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Beach and Faunal Response to the Construction of a Seawall in a Sandy Beach of South Central Chile

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ABSTRACT

JARAMILLO, E., CONTRERAS, H., and BOLLINGER, A., 2002. Beach and faunal response to the construction of a seawall in a sandy beach of south central Chile. *Journal of Coastal Research*, 18(3), 523–529. West Palm Beach (Florida), ISSN 0749-0208.

The community structure and across shore zonation of the sandy beach macroinfauna has been found to be closely related to beach morphodynamics. Thus, any changes in beach morphodynamics may result in macroinfaunal changes. The construction during 1997 and 1998, of a concrete seawall at the northern and middle section of a beach in south central Chile (ca. 39° S) to protect the coast from erosion, provided the opportunity to look at the effects of changing morphodynamics on beach fauna. To do that, we used physical and biological data collected at both sides of the beach, before and after the seawall was constructed. Sediment samples (0.03 m², 30 cm deep) were collected at ten equally spaced levels along three replicated transects extending from above the drift line to the swash zone. The sediment was sieved through a 1 mm mesh and the organisms collected were stored in 5% formalin until sorting and measuring. Physical measurements included width of the intertidal, height and period of waves, sand fall velocity and Dean's parameter. Values of this parameter showed that both sides had reflective to low intermediate features. The results of ANOVA indicate that no significant differences ($p > 0.05$) were found between before and after or control and impact sites. BACI analyses were carried out with physical characteristics, *i.e.* the means of differences between both sides of the beach were similar. We found no significant differences when similar BACI analyses were carried out with macroinfaunal community characteristics such as species richness, macroinfaunal abundances and body sizes of the most common species (the cirrolanid isopod *Excirolana hirsuticauda* Menzies and the anomuran decapod *Emerita analoga* (Stimpson)). Thus, it is concluded that during the study period the presence of the seawall has not influenced the physical and macroinfaunal characteristics at the beach studied.

ADDITIONAL INDEX WORDS: *Beach morphodynamics, beach fauna, equilibrium beach, beach sand.*

INTRODUCTION

Morphodynamic types of beaches (*i.e.*, reflective, intermediate and dissipative) are the result of the interaction between wave climate and sediment characteristics (SHORT, 1996). With established sediment sources and under specific wave climate characteristics, a sandy beach will tend toward a natural equilibrium where the waves and longshore currents redistribute the sands supplied from the sources (see *e.g.* KOMAR, 1983). The equilibrium and morphodynamic characteristics will change when jetties, breakwaters and seawalls are constructed in the coastal zone, sometimes with negative consequences, such as coastal erosion (*e.g.* NORRSTROM, 1989). Even so, dynamic characteristics of exposed sandy beaches support quite a diverse and abundant macroinfauna (see BROWN and McLACHLAN, 1990).

The community structure of sandy beach macroinfauna has been found to be closely related to beach morphodynamics; *i.e.*, the species richness, abundance and biomass of the macroinfauna increase from reflective to dissipative conditions (McLACHLAN and JARAMILLO, 1995). It has been also found that across shore zonation of the intertidal macroinfauna is

affected by beach types; *i.e.* from reflective to dissipative conditions the number of faunal zones across the intertidal increases (McLACHLAN and JARAMILLO, 1995; McLACHLAN *et al.* 1996).

Small reflective pocket beaches alternate with intermediate and in some cases, dissipative sites along the coast of south central Chile (ca. 36–40° S) (PINO and JARAMILLO, 1992; JARAMILLO and McLACHLAN, 1993). Los Molinos is a sandy beach located at Bahía de Corral, coast of Valdivia (39° 31'S, 73°45'W) (Figure 1). The approximate length of the beach is 1.2 km. While its north side is more protected from wave action, its south side is more exposed to breaking waves. After a single snapshot sampling, JARAMILLO and McLACHLAN (1993 a) found that the north side displayed reflective conditions, while the south side had more intermediate features. During 1997 and early 1998 a concrete seawall was built along the north and middle section of this beach to protect the coast from erosion by wave action; this construction took in a 3 m band of the upper beach levels. This provided an unique opportunity to test the hypothesis that the presence of that seawall affects the morphodynamic characteristics of the north side of the beach, and consequently community structure and zonation of the intertidal macroinfauna. To test this hypothesis we used the BACI (Before/After



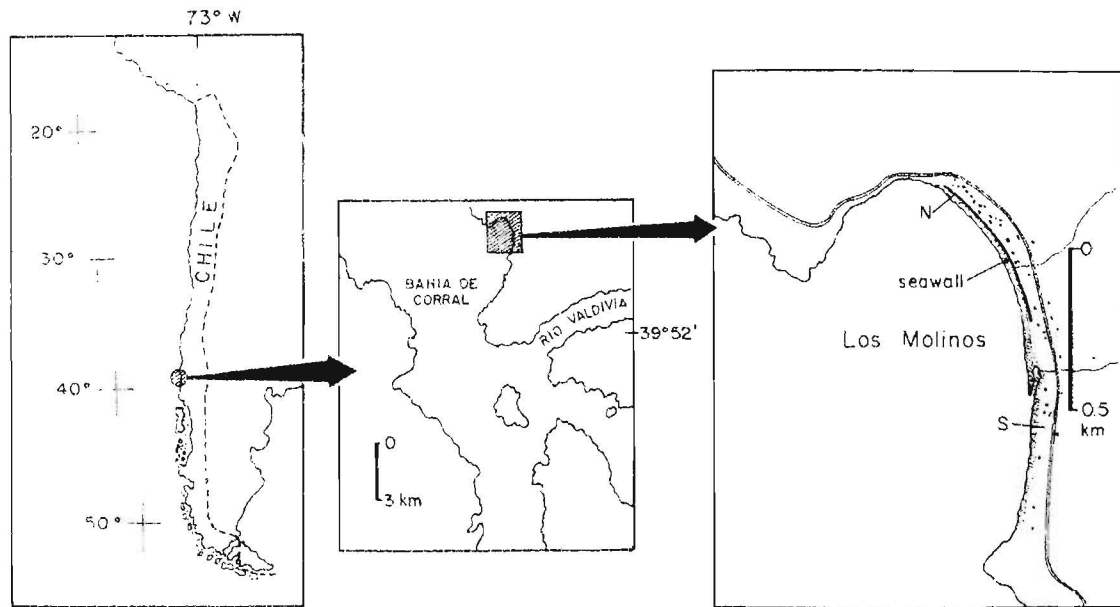


Figure 1. Location of the beach Los Molinos at Bahía Corral, south central Chile. Approximate locations of the concrete seawall and transects sampled at the north and south side of the beach are also shown.

and Control/Impact Sites) design of STEWART-OATEN *et al.* (1986), using samples collected before and after the seawall was constructed.

MATERIALS AND METHODS

To apply the BACI design, we used two data sets (physical and biological data; see below) collected at the north and south sides of the beach. The first one is represented by 14 monthly samples collected between April 1992 and August 1993 (the "before" data set); the second one is represented by 13 monthly samples collected during November 1997 and June 1999 (the "after" data set, see below).

Sediment samples (0.03 m², 30 cm deep) were collected at the north and south side of the beach (Figure 1) with plastic cylinders at ten equally spaced levels along three replicated transects (separated by 1 m) extending from above the drift line to the swash zone; *i.e.*, the uppermost station was located above the drift line, the second on the drift line and the last at the lowest limit of the swash zone (indicated by bore collapse). The sediment was sieved through a 1 mm mesh and the organisms collected were stored in 5% formalin until sorting. Abundance values per running meter of beach were obtained by linear interpolation between sampling stations, after obtaining mean abundances per m² at each sampling station. Mean abundances per m² were used to draw kite diagrams and analyze zonation of the most abundant taxa. The most representative species (see below) were measured to the nearest 0.1 mm length: the cirrolanid isopod *Excirrolana hirsuticauda* Menzies and the anomuran crab *Emerita analoga* (Stimpson). For the isopod the body size was the distance from rostrum tip to telson base, while the cephalothorax

length was used as a measure of body size in *Emerita analoga*.

Wave height was estimated by measuring the height of breaking waves with graduated poles against the horizon. The wave period (measured with a stop watch) was the time interval between breakers. Sediment samples were collected from the lower station (swash zone) for grain size analyses needed to calculate Dean's dimensionless parameter (Ω) (see below). Grain size analyses were carried out with a settling tube (EMERY, 1938). Mean grain size was calculated according to the moments computational method (SEWARD-THOMPSON and HAILS, 1973) and used to estimate sand fall velocity (GIBBS *et al.*, 1971). From estimated mean wave height, wave period and sand fall velocity, Dean's parameter was calculated: $\Omega = \text{wave height (cm)}/\text{sand fall velocity (cm s}^{-1}) \times \text{wave period (s)}$ (SHORT and WRIGHT, 1983). The morphology (*i.e.*, beach face slope at each sampling site) was determined by Emery's profiling technique (EMERY, 1961).

The eventual effect of the seawall on the physical and macrofaunal characteristics were analyzed throughout the BACI design. To do that, the following steps were followed: i) for each sampling period (*i.e.*, before and after the seawall was constructed), raw differences between the values of the variables estimated for the north and the south side of the beach were calculated, ii) testing of additivity through regression analyses (testing for zero slope) to fulfill one of the assumptions of BACI analyses (STEWART-OATEN *et al.*, 1992); those tests were carried out by using the average value calculated for each variable (*i.e.*, average resulting from the values estimated for the north and south side of the beach) as independent variable and the difference between the values

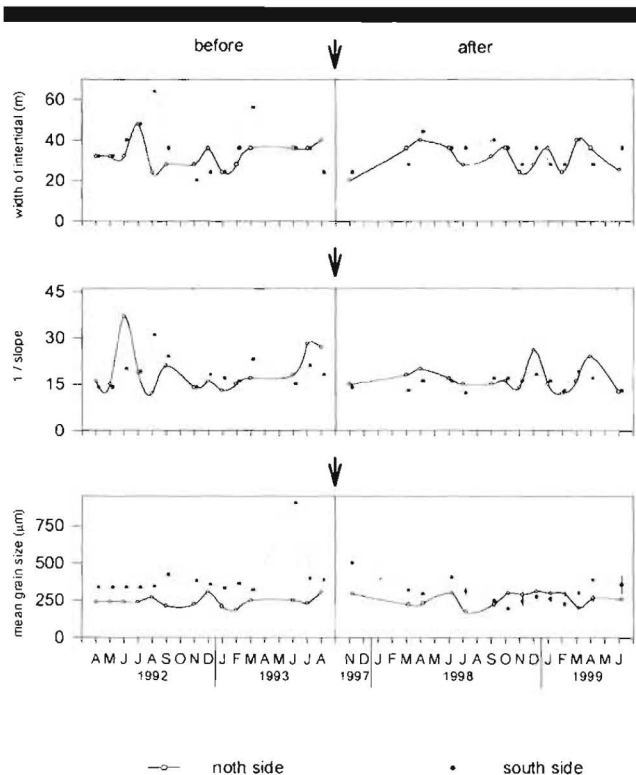


Figure 2. Temporal variability in width of the intertidal zone (i.e. from driftline to low tide level), beach face slope (1/slope) and mean grain size of sands collected from the low tide level at both sides of the beach. The arrow separates the sampling periods before and after the seawall was constructed.

calculated for each side of the beach as dependent variable (in this case, all data set was used); additivity is assumed when correlation values are not significant, iii) testing of the hypothesis of independence (another assumption of BACI analyses, STEWART-OATEN *et al.*, 1992) through regression analyses between time as independent variable and differences between the values calculated for each side of the beach as dependent variable (all the data set was used); independence is assumed when correlation values are not significant, iv) testing of normality and homoscedasticity (SOKAL and ROHLF, 1995), and v) realization of ANOVA based upon the differences in physical and macroinfaunal data from the north and south sides of the beach, calculated separately for each sampling period: before and after the seawall was constructed.

RESULTS

All analyses carried out to test additivity resulted in low values of correlation ($p > 0.05$); thus, the hypothesis of slope equal to zero is accepted and also additivity. Since the regression analyses between north and south side differences and time did not show any significant correlation ($p > 0.05$) the data were considered independent.

Figure 2 shows the temporal variability in the width of the intertidal zone, beach face slope and mean grain size of sands

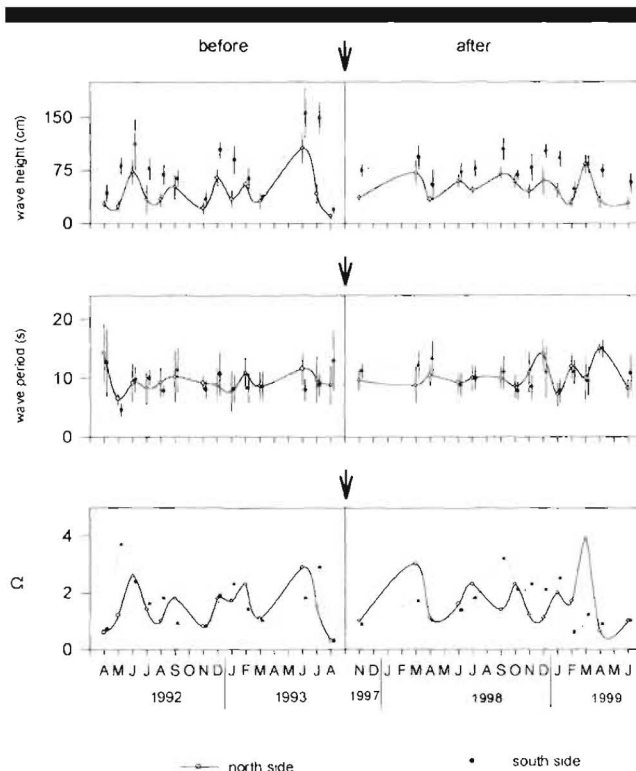


Figure 3. Temporal variability in wave height, wave period and Dean's parameter (Ω) at both sides of the beach. The values of wave characteristics are means \pm 1 standard deviation. Other details as in Figure 2.

from the low tide level at both sides of the beach. During August 1992 and March 1993 the intertidal zone of the south side was quite wider than that of the north side (64 and 56 m, respectively). During the rest of both study periods the width of the intertidal zone remained quite similar on both sides of the beach. Most of the time, the beach face slope at both sides varied between 1/15 and 1/20. The frequency of flatter slopes ($> 1/25$) was higher at the north side of the beach: 1/37 during June 1992, 1/27 during July and August 1993 and 1/26 during December 1998 (Figure 2). The flattest slopes at the south side were recorded during August 1992 (1/31). Most of the time, the sands of the swash zone were coarser at the south side of the beach, being 901 μm the coarsest grains ever recorded (June 1993) (Figure 2).

The temporal variability in wave characteristics and Dean's parameter (Ω) is shown in Figure 3. Most of the time, waves were higher at the south side of the beach, especially during June and July of the first study period (April 1992–August 1993) when waves as high as 100–150 cm were observed. Wave periods were quite similar with overall means close to 9–11 seconds. Values of Dean's parameter showed that the morphodynamic characteristics had quite a seasonal variability without well defined patterns as far as beach sides are concerned (Figure 3). Variability in Dean's parameter indicated that both sides of the beach changed temporarily between reflective ($\Omega \leq 1$) and intermediate features (Ω from 1 to 4) (*sensu* SHORT and WRIGHT, 1983).

Table 1. Values of *f* and *p* (ANOVA) for differences in physical characteristics of both sides of the beach before and after the seawall was constructed.

	<i>f</i>	<i>p</i>
Width of intertidal (m)	0.14	0.71
1/slope	0.52	0.47
Mean grain size (μm)	3.30	0.08
Wave height (cm)	1.78	0.19
Wave period (s)	0.00	0.95
Dean's parameter (Ω)	0.58	0.45

The results of ANOVA indicated that no significant differences ($p > 0.05$) were found when the BACI analyses were carried out with physical characteristics, *i.e.* the means of differences between both sides of the beach were similar (Table 1).

The cirrolanid isopod *Excirolana hirsuticauda* Menzies and the anomuran decapod *Emerita analoga* (Stimpson) were the most common species over the study period. The following species were also collected: *Orchestoidea tuberculata* Nicolet (Amphipoda, Talitridae), *Excirolana braziliensis* Richardson (Isopoda, Cirolanidae), *Macrochiridothea mehuinensis* Jaramillo and *Macrochiridothea setifer* Menzies (Isopoda, Valvifera), *Nephtys impressa* Baird (Polychaeta, Nephtyidae), *Euzonus heterocirrus* Rozbaczylo & Zamorano (Polychaeta, Opheliidae), and *Scololepis* sp. and *Scoloplos* sp. (Polychaeta, Spionidae). The last species had very low abundances or occurred in a low number of samples. Thus, the specific faunistic comparisons are based upon the abundances of *Excirolana hirsuticauda* and *Emerita analoga*.

The temporal variability in species richness, abundances of *Excirolana hirsuticauda* and *Emerita analoga* and total abundance of the macrofauna is presented in Figure 4. Before the seawall was constructed the number of species varied between 2 and 6 and 1 and 8 at the north and south sides of the beach, respectively. After the seawall was constructed the ranges in species number were 2 to 6 at both sides. The abundance of *Excirolana hirsuticauda* was higher before the seawall was constructed (Figure 4). After that, macrofaunal abundance was usually lower, with the exception of October 1998 when the abundances of *Emerita analoga* (and consequently the total abundances) were quite high (up to 64160 m^{-2} for the whole macrofauna). Figure 5 shows the across shore distribution of *Excirolana hirsuticauda* and *Emerita analoga* at both sides of the beach. While most of the specimens of the first species were collected close to the effluent line (water table outcrop), *Emerita analoga* occurred further down, close to the low tide level. Finally, body sizes of *Excirolana hirsuticauda* and *Emerita analoga* were similar on both sides of the beach (Figure 6). As with the physical characteristics, the results of ANOVA show that no significant differences ($p > 0.05$) were found when the BACI analyses were carried out on the macrofaunal characteristics; thus, the means of differences between both sides of the beach were similar (Table 2).

DISCUSSION

Exposed sandy beach habitats are among the most dynamic coastal habitats on earth (BROWN and McLACHLAN, 1990);

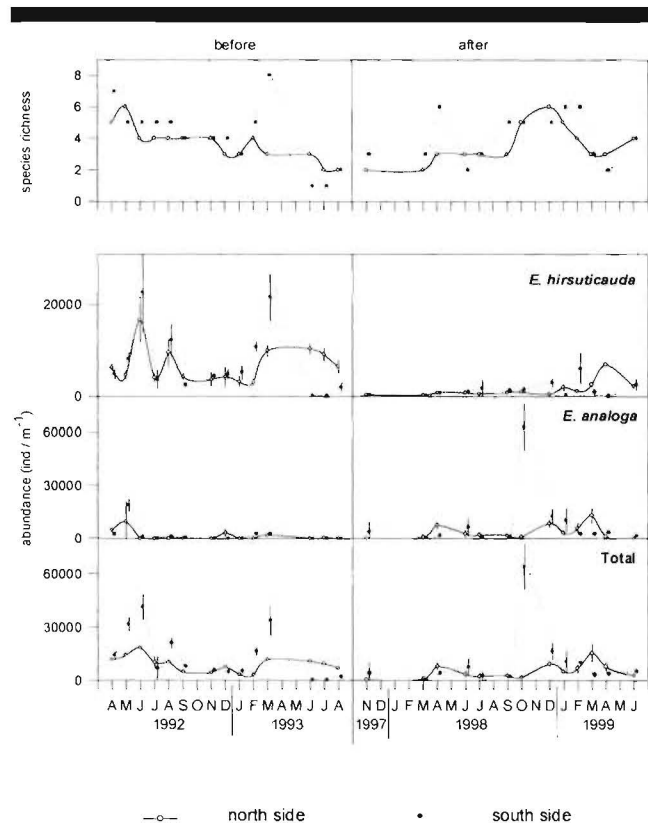


Figure 4. Temporal variability in total species richness (*i.e.* the three transects included), and mean abundances of *Excirolana hirsuticauda*, *Emerita analoga* and total macrofauna at both sides of the beach. The values of abundances are means \pm 1 standard deviation. Other details as in Figure 2.

variability in tides, longshore currents and sudden storms may produce noticeable changes in their morphology and size of grains in short periods of time (*e.g.* JARAMILLO *et al.*, 1987; JARAMILLO, 1987). Smaller, pocket beach types are especially prone to such physical changes (*e.g.* JARAMILLO, 1987). It is also known that erosion processes cause more drastic changes in fully exposed beaches, but erosion is usually more persistent on protected sandy beaches due to the fact that post-storm accretion is not enough to replace sand losses (NORDSTROM, 1989). Consequently, it is possible to hypothesize that any engineering structure installed in the back shore of sandy beaches would have more effect on small pocket beaches, as is the case of the beach at Los Molinos.

The results of this study show that the presence of the seawall has not influenced the physical and macrofaunal characteristics at the beach of Los Molinos. It must be stressed, however, that changes in sediment storage indeed occurred; as a matter of fact, the foundation of the seawall was frequently exposed, as shown in Figure 7. It must also be said that sudden storms have been regularly noticed after the seawall was constructed. Thus, it would be expected that changes in sediment size and hence in beach face slope would primarily happen during such conditions; *i.e.* rise in sea level would lead to beach erosion since the construction of the sea-

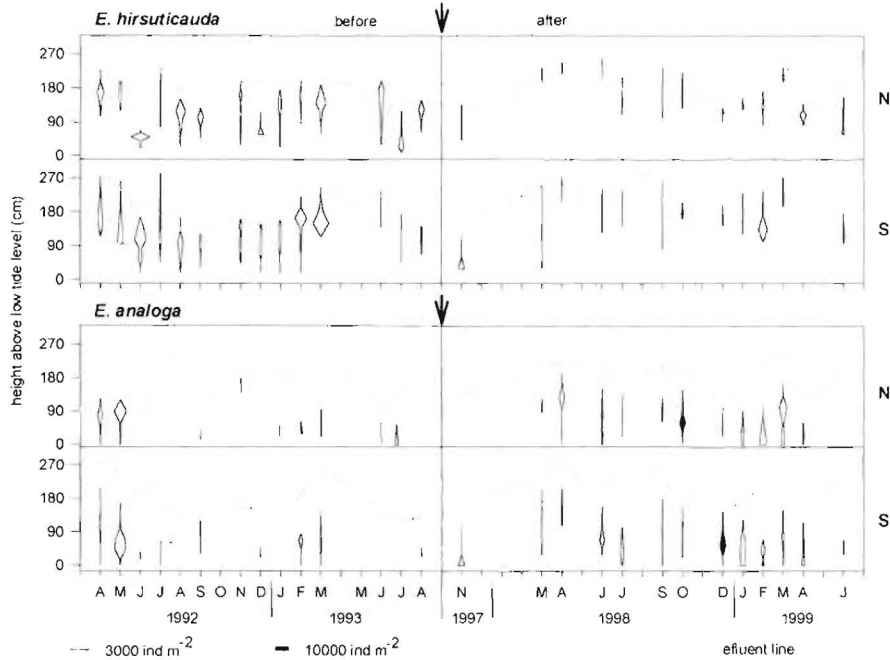


Figure 5. Position of *Excirolana hirsuticauda* and *Emerita analoga* and the effluent line (water table outcrop) relative to the low tide level (0) at both sides of the beach. Note the difference in abundance scales. Other details as in Figure 2.

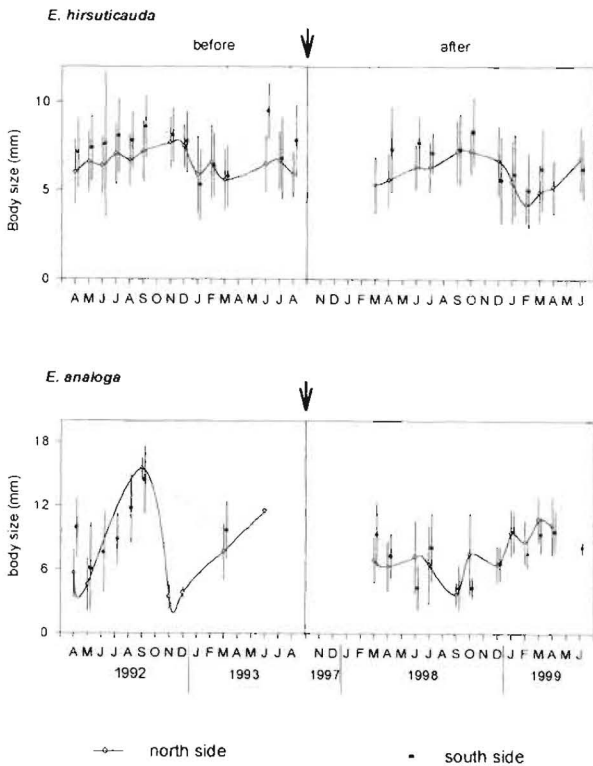


Figure 6. Temporal variability in the body sizes of *Excirolana hirsuticauda* and *Emerita analoga* for both sides of the beach. The values of body sizes are means \pm 1 standard deviation. Other details as in Figure 2.

wall took about 3 m of the upper beach levels. During one such sudden storm (June 13, 1999), waves were higher and had longer periods than during calm conditions (Table 3); thus, wave climate characteristics represented more dissipative or erosive conditions. However, three days later (after rough sea conditions abated), beach face slopes were similar on both sides of the beach (1/13) and mean grain size of sands from the lower swash zone were not much different (256 μ m at the north side and 357 μ m at the south side) from the values estimated from samples collected along the whole study period (cf Figure 2). These snapshot data show that even when storm waves reached and broke on the seawall foundation, it did not alter the physical and macroinfaunal characteristics of the beach, as the results of BACI analyses showed. Notwithstanding, we consider these conclusions valid only for the study period and for the type of beach studied. As mentioned earlier, the beach Los Molinos is located inside

Table 2. Values of *f* and *p* (ANOVA) for differences in biological characteristics of both sides of the beach before and after the seawall was constructed.

	<i>f</i>	<i>p</i>
Species richness	0.00	0.98
<i>E. hirsuticauda</i> (ind m ⁻¹)	0.00	0.99
<i>E. analoga</i> (ind m ⁻¹)	0.81	0.37
Macroinfauna total (ind m ⁻¹)	2.79	0.10
<i>E. hirsuticauda</i> (cm above low water mark)	2.62	0.11
<i>E. analoga</i> (cm above low water mark)	0.40	0.53
<i>E. hirsuticauda</i> (body size in mm)	3.89	0.06
<i>E. analoga</i> (body size in mm)	0.00	0.98

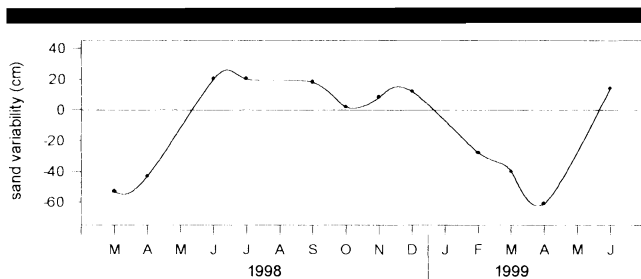


Figure 7. Seasonal sand variability in relation to the same foundation of the seawall (level 0).

a bay, and consequently is quite protected from breaking waves that affect sandy beaches located on the open coast of south central Chile (with modal heights averaging 3–4 m, unpublished data).

There is little literature on the effects of engineering structures upon macrofaunal sand beach communities. One of the few ones, is that of BOWMAN and DOLAN (1985) who studied the spatial distribution of *Emerita talpoida* at both sides of a 600 m pier in a sand beach of North Carolina, USA. They found that the spatial distribution of this crab was affected by the interaction between pier structure and incident wave energy; *i.e.* densities of *Emerita talpoida* were greater in areas where the pier provides shelter. Protected sandy areas located close to rocky promontories also harbours high density aggregations of *Emerita analoga* in sandy beaches along the coast of Chile (E Jaramillo, unpublished observations).

The most abundant species at the beach Los Molinos were *Emerita analoga* and the isopod *Excirolana hirsuticauda*. Both species, the first as inhabitant of the swash zone and the second as a shallow dwelling isopod (JARAMILLO, 1987), are vulnerable to beach modification and thus likely to exhibit a response to such activity. However, since both are active swimmers they probably relocate quite soon after any disturbance of beach deposit. Thus, we can hypothesize that any sudden change in beach characteristics at Los Molinos is followed by a quick response from these species. That seems to be the case for the results found by JARAMILLO *et al.* (1996), who, in a different context to that studied here, hypothesized that mechanical disturbance produced by summer vacationers on a sandy beach of south central Chile (ca. 39° S) affected population abundances of the intertidal macrofauna. However, the experimental exclusion of vacationers during the summer of 1992 did not result in any effect on the macrofauna. Also, HAYDEN and DOLAN (1974) found that *Emerita talpoida* from North Carolina, had a quick response to sand discharge occurring during beach nourishment activities. Thus, impact of that disturbance on *Emerita talpoida* was of short duration; it probably involved redistribution of crabs rather than massive mortality.

The absence of significant effects of the seawall construction upon macrofaunal communities may be related to the high degree of plasticity that sandy beach organism show (BROWN, 1996, SOARES *et al.*, 1999). Thus, as SOARES *et al.*, (1999) hypothesized, behavioural, ecophysiological and morphological plasticity of beach organisms allow them to cope

Table 3. Wave characteristics of both sides of the beach during the storm of June 13, 1999 and three days later (calm conditions). The values are means ($n = 20$) with standard deviations in parentheses. The measurements were carried out during low tide periods.

		During storm	Calm conditions	$F_{1,38}$	P
Wave height (cm)	North side	130.0 (16.3)	28.0 (9.6)	554.85	0.000
	South side	196.0 (23.6)	57.3 (13.0)	547.71	0.000
	$F_{1,38}$	101.7	65.4		
	P	0.000	0.000		
Wave period (s)	North side	10.2 (1.5)	8.2 (1.6)	14.96	0.000
	South side	13.0 (2.6)	10.8 (3.0)	5.85	0.020
	$F_{1,38}$	17.4	9.1		
	P	0.000	0.004		

and adapt to short and long-term changes of their dynamic habitat (*i.e.* phenotypic plasticity as adaptation to the changing habitat). For sandy beach organisms, BROWN (1996) distinguished long term and short term plasticity, the first one generally resulting from adaptations to a new environment, and the second one including responses to usually unpredictable environmental perturbations, such as storms and beach erosion. As mentioned by BROWN (1996), some sand beach organisms appear to be able to detect approaching storms and migrate up the beach (*i.e.* the talitrid amphipod *Talorchestia capensis* on sandy beaches of Cape Peninsula, South Africa). Upward movement and digging deeper may then help to cope with changing beach conditions. Thus, even when the seawall studied would indeed affect beach characteristics, that would not necessarily lead to macrofaunal mortality or changes in zonation patterns.

Coastal management is starting to be topical issue along the coast of Chile. As clearly established by UNDERWOOD (1991), BACI analyses is the correct way to evaluate eventual effects of environmental impact on coastal communities. This sort of analyses has recently been used in a variety of coastal studies, such as assessment of effluent discharges on assemblages of Australian larval fishes (GRAY *et al.*, 1996) and that of oil spillages due to pipeline rupture on rocky shore communities of the coast of Brazil (LOPES *et al.*, 1997). However, BACI analyses seldom appear in the literature. Yet, they can provide an unique opportunity to test environmental impacts and hypothesis concerning functioning of coastal communities, such as those in sandy beach habitats.

ACKNOWLEDGEMENTS

While financial support to collect the 1992 and 1993 data came from FONDECYT Project n° 191–92 given to E Jaramillo, the data collected during 1997, 1998 and early 1999 came from Project FONDAP, Oceanografía & Biología Marina (Programa Mayor n° 3) of CONICYT (Chile). We appreciate the collaboration of Pedro Quijón, Cristián Duarte, María Avellanal and Marcia González (Instituto de Zoología, Universidad Austral de Chile) during field and laboratory work. This study benefited from the reviews of Anton McLachlan (Sultan Qaboos University, Oman), Mariano Lastra (Universidad de Vigo, España) and Miriam Fernández (Pontificia Universidad Católica de Chile, Chile).

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