Environmental factors affecting benthic macrofauna along a gradient of intermediate sandy beaches in northern Spain.

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Abstract

Ten sandy beaches along the north coast of Spain were studied during September 1999 to analyze number of species, abundance and biomass of macroinfauna along a gradient of intermediate beach types and exposure range. Faunal samples were collected with metallic cylinders (25 cm diameter,15 cm depth) at 10 equally spaced shore levels along six replicated transects separated randomly and extending from above the drift line to the low tide swash zone. Exposure rate, Dean's parameter (Ω), beach state index (BSI) and relative tidal range (RTR) were estimated at each beach. Length and width of the beach, intertidal slope, sorting and median grain size and also swash amplitude and wave characteristics were measured. Number of species was between 10 and 29. Macrofaunal abundances ranged between 4962 and 71228 ind. m^{-1} and between 31 and 329 ind. m^{-2}, while biomass (ash free dry weight) per square meter of beach ranged between 0.027 and 0.278 g m^{-2} and between 3 and 61 g. m^{-1}. Results show some significant trends: number of species is the biotic variable more affected by physic and morphodynamic factors, increasing linearly with relative tidal range and decreasing with increasing average grain size; the same trend was observed from exposed to very exposed beaches; the biomass decreased exponentially with increasing average grain size. These trends agree with previous studies in different coasts in the world where coarse sands limit the benthic macrofauna. Morphodynamic parameter as Dean's parameter and Beach State Index did not show predictive value. Results suggest that different characteristics of benthic macrofauna communities in intermediate beaches are affected in different ways by the physical processes involved in beach morphodynamic.

Keywords: sandy beaches; benthic macrofauna; morphodynamic state; exposure rate; swash; northern Spain.

Introduction

Beaches are present in all coasts, latitudes and climates worldwide, having a wide spectrum of sizes, morphologies, exposure range and oceanographic conditions, together with a high diversity in biotic characteristics. The most dynamic of soft bottom habitats (McLachlan, de Ruyck & Hacking, 1996), exposed sandy beaches occur on the open coasts of tropical and temperate regions (Davies, 1972). Exposed sandy beaches can be described in terms of the interaction between wave exposure, tide ranges and sediment characteristics, also called beach morphodynamics. This ecosystem harbours a diverse and abundant macroinfauna, being Crustacea, Polychaeta and Bivalvia being the most typical taxa (Brown & McLachlan, 1990). Since exposed sandy beaches are mostly considered as physically controlled environments, interactions between the main parameters have been frequently analyzed. Several studies on micro and mesotidal coasts have shown trends in intertidal macroinfauna, with community structure related to beach morphodynamic and wave environment (McLachlan, Wooldridge & Dye, 1981; Defeo, Jaramillo & Lyonnet 1992; McLachlan, *et al.* 1993; McLachlan, de Ruyck & Hacking, 1996).

McLachlan *et al.* (1993) found that beach type, defined by the dimensionless Dean's parameter (Ω = Hb/ (Ws x T), where Hb is breaker height in cm, Ws the sand fall velocity in $cm.s^{-1}$ (Gibbs, Matthews & Link, 1971) and T the wave period in seconds.), is a good predictor of species richness, abundance and biomass for microtidal beaches across different geographic regions, thus classifying beach types into reflective, intermediate and dissipative. The scale for the morphodynamic state would be as follow: $\Omega > 6$ dissipative beach, $\Omega < 1$ reflective beach and $1 < \Omega < 6$ in the intermediate case. However, when tidal range varies among different coastal areas, tidal effects must be taken into account since elevated tidal energy (*i.e*. tidal range greater than 2-3 m) increases the dissipative nature of beaches (Masselink & Short, 1993). To account for this, McLachlan *et al*. (1993) created the beach state index (BSI = log [(Hb x M/Ws x T x E) + 1]), where M is the maximum tide range and E is the theoretical equilibrium tide for

which the earth covered in water (E=0.8 m). Based upon a comparative study of about 70 beaches, McLachlan *et al.*, 1993; suggested the following scale for BSI: <0.5 reflective beaches, 0.5-1 low to medium energy intermediate beaches, 1.0.-1.5 high energy intermediate-dissipative beaches, 1.5-2.0 fully dissipative beaches, and > 2.0 ultradissipative macrotidal beaches.

Studies on beach fauna in relation to morphodynamic state indicate that Dean's and BSI are generally well correlated with community variables such as number of species, abundance per linear meter and biomass (Jaramillo & McLachlan, 1993; McLachlan *et al*. 1993; Hacking, 1998; McLachlan *et al*. 1998; Nell, pers. comm..). The biotic characteristics of exposed sandy beaches have been related to many abiotic factors and physical variability has been emphasized as the primary force controlling macroinfaunal communities (McLachlan, 1983 a review). Beach morphology seems to have relevant consequences on the intertidal macrofauna zonation, and McLachlan (1990) and McLachlan *et al.* (1981) found significant correlations between macroinfaunal community parameters and grain size, beach face slope and beach type. Thus, species richness, as well as total abundance and biomass of the macroinfauna tend to increase from narrow beaches having coarse sands and steep slopes (*i.e.* reflective beaches, *sensu* Short & Wright, 1983), to wider beaches having finer sands and flatter slopes (*i.e.* dissipative beaches, *sensu* Short & Wright, 1983). Hence, macroinfaunal changes are related to changes in physical characteristics occurring along a gradient of beach morphodynamic types (Brazeiro 2001).

Following previous work, the aim of this study was to analyze the macroinfauna community of exposed sandy beaches along the northern coast of Spain. Variation in number of species, biomass and abundance of the intertidal macrofauna was analyzed along a coastal area where mostly intermediate sandy beaches occur with different morphologies and exposure conditions. The significance of physical and morphodynamic parameters facing biotic factors has been tested when only intermediate type of beaches was present.

Material and methods

Study area

Ten sandy beaches on the northern coast of Spain, Oyambre, Liencres, Langre, Berria, Laredo, Salvaje, Bakio, Laga, Zarautz and Hendaya (Fig.1), were sampled during low spring tides of September 1999. Beaches were located along *circa* 300 km of coast along the southern coast of the Bay of Biscay, being included the regions of Cantabria and Vasque Country. Tides in this shore are semidiurnal and mesotidal, with maximum ranges close to 4 m.

Sampling design

Macrofauna sampling was carried out at six replicated transects randomly-separated at the central area of each beach during low tide. At each transect, 10 equally spaced shore levels extending from above the drift line (level 10) to the low swash zone (level 1) were sampled. Previous studies of macroinfauna in exposed beaches (Bally, 1983) showed that the highest abundances are usually found in the first 15-20 cm depth, so, samples were collected with metallic cylinders of 25 cm of diameter penetrating 15 cm depth into the substrate. An area of 0.3 m^2 was sampled at each level, the sediment sieved through 1 mm mesh and the residue was preserved in 4% formalin. The result was 3 m^2 of total sampling surface in each beach; that means enough surface in order to get a high percentage (90%) of the total number of species and total abundance in temperate beaches, following Jaramillo, McLachlan & Dugan (1995). The individuals were later sorted from the sediments, identified and counted in the laboratory.

Shell-free biomass was determined by drying at 100ºC for 24 hours and 500ºC for 6 hours, obtaining ash free dry weigh values (A.F.W.D.). Abundance and biomass values per running meter (i.e. estimates of total macroinfauna in an intertidal across shore transect 1 m wide) were obtained by linear interpolation between sampling levels, after obtaining mean values of biomass and abundances per m^2.

Three samples of sediment for grain size analyses were collected at each level by inserting a 3 cm diameter metal corer to a depth of 15 cm. Grain size of sand was analysed using a Coulter LS 200 laser diffraction particle size analyzer and the coarser fraction (> 2 mm) by dry sieving (Folk, 1980). Wave height was estimated by measuring the height of breaking waves with graduated poles against the horizon. Beach slope at each site was determined by Emery's profiling technique (Emery, 1961). From the average wave height (Hb), wave period (T) and sand fall velocity of particles (values estimated using the mean grain-size from the swash zone and conversion tables given by Gibbs, Matthews & Link, 1971) dimensionless Dean's parameter (Gourlay, pers.comm.; Short & Wright, 1983) was calculated. The wave period was the time interval between breakers and swash environment was estimated measuring maximum swash amplitude, calculated as the distance between highest and lowest turning point of the upswash and backswash respectively during five minutes period. Beach State Index, from McLachlan *et al.* (1993), was also calculated in order to analyse differences due to differing tide range in the ten studied beaches. The 20-point rating system proposed by McLachlan (1980) was used to estimate the wave exposure rate at each beach.

Statistical analysis

Regression analyses to test for relationships between biotic and abiotic variables were carried out with SPSS program. The value of α (0.05) was modified with the sequential Bonferroni correction when the same dependent variable was analysed against various independent variables, according to Holm (1979).

Results

Physical environment

The beach face morphology is shown in Figure 2. The slopes varied between 1/22 (Bakio) and 1/48 (Oyambre and Laredo). The physical characteristics of substrate are shown in Table 1.

Sands from these beaches ranged from coarse (564 µm in Bakio) to medium sands (260 µm Berria) and sediments were very poorly sorted, varying between 1.5 φ and 1.8 φ, indicating a moderate grain selection in all the beaches sampled. Mean wave periods during sampling dates varied from 12 s (Oyambre) to 17 s (Hendaya), with wave heights from 0.31 m (Laredo) to 2.09 m (Zarautz). Maximum swash amplitude ranged from 11 to 49 m (Table 1).

The values of dimensionless Dean's parameter (table 1) tend to include most of these beaches in the intermediate morphodynamic state, except the beaches of Laredo and Hendaya which were close to a reflective state (*sensu* Short & Wright, 1983). BSI values (Table 1) classified some of the beaches in low to medium energy intermediate types (Langre, Laredo, Salvaje, Bakio, Laga and Hendaya) and others in high energy intermediate/dissipative beaches (Oyambre, Liencres, Berria and Zarautz).

The 20-point rating system proposed by McLachlan (1980) defined the beach of Hendaya as sheltered (maximum score = 10), the beaches of Langre (15) and Laredo (12) as exposed, whereas the rest of the beaches were defined as very exposed (> 15).

Composition and abundance of the macrofauna

Characteristics of the macrofauna community are shown in Table 2. The number of species was highest at the beach of Laredo (29) and the lowest at Salvaje and Bakio (10). Density values as high as 329 ind.m^{-2} were found at Salvaje while 31 ind.m^{-2} were found at Liencres. Biomass values ranged between 0.03 and 0.278 g.m^{-2}. Abundances per running meter ranged between 4962 (Liencres) and 71228 ind.m^{-1} (Salvaje) and biomass per running meter ranged between 3 (Bakio) and 61 g. m^{-1} (Laredo).

Relationships between macrofauna and environmental variables

The biplots of biotic variables (i.e. number of species, abundance and biomass) versus abiotic factors (BSI, RTR, slope, average grain size and exposure) are shown in fig. 3.

Significant correlation at $\alpha = 0.05$ was not found among macrofaunal characteristics with Dean's parameter, slope or BSI. Beach State Index has been used as a modification of the Dean's parameter to compare beaches from different geographic areas with different tide ranges (McLachlan *et al*., 1993). It was obtained a very significant linear correlation with Dean morphodynamic parameter and Beach State Index, since no different tidal range was found in the studied beaches (BSI =0.43+0.3 Dean; $r^2 = 0.97$, $p < 0.0001$, $power_{\alpha = 0.05} = 1.0$). Since Dean's parameter should really only be used for microtidal beaches and BSI combines this with a measure of tide range, we think BSI may be more appropriate here. Consequently we have not included Dean's parameter in the analysis.

The correlations between number of species and average grain size, and exposure rating were not significant when they were modified with the sequential Bonferroni correction. Thus, we should interpret the findings cautiously.

Number of species was linearly correlated with RTR (number of species = 9.32 + 1.19 x RTR; $r^2 = 0.75$, $p<0.01$, $power_{\alpha = 0.05} = 0.94$). Macrofaunal number of species was also linearly correlated with average grain size (number of species = 28.01 – 0.032 x grain size; $r^2 = 0.424$, $p<0.05$, $power_{\alpha = 0.05} = 0.54$) and with exposure rating (number of species =34.8 – 1.27 x exposure rating; $r^2 = 0.426$, $p<0.05$, $power_{\alpha = 0.05} = 0.54$). Biomass, either in m^{-2} and m^{-1}, was exponentially and linearly correlated with average grain size respectively (biomass [$g.m^{-2}$] = 0.041 + 3.25 exp (-0.011 grain size); $r^2 = 0.77$, $p<0.01$, $power_{\alpha = 0.05} = 0.95$), (log biomass [$g.m^{-1}$] = 78.5 – 0.13 x grain size; $r^2 = 0.64$, $p<0.01$, $power_{\alpha = 0.05} = 0.83$).

Discussion

Community analysis shows that macroinfauna values of density (31 to 329 $ind.m^{-2}$) and biomass (0.03 to 0.27 $g.m^{-2}$) of the ten intermediate sandy beaches in northern Spain were included within the range of density and biomass values obtained in exposed sandy beaches worldwide (e.g. McLachlan, Wooldridge & Dye, 1981a; Defeo, Jaramillo & Lyonnet, 1992; Jaramillo, McLachlan & Coetzee, 1993; McLachlan, de Ruyck & Hacking, 1996, Hacking, 1997 and Nell,

2000). Results of number of species, ranging from 10 to 29, were similar to values obtained in beaches from other temperate latitudes such as Belgium (Degraer *et al*. 1999) and California (Dugan, *et al.* pers. comm.), but differ from results for beaches in Chile and Uruguay, where values obtained were lower (McLachlan *et al*. 1993; Jaramillo, McLachlan & Coetzee, 1993, Defeo, Jaramillo & Lyonnet, 1992). Moreover, a wider range of differences in species richness can be observed by comparison with intermediate beaches from lower latitudes. Thus, our values are higher than those found in South African beaches (McLachlan, Wooldridge & Dye 1981a), lower than values obtained in Oman (McLachlan *et al*. 1998) and similar to species richness found in beaches sampled in Australia (McLachlan, 1996; Hacking, 1998). We think that this high variability comes from poorly known factors such as biogeographic, latitudinal and oceanographic conditions and particular local events, rather than just beach morphodynamic differences.

The general patterns found on sandy beach macroinfauna show a negative correlation between species richness and exposure rating and grain size (McLachlan & Jaramillo, 1995; McLachlan, 1996) as our results confirm. The greater the grain size and the higher the exposure rate, the higher flushed and oxygenated interstitial spaces will be (McLachlan, 1989), resulting in fewer macroinfauna by effects of waves and currents in exposed sandy beaches. Conversely, reduction in beach exposure and average grain size can be more favourable for macroinfauna (McLachlan & Jaramillo, 1995; McLachlan, de Ruyck & Hacking, 1996).

The results plotted in Figure 3, show that number of species is the biotic parameter most affected by the abiotic factors, increasing linearly with RTR and diminishing from exposed to very exposed beaches and also diminishing with increasing average grain size, although we have worked with only a limitated range of particles, from 260 to 564µm. On the other hand, biomass, either in $g.m^{-2}$ and log ($g.m^{-1}$), decreases exponentially with increasing average grain size. These trends agree with the predictions of McLachlan *et al*., 1981b and Brown & McLachlan 1990, stating a negative relationship between grain size and biomass. McLachlan *et al*. 1993 found all these trends in beaches of United States, Australia and South Africa, and Jaramillo, McLachlan & Coetzee, 1993 found the same trends in beaches of Chile. Further

more, Hacking (1997) and Nell (pers. comm.) found the same trends in beaches of Australia and South Africa respectively.

There are not enough differences in face slope, among the ten beaches studied, to determine macrofauna trends since we have not found significant correlations with any community variable. This low predictive value can be partially related with the similarity of intermediate beach profiles in our ten sampled beaches (Coefficient of Variation, C.V. = 31%) as compared with variability of number of species (C.V. =35%), abundance m^{-2} (C.V. =73%), abundance m^{-1} (C.V. =82%), biomass m^{-2} (C.V. =70%) and biomass m^{-1} (C.V. =80%). This result differs from previous studies where steep slopes limit beach macroinfauna (McLachlan, Wooldridge & Dye., 1981a and McLachlan, 1990).

No significant trend was found between morphodynamic state of the beaches (Dean's parameter and BSI) and macrofauna. This has been shown previously in present beaches for meiofauna (Rodriguez, Lastra & López, 2003), and it is opposite to the general patterns of sandy beach macroinfauna found in previous studies (McLachlan, Wooldridge & Dye, 1981a; McLachlan, 1983 a review; Brown & McLachlan, 1990; Jaramillo, McLachlan & Coetzee, 1993; McLachlan *et al.* 1993; McLachlan, de Ruyck & Hacking, 1996; McLachlan *et al*. 1998 and Hacking, 1998). Since we are working with parameters (Dean and BSI), which include variables such as period and wave height that do not show significant correlations with our community characteristics, the importance of these morphodynamic parameters seems to decrease. Dean's parameter values from Laredo and Hendaya show them as reflective beaches instead of real intermediate-dissipative beaches, as it is stated by their beach face slopes (1/48 and 1/47, respectively) and grain size (270±17 and 315±39 µm, respectively). The low values of Dean's and BSI parameters are mostly because of the low height break of the waves observed during our sampling date. Moreover, the values obtained from wave height and period on these beaches have a wide range of variation at different periods of time throughout the year (Lastra, pers. com.). Therefore, it can be suggested that beach morphodynamics described by Dean's and BSI parameters have low capacity in predicting community characteristics in our ten intermediate beaches. validity of morphodynamic parameters have been generally demonstrated when a full

range of beach types are included in the analysis, i.e. from reflective to dissipative (McLachlan *et al*. 1993; Jaramillo, McLachlan & Coetzee, 1993; Jaramillo & McLachlan, 1993).

On the other hand, when only intermediate beaches are studied, the different community characteristics seem to be affected by different abiotic factors. The number of species is better explained by the exposure rating (although this was not significant when we used Bonferroni´s correction) than by variables such as Dean's parameter or even beach slope, while biomass is only affected by mean grain size. This confirms that a greater ensemble of variables should be taken into account in the ecology of sandy beach macroinfauna, as previously suggested by McLachlan, de Ruyck & Hacking, 1996 and Brazeiro 2001. Hence, this shows that communities of sandy beach invertebrates are more limited by different ecological factors than for a single key factor.

In the case of RTR (Fig.3.), there was a significant correlation with number of species; so when the tide range becomes more significant than wave energy, number of species increases. Further than this, Dean's parameter is smaller in those beaches (Laredo and Hendaya) where RTR reached high values. Most of the studied beaches showed a broken profile roughly separated by mean sea level into an upper steep beach, followed by a lower flat downshore as previously found in beaches from Scotland (Eleftheriou & Nicholson, 1975) and in the North West coast of Spain (de la Huz, pers. comm.). Studied beaches have conditions of tide and wave energy strongly interacting, resulting in broad flat beaches, tide-dominated on the lower shores but tending towards swash control in the upper intertidal. When beaches become increasingly tide dominated, they tend toward tidal flats and become highly dissipative, where intertidal fauna is rich, while the high tidal zones are reflective and poorer in fauna (Brown & McLachlan, 1990). No significant correlation was found between swash amplitude and any of the biotic variables in the ten studied beaches.

As a conclusion, the intertidal benthic macrofauna inhabiting intermediate sandy beaches of northern Spain could not be fully related to beach characteristics studied because of the limited range of beaches studied. There is no unique key factor affecting benthic macrofauna, but several ecological factors influence to the different community variables. More studies covering

a complete spectrum of beach types, environmental variables and exposure rates are needed to check trends and general patterns in the intermediate type of beaches, which is the dominant morphodynamic type along the northern coast of Spain. We also need to check McLachlan & Turner's (1993) predictions in relation to morphodynamics, where intermediate situations are likely the optimum conditions for the development of an abundant interstitial fauna rich in species.

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Figures caption

FIGURE 1. Location of the ten sandy beaches studied at northern part of Spain.

FIGURE 2. Beach face slopes at the ten sites sampled.

FIGURE 3. Biplots of average values of biomass, abundance, density and number of species vs. BSI (*sensu* Short and Wright, 1983), RTR, intertidal slope, median swash grain size and exposure rating (*sensu* McLachlan, 1980a). Lines indicate significant regressions at $\alpha = 0.05$.

Special Characters

φ sorting rate

Ω Dean's parameter

TABLE 1 Physical characteristics of ten beaches of northern Spain.

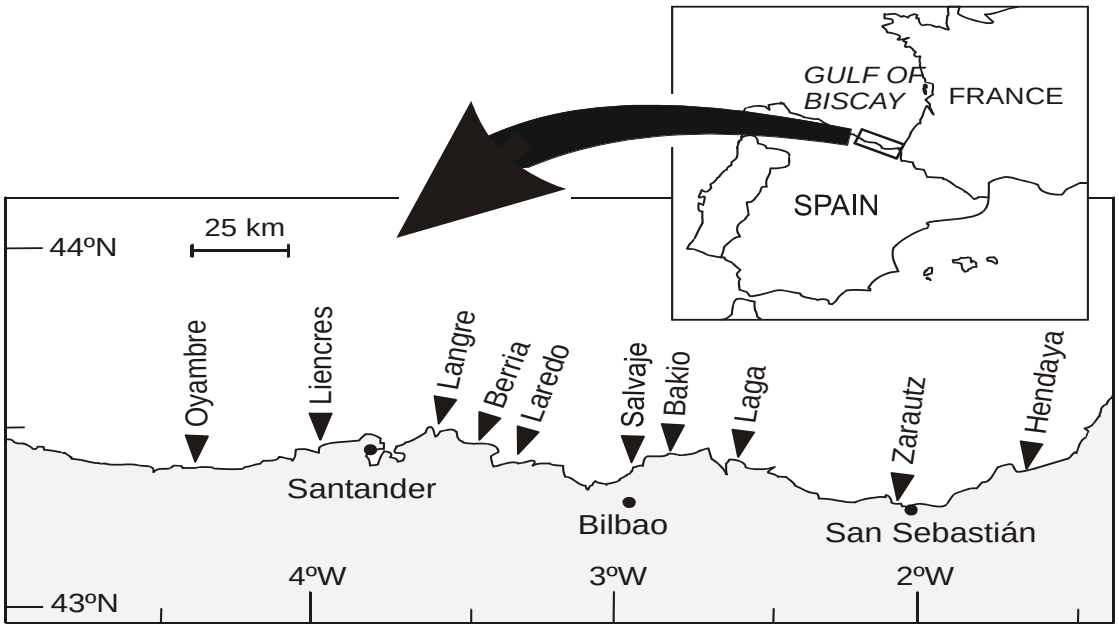
						Waves						
Beach	L (m)[a]	W (m)[b]	Intertidal slope	Median grain size (µm)[c]	Sorting[c]	Period (s)[d]	Hb (m)	Dean's parameter	RTR	Swash amplitude(m)	BSI	Exposure rating[e]
Oyambre	1800	200	1/48	344±79	1.7±0.1	12	1.25	1,9	3,2	25	1.02	16[3,1,2,6,3,1]
Liencres	2800	180	1/34	527±41	1.6±0.1	15	2.09	2,4	1,9	18	1.11	19[4,1,2,7,4,1]
Langre	800	194	1/45	400±57	1.6±0.1	12	0.91	1,4	4,3	21	0.89	15[2,0,2,6,4,1]
Berria	2000	260	1/56	260±21	1.6±0.1	14	1.17	2,2	3,5	22	1.09	16[2,1,2,6,4,1]
Laredo	4250	243	1/48	270±17	1.7±0.1	15,7	0.31	0,5	13,2	13	0.54	12[1,1,2,5,2,1]
Salvaje	752	200	1/32	438±46	1.6±0.0	14,5	2.80	1,2	1,4	39	0.83	17[4,1,2,7,3,1]
Bakio	540	115	1/22	564±40	1.5±0.1	16,4	1.40	1,2	2,8	16	0.83	17[3,1,2,6,4,1]
Laga	574	178	1/42	542±61	1.7±0.1	12,1	0.83	1,1	4,8	16	0.80	16[2,0,2,7,4,1]
Zarautz	2500	180	1/38	457±28	1.6±0.1	13,3	3.21	1,9	1,2	49	1.02	19[4,1,2,7,4,1]
Hendaya	3000	145	1/47	315±39	1.8±0.0	17	0.38	0,5	10,4	19	0.54	10[1,0,1,5,2,1]

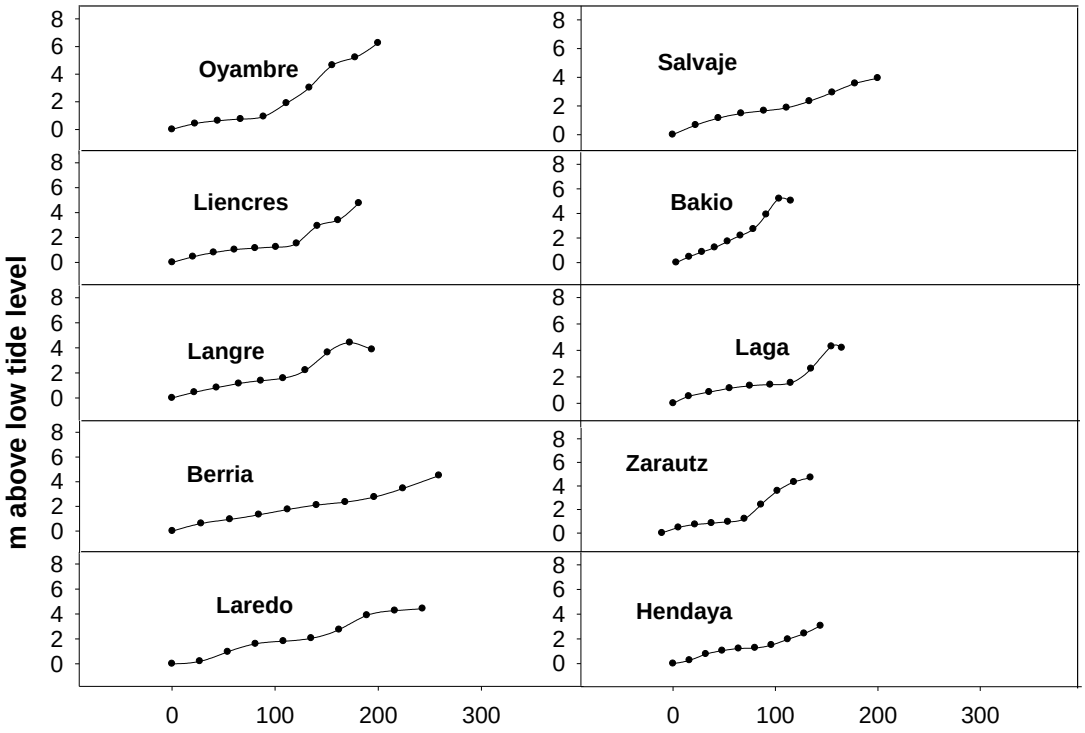
[a] Length of beach.
[b] Width of beach
[c] Mean ± SD of the measured values at each sampled transect.
[d] Mean ± SD of the measured values during low tide (n> 30)
[e] *sensu* McLachlan's (1980) rating system (i.e. [wave action, surf zone width, % very fine sand, median particle diameter and slope, depth of reduced layers, stable burrows.]

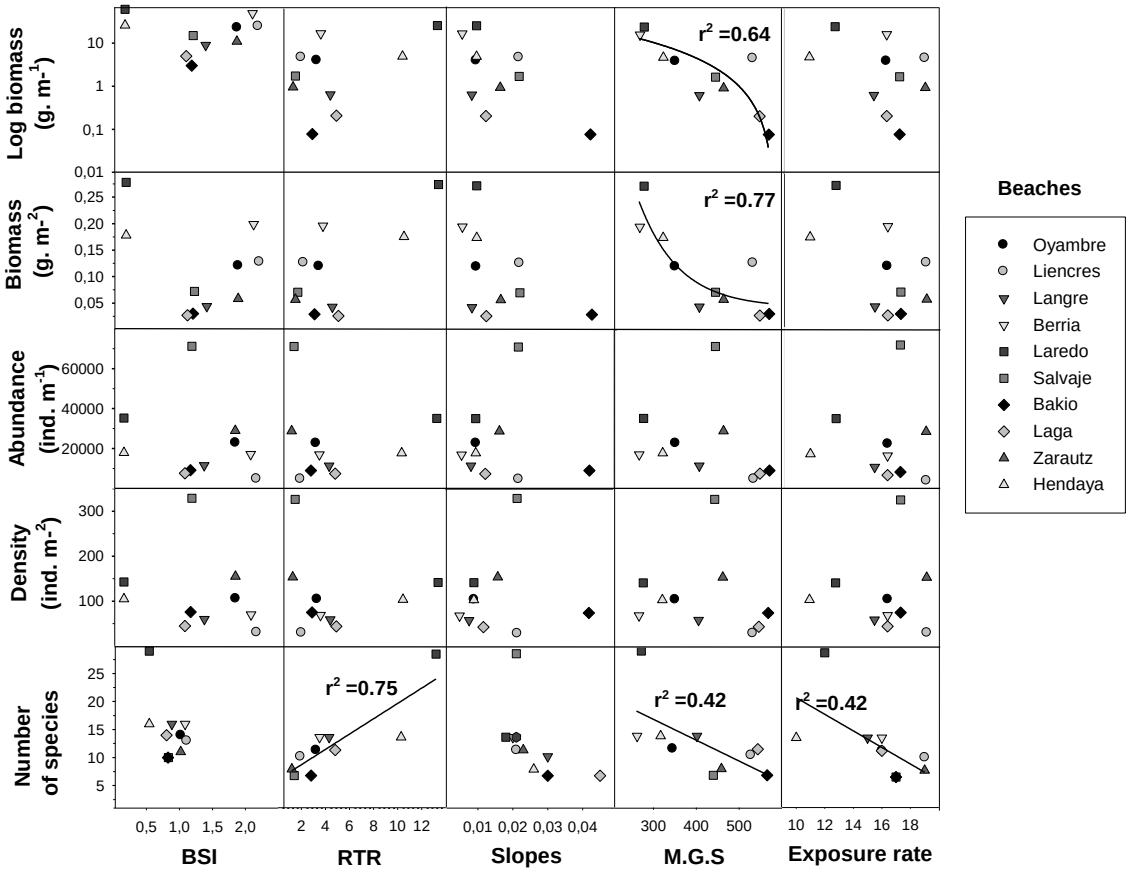
TABLE 2. Characteristics of the macrofauna at the northern studied beaches.

Beach	Number of species	Abundance(ind.m^{-1})	Density (ind.m^{-2})[a]	Biomass	
				(gm^{-1})	(gm^{-2})
Oyambre	14	22954	106±37	23	0.121
Liencres	13	4962	31±17.2	25	0.128
Langre	16	11563	60±9.7	9	0.044
Berria	16	17110	70±55.5	49	0.199
Laredo	29	35245	143±13.2	61	0.278
Salvaje	10	71228	329±98.7	15	0.072
Bakio	10	9157	76±14.2	3	0.03
Laga	14	7549	45±9.6	5	0.027
Zarautz	11	28904	155±32.3	11	0.058
Hendaya	16	17902	105±25	26	0.178

[a] Mean's of the values at each sampled transect.


GULF OF
BISCAY
FRANCE
SPAIN
25 km
44ºN
43ºN
Oyambre
Liencres
Langre
Berria
Laredo
Salvaje
Bakio
Laga
Zarautz
Hendaya
Santander
Bilbao
San Sebastián
4ºW
3ºW
2ºW


m above low tide level
Oyambre
Salvaje
Liencres
Bakio
Langre
Laga
Berria
Zarautz
Laredo
Hendaya
0
2
4
6
8
0
100
200
300


Log biomass (g. m-1)
Biomass (g. m-2)
Abundance (ind. m-1)
Density (ind. m-2)
Number of species
r2 =0.64
r2 =0.77
r2 =0.75
r2 =0.42
r2 =0.42
BSI
RTR
Slopes
M.G.S
Exposure rate
Beaches
Oyambre
Liencres
Langre
Berria
Laredo
Salvaje
Bakio
Laga
Zarautz
Hendaya