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Benavente, J., Del Río, L., Anfuso, G., Gracia, F.J. and Reyes, J.L.

Littoral and Marine Geology Research Group.
Geology Dept., University of Cadiz.
11510 Puerto Real, Cadiz,
Spain

ABSTRACT

This work deals with the estimation of beach susceptibility to storminess in the Bay of Cadiz (SW Spain), and the concomitant environmental implications. For this purpose a comparison was made between the natural behaviour of beaches and the type and amount of coastal damage made by energetic waves in every beach type. Knowledge on the morphodynamic behaviour of beaches was obtained from a monthly topographic monitoring of 32 beach transepts normal to the coastline, performed during 30 consecutive months. Widely used morphodynamic parameters, like the Surf Similarity and the Surf Scaling parameters, were applied to the data, resulting in a general morphodynamic characterization of beaches, represented in a map of beach type distribution. Maximum coastal damage by storms was estimated by visual observations. Clear relationships between morphodynamic beach trends and amount of coastal damage have been obtained, and are presented in the form of a Beach Susceptibility Matrix. The matrix permits predictions of expected coastal damage associated with storms in other nearby beaches by means of a simple beach monitoring programme.

ADDITIONALINDEXWORDS: *coastal hazards, beach erosion, morphosedimentary parameters, Gulf of Cadiz*

INTRODUCTION

Comprehension of beach dynamics requires a monitoring of its natural changes through time, according to the incident wave regime. A certain knowledge of the natural behaviour of every beach type can be obtained by means of a field monitoring long enough for the beach to attain different energetic states. Data from these studies (mainly about morphology, grain size and wave energy) can be combined by the application of morphodynamic parameters widely used in the literature. Although many of them are not very representative of the real processes acting on the shore (ANTHONY, 1998), they suppose an important basic information for further detailed geomorphological research on littoral processes, or for applied studies on coastal protection (beach nourishment, coastal preservation and management, etc., ANFUSO *et al*., 2001).

In many coastal environments storms suppose the main cause of damage on littoral settings and uses. The longshore distribution of storm effects on a coast depends on multiple variables, including subtidal morphology, wave refraction-diffraction pattern, sediment supply to the coast, beach morphological behaviour, dune development and human alterations and uses of the shoreline (BALSILLIE, 1986; LAWRENCE, 1994). Beaches and dunes constitute one of the most effective natural protections from storms. However, beach response to storm events varies notably alongshore. In this sense, coastal settings and infrastructures suffer very different amount of damage depending on the natural behaviour and characteristics of the beaches facing them. For this reason, prevention from storm effects should include knowledge about the geographical distribution of beach types and, especially, about the efficiency of every beach type in protecting the concomitant landward environments and uses. As BRUNSDEN and MOORE (1999) pointed out, the most successful coastal designs are those that fulfill the functional needs of the system: in this case, structures should adapt to the natural behaviour of beaches.

In this work a general morphodynamic study is applied to the prediction of storm damage in a wide portion of the South-Atlantic Spanish coast (Fig. 1). In this area some previous works have been made on local morphodynamic characterization of beaches (ANFUSO *et al*., 2000; BENAVENTE *et al*., 2000), but no studies exist on regional comparisons among beach types, or on the longshore distribution of beach behaviour. About storms in this zone, only some general qualitative approaches to coastal effects (REYES *et al*., 1999) or to economic losses (MUÑOZ-PÉREZ *et al*., 2001) can be mentioned.

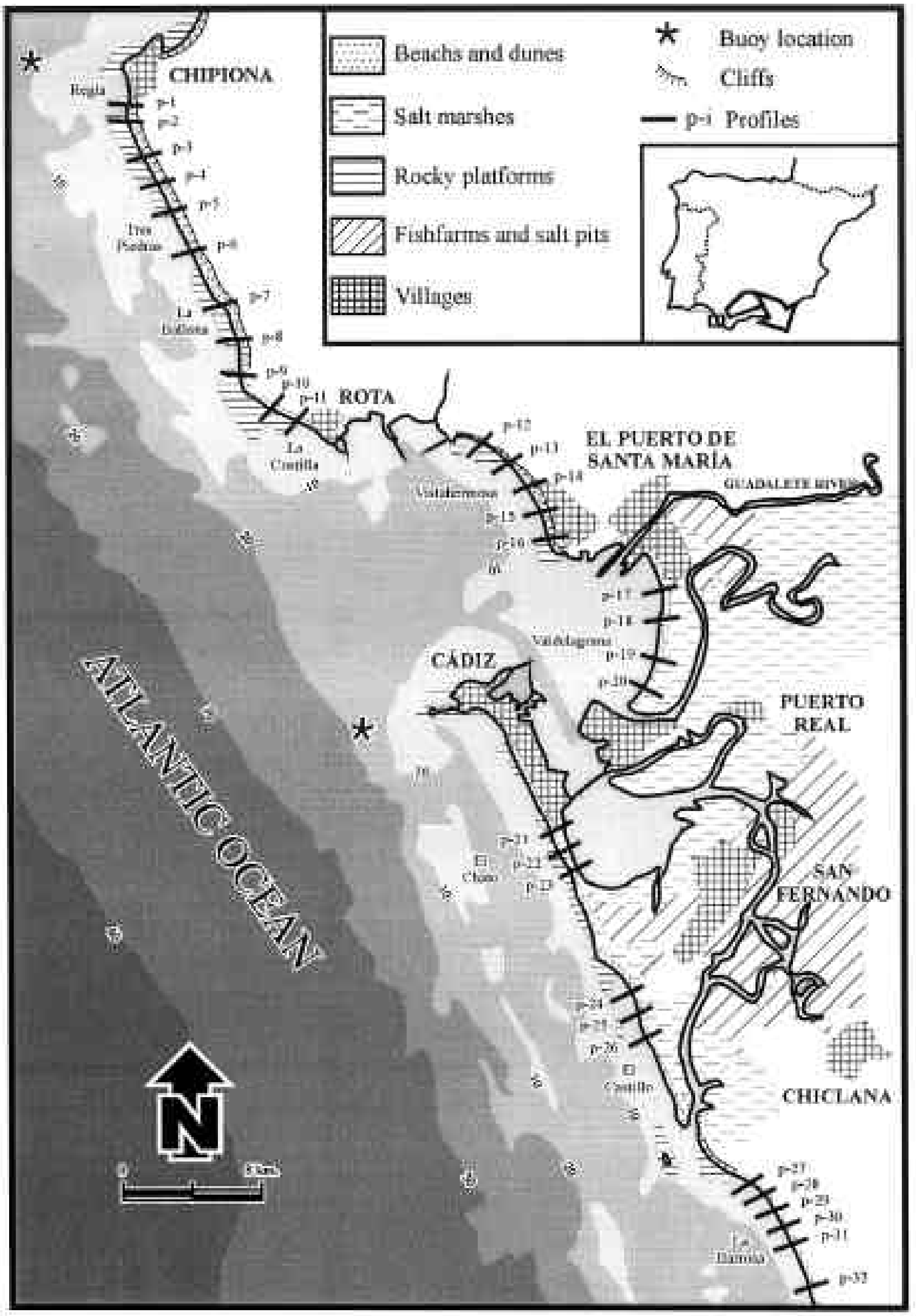


Figure 1. Location and geomorphological map of the studied coast.

FIELD SITE

The study area is located in the Gulf of Cadiz (SW Spain) and includes about 60 Km of a Southwest facing coast, mainly consisting of extensive sandy beaches (Fig. 1). These are composed of quartz-rich, medium to fine and moderately well sorted sands. Beachface slopes generally show low values and the average dry beach width ranges from 10 to 100 m. The coast is a semidiurnal mesotidal environment with a mean tidal range of 2 m. Incident waves usually approach from WNW with an average significant wave height of about 1 m and associated periods of 5-6 seconds. Due to coastal orientation, main longshore transport drifts southwards.

Coastal morphology (Fig. 1) includes exposed, linear and homogeneous beaches, many of them backed by low cliffs and faced by discontinue rocky-shore platforms. The Cadiz Bay is a partially sheltered area characterised by sandy spits, tombolos, dune ridges and salt marshes. The Guadalete river represents the main fluvial source of sediments to the Bay.

This littoral zone presents different levels of human occupation. Heavily urbanised areas, mainly for touristic use of the coast, are developed in Vistahermosa and La Barrosa beaches, and an increasing urban pressure is nowadays observable between Chipiona and Rota. Finally, the Cadiz Bay Natural Park includes natural preserved areas, like dune ridges and salt marshes of a great ecological importance.

METHODOLOGY

Most indices and parameters used for the prediction of beach morphodynamic behaviour employ simple and easily measurable variables related to wave energy and beach characteristics. The former are expressed by deep water and breaker zone wave heights (H_0 and H_b), wave period (T) and deep water wavelength (L_0). The latter are expressed by sediment characteristics (commonly, the medium grain size, D_{50}) and beach morphology (usually, the mean intertidal slope, $\tan\beta$).

In this work the classification of surf zone conditions was obtained by calculating three parameters widely used in coastal engineering: Surf Scaling (GUZA and INMAN, 1975) and Surf Similarity Parameters (BATTJES, 1974), and the Dean Number (DEAN, 1973). The first one:

$$\varepsilon = 2\,\pi^2 H_b/gT^2 \tan^2\beta \qquad (1)$$

ε = epsilon; π = pi number, 3.1416; β = beta

differentiates among reflective, intermediate and dissipative beaches. The second one:

$$\xi = \tan\beta\ (H_0/L_0)^{-0.5} \qquad (2)$$

ξ = xi

predicts wave breaking type (from surging, plunging to spilling) and is linearly related with the former expression. Initially, this parameter was described by IRIBARREN and NOGALES (1949) for breaking conditions (Iribarren Number, ξb):

$$xb = \tan\beta\ (H_b/L_0)^{-0.5} \qquad (3)$$

WRIGHT and SHORT (1984) employed the Surf Scaling Parameter and the Iribarren Number to separate reflective ($\varepsilon < 1$, $\xi_b > 2$) from dissipative ($\varepsilon > 30$, $\xi_b < 0.23$) beach states.

The Dean Number takes into account both wave and sediment characteristics:

$$\Omega = Hb/Ws\ T \qquad (4)$$

Ω omega cap.

where W_s is the dimensionless fall velocity of the sediment:

$$W_s = 273\ D_{50}^{1.1}\ (mm) \qquad (5)$$

WRIGHT *et al.* (1985) studied the range of this parameter and MASSELINK (1994) used it to differentiate between reflective ($\Omega < 2$) and dissipative ($\Omega > 5$) beach states.

BAUER and GREENWOOD (1988) stressed that these parameters are very useful to discriminate between reflective and dissipative extreme beach states, but not to characterize intermediate situations. Furthermore, ANTHONY (1998) pointed out that this kind of parameter must be tested for a wide range of natural environments, especially in low energy beaches with a long time response, which is the case of the studied area (BENAVENTE *et al*., 2000).

Field work was performed through a beach monitoring program, carried out during two years with a monthly periodicity. An electronic theodolite was used to survey beach profiles at 32 representative fixed points distributed along the littoral (Fig. 1). Topographic data led to the evaluation of beach gradient and morphology. Beach sediment samples were seasonally collected and analysed by dry sieving.

Wave data were obtained from two offshore buoys belonging to the Spanish Sea Wave Recording Network (REMRO), located in front of Chipiona and Cadiz (Fig. 1). Breaking wave height (H_b) was obtained by applying the KOMAR and GAUGHAN (1972) expression:

$$H_b = 0.39\ g^{0.2}(T\ H_0^2)^{0.4} \qquad (6)$$

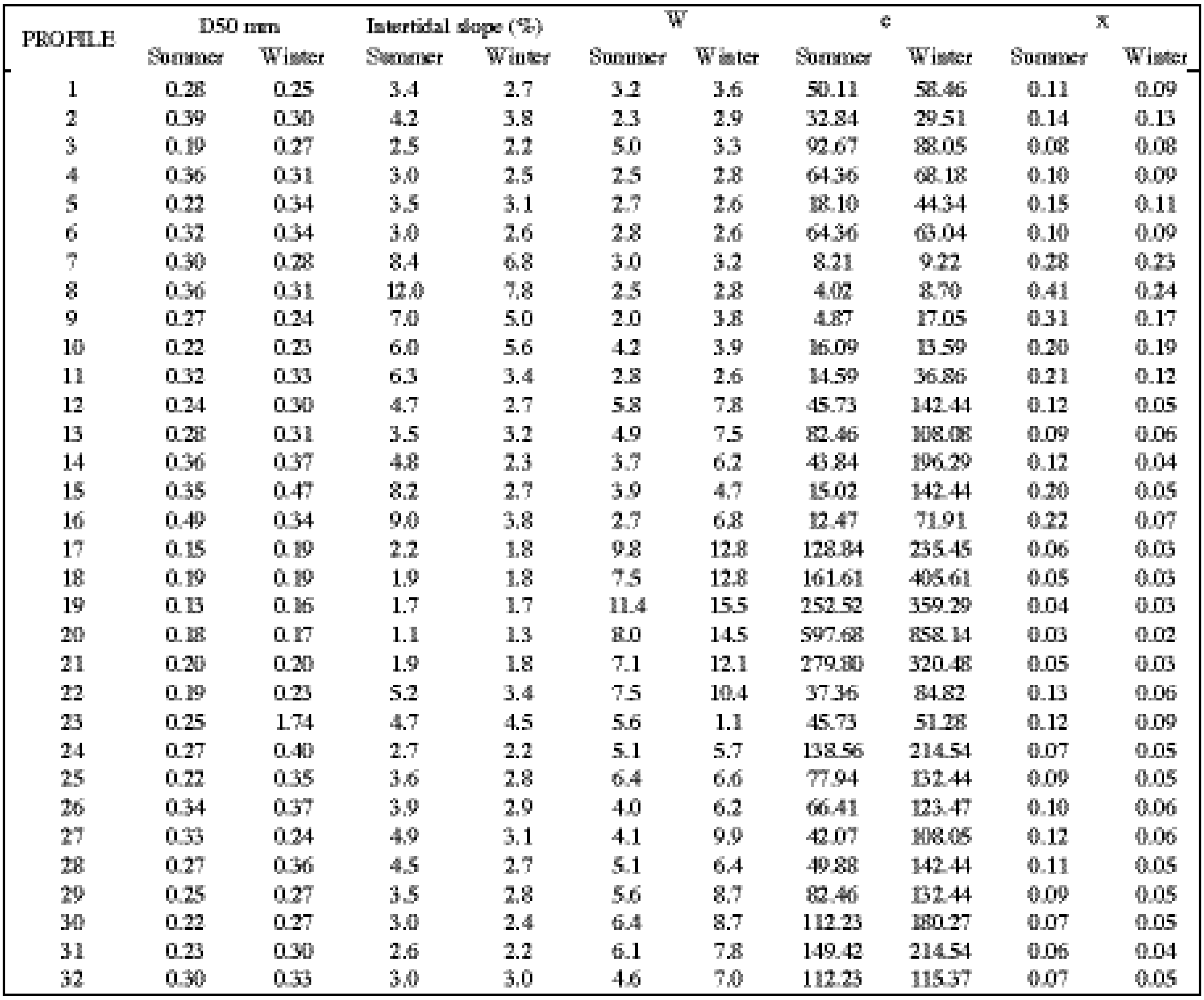
Due to the usually slow rate of beach recovery in this coastal zone (BENAVENTE *et al*., 2000), the calculation of H_b was made by considering the mean offshore wave height of the month prior to the beach profiling. Several visual inspections were made during each winter season for the period 1996-1998, in order to evaluate damages caused by most important storms in the coast, both on main natural environments and on human-made constructions distributed along the study area.

RESULTS

Beach characteristics and their broad seasonal variations are shown in Table I. Beach sediments were composed of medium sands and showed a very small longshore variation. Valdelagrana beach presented the smallest mean grain size, probably linked to the sheltered conditions of the area, the stronger effects of tidal currents and the influence of the Guadalete river mouth. Coarsest sediments dominated in beaches close to conglomeratic shore platforms.

Dealing with the intertidal beach slope, maximum values characterized the southern part of the Chipiona – Rota sector and the southernmost profiles of Vistahermosa beach. In the former area beach morphology is greatly controlled by the protective role of rocky shore platforms. In these beaches, erosive processes produce beach pivotings around the mean high water level. Consequently, small seasonal topographic and morphological variations are recorded (MUÑOZ-PÉREZ *et al.*, 1999). Values observed in the southern part of Vistahermosa beach are linked to the presence of a rocky shore platform that confines the beach, acting as a breakwater that blocks littoral drift.

Table I. Seasonal extreme values of medium grain size, intertidal beach slope and morphodynamic parameters for the studied profiles (see Fig. 1 for profile location).



PROFILE	D50 mm		Intertidal slope (%)		W		e		x	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
1	0.28	0.25	3.4	2.7	3.2	3.6	50.11	58.46	0.11	0.09
2	0.39	0.30	4.2	3.8	2.3	2.9	32.84	29.51	0.14	0.13
3	0.19	0.27	2.5	2.2	5.0	3.3	92.67	88.05	0.08	0.08
4	0.36	0.31	3.0	2.5	2.5	2.8	64.36	68.18	0.10	0.09
5	0.22	0.34	3.5	3.1	2.7	2.6	18.10	44.34	0.15	0.11
6	0.32	0.34	3.0	2.6	2.8	2.6	64.36	63.04	0.10	0.09
7	0.30	0.28	8.4	6.8	3.0	3.2	8.21	9.22	0.28	0.23
8	0.36	0.31	12.0	7.8	2.5	2.8	4.02	8.70	0.41	0.24
9	0.27	0.24	7.0	5.0	2.0	3.8	4.87	17.05	0.31	0.17
10	0.22	0.23	6.0	5.6	4.2	3.9	16.09	13.59	0.20	0.19
11	0.32	0.33	6.3	3.4	2.8	2.6	14.59	36.86	0.21	0.12
12	0.24	0.30	4.7	2.7	5.8	7.8	45.73	142.44	0.12	0.05
13	0.28	0.31	3.5	3.2	4.9	7.5	82.46	108.08	0.09	0.06
14	0.36	0.37	4.8	2.3	3.7	6.2	43.84	196.29	0.12	0.04
15	0.35	0.47	8.2	2.7	3.9	4.7	15.02	142.44	0.20	0.05
16	0.49	0.34	9.0	3.8	2.7	6.8	12.47	71.91	0.22	0.07
17	0.15	0.19	2.2	1.8	9.8	12.8	128.84	235.45	0.06	0.03
18	0.19	0.19	1.9	1.8	7.5	12.8	161.61	405.61	0.05	0.03
19	0.13	0.16	1.7	1.7	11.4	15.5	252.52	359.29	0.04	0.03
20	0.18	0.17	1.1	1.3	8.0	14.5	597.68	858.14	0.03	0.02
21	0.20	0.20	1.9	1.8	7.1	12.1	279.80	320.48	0.05	0.03
22	0.19	0.23	5.2	3.4	7.5	10.4	37.36	84.82	0.13	0.06
23	0.25	1.74	4.7	4.5	5.6	1.1	45.73	51.28	0.12	0.09
24	0.27	0.40	2.7	2.2	5.1	5.7	138.56	214.54	0.07	0.05
25	0.22	0.35	3.6	2.8	6.4	6.6	77.94	132.44	0.09	0.05
26	0.34	0.37	3.9	2.9	4.0	6.2	66.41	123.47	0.10	0.06
27	0.33	0.24	4.9	3.1	4.1	9.9	42.07	108.05	0.12	0.06
28	0.27	0.36	4.5	2.7	5.1	6.4	49.88	142.44	0.11	0.05
29	0.25	0.27	3.5	2.8	5.6	8.7	82.46	132.44	0.09	0.05
30	0.22	0.27	3.0	2.4	6.4	8.7	112.23	180.27	0.07	0.05
31	0.23	0.30	2.6	2.2	6.1	7.8	149.42	214.54	0.06	0.04
32	0.30	0.33	3.0	3.0	4.6	7.0	112.23	115.37	0.07	0.05

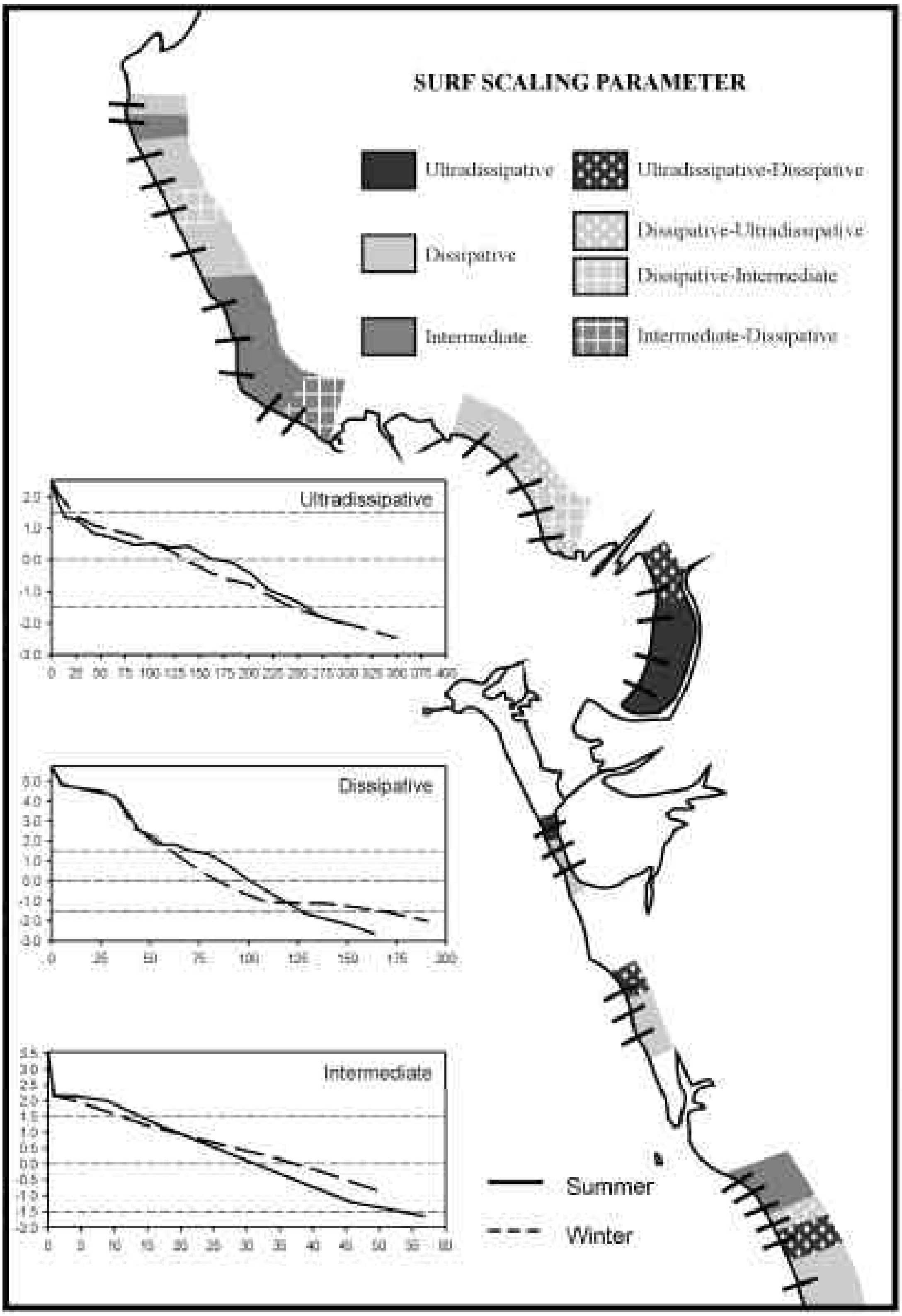


Figure 2. Geographical variations of the Surf Scaling Parameter in the studied beaches. Average seasonal profile changes are shown for the main beach types.

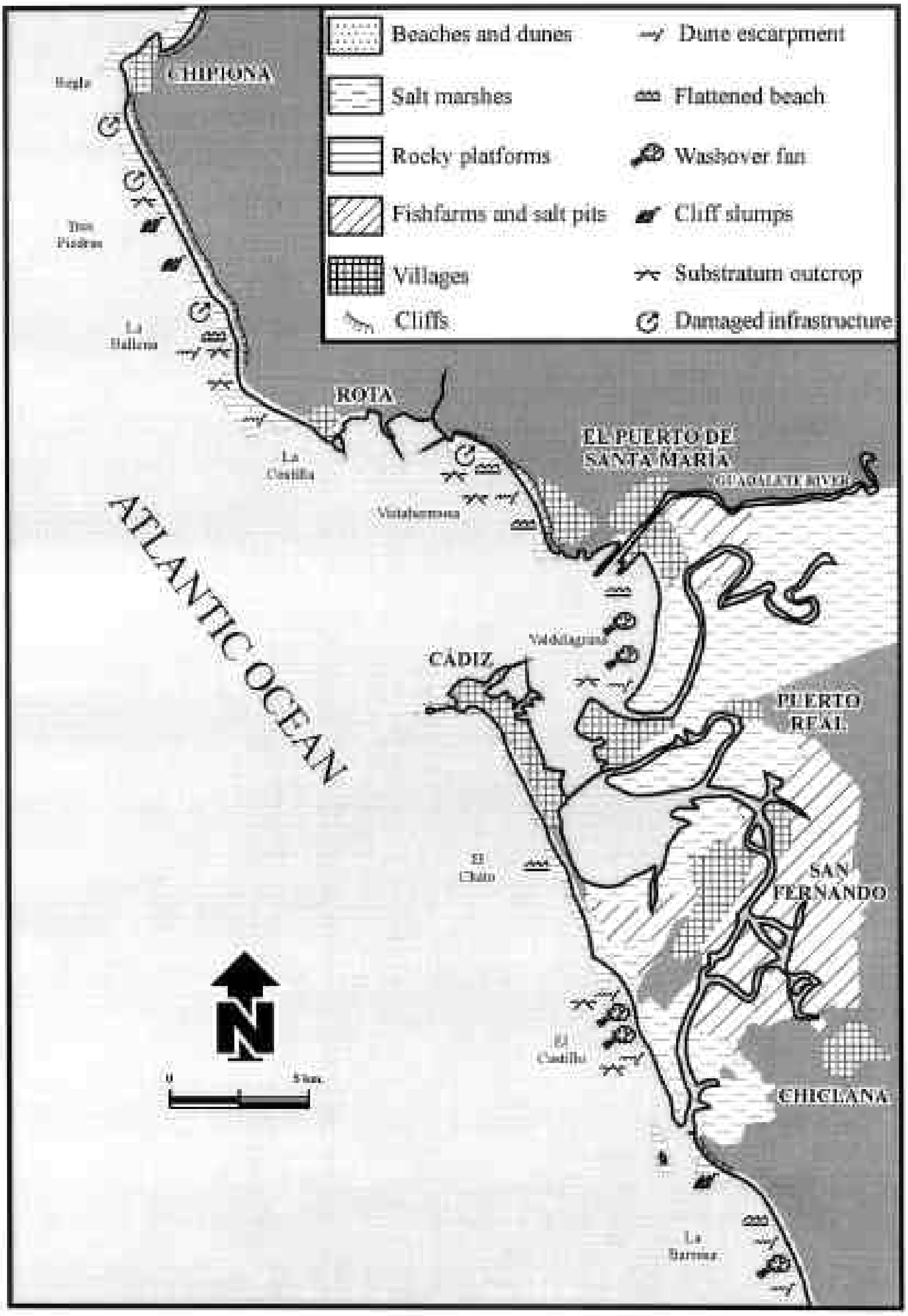


Figure 3. Geographical distribution of most common coastal damages due to winter storms in the studied zone.

Average seasonal values of Dean Number, Surf Similarity and Surf Scaling Parameters are presented in Table I. Morphological parameters show quite similar trends for each case. Dean Number classifies the studied beaches as "intermediate-to-dissipative", with almost no spatial and seasonal changes, due to the small longshore variation of grain size.

Surf Similarity and Surf Scaling parameters show similar tendencies, although the latter presents a greater range that permits to differentiate an additional morphodynamic beach state (e > 150, Table I), resembled to the theoretical "ultradissipative" state described by MASSELINK and SHORT (1993). Consequently, Surf Scaling was preferably used to characterize the morphodynamic behaviour of the studied beaches and three main states were differentiated: ultradissipative, dissipative and intermediate ones. Typical seasonal profile changes for each case are showed in Fig. 2.

Within each group a further division was made, between stable (or without variations along the studied period) and seasonally changing beach profiles. Spatial distribution of this distinct beach behaviour was also mapped (Fig. 2).

In the study littoral storms present about 10% of annual occurrence (ROM-0.3, 1991) and show a significant wave height greater than 1.5 m, with an associated period higher than 6 seconds. Average significant wave height hardly exceeds 4 m, which makes this coast a low energy environment, even during storms. Mean storm duration is usually less than 4 days, with a greater probability of occurrence during winter time, from November to February. The strongest events normally arrive during December and January, coming from WSW, with waves never reaching 8 m (BENAVENTE *et al*., 2000).

Coastal effects of energetic waves during storms are magnified when they coincide with spring tides, flooding coastal zones and upper parts of beaches that normally do not suffer severe damage during storms (REYES *et al*., 1996). Storm surge in this area usually reaches values of up to 0.5 m (INSTITUTO HIDROGRÁFICO DE LA MARINA, 1991).

Fig. 3 represents the aerial distribution of the most common coastal damage and effects due to storms. Data were obtained from systematic observations of the coast during the arrival of storms in winter periods. The figure does not represent the consequences of a single energetic event, but the average effects produced by several storms during the last years. Damage and effects have been grouped into six types of increasing severity:

- Beach flattening (removal of sand to draw a very gentle beach slope).
- Dune escarpment and general dune erosion.
- Rocky substratum outcropping by exhumation and exposition to wave action.
- Mass movements in resistant rocky cliffs: rock falls and slumping.
- Overwashing of spit barriers by energetic waves, forming washover fans.
- Infrastructure deterioration: damage on seawalls, failures on promenades and coastal roads...

DISCUSSION

The relationships between general beach morphodynamic behaviour and storm effects on sandy coasts for this zone are presented in the susceptibility matrix of Table II. As an initial premise, it could be expected a relationship by which beaches with a clear dissipative tendency would be more capable to dissipate wave energy during storms than intermediate or reflective beaches, due to the presence of nearshore bars, that act as efficient obstacles to energetic waves (CARTER and BALSILLIE, 1983). So, dissipative beaches would suffer lesser effects during storms, and human settings behind them would be more protected. In the same way, the higher beachface gradient of reflective or intermediate beaches reduces their ability to dissipate energetic waves, and they would be more sensitive to storm action, resulting in a greater erodibility (BENAVENTE *et al*., 2000). Finally, the degree of anthropic transformation of the backshore and foredunes must also influence the erosional response of beaches to storm events (MARTINS *et al*., 1997).

However, Table II demonstrates how this premise is quite simplistic. There are cases where important damage was produced by storms in promenades and buildings installed upon former dune ridges. Similarly, some natural, untransformed beaches suffered important erosion during storms, by means of overwashing processes that severely affected dune ridges. But in other cases, both in natural and transformed beaches, no significant damage was produced during storms, with a non evident influence of the degree of beach anthropization. Only in the case of transformed beaches belonging to the same beach type, storm damage was lesser in the presence of a more or less preserved dune ridge.

Matrix on Table II indicates that beach susceptibility to storm erosion depends mainly on the ability of beaches to change their morphodynamic state: seasonal beaches, characterized by an alternation between two or more states through the year, are more resistant to storms than uniform unchanging beaches. Beach seasonality appears to be a key variable in the severity of coastal damage by storms. Surprisingly, there is not a great dependency on the specific prevailing morphodynamic state, although whole-year-ultradissipative profiles are more resistant than whole-year-dissipative ones.

Table II. Beach susceptibility matrix to storm action for the studied coast.

Surf scaling parameter ←

Damage severity ↓	Ultradissipative		Dissipative			Intermediate	
	Whole year	**Seasonally dissipative**	**Seasonally ultradissipative**	**Whole year**	**Seasonally Intermediate**	**Seasonally Dissipative**	**Whole year**
Beach flattening	•	•	•	•			•
Dune erosion	•	•	•	•	•	•	•
Substratum exposition	•			•			
Cliff slumping				•			•
Overwashing	•			•			
Infrastructure damaging				•			•

The reason for this is that drifting from one morphodynamic state to another one is directly related to the beach ability to adapt its profile to new energetic conditions. This autodefensive behaviour depends mainly on the amount of sand available for the change: if there is enough sand in the beach during the arrival of a storm, eroded sediments form nearshore bars, which act as an obstacle to the following energetic waves, protecting the shore. The drift from dissipative to ultradissipative states increases the amount of suspended sediment, which reduces wave erosivity. Furthermore, the associated slope decline produces a decrease in the intensity of rip currents. In places where there is not enough sand for the beach to acquire a complete barred-dissipative profile, the beach is severely eroded and energetic waves reach the backing structure, no matter whether it be natural (beach ridges) or artificial (promenades, buildings, roads).

So, beach monitoring can be used as an initial tool for the prediction of coastal damage by storms. The efficiency of this technique is restricted, however, to not very strong storms, that permit some beaches to maintain enough mobile sand across their active profiles. The arrival of extremely violent storms (associated to hurricanes, or to long-recurrence interval events) would completely flatten all the beaches and huge amounts of sand would be lost. In such a case, the morphodynamic characteristics of the beaches would be deeply transformed and their future behaviour would be very difficult to predict. A new step in this research will be to characterize the storm energy needed to break the seasonal behaviour of beaches, exposing all the coastal zone to severe damage.

CONCLUSIONS

The ability of beaches to recover after storm events depends on the availability of enough sand for them to complete a morphodynamic change, that is, to sufficiently adapt their profiles to the new energetic conditions. The amount of sediment needed or present in the shore is not always dependent on the intensity of coastal anthropization: some urban beaches have acquired a dynamic equilibrium with the prevailing wave regime, by which they do not lose important quantities of sand after the passing of a storm or, if they do, almost all the eroded sand progressively returns to the beachface during the fair weather period.

The location of the main sedimentary inputs (river mouths) and other contouring conditions, favours a greater availability of sand in some beaches which, from a morphodynamic point of view, become more mobile and self-protected against storms.

As an initial tool in the study of coastal hazards related to storms, the construction of a susceptibility matrix can be very useful for coastal management purposes. Its design needs a monthly or seasonal beach monitoring, in order to identify beach changes and to evaluate the ability of every beach type to pass over several morphodynamic states. The susceptibility matrix must include the specific processes involved in the coastal erosion and/or the morphological consequences of their action, and should embrace all coastal environments, natural or anthropogenically transformed.

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LITERATURE CITED

ANFUSO, G.; GRACIA, F.J.; ANDRÉS, L.; SÁNCHEZ, F.; DELRÍO, L., and LÓPEZ-AGUAYO, F., 2000. Depth of disturbance in mesotidal beaches during a single tidal cycle. *Journal of Coastal Research*, 16 (2), 446-457.

ANFUSO, G.; BENAVENTE, J., and GRACIA, F.J., 2001. Morphodynamic response of nourished beaches in SW Spain. *Journal of Coastal Conservation*, 7 (1), 71-80.

ANTHONY, E.J., 1998. Sediment-wave parametric characterization of beaches. *Journal of Coastal Research*, 14 (1), 347-352.

BALSILLIE, J.H., 1986. Beach and coast erosion due to extreme event impact. *Shore and Beach*, 54 (4), 22-37.

BATTJES, J.A., 1974. Surf similarity. *Proceedings of the 14th International Conference on Coastal Engineering,* ASCE, pp. 446-480.

BAUER, B.O. and GREENWOOD, B., 1988. Surf-zone similarity. *Geographical Review*, 78, 137-147.

BENAVENTE, J.; GRACIA, F.J., and LÓPEZ-AGUAYO, F., 2000. Empirical model of morphodynamic beachface behaviour for low-energy mesotidal environments. *Marine Geology*, 167, 375-390.

BRUNSDEN, D. and MOORE, R., 1999. Engineering geomorphology on the coast: lessons from west Dorset. *Geomorphology*, 31, 391-409.

CARTER, R.W.G. and BALSILLIE, J.H., 1983. A note in the amount of wave energy transmitted over nearshore sand bars. *Earth Surface Processes and Landforms*, 8, 213-222.

DEAN, R.G., 1973. Heuristic models of sand transport in the surf zone. *Proceedings of Conference on Engineering Dynamics in the Surf Zone* (Sydney, Australia), pp. 208-214.

GUZA, R.T. and INMAN, D.L., 1975. Edge waves and beach cusps. *Journal of Geophysical Research*, 80, 2997-3012.

INSTITUTO HIDROGRÁFICO DE LA MARINA, 1991. *Anuario de mareas*. Ministerio de Defensa, Madrid.

IRIBARREN, R. and NOGALES, C., 1949. Protection des ports. *Proceedings of the 17th International Naval Congress* (Lisboa), Sec. II-4, pp. 31-82.

KOMAR, P. and GAUGHAN, M.K., 1972. Airy wave theory and breaker height prediction. *Proceedings of the 13th Conference on Coastal Engineering*, ASCE, pp. 405-418.

LAWRENCE, P.L., 1994. Natural hazards of shoreline bluff erosion: a case study of Horizon View, Lake Huron. *In*: MORISAWA, M. (ed.), *Geomorphology and Natural Hazards. Geomorphology,* 10, 65-81.

MARTINS, J.T.; FERREIRA, O., and DIAS, J.A., 1997. A susceptibilidade da Praia de Faro à erosão por tempestades. *Comunicações do 9º Congresso do Algarve*, Racal Clube, pp. 206-213.

MASSELINK, G., 1994. *Morphodynamics of microtidal beaches. Examples from Central Queensland, Australia*. University of Sydney, Australia, Ph. D. thesis.

MASSELINK, G. and SHORT, A.D., 1993. The effect of tide range on beach morphodynamics and morphology: a conceptual beach model. *Journal of Coastal Research*, 9 (3), 785-800.

MUÑOZ-PÉREZ, J.J.; TEJEDOR, L., and MEDINA, R., 1999. Equilibrium beach profile model for reef-protected beaches. *Journal of Coastal Research*, 15 (4), 950-957.

MUÑOZ-PÉREZ, J.J.; LÓPEZ, B.; GUTIÉRREZ-MAS, J.M.; MORENO, L., and CUENA, G.J., 2001. Cost of beach maintenance in the Gulf of Cádiz (SW Spain). *Coastal Engineering*, 42, 143-153.

REYES, J.L.; BENAVENTE, J.; GRACIA, F.J., and LÓPEZ-AGUAYO, F., 1996. Efectos de los temporales sobre las playas de la Bahía de Cádiz. *Cuadernos do Laboratorio Xeoloxico de Laxe*, 21, 631-643.

REYES, J.L.; MARTINS, J.T.; BENAVENTE, J.; FERREIRA, O.; GRACIA, F.J.; ALVEIRINHO-DIAS, J., and LÓPEZ-AGUAYO, F., 1999. Gulf of Cádiz beaches: A comparative response to storm events. *Boletín del Instituto Español de Oceanografía*, 15 (1-4), 221-228.

ROM-0.3, 1991. *Clima marítimo en el litoral español*. Dirección General de Puertos. Ministerio de Obras Públicas, Madrid.

WRIGHT, L.D. and SHORT, A. D., 1984. Morphodynamic variability of surf zones and beaches: a synthesis. *Marine Geology*, 56, 93-118.

WRIGHT, L.D.; SHORT, A.D., and GREEN, M.O, 1985. Short-term changes in the morphodynamic states of beaches and surf zones: an empirical predictive model. *Marine Geology*, 62, 339-364.