The effect of physical and chemical parameters on the macroinfaunal community structure of San Vicente bay, Chile

Efectos de parámetros físicos y químicos en la estructura comunitaria de la macroinfauna en la bahía de San Vicente, Chile

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ABSTRACT

San Vicente bay is a heavily industrialised bay located in central Chile, which has a sand beach extending from an area of recreational use in the south to an area of industrial use and discharge in the north. A survey of the macrofauna in the intertidal zone revealed a non-homogeneous distribution; a maximum of five invertebrate species were found with all five only occurring in one of six transects down the beach. The density ranged from 0 to 188 individuals m^{-2}, with the highest density at the recreational end. The most common species, *Emerita analoga* (Stimpson), was chosen to study the macrofaunal response to beach morphodynamics, physicochemical parameters and metal concentrations. The *E. analoga* distribution was not significantly correlated with the results of the physicochemical analyses of interstitial water (pH, temperature, salinity and oxygen concentrations). However, oxygen concentrations decreased to 3 ml O$_2$ l^{-1} in the lower intertidal closest to the recreational area where the highest numbers of intertidal macrofauna were observed. Analyses of 12 metals in the sediments showed three distinct distribution patterns across the beach in which the metals could be classified: a representative metal was chosen for each distribution. The concentration of tin ranged from 3.4 to 11.58 mg g^{-1}DW sediment, representing the 'wave' pattern. The concentration of cadmium ranged from 0 to 0.23 mg g^{-1}DW sediment, representing the 'banded' pattern. The concentration of chromium ranged from 1.97 to 3.18 mg g^{-1}DW sediment, representing the 'intermediate' pattern of metal distribution. The *E. analoga* distribution was not significantly correlated with the concentrations of any single metal, although multivariate statistical analysis indicated that Sn and Fe had the largest negative effect and Mn had the largest positive one. The distribution of *E. analoga* across the sandy beach of San Vicente bay was significantly correlated with the relative tidal range (RTR) beach morphodynamic parameter. There was also a significant linear relationship between *E. analoga* and 1/slope parameter. Although there was a significant correlation between the physical parameters of the beach and *E. analoga* distribution, these results should not be taken as conclusive for we must not exclude other possible factors, including chemical ones, which were not measured in this study. Absence of the amphipod *Orchestoidea tuberculata* Nicolet at the high water mark in the industrial zone can be explained by destruction of hàbitat due to direct human disturbance.

Key words: intertidal macrofauna, central Chile, sandy beaches, beach morphodynamics, interstitial water, heavy metals.

RESUMEN

La bahía de San Vicente, situada en la zona central de Chile, está altamente industrializada y posee una playa arenosa que se extiende desde un área de uso recreativo a otra de uso industrial, en la que se vierten residuos líquidos. El estudio de la macroinfauna de la zona intermareal mostró una distribución heterogenea de la misma. Un máximo de cinco especies de invertebrados fue hallado en sólo 1 de 6 transectos muestreados a lo largo de la playa. La densidad varió de 0 a 188 individuos m^{-2}, alcanzándose los valores más altos en la zona recreativa y los más bajos en la zona industrializada. La especie más abundante, *Emerita analoga* (Stimpson), fue elegida para estudiar la posible respuesta de la macrofauna frente a las variables de morfodinámica de la playa, a los parametros fisicoquímicos y a la concentración de metales pesados en el sedimento. *E. analoga* mostró su más alta densidad en la zona recreativa de la playa, al nivel medio-bajo del intermareal. La densidad de *E. analoga* a lo largo de la playa estuvo correlacionada significativamente con los valores de pH, temperatura (°C), salinidad (‰) y concentraciones de oxígeno (ml O$_2$ l^{-1}) en el agua intersticial. Sin embargo, la concentración de oxígeno tuvo un mínimo de 3 ml O$_2$ l^{-1} en la zona baja intermareal más cercana al area recreativa donde se contó el mayor número de individuos de macroinfauna. El análisis de 12 metales en los sedimentos mostró tres patrones de distribución característicos a lo largo de la playa. Un metal representativo fue elegido para cada patrón de distribución. La concentración de estaño varió de 3,4 a 11,58 mg por g seco de sedimento, y se distribuyó a lo largo de la playa con un patrón tipo 'ola'. La concentración de cadmio varió de 0 a 0,23 mg por g seco de sedimento, distribuyéndose con un patron tipo 'bandeado'. La concentración de cromo varió de 1,97 a 3,18 mg por g seco de sedimento, representando un patrón 'intermedio'. La abundancia de *E. analoga* no se correlacionó

430   SIEMENS ET AL.

significativamente con la distribución de ninguno de de metales separadamente. Sin embargo, un análisis estadístico multivariado mostró una correlación negativa de la densidad de *E. analoga* con estaño y fierro y una correlación positiva con la concentración de manganeso. El parámetro morfodinámico RTR (rango relativo de mareas) mostró estar significativamente correlacionado con la distribución de *E. analoga* a lo largo de la playa. También existió una correlación lineal significativa entre la distribución de *E. analoga* y el valor de 1/pendiente. A pesar de que existe una correlación significativa entre los parametros físicos de la playa y la distribución de *E. analoga*, estos resultados no deben considerarse definitivos ya que no se puede excluir la posibilidad de la interacción con otros factores, incluyendo los químicos, que no fueron tomados en cuenta en el presente estudio. La ausencia del anfípodo *Orchestoidea tuberculata* Nicolet en la zona alta intermareal de la zona industrial de la playa se puede deber a la destrucción de su habitat por impacto humano.

Palabras clave: macroinfauna intermareal, Chile central, playas arenosas, morfodinámica de playas, agua intersticial, metales pesados.

INTRODUCTION

Studies of the ecology of sandy beaches of central Chile are scarce, with a limited number of studies in the southern region of the country (Jaramillo et al. 1996, Hernández et al. 1998). The sandy beach considered in this study is located in the coastal region of central Chile (see Fig.1) within San Vicente bay (36° 44' S, 73° 09' W). Hydrographic current studies in San Vicente bay have determined an anticlockwise flow of the subsurface waters all year round, though surface water currents vary depending on the season (Brito 1993). Salinity measurements in the bay vary little in the water column throughout the year ranging from 33.6 ppt to 34.5 ppt (Brito 1993). However, no coastal salinity values have been published. The

mean grain size at Lenga Beach ranged from 0.4 mm to 0.53 mm (Hernández et al. 1998). There are no previous studies on wave action along the coast of San Vicente bay although a tentative classification was presented by Hernández et al. (1998) who considered the beach of Lenga to be "semi-reflective".

Metal analysis in San Vicente bay has been mainly restricted to subtidal sediments, water column and macrofauna in the bay rather than the sandy beach (Carrera et al. 1993, Ahumada 1994). An exception is a study on the effect of toxicity of cadmium in *Emerita analoga* (Stimpson) compared at three different localities in south central Chile, one of which was Lenga beach (Hernández et al. in press).
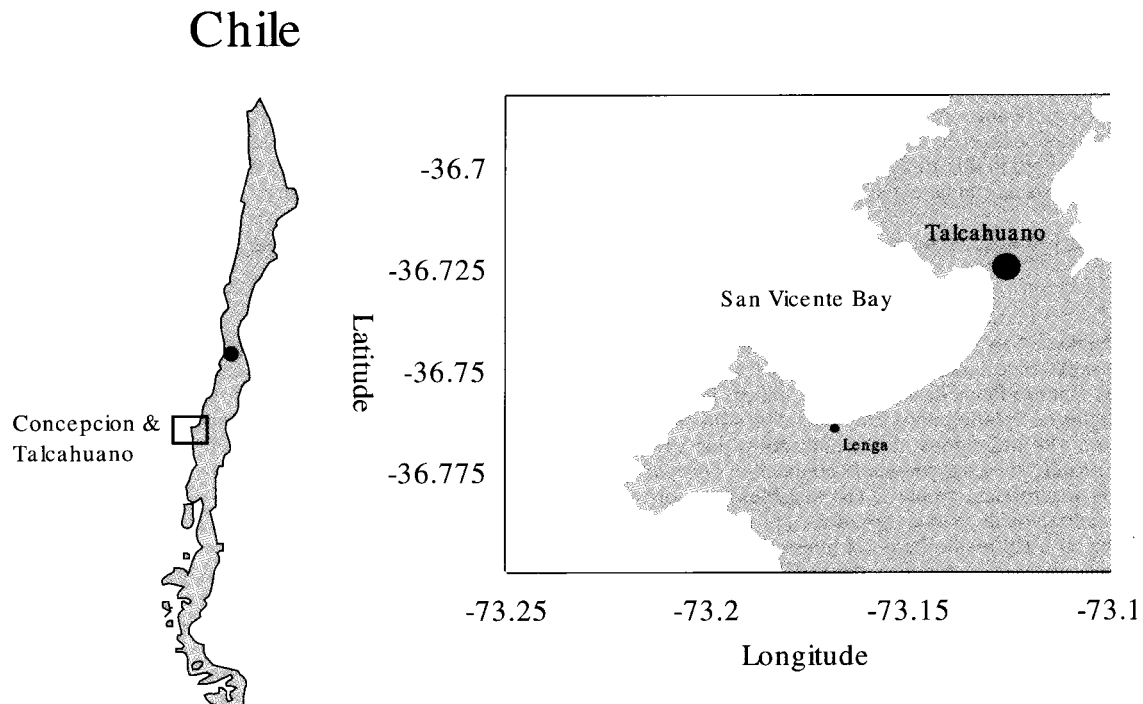

Fig. 1: Inserted map with central Chile highlighted and detail of the region around San Vicente bay.
Mapa de Chile y localización de la zona de estudio.

Previous studies of the community structure of the macrofauna in beaches of southern Chile have shown that the upper levels of the beach were mainly occupied by the amphipod *Orchestoidea tuberculata* Nicolet. The isopod *Excirolana hirsuticauda* Menzies made up the main component of the mid beach levels, while the polychaete *Euzonus heterocirrus* Rozbaczylo & Zamorano and the anomuran crab *E. analoga* were the dominant organisms of the low beach levels (Jaramillo & González 1991).

Intertidal sandy beach macrofaunal associations in the coastal mid region of Chile are characterised by being poor in diversity and having a sole dominant species (Palma et al. 1982). Previous macrofauna studies in Lenga beach have confirmed these observations (Hernández et al. 1998). The work by Hernández et al. (1998) on the distribution and community structure of species in the intertidal zone of Lenga beach concluded that *O. tuberculata* and *E. analoga* were present in all of the transects; specific richness and abundance were greatest near the recreational end of Lenga beach and that the number of macrofauna species decreased as the sampling sites approached the industrial zone.

Previous chemical studies of the sub-tidal sediments (Mudge & Seguel 1999) have indicated severe organic contamination in the northeast corner of the bay with dispersion towards the west. Similarly, Marshall (1998) measured elevated ammonium concentrations in the waters of the same region. However, chemical factors are not expected to vary greatly across the beach due to the buffering effect of seawater and the relatively coarse grain size of the sediments. Thus, their influence on macrofauna diversity and distribution is potentially limited. Less soluble chemical pollutants, such as the heavier metals found in the sediments, may concentrate in specific areas through complex sorting mechanisms and their effect on the macrofauna will depend greatly on the bioaccumulating capacity of the animal species. This study sought to determine whether the intertidal macrofauna diversity and distribution within the sediments of the sand beach of San Vicente bay could be explained by either the physical or chemical factors in the bay and intertidal zone.

MATERIAL AND METHODS

The sampling of the intertidal zone of the sandy beach in San Vicente bay was divided into several days. The total length of the surveyed beach extending from Lenga village to the property of

the Huachipato steel industry was some 4 km. The sandy beach studied consisted of two sections (see Fig. 2); Lenga beach, open to the general public, in which an established town, leisure and local fishing activities dominate. The other section belongs to the Huachipato steel industry, a steel company founded in the 1940s. Up to eight waste discharge pipes go into the sea from this site. In the boundary between the public and the private area of Lenga beach there is a discharge pipe from local chemical industries.

The present study is based on the sampling along six transects across the intertidal zone of the sandy beach of San Vicente bay (Fig. 2). Four of the transects were on Lenga beach and the remaining two in the Huachipato industrial estate beach. The three main sampling and analysis procedures of this study are described separately.

Biological survey

Intertidal macrofauna in the sediments was collected along the six transects identified above. Table 1 presents a description of the transects' layout and dates of collection of macrofauna and sediment samples. Transects were perpendicular to the waterline. Figure 2 shows the location of the
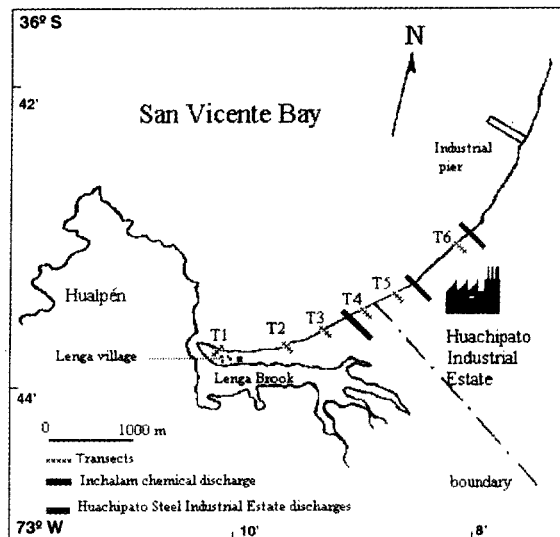

Fig. 2: Detailed map of San Vicente bay. The position of the six transects has been drawn approximately to scale. The transects are labeled T1 to T6, showing their relative positions along the sandy beach.

Mapa detallado de la bahía de San Vicente. La posición de los seis transectos ha sido dibujada aproximadamente a escala. Los transectos estan marcados T1 a T6, mostrando sus posiciones relativas a lo largo de la playa arenosa.

TABLE 1

Transect positions and brief description of their main characteristics along the sandy beach in San Vicente bay. Dates of collection of the intertidal macrofauna, chemical analyses and sampling of sediments for metal content analyses and grain size analyses are also shown

Posición de los transectos en la playa arenosa de la bahía de San Vicente y descripción breve de sus principales características. También se muestran las fechas de recolección de la macroinfauna y sedimentos para análisis de metales, análisis químicos y granulometría

Transect number	Transect position and brief description	Date of macrofauna collection	Date of chemical analyses	Date of sediment collection
1	Western-most transect, located nearest to the fishing village of Lenga and Lenga brook; relatively sheltered from the main circulation and waves of the bay	25/6/98	10/7/98	7/9/98
2	Mid-way between Lenga village and the end of the public beach; exposed to waves coming directly into the bay	25/6/98	10/7/98	7/9/98
3	On southern side of Inchalam chemical outlet pipe which discharges straight into the beach; very exposed to waves	25/6/98	10/7/98	7/9/98
4	Next to the Inchalam chemical outlet pipe which discharges straight into the beach; very exposed to waves	25/6/98	10/7/98	7/9/98
5	Within the privately owned beach, north of the stone wall, relatively undisturbed by human activity; very exposed to waves	23/7/98	8/9/98	
6	Eastern-most transect located nearest to the Huachipato steel industrial site; high water end of the beach had been destroyed in order to gain land into the sea to build a road; extremely exposed	26/6/98	8/9/98	

transects drawn to scale. Sampling started at the time of high water and followed the ebb down the beach. The dates chosen for surveying coincided with spring tides. Stations were placed every 2 m down the transect and replicates were taken 2 m on either side of the transect line. Steepness of the transects was measured by the Emery method (1961). Samples of the intertidal macrofauna were collected by coring 200 mm into the sediment (core diameter = 170 mm). The samples were sieved through 1 mm sieves with seawater and the larger particles (> 1mm) were stored in plastic bags with 10 % formalin solution. In the laboratory the biological samples were identified using a magnifying glass where necessary; local field guides as well as specific studies on isopods of the Chilean coastline (Jaramillo 1982) were also employed. Based on the total number of individuals and species found specific richness, species diversity and evenness values were calculated for each transect. A dendrogram displaying the clustering of the six transects based on the Jaccard similarity index was also determined. In order to determine the response of the macroinfauna to the abiotic factors studied, the abundance of the most common species (*Emerita analoga*) was chosen to

correlate with information on beach morphodynamics, physicochemical parameters and metal concentrations. A multivariate analysis (PLS, Mudge & Seguel 1999) was also used to detect the possible effects of metals on abundance of *E. analoga* along the beach.

Chemical survey

Two main chemical studies took place: initially basic physicochemical measurements were made on the interstitial water that percolated into holes excavated during low tide at the upper, mid and lower shore along the main transects. The features considered were temperature, pH, salinity and dissolved oxygen concentration. The other chemical study was on the concentration of acid-exchangeable metals attached to sediment samples taken along the transects.

For the physicochemical analyses a hole was dug to 50 cm and the interstitial water collected from the base. Such water was regarded to represent interstitial seawater since care was taken to collect the water from holes at which no waves entered while digging or water collecting. Mea-

surements of pH, temperature and salinity were made in situ using the appropriate devices and oxygen concentrations were fixed with $MnSO_4$ and alkaline iodide. Oxygen concentrations were later determined in the laboratory following the Winkler titration technique (Grasshof et al. 1983).

The sediment samples for metal analysis were air dried for 20 days. Aliquots of sediment (~ 1g) were acid digested using 2 ml concentrated nitric acid for 2 h at room temperature. Samples were diluted with 10 ml of deionised distilled water, filtered through a grade 4 Whatman paper filter and analysed by ICP-AES to obtain the concentrations of 12 relevant metals: tin (Sn), mercury (Hg), chromium (Cr), zinc (Zn), lead (Pb), nickel (Ni), cobalt (Co), cadmium (Cd), manganese (Mn), iron (Fe), copper (Cu), and aluminium (Al).

Physical survey

Physical measurements of the beach characteristics included slope at each transect measured by the Emery method (1961) and sediment samples collected from each transect at 15 cm depth to determine grain size and organic matter content. Further data was collected on height of waves and wave period during 5-min measurement sessions carried out simultaneously by three people at different places along the beach. Sand fall velocities were taken from Gibbs et al. (1971) based on the estimated mean sand particle sizes per transect (McLachlan et al. 1996). A morphological classification of the sandy beach according to Masselink & Short's (1993) description was therefore possible.

A sieving method was employed to determine sediment grain size after the samples had been oven-dried at 60 °C for 2 days. Grain size ranges extended from 2 mm (coarse sand) down to 0.031 mm (fine clay). Organic matter content was determined by weight loss on ignition of the sediment samples in a furnace at 450 °C.

To determine the breaker height of the waves at the transect sites a special instrument had to be designed. A tethered floating buoy was attached to a weight with a chain ~3 m long. A rope 30 m in length acted as the line to enable its retrieval. The buoy was launched into the surf zone where the waves broke. The buoy would bob up and down in a vertical line for most of the waves coming in. Standing at a distance, and holding a scaled vertical stick, it was possible to measure the movement of the buoy with the in-coming waves relative to the size of the buoy. The wave period was counted as the number of waves per minute (averaged over a 5-min period) and took place on the dates the sediment samples were collected.

RESULTS

Biological survey

A maximum of five intertidal macrofauna species were collected from the six transects along the shoreline of the sandy beach in San Vicente bay extending from the Lenga village to the Huachipato steel industrial. Table 2 presents a summary of the data obtained from the biological

TABLE 2

Summary of the results obtained from the intertidal macrofauna survey of the sandy beach in San Vicente bay. Maximum number of species was found in transect 1, furthest away from the chemical and steel industries section of the bay. Total number of individuals for a given transect was taken to be the sum of animals for both replicates of each station

Resumen de los resultados de la macroinfauna obtenida en la zona intermareal de la playa arenosa de la bahía de San Vicente. En el transecto 1 se encontró el mayor número de especies. El total de individuos en un transecto corresponde a la suma de dos réplicas para cada estación

Transect	Total number of individuals of each species				
	Orchestoidea tuberculata	*Excirolana hirsuticauda*	*Emerita analoga*	*Euzonus heterocirrus*	*Scolelepis chilensis*
1	4	30	803	10	4
2	88	2	198	0	0
3	69	1	18	0	0
4	24	0	0	0	0
5	5	0	11	0	0
6	0	0	1	0	0

survey. Note that only in transect one are all the five species present.

When present in a transect, the amphipod *Orchestoidea tuberculata* was always found at the highest part of the shoreline along the high tide mark. The isopod *Excirolana hirsuticauda* was found in the mid-shore region of the transect together with the anomuran *Emerita analoga* though the latter species extended well into the low water section of the intertidal zone. When present, *E. analoga* accounted for the highest numbers of total individuals present in any of the six transects in the low water band. In transects three and four *O. tuberculata* was the most abundant species, though restricted to the intertidal high water band. Two species of polychaetes were found in transect one in the stations nearest to low water. *Euzonus heterocirrus* appeared in the mid to low water zone, whereas *Scolelepis chilensis* (Hartmann-Schröder) was only found in the lowest station of the same transect.

Transect four contained only *O. tuberculata,* which were found near the high water mark. In transect six, nearest to the steel and chemical industrial area of the bay of San Vicente only one individual of *E. analoga* was collected in the station located at the lowest water level of the intertidal range.

Diversity indices and evenness for the data are presented in Table 3. Note the low degree of evenness for all transects except for number five. There seems to be a slight discrepancy between the Shannon-Weiner and the Margalef indices. The Shannon-Weiner index appears to show more diversity as we go from transect one to six, whereas the Margalef index shows the opposite trend. This is due to the inherent nature of the formulae which determine each parameter. Shannon-Weiner takes into account the presence of each individual species as part of the whole community, so that when a species dominates such as *E. analoga* in transect one, the diversity index is low. On the other hand, Margalef considers all species as part of the total number of individuals observed. This parameter does not discriminate against each species' individual input so diversity appears to be high when the number of present species is high. The evenness parameter depends directly on the

TABLE 3

Results from the biological survey of the intertidal macrofauna of the sandy beach in San Vicente bay expressed in terms of diversity indices Shannon-Weiner and Margalef, and Evenness. Their respective formulae are shown where S = number of species present along a transect, n = total number of individuals and p_i = proportion each species represents in relation to the total number of animals collected in a given station. Column two represents the total number of collected individuals which, for a given transect, was taken as the sum of all the animals collected at both replicates of each station. Column three represents the density of organisms collected per transect; values have been approximated to the nearest whole number. Specific richness for each of the six transects across the intertidal zone of the sandy beach of San Vicente bay is shown in column four

Resultados del muestreo biológico de la zona intermareal de la bahía de San Vicente en términos de índices de diversidad Shannon-Weiner, Margalef y Uniformidad con sus fórmulas correspodientes, donde S = número de especies en un transecto, n = número total de individuos y p_i = proporción que cada especie representa del total de animales recolectados en una determinada estación. La columna dos presenta el número total de individuos recolectados por transecto, y resulta de la suma de todos los animales recolectados en ambos duplicados de cada estación. La columna tres presenta la densidad de organismos por transecto; los valores han sido aproximados al número entero más cercano. La riqueza específica para cada uno de los seis transectos de la zona intermareal de la playa arenosa de la bahía de San Vicente se muestra en la cuarta columna

Transect	Total number of individuals	Density indiv m^{-2}	Number of species or specific richness	Shannon-Weiner $H' = -\sum p_i(\ln p_i)$	Margalef $D_{mg} = S{-}1/\ln N$	Evenness $J = H'/\ln S$
1	851	188	5	0.28	0.59	0.17
2	288	53	3	0.65	0.35	0.60
3	88	15	3	0.52	0.45	0.47
4	24	7	1	0	0	0
5	16	3	2	0.62	0.36	0.90
6	1	0	1	0	0	0

Shannon-Weiner index and so it follows a trend similar to it. For both diversity indices at least two species had to be present for there to be any diversity so that transects four and six are zero. Density (number of individuals per m^2 as integers) is also presented in Table 3. Transect one shows the highest value for this parameter, which seems to decrease exponentially towards transect six. Specific richness has a general trend towards lower values from transect one to six. The transect with the highest specific richness was number one. Transects four and six had the lowest ranking for specific richness out of all the transects.

A pictorial view of the distribution of all species density, and by inference the biomass, is shown in Fig. 3. This contour plot shows the presence or absence of a species along the six transects throughout the tidal range measured as individuals per litre of sediment. The tidal range presented on the y-axis is 100 % at the high water mark and 0 % was the last station at low water. Transect positions are presented on the top x-axis and, from left to right, indicate the relative position of each transect across the beach as we look landward to the beach from a seaward position. Stations are symbolically presented down the vertical where the number of dots reflects the number of stations per transect. The density function was compiled from the two replicates. The
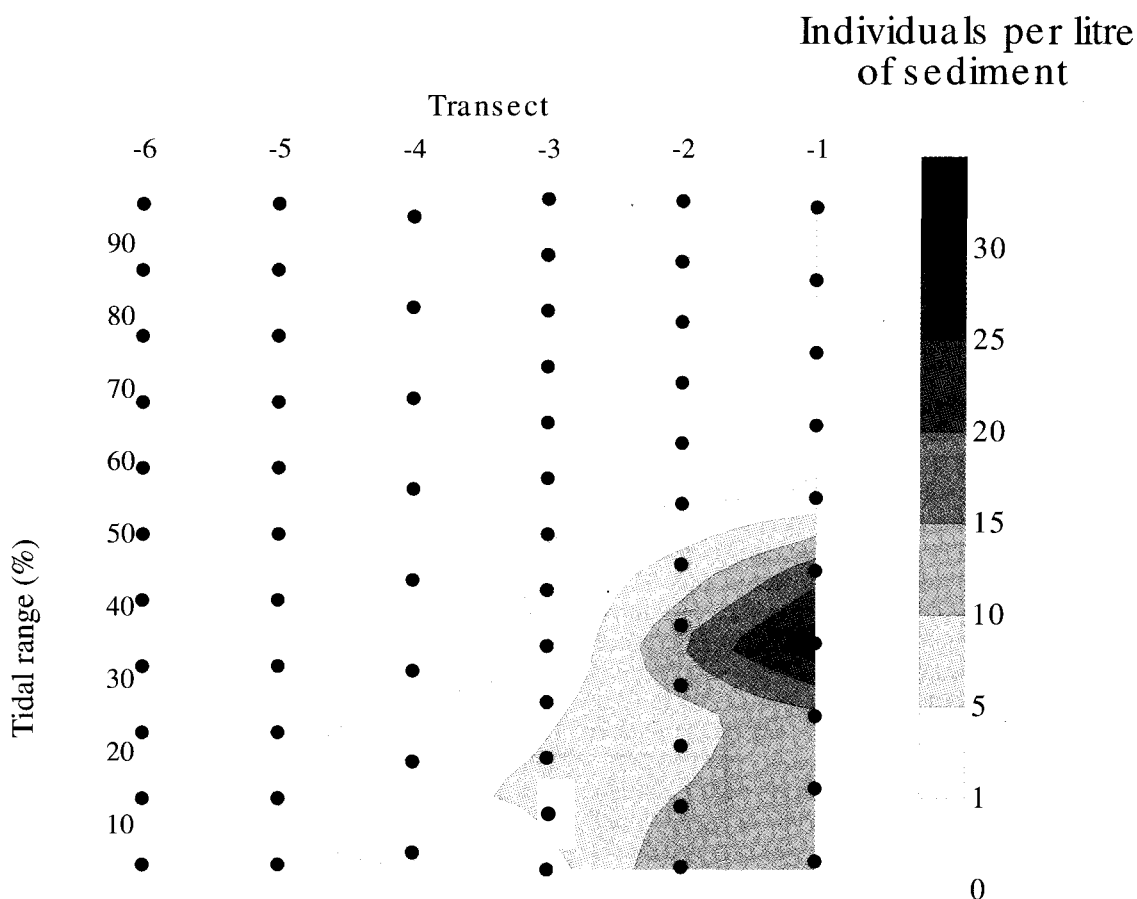

Fig. 3: Contour map for the macrofauna distribution along the six transects across the sand beach of San Vicente bay. Units are in ind l^{-1} sediment. Transects appear from left (industrial zone) to right (recreational area) looking landwards from the sea. Tidal range is the percentage above zero datum elevation. The black dots down each transect are the number of stations which were sampled.

Distribución de la macroinfauna a lo largo de los seis transectos en la playa arenosa de la bahía de San Vicente. Las unidades corresponden a número de individuos por litro de sedimento, las líneas en el mapa de contorno unen puntos de igual densidad. La disposición de los transectos es de izquierda (zona industrial) a derecha (zona recreativa) mirando desde el mar hacia tierra. La altura en la zona intermareal se expresa en porcentaje sobre el nivel cero de mareas. Los puntos negros representan las estaciones a lo largo de los transectos.

maximum number of individuals was found in the mid-lower stations of transect one and two, where a 'wave' pattern can be distinguished and seen to have a maximum at 30 % tidal range. Minimum values for macrofauna abundance are typical of transect six and five, extending from left to right, predominating between 50 % to 80 % tidal range.

Figure 4 presents the clustering of the six transects with respect to the total number of individuals found per species along each one of the transects. The similarities between each of the transects is shown as a percentage. The greatest difference exists between transect one and any of the other transects, where only a similarity of 35 % is found. Transects four, five and six show a similarity of close to 100 % between each other. Using the 50 % similarity criterion, from the dendrogram we can recognise two main faunistic units: one comprised solely by transect one and the other one comprised by the rest of the transects. No other standard statistical methods were appropriate to establish confidence levels when comparing the data due to the inherent nature of the observations, which proved to be non-normally distributed and have significant heterogeneity of variance.

Evidence from the biological survey suggests a general decrease (expressed as total number of individuals l^{-1} of sediment and density) in the presence of intertidal macrofauna in the sedi-

ments of the sandy beach of San Vicente bay as we move from transect one towards transect six. In order to correlate the results from the biological survey with either the chemical or the physical parameters, the total number of individuals of *E analoga*, the commonest species, was used (see below).

Chemical survey

Chemical analysis of the interstitial waters obtained from holes excavated down to the water table at different heights along each of the six transects is presented in Table 4. The pH values are all close to 7.8, except for the mid shore values of the third and fourth transects. These two transects happen to be within 50 m on either side of the Inchalam works discharge, which goes straight into the beach (see Fig. 2). The temperature of the waters varied from 11.9 °C to 14.3 °C. Even within the same transect variations of more than 1 °C can be seen although no general pattern can be described. Salinity values in parts per thousand varied between 27.8 and 32.3. Again, no general trend can be described as the salinity values seem to be similar for all six transects along the sandy beach.

Oxygen concentrations (in ml O_2 l^{-1}) varied from 3.0 in the lower shore of transect one to 7.1
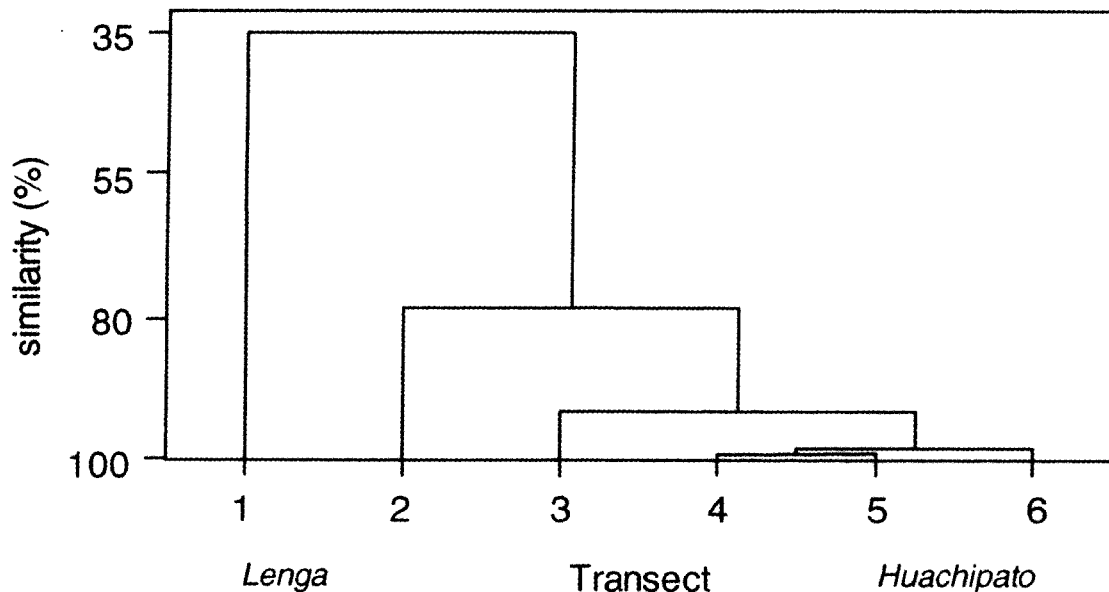

Fig. 4: Dendrogram displaying the clustering of the six transects along the sandy beach of San Vicente bay based on the comparison of total number of individuals per species counted per transect. The Jaccard similarity index in a UPGMA analysis was used.

Dendrograma ilustrando la agrupación de los seis transectos a lo largo de la playa arenosa de la bahía de San Vicente basado en la comparación de número total de individuos hallados por transecto y por especie. Se usó el índice de similitud de Jaccard y un análisis UPGMA.

TABLE 4

Results of the basic chemical analysis of the interstitial waters obtained from holes excavated along each of the six transects at high, mid and low water levels. For transect five and six only mid shore results are available

Resultados de los análisis químicos de las aguas intersticiales obtenidas tras excavar en cada transecto a distintas alturas de la zona intermareal. Para los transectos cinco y seis sólo se obtuvo resultados para la zona media

Transect	Height on shore	pH	T(^{o}C)	Salinity (ppt)	O_2 (ml O_2 l^{-1})
1	Upper	7.8	12.5	30.3	5.7
	Mid	7.6	12.3	28.1	3.5
	Lower	7.5	12.0	27.9	3.0
2	Upper	7.8	14.3	30.0	6.2
	Mid	7.8	14.3	29.8	7.1
	Lower	7.9	13.0	30.3	6.0
3	Upper	7.7	13.5	29.5	5.7
	Mid	9.4	14.0	32.3	6.4
	Lower	7.8	14.0	27.8	6.4
4	Upper	7.7	13.0	25.8	6.5
	Mid	8.3	14.0	30.3	6.6
	Lower	7.8	13.1	30.0	5.8
5	Mid	7.8	11.9	29.8	6.1
6	Mid	7.8	13.1	30.8	5.2

in the mid shore of transect two. Only in transect one was there a general reduction in oxygen concentration down the water line, reaching a minimum at the lowest station of this transect. The rest of the transects do not offer a trend in oxygen levels with respect to height on the intertidal region, nor does there seem to be any correlation with the other measured factors, such as temperature or salinity.

The results from this general chemical analysis do not offer any consistent trend across the shoreline or along the transects for any of the measured parameters except for the oxygen concentrations observed down transect one. However, these did not prove statistically significant within the 95 % confidence level when analysed by the Kruskal-Wallis test.

The concentrations of the twelve metals that were analysed in the sediments of the transects across the sandy beach of San Vicente bay had the following decreasing order:

Fe > Al > Mn > Zn > Sn > Pb > Cr > Ni > Cu > Co > Hg > Cd

These 12 metals can be divided into three groups according to their observed distributions on contour maps. Some kind of differential sorting pro-

cess or source seems to be acting upon the distribution of the metals in the sediments. However, no significant correlation was established between concentration order and grouping of the metals. For each group, a representative metal with the characteristic contour distribution for all the metals in that group was chosen. The three metal groups are those represented by Sn, Cd and Cr. Table 5 presents the metals grouped into the three categories: 'wave', 'banded' and 'intermediate', and shows the mean concentrations in mg.g^{-1} dry weight sediment.

These three types of distributions are represented in their respective contour maps (Fig. 5). Tidal range is always presented on the y-axis where 0 % is at low water and goes up to 100 % at the high water mark. Transect positions are presented on the top x-axis and, from left to right, indicate the relative position of each transect across the beach as we look landward to the beach from a seaward position. The different stations along each transect are shown as dots down the vertical.

Figure 5a is the contour diagram for Sn. A clear 'wave' pattern can be seen to emerge and expand from left to right, that is from the industrial to the recreational end of the beach. The three highest concentrations are observed at 0 %, 50 % and 75 %

tidal range. Figure 5b is the contour diagram for the Cr 'intermediate' group distribution. It presents similar features to the Cd distribution (see below), yet the concentrations appear to have a left to right sweep. The highest concentrations are observed at 0 %, 40 %, 70 % and 100 % tidal range. Transects three and four quite clearly influence this contour pattern, as they also do for the Cd contour plot. Figure 5c is the contour diagram for Cd. The main feature of this contour plot is that we observe horizontal 'bands' going across all the transects and the concentration gradient is more vertically-dependent than that of Sn. Highest concentrations appear at 0 %, 40 % and 100 % tidal range. The banding of the concentrations seems to come from the right and move leftwards.

Statistical analysis of metal concentration means down the transects in the across the sandy beach gradient using non-parametric Kruskal-Wallis test revealed that there was no significant difference at a 95 % confidence level between means for Cr nor for Cd. The same analysis for Sn showed that concentrations at $T_1 \neq T_2 = T_3 \neq T_4 = T_5 \neq T_6$ (where T represents each transect with its respective subscript and $\neq$ symbolises a significant difference between the means at a 95 % confidence level); the highest concentration was at transect six.

Statistical analysis of metal concentrations down the tidal range spectrum using the Kruskal-Wallis test showed that there was no significant difference between concentrations at the 95 % confidence level for any of the three representative metals tested. The different patterns observed on the contour plots, whether 'wave', 'banded' or 'intermediate' type, do not show statistical significantly different metal concentrations as we move down the intertidal range.

The concentrations for these three metals were the ones chosen for further statistical analysis when correlating them with the biological results. The concentration of each metal down a particular transect was tested for correlation with the total number of E. analoga individuals down the intertidal zone of that same transect. Concentrations of the three representative metals Sn, Cr and Cd showed no significant correlation within the 95 % confidence level with the E. analoga distribution along any of the transects across the beach. However, the multivariate analyses (PLS) detected a negative correlation between abundance of E. analoga and the concentration of both Sn and Fe (r = -0.20 and -0.10, respectively) while a positive one with Mn (r = 0.40). Correlation with all other metals was close to zero. Note that the highest macrofaunal density at 30 % tidal range in

TABLE 5

Grouping of the twelve analysed metals into three categories according to their characteristic distributions observed across the intertidal zone of the sandy beach of San Vicente bay. A representative metal was chosen for each group on the basis of having the most characteristic contour distribution defined by that group. The metals were classified as having wave, banded or intermediate contour patterns. Beneath each metal its corresponding mean concentration in mg g^{-1} dry weight sediment ± standard deviation is shown, along each of the six transects

Clasificación de los doce metales analizados en tres categorías, de acuerdo con su patrón de distribución característico en la zona intermareal de la playa arenosa en la bahía de San Vicente. Cada grupo va encabezado por el metal más reprentativo de cada patrón. Los metales fueron agrupados en los patrones de tipo ola, bandeado o intermedio. Debajo de cada metal aparece su concentración promedio en mg g^{-1} peso seco de sedimento ± desviación estandard en los seis transectos

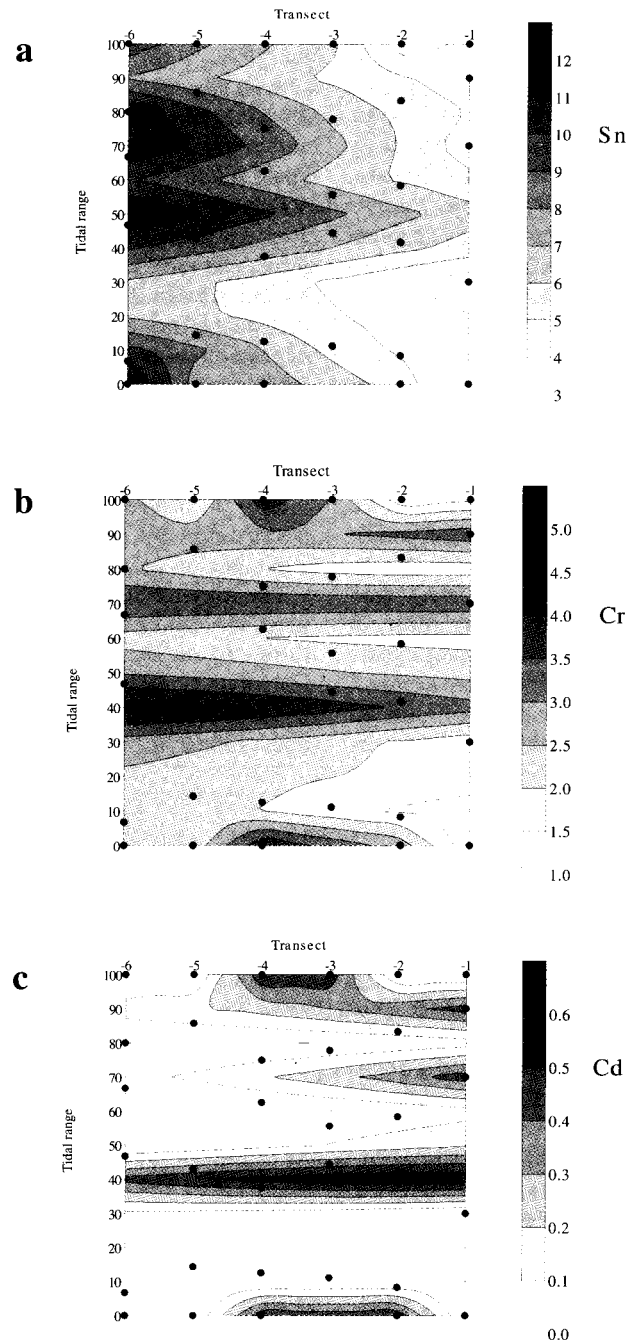|	Representative metals for each of the characteristic distributions across the sandy beach		
	Sn 7.13 ± 2.61	Cd 0.15 ± 0.23	Cr 2.52 ± 0.91
Other metals in the same group	Zn 33.28 ± 12.11	Hg 0.63 ± 0.79	Ni 2.00 ± 1.44
	Fe 3933 ± 975	Mn 58.81 ± 23.89	Cu 1.49 ± 0.79
	Al 855.60 ± 174.80	Pb 4.07 ± 1.19	Co 0.95 ± 1.22
Type of contour pattern	Wave	Banded	Intermediate

Fig. 5: Contour maps for metals. Transects appear from left (industrial zone) to right (recreational area) looking landwards from the sea. Tidal range is the percentage above zero datum elevation. The black dots down each transect are the number of stations which were sampled. Units are in mg g^{-1} dry weight sediment. (a) Tin (Sn), which was the metal chosen to represent the 'wave' pattern. (b) Chromium (Cr), which was the metal chosen to represent the 'intermediate' pattern. (c) Cadmium (Cd), which was the metal chosen to represent the 'banded' pattern.

Distribución de la concentración de metales en la zona intermareal de la playa arenosa de bahía San Vicente. Las líneas en el mapa de contornos unen puntos de igual concentración. La disposición de los transectos es de izquierda (zona industrial) a derecha (zona recreativa) mirando hacia tierra desde el mar. La altura en la zona intermareal se expresa en porcentaje sobre el cero de mareas. Los puntos negros representan las estaciones a lo largo de los transectos. Las unidades son mg g^{-1} peso seco de sedimento. (a) Estaño (Sn), elegido para representar el patrón de distribución tipo 'ola'. (b) Cromo (Cr), elegido para representar el patrón de distribucion tipo 'intermedio'. (c) Cadmio (Cd), elegido para representar el patrón de distribución tipo 'bandeado'.

transect one (Fig. 3) corresponds to the point at which the metals distributed in "waves" (Sn and Fe included) reach a low concentration (Fig. 5a).

Physical survey

The physical properties of each of the transects surveyed across the sandy beach of San Vicente bay are presented in Table 6. The organic matter content of the sediment samples (% TOC) of each transect show very little difference between each transect with the low values reflecting the coarse grain size. The grain size ranged between 0.34 mm (medium sand) at transect two to 0.54 mm (coarse sand) at transect three. Intermediate values resulted in the rest of the transects and no general pattern can be described. The slopes of the transects ranged from 1 in 7 m at transect one to 1 in 13 m at transect six. There is an indication of a predominant pattern leading to variations in the slopes across the sandy beach at a large scale where small troughs and cusps alternate. A correlation does exist between 1/slope and the total number of individuals per transect where the cor-

relation coefficient $r = 0.62$, with $P < 0.05$, within the 95 % confidence level. However, the regression analysis was not strong and only explained 36 % of the observed variability. No other apparent correlation seems to exist between any of the basic parameters.

Further consideration of other physical parameters is also presented in Table 6. The different transects across the sandy beach of San Vicente bay have been classified according to the conceptual beach model (Masselink & Short 1993). An overall view of the sandy beach of San Vicente bay based on these parameters is possible. The dimensionless parameters on which the beach classification is based are the dimensionless fall velocity (Ω) and the relative tide range (RTR). $\Omega = H_b/w_sT$, where H_b is the breaker height (m), w_s is the sediment fall velocity (m s^{-1}) and T is the wave period (s); RTR = tide range/H_b.

The dimensionless fall velocity parameter Ω is used as an index of degree of dissipativeness of the surf zone. The Ω parameter for all transects is less than 2, so all transects fall under the category of reflective. Note, however, that a general trend does appear to take place and Ω values increase

TABLE 6

Physical parameters of the six transects across the sandy beach of San Vicente bay. Organic matter content is presented as %; grain sizes of the sediment samples collected at each transect are in mm; 1/slope (m) refers to metres advanced in the horizontal with respect to 1 m change in the vertical. Parameters Ω and RTR describe the transects according to the conceptual beach model (Masselink & Short 1993). Ω is a dimensionless parameter which depends on breaker height (m), wave period (s) and sediment fall velocity (m s^{-1}). Ω ranges from zero (reflective) to more than five (dissipative). RTR is the relative tide range and is given by the ratio of tide range to breaker height. RTR ranges from less than three (fully reflective) to > 15 (ultra-dissipative), and gives an indication of whether the beach is tide-dominated (larger values) or wave-dominated (smaller values)

Parámetros físicos de los seis transectos de la playa arenosa de la bahía de San Vicente. La materia orgánica aparece como porcentaje del total del peso seco; tamaño de grano en mm; 1/pendiente describe los metros avanzados en la horizontal con respecto a 1 m en la vertical. Ω es un parámetro sin dimensión que depende de la altura de la ola rompiente (m), del periodo del oleaje (s) y de la velocidad de caída del sedimento (m s^{-1}). Valores de Ω cercanos a cero representan una playa reflectiva. RTR, es el rango relativo de mareas y corresponde a la razón entre el intervalo de mareas y la altura de las olas rompientes. Valores de RTR menores que tres representan playas reflectivas de acuerdo con el modelo conceptual de playas descrito por Masselink & Short (1993)

Transect	Organic matter content (% TOC)	Grain size (mm)	Ω (no units)	RTR (no units)	Beach classification according to the conceptual beach model		1/slope (m)
1	0.10	0.44	0.48	5.2	All	3 < RTR < 7;	7
2	0.09	0.34	0.81	3.1	transects	low tide	9
3	0.09	0.54	0.65	3.3	have Ω < 2	terrace with rips	12
4	0.08	0.38	1.81	1.2	they are	RTR < 3	8
5	0.09	0.38	1.01	2.1	reflective	fully reflective	8
6	0.08	0.44	1.94	1.3			13

steadily from transect one to six. The description of the beach face according to the Ω parameter refers to it as steep, generally cusped, and a pronounced step is present at the base of the swash zone (Fig. 6). Wave height is small and beach sediments are coarse (Masselink & Short 1993). The relative tide range (RTR) is used an as index of the relative role of tides and waves in allowing swash, surf zone and shoaling wave processes to mobilise sediments (McLachlan et al. 1996). The small values of the RTR parameter indicate that the beach is mainly wave-dominated since these coasts are essentially micro-tidal. Combinations of Ω and RTR divide the sandy beach of San Vicente bay into two categories. Transects four, five and six closest to the steel/

chemical industrial zone are fully reflective with $\Omega < 2$ and RTR < 3 whereas transects 1, 2 and 3 nearest to Lenga village are described as reflective with low tide terrace with rips with $\Omega < 2$ and $3 < RTR < 7$ (Fig. 6). The RTR values were statistically tested using Kruskal-Wallis. The RTR values for transects one, two and three were significantly different from the RTR values of transects four, five and six at the 95 % confidence level. The total numbers of *E. analoga* individuals counted per transect was compared with the RTR values and correlation proved significant at the 95 % confidence level.
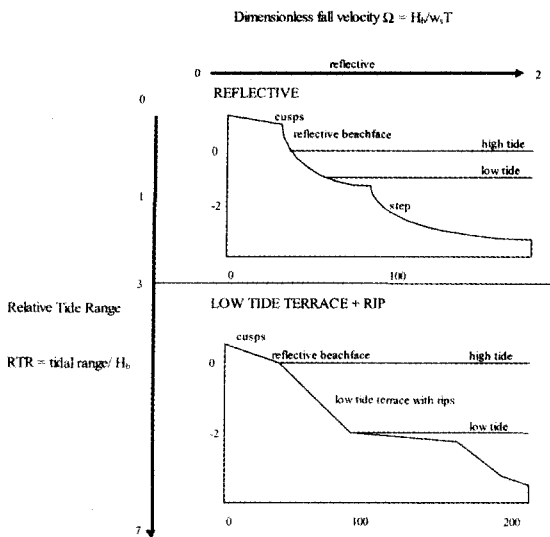

Fig. 6: Summarised presentation of the different classifications of beaches according to the conceptual beach model (redrawn from Masselink & Short 1993). RTR = tidal range/H_b; $\Omega = H_b/w_sT$. Where H_b is the breaker height (m), w_s is the sediment fall velocity (m s^{-1}) and T is the wave period (s). Note that subdivisions within each range for the RTR and Ω parameters do not exist, so that beaches can be classified within one same category even though their values for RTR and Ω parameters can vary up to two or more units.

Clasificación simplificada de los diferentes tipos de playa de acuerdo con el modelo conceptual de playas (basado en el trabajo de Masselink & Short 1993). $\Omega = H_b/w_sT$. Donde H_b es la altura de la ola rompiente (m), w_s es la velocidad de decantación del sedimento (m s^{-1}) y T el periodo del oleaje (s). Valores de Ω cercanos a cero representan una playa reflectiva. RTR, el intervalo relativo de mareas es la razón entre el rango de mareas y la altura de olas rompientes (H_b). Las subdivisiones dentro de cada intervalo son amplias para los parametros RTR and Ω y aunque varien para una playa en dos o más unidades, estas siguen siendo clasificadas bajo una misma categoría.

DISCUSSION

Results from the biological survey of the sandy beach of San Vicente bay in central Chile indicate that distribution and specific richness of the intertidal macrofauna across the beach are not homogeneous. There is a skewed distribution of the macrofauna towards the Lenga village end of the beach, which results in a decrease of specific richness towards the chemical industry dominated area of the beach. These findings are similar to those published by Hernández et al. (1998). The decapod *E. analoga* is the dominant species of the sandy beach of Lenga in central Chile (Hernández et al. 1998). The present study found *E. analoga* to be the most abundant species in the mid to low intertidal regions. The dendrogram showing the clustering of the transects according to a comparison between the total number of specimens collected at each transect clearly separates transect one from all the others. Certain conditions, whether chemical or physical are clearly influencing the abundance of species and individuals along this transect. Transect one was located nearest to the Lenga Brook, which might influence the amount of total organic matter (TOC) reaching that zone, enhancing the macrofauna diversity (Hernández et al. 1998) although the % TOC was essentially the same along the beach (see Table 6 and Hernández et al. 1998). It may also be possible for fresher waters from the lagoon (Fig. 2) to pass through to the sands although there was no direct evidence of this occurring during the sampling period.

Comparison of the contour maps of the fauna distribution with those of the three selected metals was inconclusive. The 'wave' metals, represented by Sn, have a distribution almost opposite to the one observed for the macrofauna abundance. However, no statistical test appeared to establish a significant correlation between them except for multivariate analyses (PLS, Mudge & Seguel 1999),

which indicated a negative correlation for the "wave" metals Sn and Fe and a positive one for Mn, a "banded" metal. Interesting enough, the highest macrofaunal density at 30-40 % tidal range in transect one (Fig. 3) corresponds to the point at which the "wave" distributed metals (Sn and Fe included) reach a low concentration (Fig. 5a) and the "banded" metals (Mn included) reach a high concentration. For most of the other metals in the groups, represented by Cr and Cd, no apparent trend related to the macrofauna distribution was seen in the contour plots and this was reflected in the non-significant statistical relationships. Therefore, in the intertidal zone in the sandy beach of San Vicente bay metals did not appear to influence the distribution of the macrofauna, and this is so because the relation between concentrations of metals in the sediments and macrofaunal distribution is not a simple one. Ahumada (1994) showed that active bioaccumulation of certain metals by invertebrates in San Vicente bay concentrated metals inside the organisms differently to concentrations in the sediments. Ahumada (1995) measured the metal concentrations in the sediments of the San Vicente bay. The author found two different types of metal groups according to their behavior: Cd, Cu, Pb and Zn were found to associate with anoxic fine sediments, rich in organic matter. The second group made up of Cr and Ni, did not show a consistent pattern in their distribution. Further studies of bioaccumulation of metals in the different tissues of the macrofauna species in the sandy beach of San Vicente bay are required to obtain more conclusive results on metals and their levels of toxicity, if any, which might influence the abundance and distribution of the macrofauna.

Of the physicochemical measurements made, only the oxygen concentrations shows any systematic variation across the beach. Concentrations in transect one reached low values of 2.96 ml O_2 l^{-1}, close to 40 % air saturation. Even though this value was lower than any other recorded in any of the other stations along any of the transects, it occurs at the same tidal range where the greatest number of macrofauna species and individuals were collected. The low oxygen concentrations may be explained by biological consumption and were not a limiting factor in macrofauna distribution in the sandy beach of San Vicente bay. Oxygenated water penetrates down to a few metres into the interstitial spaces in beaches with coarse sand (Eagle 1983). The rest of the oxygen concentrations in the other transects are close to saturation. The low salinity value of 25.8 recorded in transect four might be explained by seepage of freshwater through the sand barrier to the Lenga Brook.

The basic physical parameters were in accordance with the results from previous studies by Hernández et al. (1998), both in grain size and slope, yet differ when considering the percentage of organic matter. The results from the present study are well below other organic matter content results for Lenga beach and other beaches of the area (Palma et al. 1982, Hernández et al. 1998). A possible explanation might be the time of year the sediments were collected which for this study (mid-winter).

The only results which present evidence of a statistical significant relationship are those between the total number of individuals of E. analoga per transect and the dimensionless parameter relative tide range (RTR), and between the total number of individuals of E. analoga per transect and 1/slope. Figure 6 shows some of the different beach states according to the conceptual beach model by Masselink & Short (1993). Note that this classification is so broad that subtle changes in the values of RTR or Ω are dismissed. Perhaps if there were narrower boundaries between the subdivisions, a clearer view of the significance of these results would be available. RTR is a physical parameter dependent on breaker wave height and tidal range affecting the beach. These are important in determining grain size of the sandy beach and slope, and essentially control the O_2 content of the water in the interstitial spaces and therefore the distribution on macrofauna in the intertidal zone (Jaramillo 1994, Dugan & Hubbard 1996, Brazeiro 1999). The RTR values for transects one, two and three where significantly different (and higher) then those for transects four, five and six. Higher values of RTR imply a more dissipative beach, which favours increased biological complexity (McLachlan et al. 1996), which could explain the higher species richness observed at transect one.

These results suggest that the intertidal macrofauna diversity and distribution within the sediments of San Vicente bay depends mainly on the physical factors measured in the bay and intertidal zone. However, transect one proved to have a clustering dissimilar to any of the other transects, and such great abundance and diversity does perhaps mean that there are some biological or chemical interactions which might have to be considered, in addition to physical ones, in order to explain such results. Transect one was nearest to the mouth of Lenga Brook. The area of the brook adjacent to Lenga village (see Fig. 2) is used extensively by the local people to harvest the macroalgae Gracilaria chilensis. Leaching of chemicals from this harvesting zone could be affecting the macrofauna in transect one. Multi-

variate statistics (PLS) using both the metal and exposure data indicate weak relationships between the Mn, inverse Sn and RTR values that explain about 60 % of the variation in the species abundance data. This result is not considered to be particularly strong but does indicate a trend.

The absence of the amphipod *Orchestoidea tuberculata* from the high water mark of transect six may be due to the destruction of its habitat. The industrial site has had to gain land to create a road along the shore. Artificial concrete boulders exist all along the shoreline immediately in front of the steel company. The natural high water mark has disappeared, preventing the presence of *O. tuberculata* in this part of the intertidal zone of the sandy beach of San Vicente bay.

Even though the results from the measurements of the physical parameters proved significant, they should be taken with caution because sampling only took place during very specific and limited days. It is not possible to generalise the dominating patterns of the morphodynamics of a sandy beach with only some measurements from a brief period of time.

Ahumada et al. (1989) studied the pollution in the water column and sediments of San Vicente bay. Anomalous results in nutrient concentrations and presence of phenols were reported. Pelagic and benthic fauna in the bay were affected by these conditions. The heavy industrial use of the bay was the most likely origin for these results. Similar studies of the water and sediments of the intertidal zone of the sandy beach of San Vicente bay are needed.

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