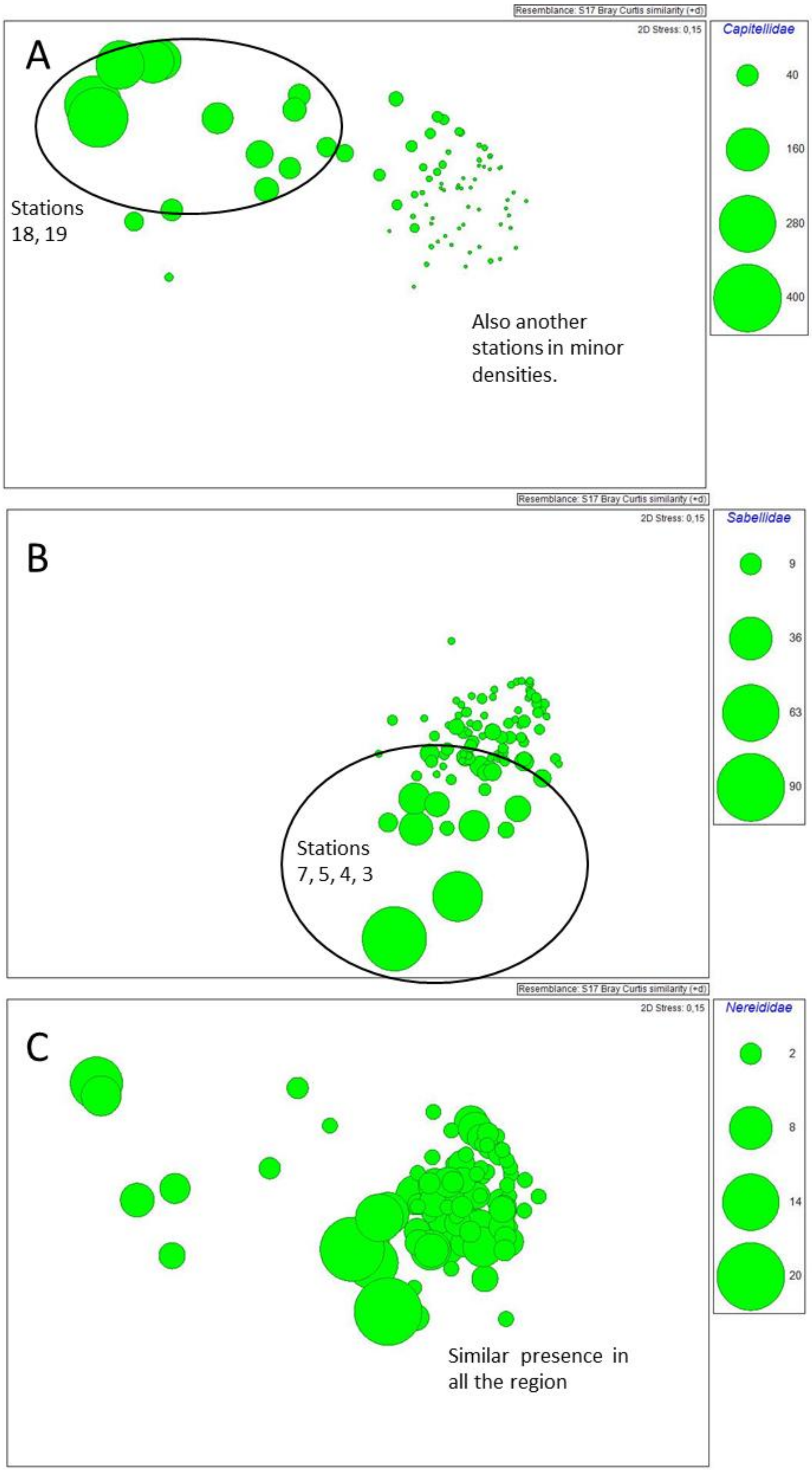

Figure 7. MDS Bubble's analysis based on the abundance of 3 of the 5 most relevant polychaete families: Capitellidae (A), Sabellidae (B) and Nereididae (C).

Sediment characteristics may also determine variation patterns (Jaramillo *et al*. 1998, Van Hoey *et al*. 2004, Guzmán-Alvis *et al*. 2006). Our results indicated that significant differences were given due to high values in some specific stations and sampling dates. For example, high density values and low richness were recorded at station 18 during the Sep-09 sampling (dominated by capitellids), and at station 19 during Jul-08 (dominated by spionids). These stations had finer sediment texture and large proportions of organic matter, being also the closest to the refinery located in the south zone.

The two most abundant families (Capitellidae and Spionidae) associated to these particular stations showed high and variable population densities. Their patterns of temporal variation did not indicate consistent population dynamic associated to seasonal changes, suggesting that the dynamic of these families is probably mediated by specific environment conditions prevailing in some sampling dates and stations. These families are recognized for presenting opportunistic species that can rapidly colonize and dramatically increase their populations under certain conditions. Several authors have reached the same conclusions. For example, Chesney & Tenore (1985) with *Capitella capitata* in colonization experiments carried out in the laboratory and Cruz & Bone (1997) after performing dredging simulation experiments in the field. These last authors found that *Prinospio dayi* and *Capitella capitata* were the first to re-colonize the substrate after disturbances. They also reported that these species suffer immediate reductions after prompting a sudden increase in their densities, justifying the high variation associated to these species.

Despite the atypical behaviour in stations 18 and 19, the lack of chemical information limits the analysis that could be made with the present data. Venturini *et al.* (2008) highlight the importance of conducting multivariate analysis that combines information of the chemical and biological variables, so that the study of anthropogenic impact over these ecosystems can be approached in a more efficient way. Nonetheless, our results clearly showed that richness was very low and densities were very high in stations 18 and 19. These presence-absence patterns and density variations of capitellids and spionids suggest the presence of some local disturbance events, associated with the activities of the Paraguaná Refining Complex - Cardón, affecting the biodiversity of the marine community established in this coast-line of the “Península of Paraguaná”.

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Received December 2012
Accepted August 2013
Published online September 2013