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Research Article

Influence of riverine outputs on sandy beaches of Higuerote, central coast of Venezuela

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ABSTRACT. The influence of riverine outputs from the Tuy River on the coastal processes of near sandy beaches was assessed by measuring the physical and chemical characteristics of water and sediment samples at eight sites along the north central Venezuelan coast and from the rivers that flow through this region into the sea (Tuy, Capaya, Curiepe) during two field surveys. In addition, the behavior of the Tuy River discharge plume was evaluated using remote sensors, and its effect on the population abundance and size structure of the clam *Tivela mactroides* was determined. Of the three rivers evaluated, the Tuy River had the highest impact on the coastal zone (789.15 ± 190.63 km^2) in terms of flow rate (246.39 $m^3 s^{-1}$), nutrients (659.61 ± 503.27 g s^{-1} total nitrogen; 52 ± 53.09 g s^{-1} total phosphorus) and sedimentary material (9320.84 ± 9728.15 g s^{-1}). The variables measured (salinity, total nitrogen and phosphorus, pH, turbidity, and total organic carbon) showed a spatial gradient along the coast. *Tivela mactroides* had the highest biomass and density (9126.8 ± 1562 g m^{-2}; 9222.22 ± 1976.72 ind m^{-2}) at the sites farthest from the river mouths and smaller sizes (< 13 mm long) at sites close to the river mouths. The Tuy River plume modifies the functioning of the coastal system processes by discharging large amounts of nutrients and sedimentary material into the water column, which are then distributed by marine currents and alongshore transport. These contributions are used by *T. mactroides* populations, which show high abundances and differentiation in size structure along this coastline.

Keywords: nutrients, river plume, physical and chemical gradient, *Tivela mactroides*, biomass, size structure, Venezuela.

Influencia de aportes fluviales en playas arenosas de Higuerote, costa central de Venezuela

RESUMEN. Para evaluar los aportes del río Tuy sobre los procesos costeros en playas arenosas cercanas, se examinó en dos campañas de muestreo, las características fisicas y químicas a nivel de agua y sedimento en ocho estaciones ubicadas a lo largo de la costa centro norte de Venezuela, el cauce de los ríos que allí desembocan (Tuy, Capaya, Curiepe), además del comportamiento de la pluma del río Tuy mediante sensores remotos y su influencia sobre las poblaciones de la almeja *Tivela mactroides* en cuanto a abundancia y estructura de talla. El río Tuy tuvo mayor predominio sobre la zona costera (789,15 ± 190,63 km^2), presentó el mayor aporte líquido (246,39 $m^3 s^{-1}$), de nutrientes (659,61 ± 503,27 g s^{-1} nitrógeno total; 52 ± 53,09 g s^{-1} fósforo total) y material sedimentario (9320,84 ± 9728,15 g s^{-1}). Existe un gradiente espacial de las variables medidas a lo largo de la costa (salinidad, nitrógeno y fósforo total, pH, turbidez, carbono orgánico total). *Tivela mactroides* presentó mayor biomasa y densidad (9126,8 ± 1562 g m^{-2}; 9222,22 ± 1976,72 ind m^{-2}) en las estaciones alejadas de la desembocadura de los ríos, y presentó menores tallas (< 13 mm) en estaciones cercanas a la desembocadura de los ríos. Se concluye que la pluma del río Tuy modula el funcionamiento del sistema costero, mediante el aporte de nutrientes y material sedimentario en el agua, distribuyéndose mediante las corrientes marinas y el transporte litoral. Esto es aprovechado por las poblaciones de *Tivela mactroides*, presentando altas abundancias y diferenciación en la estructura de tallas a lo largo de la costa.

Palabras clave: nutrientes, pluma del río, gradiente físico y químico, *Tivela mactroides*, biomasa, estructura de talla, Venezuela.

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INTRODUCTION

The coastal zone can be defined as the interphase between the land and the open sea, with an oceanic primary productivity estimated at 30% (Holligan & Reiners, 1992). This productivity is affected by the inputs of nutrients from continental sources (rivers, runoff), upwelling processes and the atmosphere. It has been estimated that the rivers of the world drain close to 60% of the land area (1,5 x 10^8 km^2) into the oceans, with annual discharges of 26 x 10^9 tons of sediment and close to 38 x 10^3 km^3 of fresh water (Alongi, 1998).

Because rivers are important modulators of coastal processes, their flow rates and interactions with other factors, such as tides and wave action, have been used to establish a hydrographic classification of coastal systems (Dronker, 1988). Coastal systems whose functional dynamics depend on the increase or reduction of the temporal discharges of rivers and their interaction with tides are called tropical tidal rivers, and the interaction of these rivers with oceanic water masses has been extensively studied for large South American rivers, such as the Amazon River in Brazil, and the Orinoco River in Venezuela (Rhyther *et al.*, 1967; Cochrane, 1969; Edmond *et al.*, 1981; Dronker, 1988; Bonilla *et al.*, 1993; Alongi, 1998; Signorini *et al.*, 1999; Mann & Lazier, 2006).

As well as the Orinoco River, there are other tidal rivers in Venezuela with lesser flow rates, but of great relative importance for the coastal areas into which they drain. The catchment basin of the Tuy River is located in the north-central region and captures the wastewaters of the metropolitan area of the capital city, Caracas, as well as draining an area of approximately 6600 km², including extensive industrial and agricultural areas (Jaffe *et al.*, 1995). The influence of the Tuy River on water quality, sediment and biota (flora and fauna) in terms of the extent of contamination generated by a variety of anthropogenic compounds has been demonstrated (Jaffe *et al.*, 1995). Nevertheless, its nutrient and sediment load, and how these affect water quality and biological populations associated with sandy beaches located along the north-central (Barlovento) coastline has not been assessed.

The influence of the river plume on associated biological communities has been assessed for many coastal ecosystems, particularly in sandy beach environments. The abundance, diversity and species richness of benthonic communities has been related to different parameters modified by the contributions of rivers as well as their distance from river mouths (Lercari *et al.*, 2002; Lercari & Defeo, 2003, 2006; Defeo & Lercari, 2004; Lastra *et al.*, 2006; Defeo *et al.*, 2009).

Tivela mactroides (Born, 1778) is one of the most abundant and commercially important species of beach clams. It is widely distributed along sandy beaches in South America and the Caribbean (Warmke & Abbott, 1961) where it grows in dense populations, especially close to the mouths of rivers (McLachlan *et al.*, 1996). Changes in both the size structure and abundance of the clams depending on their relative distance from river mouths have been demonstrated for Brazilian populations (Denadai & Amaral, 2005), and embryonic development has been investigated in Guadalupe (Silberfel & Gros, 2006). In Venezuela, several aspects of the biology of these clams have been studied, including: population dynamics (Mendoza & Marcano, 2000; Delgado *et al*., 2003; Arrieche & Prieto, 2006), microbiological quality (Chourio & Montiel, 1997; Iriarte, 1999; Herrera & Suárez, 2005) and their use as indicators of pollution (Jaffe *et al*., 1995; Acosta *et al*., 2002; Acosta & Lodeiro, 2003, 2004; La Brecque *et al.*, 2004). Nevertheless, a direct relation between the variation in the abundance and size structure of *T. mactroides* populations, and relative river loads has not been established. The aim of this study was to evaluate the effect of the Tuy River on coastal processes, and its influence on the abundance, biomass and size structure of populations of *T. mactroides*.

MATERIALS AND METHODS

Study site

The coastal zone evaluated (Higuerote), is located in the central region of Venezuela, from Los Canales beach, Rio Chico (some 3 km east of the mouth of the Tuy River (10°21'34"N, 65°57'11"W) to the village of Carenero (10°30'57"N, 66°06'06,54"W), giving a distance of approximately 23.53 km, and from the tip of Cape Codera to the extreme southwestern point of the coast, approximately 10 km, giving a total coastal area of 235 km^2. The coastline zone has many sandy beaches with surf that dissipates over a wide breaker zone. Along this stretch of coastline there are two rivers of lesser importance; the Capaya and Curiepe Rivers, which also flow into the sea, and are also evaluated.

Sampling design

Water and sediments were characterized at eight sampling sites along the coast. Samples were taken at two points in the littoral zone (intertidal, and sub-littoral) and at one point behind the surf zone at a depth of 5 m, at each site. Sampling was done during two field surveys, in October and November 2000, chosen to include the time of year with the highest rainfall for the area under study. The geographical location of each sampling site is shown in (Fig. 1).

Environmental variables

During the field surveys, the following environmental parameters were measured using a multiparametric probe (model Hydrolab DS4): surface water temperature (ºC), salinity, conductivity (μSm), dissolved oxygen concentration (mg L^{-1}), percentage of dissolved oxygen and pH. In addition, water was collected in a plastic bottle for the later analysis of total suspended solids (TSS; Standard Methods, section 209-C and D, in APHA, AWWA, WEF, 1995), total nitrogen concentration (TN; macro-Kjeldahl method, section 4500-Norg-B, in APHA, AWWA, WEF, 1995) and total phosphorus (TP; ascorbic acid method, section 4500-P-E, in APHA, AWWA, WEF, 1995).

In order to measure total organic carbon (TOC), superficial sediment samples were taken from the eight coastal sampling sites and the two sites from each of the Tuy, Capaya and Curiepe rivers, and bottled in 0.5 L jars. Total organic carbon was measured using the methodology for the determination of oxidable carbon using chromic acid with sulphuric acid and a dilution value, as described by Walkley (1947) and later modified by Jackson (1970). The granulometric characteristics of the sediment were determined using the methods described by Folk & Ward (1957).

Biological variables

The macrofauna was collected by filling six cylinders (0.1 m^2) with sand at each of the eight coastal sampling sites. After collection, the samples were preserved in a 10% formalin solution and later washed through a 0.5 mm-mesh sieve to retain the macrofauna. All organisms were sorted and identified at the species level. Abundance was measured as the number of individuals collected in the six cylinders from each of the sampling sites and for each of the two field surveys undertaken. All *T. mactroides* individuals collected from each beach and during each sampling effort were weighed and the total weight obtained was divided by the total sampling area at each beach to obtain the biomass. For the determination of size structure, the maximum length of each *T. mactroides* individual was measured using a Vernier. At site 4, from October 2000 to October 2001, the accompanying benthonic macrofauna was also identified and the density estimated for each species.

River measurements

The rivers (Tuy, Capaya, Curiepe) were measured at their mouths (external site) and at about 500 m upstream (internal site). During each sampling effort cross sections of each river were made and the flow rate, channel depth and current velocity using current meters were measured. Water samples were taken for the analysis of nutrients and sediment, following the same methods as those used for the field sites located along the coastline.

The dynamics of the influence of the Tuy River discharge plume were examined using the mean weekly satellite images of the chlorophyll spectrum for October-December 2000 obtained from SeaWifs. The maximum distance under the influence of the discharge plume following the prevailing direction (maximum influence), maximum impact (values over 1.0 mg m^{-3} of chlorophyll and suspended material) and minimum impact (values over 10.0 mg m^{-3} of chlorophyll and suspended material) were calculated. The coastal area evaluated was estimated at a scale of 1:459.824, using a Geographical Information System (GIS) designed by the Venezuelan Geographical Institute Simón Bolívar (2003).

Statistical analysis

The gradients of the environmental parameters measured from both the water column and the sediment from the coastal field sites were determined using Principal Components Analysis, CANOCO program version 4.0 (Ter Braak, 1986). Each variable was standardized and normalized and the differences between the groups established by the principal components were evaluated using a multivariate analysis of variance (MANOVA), STATISTICA program version 7.0. A two-way ANOVA was used to analyze the differences in density, biomass and maximum length between sites close to, and far from the mouths of the rivers. The relationships between the density (after a log base 10 transformation for better adjustment) of *T. mactroides* and the environmental variables measured from the water column and sediments were analyzed using a forward stepwise multiple regression, with the standardized regression coefficients (Beta) being estimated for every independent variable.

RESULTS

The influence of the rivers on the receiving waters

Of the three rivers that drain into the coastal zone, the Tuy River had the largest volume; on average 15 times greater than the second most important river, the Capaya, and 80 times greater than the Curiepe River

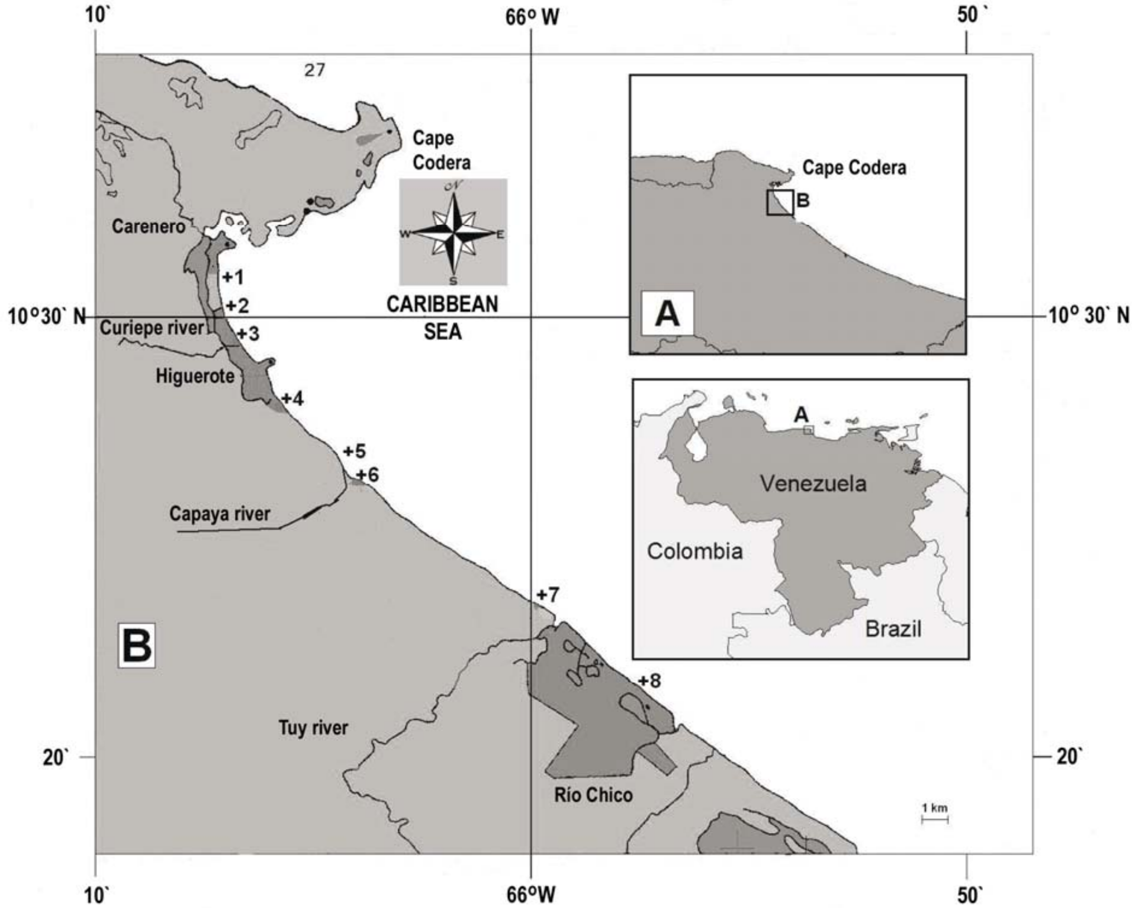

Figure 1. Map of the study area, showing the localization of the coastal stations and river sites evaluated.

Figura 1. Mapa del área de estudio, mostrando la ubicación de las estaciones costeras y ríos evaluados.

(Table 1). The Tuy River also transported the highest average loads of TN (659.61 ± 503.27 g s^{-1}) TP (52 ± 53.09 g s^{-1}), and TSS (9320.84 ± 9728.15 g s^{-1}) and was greater with respect to other variables related to the size of the river, such as current speed and depth (Table 1). The contributions of nutrients and sediment by the Tuy River have an important impact on the dynamics of the Barlovento coastline. Table 2 shows the areas of maximum and minimum impact, as well as the direction of the discharge plume and its maximum influence in terms of distance. It can be observed that between October and December 2000, the maximum impact area showed two high values: one during the third week of September, week 38 (1209 km^2, 5 times the coastal area under study), and the highest during the first week of December, week 49 (2346.61 km^2, 10 times the coastal area under study). The minimum impact area showed a maximum value during the first week of September; week 36 (349.75 km^2, 1.5 times the coastal area evaluated).

The water column in the coastal zone

The physicochemical parameters showed a marked variability along the stretch of coastline evaluated (Table 3). The highest temperature was recorded at site 1 (30.65 ± 1.34°C) and the lowest at site 8 (27.95 ± 0.5°C). Salinity was also highest at site 8 (35.60 ± 2.12) and lowest at site 6 (20.45 ± 15.20), with conductivity showing a similar tendency. The dissolved oxygen concentration was highest at site 8 (4.65 ± 0.35 mg L^{-1}) and lowest at site 5 (3.75 ± 0.64 mg L^{-1}), with the percent saturation showing the same tendency. Turbidity was highest at site 6 (442 ± 0) and lowest at site 4 (0). The pH was close to neutral at sites 7 and 8 (7.9 ± 0.28) and alkaline at site 6 (8.35 ± 0.21). Nutrient concentrations were high at sites 1 (Littoral TN, 2.2 ± 3.03 mg L^{-1}) and 7 (Littoral TP, 2.09 ± 2.32 mg L^{-1}) and low at sites 3 (Littoral TN, 0.54 ± 0.69 mg L^{-1}) and 8 (behind Surf Zone TP: 0.24 ± 0.21 mg L^{-1}). Specifically, low salinity and high turbidity were recorded at sites close to the mouths of

Table 1. Means (± standard deviation) of the physical and chemical parameters, contributions and characteristics of each river evaluated.

Tabla 1. Promedios (± desviación estándar) de parámetros físicos y químicos, aportes y características del cauce en cada río evaluado.

Parameter	River		
	Tuy	Capaya	Curiepe
Temperature (ºC)	27.05 ± 2.09	27.37 ± 0.89	28.09 ± 1.23
Conductivity (μScm)	448.75 ± 9.46	434 ± 30.57	635 ± 315.83
Salinity	0.28 ± 0.02	0.28 ± 0.03	2.48 ± 2.59
Dissolved oxygen (mg L^{-1})	3.63 ± 1.56	7.05 ± 3	5.12 ± 2.53
(%) Saturation of dissolved oxygen	46.33 ± 16.42	91.15 ± 31.67	71.6 ± 38.55
Turbidity (NTU)	468.5 ± 394.14	337.77 ± 175.71	256.1 ± 178.68
pH	7.9 ± 0.12	8.64 ± 0.57	8.57 ± 0.5
Total N contribution (g s^{-1})	659.61 ± 503.27	25.85 ± 31.16	0.53 ± 0.74
Total P contribution (g s^{-1})	52 ± 53.09	1.05 ± 0.78	0.13 ± 0.18
Mean depth (cm)	317.5 ± 10.61	288.5 ± 89.8	148 ± 11.31
TSS contribution (g s^{-1})	9320.84 ± 9728.15	2556.86 ± 3381.02	52.7 ± 74.53
Current velocity (m s^{-1})	2.19 ± 0.02	0.35 ± 0.28	0.26 ± 0.37
Volume (m^3 s^{-1})	246.39 ± 60.66	16.286 ± 9.21	2.64 ± 3.73

the rivers; indicative of the riverine influence at those sites.

Environmental gradients

Principal Components Analysis (Fig. 2a-b) indicated that there was a marked gradient from a riverine influence to a marine one along the section of coastline evaluated. For the October field survey (the first factor explains 51.6% of the variance and the second 26.6%), sites 1, 2, 3, 4 and 8 were positively related to salinity, whilst sites 5, 6 and 7 were negatively related to this variable and strongly positively related to the concentration of nutrients (total nitrogen and phosphorus), pH, dissolved oxygen and turbidity; the first factor explains 85.7% of the variability in the turbidity, 85.1 and 74.8% of the variability of total nitrogen and phosphorus respectively and 51.3% of the variability in salinity; whilst the second factor explains 81.3% of the variability in the pH and 28.8% of the variability in the concentration of dissolved oxygen. The same relationships between the sites and the environmental variables measured were observed during the November field survey (Fig. 2b), where the first factor explains 47.6% of the total variance of the parameters, especially pH, where 93.6% of the variability was explained by this factor, the total nitrogen and phosphorus where 67.4 and 41.1% of the variability was explained, respectively, and the salinity where 34.5% of the variability was explained, whereas the second factor explains 23.6% of the total variance, with 55% of the variability in the concentration of dissolved oxygen explained by this factor, and 31.9% of the variability in salinity and turbidity explained. There were significant differences (MANOVA, $P < 0.01$) between the sites under marine (sites 1, 2, 3, 4 and 8) and riverine (sites 5, 6 and 7) influence and between sampling efforts (October and November).

Sediments

The nearshore zone sampling points (behind the breaker line) were associated with high percentages of mud and silt (Fig. 3), whilst the littoral sites were associated with a high percentage of sand and a gravel gradient (the first factor explains 54% of the variance and the second factor 22.2% of the variance). The sediment also showed a gradient of total organic carbon (TOC) along the coast. The littoral sites 1, 2, 4 and 6 were associated with this as were the behind the surf-zone sites 1, 2, 3, and 7. The other sampling points were inversely related to TOC.

Benthic macrofauna and its relationship with environmental variables

The structure and composition of the macrofauna collected are shown in Table 4. The clam, *Tivela mactroides* was the most important in terms of its abundance, representing 95.6% of the macro faunal community, with an average density of 3250.01 ± 2245.09 ind m^{-2} for 2000-2001. Next in the order of dominance were the polychaetes with eight species collected, of which *Scoloplos capensis* had the highest average density (24.48 ± 21.70 ind m^{-2}). A total of seven crustacean species were identified, with the

Table 2. Direction, influence towards the north and impact area of the sediment plume on the Río Chico-Carenero system, estimated from satellite images. *Maximum impact: values > 1.0 mg m^{-3}; **Minimum impact = values > 10 mg m^{-3}.

Tabla 2. Dirección, influencia al norte y área de impacto de la pluma de sedimentos sobre el sistema Río Chico-Carenero, estimado a partir de las imágenes satelitales. *Impacto máximo: valores > 1,0 mg m^{-3}; **Impacto mínimo: valores > 10 mg m^{-3}.

Week	Date	Maximum influence (N) (km)	Prevailing direction	Maximum area of impact (km^2)*	Minimum area of impact (km^2)**
36	09/02 to 09/08	33	NE	662.75	349.75
37	09/09 to 09/15	22	NE	337.25	196.75
38	09/16 to 09/22	78	NNE	1209.00	386.75
39	23/09 to 29/09	19	NE	436.90	352.44
41	07/10 to13/10	28	NE	706.46	363.63
42	14/10 to 20/10	22	NE	368.42	86.00
47	11/18 to 11/24	33	NW	441.60	157.81
49	12/02 to 12/08	111	NNW	2346.61	369.47
50	12/09 to 12/15	44	NE	708.53	91.61
52	12/23 to 12/29	44	NW	674.00	142.30
Mean October-December 2000		43 ± 9		789.15 ± 190.63	249.65 ± 39.62

Table 3. Means (± standard deviation) of the physical and chemical parameters and nutrients for the eight study sites along the coast.

Tabla 3. Promedios (± desviación estándar) de parámetros físicos y químicos y nutrientes en las ocho estaciones en el eje costero evaluado.

Sites Parameters	1	2	3	4	5	6	7	8
Temperature (ºC)	30.65 ± 1.34	29.9 ± 0.85	29.6 ± 0.57	28.65 ± 0.07	30.5 ± 0.57	29.85 ± 1.77	28.95 ± 0.5	27.95 ± 0.5
Salinity	33.85 ± 3.19	32.95 ± 1.2	31.65 ± 0.07	33.95 ± 1.2	28.4 ± 4.67	20.45 ± 15.2	32.6 ± 5.23	35.6 ± 2.12
Conductivity (mS cm^{-1})	51.35 ± 4.17	50.25 ± 1.63	48.4 ± 0.14	51.5 ± 1.7	43.9 ± 6.51	32.2 ± 22.06	48.3 ± 9.05	53.75 ± 2.9
Dissolved oxygen concentration (mg L^{-1})	3.9 ± 0.71	4.3 ± 0.71	4 ± 0.71	4.35 ± 0.21	3.75 ± 0.64	4.25 ± 0.07	4.35 ± 0.35	4.65 ± 0.35
(%) Saturation of dissolved oxygen	72.4 ± 12.3	76.55 ± 16.61	73.95 ± 9.69	80.75 ± 3.61	67.05 ± 6.86	73.4 ± 7.5	78.5 ± 3.39	85.6 ± 7.07
Turbidity (NTU)	207 ± 123.04	170 ± 65.05	128.5 ± 44.55	0 ± 0	287.05 ± 296.91	442 ± 0	337 ± 476.59	104.5 ± 147.78
pH	8.1 ± 0	8.05 ± 0.07	7.95 ± 0.21	8.2 ± 0	8.35 ± 0.21	8.2 ± 0.42	7.9 ± 0.28	7.9 ± 0.28
TN (mg L^{-1})								
Littoral point	2.2 ± 3.03	0.86 ± 1.15	0.54 ± 0.69	0.9 ± 1.2	1.05 ± 1.41	2.05 ± 2.82	1.32 ± 1.58	1.47 ± 2.01
Behind surf zone point	0.55 ± 0.71	0.59 ± 0.76	0.55 ± 0.71	0.75 ± 0.99	0.74 ± 0.98	0.91 ± 1.22	1.9 ± 2.61	1.44 ± 1.96
TP (mg L^{-1})								
Littoral and sub littoral points	0.82 ± 0.8	0.84 ± 0.8	0.83 ± 0.74	0.83 ± 0.72	1.26 ± 1.22	1.47 ± 1.44	2.09 ± 2.32	0.63 ± 0.36
Behind surf zone point	0.9 ± 1.21	0.75 ± 0.98	0.97 ± 1.22	0.45 ± 0.57	0.42 ± 0.51	0.54 ± 0.7	0.77 ± 0.86	0.24 ± 0.21

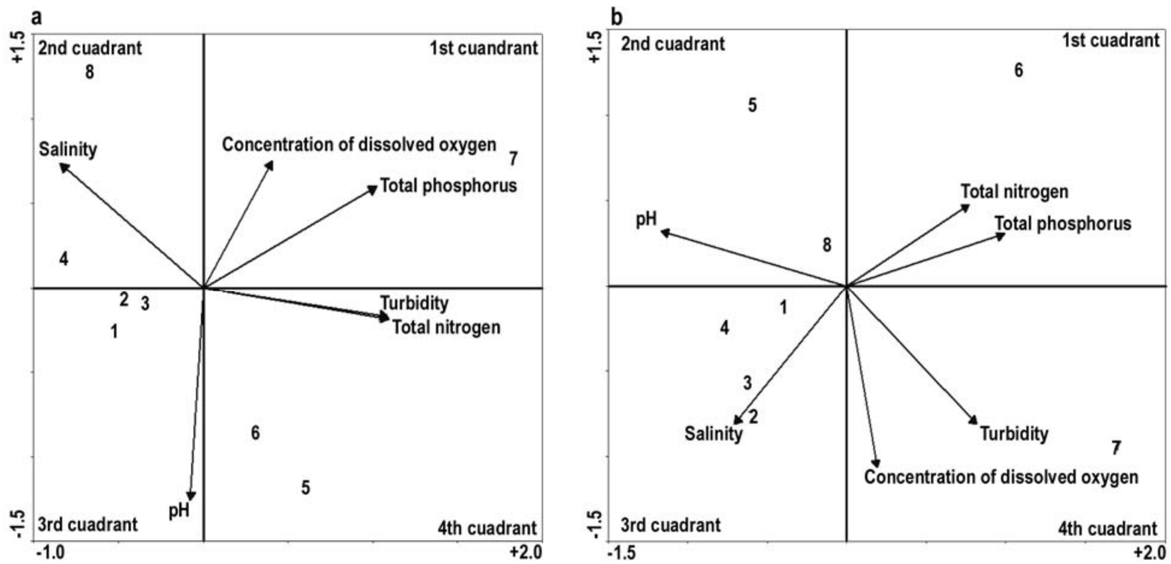

Figure 2. Principal components analysis of the physical and chemical parameters and nutrient concentrations measured from the water column at each of the eight study sites. a) October 2000, b) November 2000.

Figura 2. Análisis de componentes principales de los parámetros físicos y químicos y concentración de nutrientes medidos en la columna de agua de las ocho estaciones. a) octubre 2000, b) noviembre 2000.

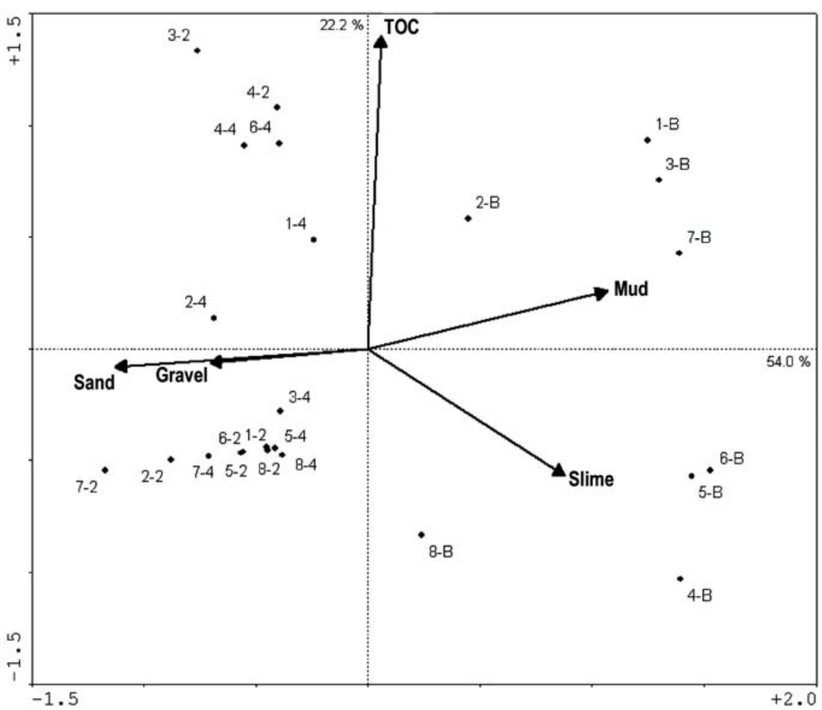

Figure 3. Principal components analysis of the granulometric composition at each of the sampling points for samples taken in October. The first number indicates the site and the second number the sampling point (2: littoral; 4: sub-littoral; B: behind surf zone).

Figura 3. Análisis de componentes principales de la composición granulométrica en cada uno de los puntos de muestreos, en octubre. El primer número indica la estación y el segundo número el punto de muestreo (2: litoral; 4: sub-litoral; B: detrás de la zona de rompiente).

Table 4. Mean annual density (± standard deviation) and percentage abundance of the species composition of the macrofauna associated with the sandy beach at site 4, from October 2000 to October 2001.

Tabla 4. Densidad promedio anual (± desviación estándar) y abundancia porcentual de la composición de especies de la macrofauna asociada a la playa arenosa en la estación 4, de octubre de 2000 a octubre de 2001.

Species composition	Mean annual density (ind m^{-2})	Abundance (%)
Polychaeta		
Spionidae		
Scololepis squamata	3.77 ± 3.99	0.11
Dispio uncinatta	13.18 ± 12.31	0.39
Magelonidae		
Magelona riojai	1.26 ± 2.49	0.04
Orbiniidae		
Scoloplos capensis	24.48 ± 21.70	0.72
Pilargidae		
Sigambra tentaculata	1.26 ± 2.49	0.04
Lumbrineridae		
Lumbrineris verilli	5.02 ± 6.59	0.15
Glyceridae		
Hemipodus sp.	0.63 ± 1.88	0.02
Sigalionidae		
Fimbriosthenelais sp.	1.26 ± 3.77	0.04
Crustácea		
Decapoda		
Lepidopa richmondi	6.28 ± 6.59	0.18
Emerita brasiliensis	3.77 ± 7.47	0.11
Amphipoda		
Heterophoxus oculatus	25.11 ± 36.95	0.74
Talitridae sp. 1	1.26 ± 3.77	0.04
Isopoda		
Natatolana gracilis	26.99 ± 37.45	0.79
Ancinus brasiliensis	0.63 ± 1.88	0.02
Mollusca		
Bilvavia		
Tivela mactroides	3250.01 ± 2245.09	95.64
Donax striatus	10.04 ± 18.48	0.30
Donax denticulatus	7.53 ± 18.74	0.22
Hemichordata		
Enteropneusta	15.69 ± 17.36	0.46
Total Density	3398.16 ± 2254.05	

isopod *Natatolana gracilis* having the highest annual density (26.99 ± 37.45 ind m^{-2}).

The *T. mactroides* populations varied along the coast and were least abundant (density and biomass) at the sites closest to the river mouths (3, 5, 6, 7) compared to the sites farthest from the river mouths (1, 2, 4, 8) (ANOVA, $P < 0.05$), but not between surveys. The highest biomass and density was reported at site 2 (9126.89 ± 1562.3 g m^{-2}; 9222.2 ± 1976.72 ind m^{-2}), and the lowest at site 3 (41.43 ± 100.74 g m^{-2}; 23.15 ± 50.02 ind m^{-2}) (Table 5). Density was significantly related to salinity (Beta: 1.61), mean grain size (Beta: -1.06) and nutrients such as TOC (Beta: -0.25), total littoral nitrogen (Beta: 0.28) and total littoral phosphorus (Beta: 0.33) ($P < 0.01$; R^2_{adj}: 0.77). There were also significant differences in the mean maximum length of *Tivela mactroides* between the sites farthest from, and closest to the river mouths, and between surveys (ANOVA, $P < 0.05$). The size structure varied along the coast, the smallest sizes being collected from sites close to the river mouths where 50% of the individuals collected were smaller than 13 mm (Median), whereas at the sites farthest from the river mouths 50% of the

Table 5. Biomass and mean density of *Tivela mactroides* (± standard deviation) at each study site.

Tabla 5. Biomasa y densidad promedio de *Tivela mactroides* (± desviación estándar) de las estaciones evaluadas.

Location	Site	Biomass	Density
Far	1	1544.69 ± 842.88	842.88 ± 620.37
	2	9126.8 ± 1562.3	1562.3 ± 9222.22
	4	4016.64 ± 4726.56	4726.56 ± 1711.11
	8	4401.96 ± 2924.8	2924.8 ± 2150.79
	Mean	3783.59 ± 3512.55	3512.55 ± 2426.59
Close	3	41.43 ± 100.74	100.74 ± 23.15
	5	5990.84 ± 2344.41	2344.41 ± 8152.78
	6	289.22 ± 364.97	364.97 ± 261.11
	7	62.83 ± 169.85	169.85 ± 106.48
	Mean	754.9 ± 1982.32	1982.32 ± 992.49

individuals collected were larger than 17 mm (Median) (Fig. 4).

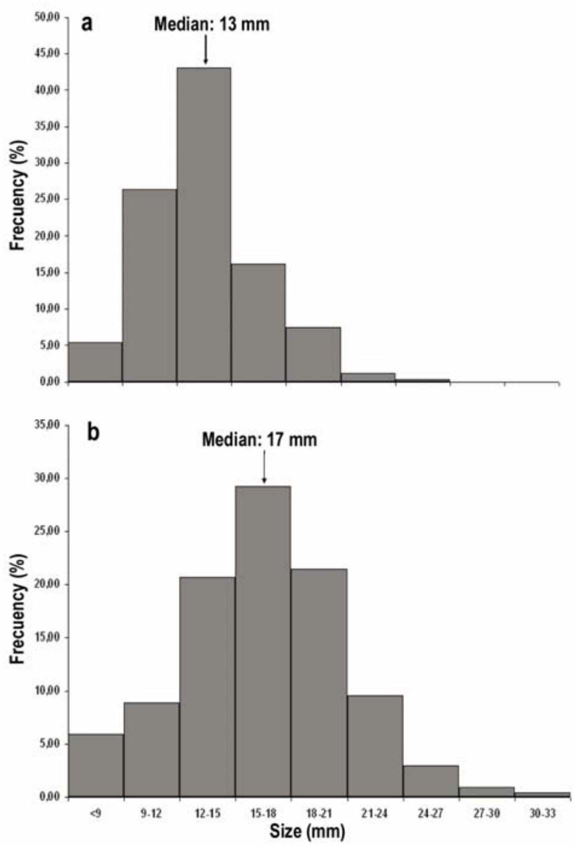

Figure 4. Size structure of *Tivela mactroides* (mm) along the coastline evaluated. a) Sites close to the river mouths, b) sites farthest from the river mouths.

Figura 4. Estructura de talla de *Tivela mactroides* (mm) a lo largo del eje costero evaluado. a) Estaciones cercanas a las desembocaduras de los ríos, b) estaciones alejadas de las desembocaduras de los ríos.

DISCUSSION

Of the three rivers evaluated the Tuy exerted the most influence, principally due to its larger volume and higher mean current velocity, as well as its greater loads of total suspended solids, total nitrogen and phosphorus. This was confirmed by satellite images, which show the annual variations in the area of influence and orientation of the river plume. It can be seen that the values of maximum impact occurred during two weeks between October and December of 2000. In spite of this, the maximum impact area of the plume did not change significantly. What did change, however, was the minimum impact area of the plume which reduced in size towards the end of 2000. This appears to be contradictory, since the maximum impact remained constant, but in fact indicates that the Tuy River in spite of its determining influence is not the only factor governing the processes along this coastal region. Another factor responsible for the high chlorophyll bloom and suspended material found all along this coastal zone are upwelling events associated with the Cariaco Trench located to the northeast of the area under study, opposite the Unare shelf (Penchaszadeh *et al*., 2000). Muller-Karger *et al.* (2001) showed that the highest upwelling occurs to the east of the Cariaco Trench, where the plume extends over an area of 40,000 km^2 and may sometimes reach up to 90,000 km^2.

The evidence of the influence of the Tuy River plume on the coastal region, as observed from the satellite images, is reinforced by the results of the Principal Components Analysis, which indicate that there is a gradient associated with the variation in both the physicochemical parameters of the water and the sediments at each of the sites evaluated along the coast. This gradient results from changes in the parameters related to the riverine contributions, such as the concentrations of total nitrogen and phosphorus, as well as the confluence of marine currents with these contributions, and is expressed as variations in the salinity, dissolved oxygen, turbidity and pH for the water samples, and greater concentrations of total organic carbon and the percentage of mud and silt in the sediments, between the nearshore zone and the intertidal sampling points. Furthermore, this gradient may change over time, as shown by the different patterns represented by the ordination diagrams done for each field survey, and the physicochemical analyses.

The nutrients, organic carbon and sediment transported by the Tuy River and the upwelling processes are principally distributed along the coast by alongshore transport, which is associated with littoral currents, wave action produced by the trade winds, and currents generated by changes in the tides. In the Barlovento region, alongshore transport is less intense and constantly changes direction, probably because the mountains of Cape Codera jut out at a right angle to the coast, cutting across and altering the marine currents (Solana, *pers. comm*.).

These types of coastal dynamics and their products have been studied in other river influenced regions, in particular stratification, which can be horizontal along a coastline or river plume, or vertical along a depth gradient. For example, the turbid and nutrient rich Mississsipi River plume which empties into the Gulf of Mexico, limits primary production in the zone closest to the delta due to the lack of light caused by the turbidity. Further away, however, there is a zone of intermediate salinity (15 to 30) where high loads of suspended sediment have settled enough to permit the penetration of a greater degree of light. This, together with the high nutrient concentrations that persist, facilites a high rate of phytoplanktonic production (5 g C m^{-2} d^{-1}). Primary production here is significantly correlated with flow and the concentration of nitrates and nitrites (Lorenz *et al*., 1997). Phytoplanktonic activity and available nutrients decline at those points farthest from the delta due to the consumption of these elements by organisms from other levels in the food chain and by their sedimentation on the bottom of the sea bed (Bierman *et al*., 1994; Del Castillo & Millar, 2008).

Another type of gradient may be defined for the Rhone River in the northeast Mediterranean, whose plume is delimitated by abrupt borders and by its stratification in a three tiered structure: a superficial layer of fresh water one meter thick, rich in suspended particulate material and dissolved nutrients and a sub aquatic layer, composed of nutrient-poor sea water, separated by a discontinuous boundary layer. The plume is normally 1 to 6 km long, and discharges into a narrow margin on the shelf (Soto *et al*., 1993; Bianchi *et al*., 1994).

The Po River discharges into the north of the Adriatic Sea. The coastal area into which this river flows can be divided into three different zones: coastal, offshore and an intermediate zone which separates the two. The concentrations, both of nitrate and chlorophyll are positively correlated with distance from the coast, forming an abrupt gradient from the Po River plume to the offshore zone, as well as decreasing with depth, from the surface to deeper layers (Revelante & Gilmartin, 1992; Mangoni *et al*., 2008). These same patterns in the variation of nutrients and chlorophyll have been demonstrated for other coastlines, such as the Gulf of Vizcaya in Spain (Albaina & Irigoien, 2007; Marquis *et al*., 2007) and Arcachon Bay in France (Glé *et al*., 2008), where nutrient load delivered by rivers determines the composition and abundance of species in both phytoplankton and zooplankton communities.

With respect to tropical tidal rivers, the stratification of the discharge plume of the Orinoco River and its influence on the physical and chemical parameters of the water column has been studied. Bonilla *et al*. (1993) investigated the stratification in salinity and the nutrient distribution and primary productivity in both the wet and dry seasons. The patterns of nutrient concentration and primary productivity suggest that upwelling associated with the continental shelf, together with the behavior of the Orinoco River, exert most influence on the dynamics of this coastal system (Bonilla *et al*., 1993). Rodríguez & Schneider (2005) corroborated the patterns of nutrient distribution observed by Bonilla *et al*. (1993) and established that the waters of the Orinoco River with their high content of silicates and phosphates, bathe the whole continental shelf as they head northwestwards directed by the action of the currents.

In addition, studies of the contributions of rivers with a lower volume discharge than the Orinoco have been undertaken. For example, the Manzanares river in Sucre state, Venezuela has a catchment area of 1.652 km^2 and an average annual discharge of 558 x 10^6 m^3 of water at its mouth in the Gulf of Cariaco which produces a laminated plume generally directed towards the southwest as a consequence of the trade winds (Martínez *et al*., 2001). In the dry season, heterotrophic processes associated with the temporal nature of the river's expenditure dominate both in the riverine and mixing zones, with considerable reductions in the pH and dissolved oxygen, whilst in the marine zone autotrophic processes take over. The amount of suspended material is related to the expenditure of the river, being greater in the rainy season and lesser in the dry season, and showing a linear relationship with the concentration of nitrates, phosphates and silicates (Martínez *et al*., 2001).

In this investigation we included the benthic macrofauna as part of the study as well as measuring the environmental variables. This is the first time in Venezuela that coastal processes have been related to the abundance of organisms on sandy beaches. This community was clearly dominated by *T. mactroides* along the whole of the coastline studied. As our results show, the variations in the population characteristics of benthonic organisms such as *T. mactroides* are related to parameters governed by coastal zone processes, with differences being recorded in their abundance and size structure along the stretch of coastline studied. The variation in the density of this clam along the coast was related to salinity changes, average grain size and the concentration of nutrients, such as organic carbon, and total nitrogen and phosphorus. McLachlan *et al*. (1996) reported that *T. mactroides* populations seem to be associated with both river mouths and the presence of organic material. In contrast, our results show that *T. mactroides* was least abundant (in terms of both density and biomass) at sites close to the river mouths. Denadai *et al*. (2005) reported an average global density of 77 ind m^{-2} on beaches at Caraguatatuba Bay, Brazil, and showed that the size structure of this bivalve varied along the coast, with smaller sizes in the vicinity of river mouths, thus agreeing with the patterns observed in this study.

The densities measured here are indeed among the highest reported for Venezuela; 3250.01 ± 2245.09 ind m^{-2} compared to Arrieche & Prieto (2006) who reported average densities of only 53.83 ind m^{-2} on Caicara beach, Anzoátegui state, Venezuela.

A variety of community descriptors of the macrofauna on sandy beaches in South America and Spain have been linked to environmental parameters such as beach morphodynamics, the concentration of organic material and the contribution of rivers. Incera *et al*. (2006) established that the slope of the beach had a marked effect on species richness, density and biomass of the macrofauna in the intertidal zone on 11 beaches along the northwest coast of Spain. These community descriptors, however, were not related to food availability, or elements such as biopolymer carbon and chlorophyll-*a* in sediment. In contrast, Lastra *et al*. (2006) using a multiple regression analysis, demonstrated that the number of species increased significantly with proximity to an upwelling zone and with a decrease in grain size, on 14 beaches in northern Spain. The biomass increased significantly with food availability estimated as the concentration of chlorophyll-*a* in the water column in the surf zone. Lercari & Defeo (2006) evaluated the influence of a salinity gradient produced by the Río de La Plata estuary, on species richness and abundance at 16 beaches in Uruguay. Using linear and non-linear models, these authors established that species richness increased with salinity, the width of the surf zone and Dean’s parameter (index describing the state of a beach), and decreased with the salinity interval and the slope of the beach, when they included these as prediction variables in the regression model (as well as grain size, the selection coefficient, penetrability and the organic material content of the sediment). Selleslagh & Amara (2008) established that temporal variations in fish and crustacean communities on sandy beaches on the French coast bordering the English Channel, responded significantly to factors such as temperature, tides, salinity, oxygen, turbidity and phytoplanktonic biomass.

In summary, the results of this study provide evidence for the influence exerted by the discharge of continental waters on coastal areas and the ways in which they modify the environmental variables of the receiving waters, both in the water column and the sediment. The discharge plume of the Tuy River modulates the coastal system processes, by contributing large quantities of nutrients and sedimentary material to the water column. This material affects the abundance and size structure of *Tivela mactroides* populations associated with sandy beaches.

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