Journal of Coastal Research | 31 | 4 | 1023–1034 | Coconut Creek, Florida | July 2015

TECHNICAL COMMUNICATIONS

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New Methodology for the Classification of Gravel Beaches: Adjusted on Alicante (Spain)

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ABSTRACT

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Aragonés, L.; López, I.; Villacampa, Y.; Serra, J.C., and Saval, J.M., 2015. New methodology for the classification of gravel beaches: Adjusted on Alicante (Spain). *Journal of Coastal Research,* 31(4), 1023–1034. Coconut Creek (Florida), ISSN 0749-0208.

In this article, a methodology is presented for the classification of gravel beaches, which can be applied internationally. Such beaches' defence against the energy of incoming water flow is due to their steep slopes and the high permeability of infiltration, but that defence is reduced with increasing sand fraction. The objective of this research was to understand the variables involved in the formation of gravel beaches, to classify them according to the distribution and position of sediment along the transversal profile, and to obtain a discriminant function. To apply the methodology, 34 gravel beaches in the province of Alicante, Spain, were first classified visually into five different types: Type 1: Sand and gravel beaches, Type 2: Sand and gravel separated beaches, Type 3: Gravel and sand beaches, Type 4: Gravel and sand separated beaches, and Type 5: Pure gravel beaches. In addition, a major study was performed to reduce the number of variables because one of the concerns was to find the variables that characterize and classify the beaches. Thus, the 45 variables, grouped according to material characteristics, wave, boundary conditions, and geometry of the beach, were first reduced to 25 by making comparisons among them and the type of beach and were finally reduced to 14 using the discriminant method. Note the use of the important variable *Posidonia oceanica* in the Mediterranean area, which, because of the changes produced in the swell, was actively involved in the classification. Finally, the discriminant function obtained was validated.

ADDITIONAL INDEX WORDS: *Discriminant method, variables,* Posidonia oceanica.

INTRODUCTION

Gravel beaches make up a significant proportion of the world's coastline, being particularly widespread along the coastlines of Northern Europe (especially Russia, the United Kingdom, and Ireland), Canada, the United States, Japan, New Zealand, and Latin America (Buscombe and Masselink, 2006); however, in the SE part of Spain, there is a large extension of such beaches. Although most studies have focused on long-term evolution (Forbes *et al.*, 1991; Jennings *et al.*, 1998; Orford *et al.*, 1995) or zoning sediments (Bluck, 1967, 1998; Orford, Forbes, and Jennings, 2002), research aimed at short-term, morphodynamic aspects are limited to several recent studies (Austin and Masselink, 2005; Holmes *et al.*, 2002; Horn *et al.*, 2003; Pedrozo-Acuña *et al.*, 2006). The larger grain size of gravel beaches allows them to maintain steeper slopes at the beachface than sandy beaches have, often exceeding 10° (Longuet-Higgins and Parkin, 1962), leading to a highly reflective domain, which is characterized by a hydrodynamics and morphology that are markedly different from those produced on sandy beaches. However, compared with their counterparts in sand, gravel beaches have received little attention in the coastal literature. This is partly because gravel beaches are not as widely used, but it is also because of the considerable logistical challenges associated with obtaining meaningful measurements of water depths, flow velocities and sediment flows at gravel beaches (Masselink *et al.*, 2010).

Sediments of gravel beaches have a characteristic size and homogeneous shape (Carter, 1988) because the physiographic context of the development of gravel beaches is glacial and mountain weathering (Buscombe and Masselink, 2006). Therefore, the geographic coverage is distinctly high latitudinal; however, there are areas where, because of their topographic relief near the coast and the short length of their ravines or gullies, eroded elements are deposited on beaches almost without being decanted. However, when the same beach has two different supply sources (rivers and gullies), the differences

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DOI: 10.2112/JCOASTRES-D-14-00140.1 received 14 July 2014; accepted in revision 13 September 2014; corrected proofs received 22 October 2014; published pre-print online 20 November 2014.

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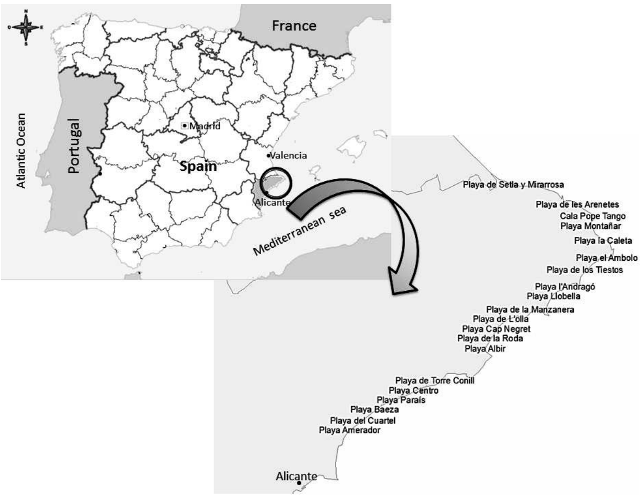

Figure 1. Beach locations in the study area.

can be seen visually, put precisely that combination of sources makes the behaviour differ from one beach to another. As is well known, an important advantage of gravel beaches is their ability to absorb wave energy efficiently over a short distance because of the infiltration flow allowed on the beach. That advantage over sandy beaches quickly disappears as the sand fraction increases. These beaches have behaviours substantially different from the gravel beaches, but there is no clear definition of what proportion of sand is required for a beach to be considered a *mixed beach* because fractions between 15 and 68% have been found (Mason and Coates, 2001).

Quick and Dyksterhuis (1994) suggested that gravel cannot protect a beach against the attack of waves above a critical value, so they can lose their protective function over time (Horn and Walton, 2007). Therefore, if we can classify the different types of gravel beaches, we can understand their performance against wave actions. The increase in the sand fraction relative to pure gravel beaches means beaches must be classified by the relative position of the sand with respect to the gravel because that position, relative to the breaking zone, makes beach behaviour different. Several studies have classified gravel beaches, such as (1) Pye (2001), where they were classified into three groups: pure gravel beaches, beaches with sand in the tidal zone, and beaches where sand and gravel coexist, or (2) Jennings and Shulmeister (2002), whose classification included pure gravel beaches, mixed sand and gravel beaches, and composite gravel beaches.

On the other hand, it is well known that marine vegetation dissipates the energy of waves and turbulence, helping to protect the coast from erosion (Fonseca and Cahalan, 1992; Gacia and Duarte, 2001; Ifuku and Hayashi, 1998). Moreover, vegetation can influence coastal hydrodynamics, depending on its size, location, density, distribution, and morphology (Mendez and Losada, 2004). There are numerous examples that show the importance of vegetation in shallow water, *e.g.,* the protection of *Posidonia oceanica* meadows along the Mediterranean coast (Gacia and Duarte, 2001), and the dissipation of wave energy by *Spartina alterniflora* fields in the British marshes (Moller, Spencert, and French, 1996; Moller *et al.*, 1999).

The main objective in our research was to classify the gravel beaches of Alicante, Spain. To achieve that, 45 variables involved in the formation of such beaches were determined. The number of variables was then reduced, enabling us to obtain a classification while disregarding small changes in some variables that do not affect gravel beach behaviour. Thus, any researcher may classify gravel beaches at any time using the methodology proposed here. Therefore, we intended to obtain a discriminant function that would allow us to classify the beaches studied, employing the fewest variables, and determining the importance of those variables within the classification.

Study Area

The study area was located in the northern part of the province of Alicante, Spain. The study comprised the 34 gravel beaches found in that area (Figure 1).

Alicante is in the SE part of Spain. It has a total coastal length of 244 km and can be morphologically divided into two zones: (1) an area with mainly gravel beaches, ranging from the northern boundary of the province to the Cabo de las Huertas, Spain; and (2) a zone composed almost entirely of sandy beaches, ranging from Cabo de las Huertas to the southern border of the province (Figure 2).

The northern area, where the gravel beaches that were the subject of this study are located, can be divided into two areas, both dominated by the presence of *Posidonia oceanica* beds. An area from the northern boundary to Cabo de la Nao is dominated by limestone cliffs and ENE wave directions, with the NE swells being the strongest. The southern region consists of small gravel and silt cliffs and a higher frequency of waves from the east. The wave incident along this coast is microtidal and astronomical, with an amplitude between 20 and 30 cm and weather that can sometimes cause waves to reach 1 m (echo cartographic study of the provinces of Valencia and Alicante, Spain, from the General Directorate of Coasts [Ecolevante]).

Background

One of the first classifications of beaches was based on the transverse distribution of the sediment and particle shape (Bluck, 1967). Bluck (1967) identified two distinct areas, representing high and low energies. Those two types of beach were composed of gravel sizes ranging from –40 to –70 (16 to 128 mm) (Krumbein, 1934) and faced an intertidal rock platform. Williams and Caldwell (1988) found that, in high energy gravel beaches, better discrimination could be made with a sedimentological classification using particle size instead of shape. They showed that there was a statistically significant difference between 10 different configurations identified but were unable to determine the main physical processes that controlled the evolution of the profile. Carter and Orford (1993) suggested that there are two main types of beach gravel based on morphology: (1) a single slope from the beach crest to wave base, ignoring small scale bars and berms; and (2) a slope composed of a beach ridge to the base wave, with a steep upper intertidal zone (gravel) and a lower intertidal zone of low

Figure 2. (A) Southern province with flat landscapes, (B) northern area dominated by cliffs, (C) Cliffs south of Cabo de la Nao predominated by gravel and silt, and (D) chalk cliffs north of Cabo de la Nao.

angle (sand). These types of beaches are composed of varying proportions of each component and different positions within the beach (Carter and Orford, 1984). Some authors, such as Pye (2001), used a classification that differentiated beaches by the relative proportions and distributions of sand on the beach or backshore and were classified as (1) pure gravel beaches; (2) beaches with an upper foreshore and backshore of gravel and a lower foreshore of sand; and (3) mixed-sand-and-gravel types (mixed beaches), where no clear spatial division exists between the sand and gravel components.

Furthermore, Masselink and Short (1993) argued that natural beaches could be grouped into several types depending

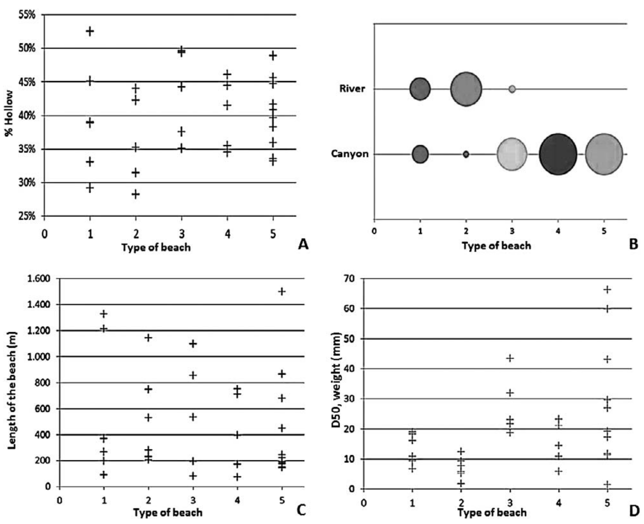

Figure 3. Charts for a first discrimination of influential parameters in the classification. To the left are the discarded variables: (A) percentage of hollow, and (C) the length of the beach. To the right are the accepted variables accepted: (B) the source (river or canyon), and (D) D_{50} weight.

on the height of the wave breaking (H_b), the period (T), the fall rate of the sediments (w_o), and the tidal range (TR). These four variables were quantified by two parameters: the dimensionless fall velocity ($\Omega = H_b/w_oT$) used by Wright *et al.* (1984) to classify microtidal beaches, and the relative tidal range ($RTR = TR/H_b$). The value of the dimensionless fall velocity indicates whether the conditions of the surf zone are reflective, intermediate, or dissipative, whereas the relative tidal range reflects the relative importance of surf and swash areas and the shoaling processes. In the model proposed by Masselink and Short (1993), there were three thresholds related to tidal range that depend on the relative importance of the processes in the swash, surf, and shoaling. Jennings and Shulmeister (2002) proposed a simple classification from observing the beach, which can be applied globally and is based on the geomorphological differences between the types of beaches. The three types identified were pure gravel beaches, beaches of mixed sand and gravel, and composite gravel beaches. That classification uses 10 variables, which were ultimately reduced to six that combined those above for the discriminant function. Those six variables were (1) the Iribarren number (wave height and period in deepwater and the slope of the beach), (2) beach width, (3) the average grain size as the average of three samples collected from beaches, (4) the height of the storm berm, (5) the number of berms, and (6) the slope of the active profile. One of the last classifications that took place was conducted by Scott, Masselink, and Russell (2011) in which the morphological, sedimentological, and hydrodynamic characteristics of 92 beaches in the U.K. were collected. Using a cluster analysis identified nine different coastal types. In addition to traditional morphodynamic indices Ω and RTR, the energy level of the absolute wave is also important in controlling the type of beach.

As we can observe, the variables used by the authors for classification were different, except for the wave parameters, and, in turn, those variables present some important issues because some of those parameters vary throughout the year, especially the slope of the active profile, the height of the storm berm, and the number of existing berms on the beach. Sometimes when the beaches are short in length and are protected with small capes, like the study area, boundary conditions next to the coast change the swell, so the use of wave characteristics in deep water is not appropriate.

METHODS

As a first approach, a visual classification of the 34 beaches was conducted, and five groups were distinguished according to the spread of sand and gravel. Thus a distinction has been made between sandy and gravel-separated, sand and gravel, gravel and sand, gravel and sand separate, and pure gravel beaches.

One concern of this research was to understand the parameters that characterize and classify the beach. Therefore, 45 variables were managed for each of the 34 beaches that comprised the study area. Those variables depended on both the material characteristics of the beach, like the waves, and the boundary conditions and geometry of the beach.

Sampling, cross-sections, and characterization of the waves and measurements of each of the beaches were performed with that in mind.

Groups of Variables

This section describes each of the variables used and a first discrimination will be made to reduce their number and keep those that most influence the classification of the beach, before proceeding to the discriminant analysis. For this first reduction a comparison of these with each of the types of beach classified will take place, seeing if there is any relationship between them or not (Figure 3).

Material Properties

On each beach, four samples of material were collected, three of them in the dry zone in the N, centre, and S of the beach, and a fourth sample in the swash zone in the centre of the beach. From each of the samples and beaches, the following variables were obtained:

(1) % hollow
(2) Bulk density
(3) D_{50}, arithmetic means
(4) D_{50}, medium weight
(5) D_{10}, medium weight
(6) D_{90}, medium weight
(7) Sorting (S_o)
(8) Skewness (S_k)
(9) Kurtosis (K)
(10) Uniformity coefficient (C_u)
(11) Coefficient of concavity (C_c)

From these parameters, D_{10} and D_{90} were chosen because the study area consisted generally of mixed sediment beaches, which were bimodal, and the use of standard parameters such as the mean, sorting, skewness, and kurtosis can produce results that have no physical meaning; *e.g.*, if two modes are present, the average may fall into the gap between modalities and, therefore, represent a fraction of size with little or no sediment (Horn and Walton, 2007).

The weight average size D_{50} was also used in the classification because it better represented all beaches than the arithmetic mean did and because there were some primary, unimodal beaches, such as those of Types 1 and 2 that were better represented by the average size for D_{10} and D_{90}.

Wave Characteristics

With respect to energy, different wave heights, periods, directions, and frequencies were accounted for mainly because most of the beaches in the study area were small or had capes with sheltered locations against the swell, although there are also some less-protected, extensive beaches, such as Albir beach or Paraís beach. The different wave heights and periods used are

1. Swell higher frequency
   a. Wave height in deep water (H_o)
   b. Period (T_p)
   c. Frequency
   d. Direction
   e. Wavelength deepwater (L_o)
2. Swell of highest wave
   a. Wave height in deep water (H_o)
   b. Period (T_p)
   c. Direction
   d. Wavelength deepwater (L_o)
3. Swell perpendicular to the coast
   a. Wave height in deep water (H_o)
   b. Breaking wave height (H_b)
   c. Period (T_p)
   d. Frequency
   e. Direction
   f. Wavelength deepwater (L_o)
4. Depth of *Posidonia oceanica*

Thus, the waves chosen were those with swells perpendicular to the coast because they were less affected by boundary conditions. To do that, the wave height in deep water was used to obtain the surf break from the correlation between the Iribarren number (Iribarren Cavanilles and Nogales, 1949) and the Surf Similarity Index (Battjes, 1974) because, as stated above, most of the beaches were small and were protected by capes or artificial breakwaters. The depth of *Posidonia oceanica* was also included in this group, given its energy-reducing character (Gacia and Duarte, 2001). Hence, its use will be considered later because it is a differentiator for the beaches in the study because it can be found in 33 of the 34 beaches.

Boundary Conditions

In this group, all those variables that depend on the environment in which the beach is located are attached, *i.e.* the origin and sources of material supply to the beach, and morphological seabed conditions, which also influence the energy reaching the coast and especially the transport of sediment. These variables included the following:

(1) Modality, whether it was a unimodal or bimodal beach because that indicates whether there were one or two sources supplying material;

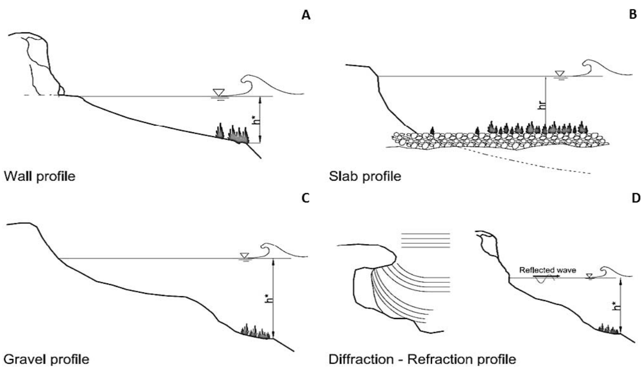

Figure 4. Schematic profile types.

(2) Profile type: gravel, wall and diffraction–refraction profile, gravel profile, gravel and diffraction–refraction profile, gravel and wall profile, and slab and diffraction–refraction profile (Figure 4);
(3) Source, according to whether the main source was a river or ravine;
(4) Distance to the source, measured from the source to the centre of the beach.

These variables will all be taken into account when classifying the beaches by a simple comparison between them and the kind of beach where some influence is seen by them grouped according to the type of beach.

Geometry of the Beach

In the latter group are the variables that depend on the geometry and geomorphology of the beach. This is the largest group because the same variable can be defined in different ways. The variables in this group included the following:

1. Length of the beach
2. Width of the beach
3. Slopes
   a. Swash slope, average profiles to a depth of 1–1.5 m;
   b. Slope to change of the sediment;
   c. Slope to the closure depth of the sediment;
   d. Slope to the closure depth as described by Hallermeier (1981);
   e. Slope to the closure depth as described by Birkemeier (1985).
4. Berm's characteristics
   a. Height
   b. Width
   c. Slope
5. Closure depth of the sediment.
6. Profile's length to the closure depth of the sediment.
7. Iribarren number (Iribarren Cavanilles and Nogales, 1949).
8. Surf Similarity Index (Battjes, 1974).

First, the length and width of beach were discarded because for the same type of beach, there are some very long ones with a length of more than 1 km and other very small beaches measuring only a few metres. The same goes for beach width. Regarding slopes, it could be observed visually that the slope to the closure depth of sediment and the swash slope were best at defining beach types. Regarding the berm, the slope was chosen by directly relating it to its height and width. Finally, the length of the profile to the closure depth of the sediment was also used when observing a certain relation to the type of beach.

Once compared two by two, the number of variables was reduced to 25, and then a discriminant method was used as a comparative and differentiating element between them.

Classification Model

Discriminant analysis has been used before to test a predictive analysis for the classification of sandy beaches (Wright, Short, and Green, 1985) and also for gravel beaches (Jennings and Shulmeister, 2002). The discriminant analysis defines a linear combination of the variables used to better differentiate the proposed groups, called *canonical functions*. The maximum number of linear canonical functions is equal to the number of groups minus 1, and they are independent of each other (Engelman, 1998). To perform this analysis, we used the SPSS program (version 20). The statistical significance of the discriminant analysis was tested using Wilks λ multivariate statistical analysis of variance (Engelman, 1998).

The 25 variables were used to carry out a discriminant function that classified the 34 beaches of the study according to their proposed types. However, the proposed objective was to obtain a discriminant function that provided us with the same classification but with fewer variables. For that, variables were eliminated one by one. and the functions were obtained to provide the same classification, so that number could be reduced to 14 variables associated with a discriminant function classified according to defined groups, with the final variables: modality, D_{50}, D_{10}, D_{90}, source, breaking wave height perpendicular to the beach (H_b), period (T_p), frequency, direction, profile type, profile's length to the closure depth of sediment, the berm's slope, the depth of the *Posidonia oceanica*, and the distance to the source.

Subsequently, the discriminant function was validated; it has been used for data collected in January, March, April, and May 2014 on five of the beaches that make up the 34 beaches studied, each of a different type. A campaign of sampling and transverse profiles was performed. The procedure was as follows: Three cross-sections at each beach, N, S, and central areas, always taking the profile from the same point, for this analysis, the bases, and the landmarks of each beach were located. Three samples on each of the profiles were also collected in the swash, in the middle and on the crest of the berm. The purpose of this gathering was to check whether there was a significant variation of these variables because they are quite sensitive to changes, and the intention was to see whether those changes influenced the classification made by the discriminant analysis.

RESULTS

Gravel beaches with different morphology were found all along the area of Alicante coastline studied, and five groups could be distinguished (Figure 5). These groups can be distinguished generally as mixed beaches (type 1 to type 4) and pure gravel beaches (type 5). The five groups are described below.

Type 1 Beaches: Sand and Gravel

Sand and gravel are mixed beaches, where the materials are mixed more or less along the entire beach, but where the proportion of sand is much greater than the proportion of gravel. They are usually unimodal beaches whose material comes from both rivers and ravines and has the following diameters: $D_{10} < 15$ mm, $D_{50} < 20$ mm, and D_{90} between 15 and 50 mm.

Type 2 Beaches: Sand and Gravel Separated

Sand and gravel separated are those in which a clear separation exists between the gravel area and the sand area, which lies in the swash zone, and the sand proportion is far greater than that the gravel proportion. These beaches are also usually unimodal; however, in this case, the material comes exclusively from rivers, and the sizes are $D_{10} < 5$ mm, $D_{50} <10$ mm, and $D_{90} < 40$ mm.

Type 3 Beaches: Gravel and Sand

Gravel and sand beaches are the opposite of type 1 beaches, although, in this case, the materials are also mixed at the beach, but the gravel ratio is much higher. These beaches are the only ones that are unimodal, and their materials come from ravines, with a D_{10} between 5 and 35 mm, a D_{50} between 20 and 35 mm, and D_{90} between 40 and 85 mm.

Type 4 Beaches: Gravel and Sand separated

Gravel and sand separated beaches are the last case in sand is found on the beach and is distinguished by a clear separation between the two materials, with the fraction of gravel being in the area of the seashore and the sand fraction in the interior region. These beaches are strongly bimodal with material from ravines. Its characteristic diameters are $D_{10} < 15$ mm, D_{50} between 5 and 25 mm, and D_{90} between 40 and 80 mm.

Type 5 Beaches: Pure Gravel

Finally, pure gravel beaches are, as the name suggests, only gravel, which is found along the entire beach. These beaches, like type 4 beaches, are generally bimodal, differentiating themselves by the absence of sand, leading to differences in the diameters of the sediment. As expected, diameters are larger than those of type 4 beaches, being $D_{10} < 25$ mm, $D_{50} < 70$ mm, and D_{90} between 10 and 90 mm.

From the discriminant analysis, we can see that the value of Wilks λ and χ^2 tests show that substantial differences can be observed among the groups. According to Noruešis (2011), Wilks λ values close to one indicate a strong resemblance among the groups, whereas values close to zero indicate a difference among them. Furthermore, the transformed value (χ^2 test) is associated, *e.g.*, for case 1, with 56 degrees of freedom, the critical level (Sig) is 0.001 (Table 1), so we reject the null hypothesis that the groups being compared have averages equal in the discriminant variables.

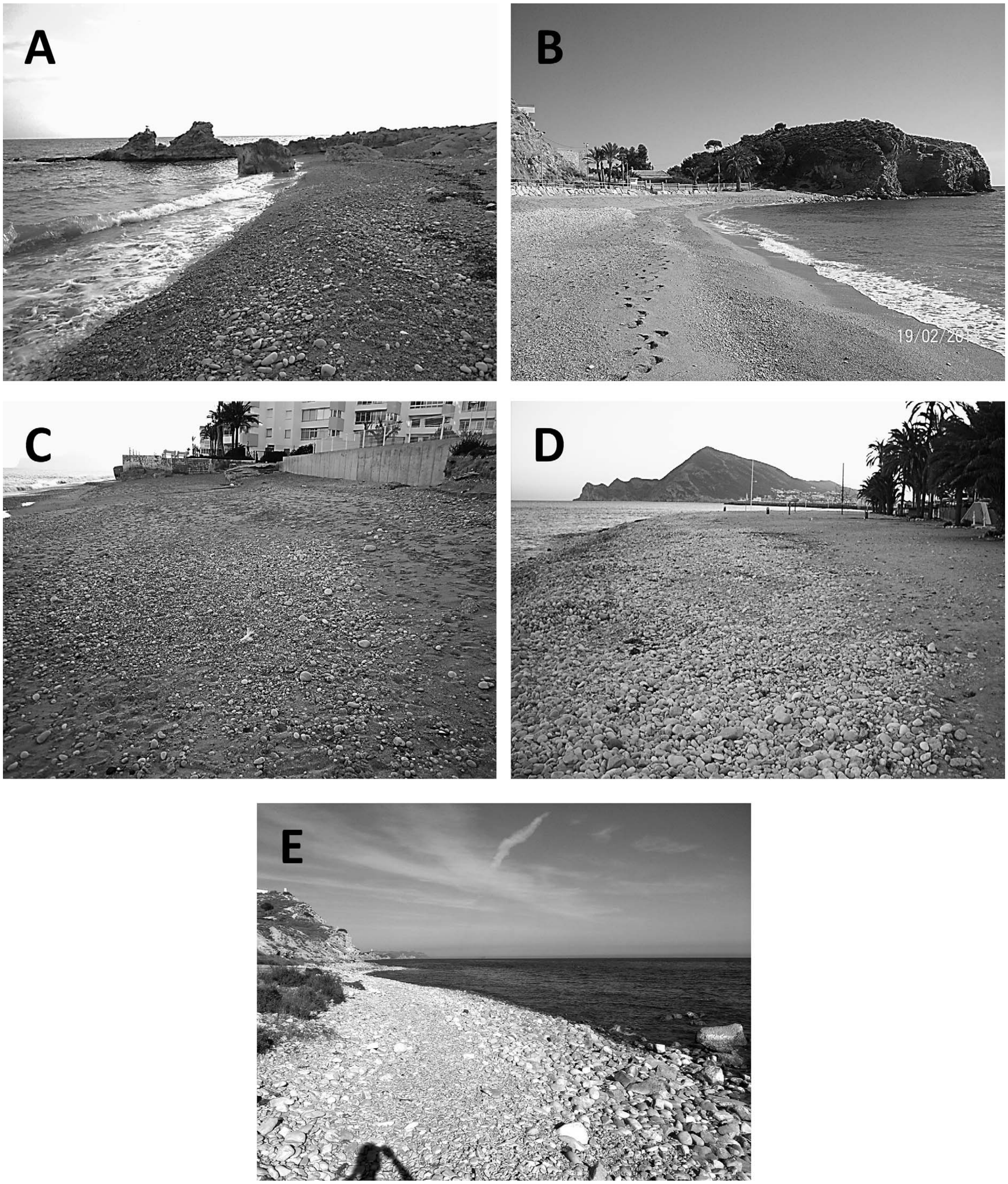

Figure 5. Types of classified beaches: (A) Tio Roig beach (type 1), (B) Bonnou beach (type 2), (C) Cap Negret beach (type 3), (D) Roda beach (type 4), and (E) Carritxal beach (type 5).

The discriminant functions show the contribution of each variable to the discrimination among each group. As shown in Table 2, wave frequency, the source, the slope of the berm, and modality are the most influential parameters in the classification. Finally, we can see how the discriminant analysis correctly classified 100% of the original cases (Table 3).

From the coefficients in Table 2, the discriminant function as a linear combination of the various variables is harvested, as follows:

Table 1. *Statistical data of the discriminant analysis.*

Contrast Functions	Wilks λ	χ^2 Test	Degrees of Freedom	Significance
1–4	0.018	94.25	56	0.001
2–4	0.108	52.40	39	0.074
3–4	0.344	25.09	24	0.401
4	0.661	9.73	11	0.555

$$-0.050 \times D_{50} - 0.737 \times M + 0.019 \times D_{90} + 0.021 \times D_{10} + 0.394 \times H_b + 0.152 \times T_p + 4.090 \times F + 0.466 \times D + 0.461 \times TPr + 2.7853 \times S + 0.001 \times DS + 0.003 \times PL + 1.244 \times BS + 0.005 \times P - 11.067 \quad (1)$$

where M is modality: (1) unimodal, and (2) bimodal; F is frequency; D is direction: (1) N, (2) NNE, (3) NE, (4) ENE, (5) E, (6) ESE, (7) SE, (8) SSE, (9) S, (10) SSW, (11) SW, and (12) WSW; TPr is type of profile: (1) gravel profile wall and diffraction–refraction, (2) gravel profile, (3) gravel and diffraction–refraction profile, (4) gravel and wall profile, (5) slab and diffraction–refraction profile; S is source: (1) ravine, and (2) river; DS is distance to the source; PL is profile length; BS is the berm slope; and P is the depth of *Posidonia oceanica*.

Figure 6 shows the values of the canonical functions for the first and the second functions, which represent 57.6% and 25.7% of the variance, respectively. Figure 6 shows there is good discrimination between the five groups of gravel beaches. In Figure 6, group 3 could be included in group 4; however, that is because only function 1 and function 2 are represented because of the difficulty of representing the four canonical functions in the same figure.

Furthermore, the results of the data collection from the five beaches that characterize the model during the months of January to May 2014 can be seen in Table 4. Significant changes in the parameters can be seen; in fact, if we classify the form of breaking through the Iribarren number, it shows how much it varies from one month to another. In addition, the average diameter changed from 7.87 mm in January to 0.849 mm in May, but reached 31.95 mm in March on the Torres beach (Table 5).

Table 2. *Coefficients of canonical discriminant functions (nonstandardized coefficients).*

	Function			
	1	2	3	4
D_{50} (mm)	−0.050	−0.098	−0.104	0.029
Modality (unimodal or bimodal)	−0.737	0.327	−1.218	−0.850
D_{90} (mm)	0.019	0.039	0.080	−0.034
D_{10} (mm)	0.021	0.116	0.130	0.049
H_b (m)	0.394	−0.605	0.414	0.314
T_p (s)	0.152	−0.058	−0.199	0.393
Frequency (°/1)	4.090	3.099	−1.777	0.152
Direction	0.466	−0.411	−0.350	0.440
Profile type	0.461	0.689	−0.986	−0.044
Source (river or ravine)	2.785	−0.218	1.187	−0.016
Distance to the source (m)	0.001	0.000	0.000	−0.001
Profile length (m)	0.003	0.009	0.003	−0.001
Berm slope	1.244	0.092	0.338	−6.155
Depth of *Posidonia oceanica* (m)	0.005	−0.001	0.003	−0.002
(Constant)	−11.067	0.720	2.453	−3.572

Table 3. *Classification results of the discriminant analysis.*

	Predicted Group Membership					
Classification	1	2	3	4	5	Total
Count						
1	8	0	0	0	0	8
2	0	6	0	0	0	6
3	0	0	5	0	0	5
4	0	0	0	5	0	5
5	0	0	0	0	10	10
%						
1	100.0	0.0	0.0	0.0	0.0	100.0
2	0.0	100.0	0.0	0.0	0.0	100.0
3	0.0	0.0	100.0	0.0	0.0	100.0
4	0.0	0.0	0.0	100.0	0.0	100.0
5	0.0	0.0	0.0	0.0	100.0	100.0

Thus, using the SPSS programme, ground truthing of the new variables was validated on the beaches (Figure 6), and all beaches coincided, except the Almadraba beach, which in any case was classified as type five, a pure gravel beach.

DISCUSSION

The result of the discriminant analysis confirmed the assumption made that there are five types of gravel beaches, and also indicated that they were statistically different, given that these five types of beaches show considerable morphological difference; depending on the frequency of the waves; the main supply source (river or ravine), the berm slope; the modality of the samples; the wave direction; the type profile; the normal break wave height to the beach and its corresponding period; the diameters D_{50}, D_{90}, and D_{10}; the depth of *Posidonia oceanica*; the profile length to the closure depth of sediment; as well as the distance to the source. Because these beaches are morphologically distinct, presumably the processes that occur in them are also different (Wright *et al.*, 1984).

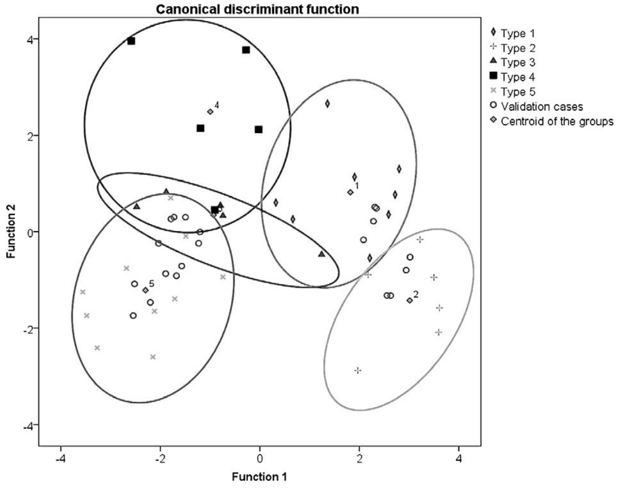

Figure 6. Representation of the first two canonical functions, which explain 57.6% and 25.7% of the variance. Ellipses delimit the approximate correspondence group, acquiring a good discriminant function. The validation cases are shown as open circles.

Table 4. *Iribarren number for months.*

Beach	January		March		April		May	
El Torres	2.16	Plunging	1.74	Plunging	3.09	Collapsing	3.09	Collapsing
Paraís	1.14	Plunging	1.21	Plunging	1.55	Plunging	1.55	Plunging
Barranc d'Aigües	3.46	Surging	4.69	Surging	6.23	Surging	6.23	Surging
Amerador	3.61	Surging	3.04	Collapsing	1.97	Plunging	1.97	Plunging
Almadraba	0.85	Plunging	1.11	Plunging	2.10	Plunging	2.10	Plunging

Based on these results, a model that differentiates between different types of gravel beaches has been developed and presented using the 14 variables listed above, which mainly depend on the morphology, particle size, and dynamics of the beach. The five proposed types of beaches are (1) sand and gravel, (2) sand and gravel separated, (3) gravel and sand, (4) gravel and sand separated, and (5) pure gravel beaches.

The advantage of this classification with respect to other classifications found in the literature is mainly due to the ease of obtaining the various variables. When using the other classifications, doubts can arise about how to determine some of the variables, *e.g.*, between which points the slope of the beach can be determined or how and where to obtain the wave height at breaking. Moreover, most of the beaches in the other classifications were very wide and long (Jennings and Shulmeister, 2002; Pye, 2001; Scott, Masselink, and Russell, 2011), and therefore, do not account for, or are not affected by, reflection or by diffraction, which occur when beaches are well protected.

It has often been assumed that gravel beaches have a high permeability (Bluck, 1967). This assumption implies that the levels of infiltration into gravel beaches is enough to cause the transport of sediments to the predominant land mass; however, the study by Mason *et al.* (1997) showed that in mixed beaches, despite the open structure of the gravel surface, the behaviour of the water was controlled by the sand layer. Moreover, the sand content significantly changes the slope of the beach and, therefore, the reflective nature of it (Sherman, Orford, and Carter, 1993). Hence, the importance of dividing the mixed beaches into four different groups, depending on the composition of the beach in the surf zone is necessary because the behaviour of each type of beach will be different during storms (Masselink *et al.*, 2010; Masselink and Turner, 2012) and will be different in its type of wave breaking. For example, a type 2 beach will behave more like a sandy beach because the surf zone consists mainly of sand; however, type 4 beaches will behave like pure gravel beaches. As for types 1 and 3, because their surf zones consist of mixed sand and gravel, their behaviour will be different from beaches of types 2, 4, and 5 and will depend on the amount of sand the beach contains. That is why it was decided to classify beaches into five groups, instead of three (*e.g.*, Jennings and Shulmeister, 2002). As mentioned, the importance of separating the beaches into these types is due to the different behaviour they present against storms, because, as many authors suggest (Bakhtyar *et al.*, 2009; Horn, 2002; Masselink and Turner, 2012), the higher the gravel content, the better is the behaviour against erosion because wave reflection occurs and the infiltration reduces the erosion of the beach; so, we believe it is important to classify the beaches in these five groups.

On the other hand, as is known, the characteristics of the beaches vary throughout the year, mainly a change in slope and grain size, which can cause their permeability and hence their hydrodynamic behaviour to change at any given time, which begs the question, is it correct to classify beaches in response to variables, such as grain size or slope?

The answer to that question is partially answered with the results from our discriminant validation because, as shown, modifying the corresponding variables from one month to another did not change the classification, except for the Almadraba beach.

The failure in the classification of Almadraba is due to its special characteristics, and if the beach is studied in more detail, by looking, *e.g.*, at its location and distribution of material along the beach, the beach has two very different orientations, which makes the distribution of material throughout its length very different, finding very thick materials (boulders) in the south and sands in the north (Figure 7). Almadraba is also a beach that accumulates a lot of *Posidonia oceanica*, which makes it difficult to obtain slope data during the months of January, April, and May, to the point of not being able to obtain samples of material for sieve tests in April.

Table 5. *Parameters of the beaches studied variables for discriminant validation.*

Beach	El Torres	Paraís	Barranc d'Aigües	Amerador	Almadraba
2006					
D_{50} (mm)	9.305	1.725	26.910	31.940	14.450
D_{90} (mm)	39.595	12.498	52.886	83.353	44.196
D_{10} (mm)	2.222	0.596	3.849	11.580	0.152
Slope	0.260	0.220	0.160	0.230	0.460
January					
D_{50} (mm)	16.269	21.286	38.365	23.152	24.329
D_{90} (mm)	51.403	78.643	58.082	59.960	50.960
D_{10} (mm)	1.448	0.580	12.214	2.308	0.219
Slope	0.125	0.110	0.305	0.317	0.156
March					
D_{50} (mm)	18.627	8.052	21.586	32.614	28.446
D_{90} (mm)	51.706	39.111	39.191	68.264	56.170
D_{10} (mm)	0.734	0.424	1.113	2.955	0.199
Slope	0.205	0.138	0.374	0.121	0.154
April					
D_{50} (mm)	13.559	20.571	26.091	15.428	0.251
D_{90} (mm)	26.442	51.523	43.765	41.571	3.170
D_{10} (mm)	1.655	2.279	8.322	1.884	0.138
Slope	0.220	0.105	0.606	0.068	0.212
May					
D_{50} (mm)	12.733	18.761	25.893	20.500	0.374
D_{90} (mm)	44.648	49.989	43.952	55.344	9.528
D_{10} (mm)	0.514	1.242	0.895	1.816	0.150
Slope	0.130	0.134	0.199	0.105	0.139

Figure 7. Almadraba Beach: (A) north, where sand predominates, and (B) south, where boulders predominate.

Because the classification of the beaches studied in the validation was not compromised by the variation of D_{50}, D_{90}, D_{10}, and the slope of the berm, which, as mentioned are very sensitive to changes in the beach, the classification is mainly due to the weight of those variables within the canonical discriminant function. As shown in Table 2, the values assigned to those variables are –0.05, 0.019, 0.021, and 1.244, respectively. The values are quite low compared with the 4.090 of the wave frequency or 2.785 of the source. Furthermore, because the classification of the beaches validated did not change during the winter months, when wave heights are higher from storms, the classification can be maintained throughout the year.

Finally, using the depth of *Posidonia oceanica* has not, to our knowledge, been used in any other classifications; however, it is an important data input, especially along the Mediterranean coast, where its presence is especially important. The use of this variable is shown when performing the discriminant analysis because it supposes that all beaches were correctly classified visually or, on the contrary, that six of the beaches were incorrectly classified, leading to a margin of error of 17.6%. This shows that the presence of *Posidonia oceanica* is important during the classification of beaches because its presence changes the energy of the incident wave and, therefore, the characteristics of the beach are influenced by it.

The methodology proposed in this article should be valid for any point worldwide. However, the variables in the corresponding area would need to be studied to determine whether the coefficients of the canonical functions obtained here were still valid or whether new ones would be needed, following the methodology proposed here.

CONCLUSIONS

The model presented in this article allows the classification of gravel beaches in Alicante, Spain, into five different types, namely: type 1: sand and gravel beaches, type 2: sand and gravel separated beaches; type 3: gravel and sand beaches; type 4: gravel and sand separated beaches; and type 5: pure gravel beaches. Forty-five variables involved in the formation of these types of beaches were used. Subsequently, the number of variables was reduced using two methods; in the first, comparisons were made two by two between the classification and the variable, and in the other, a discriminant function was used that classified the beaches under the proposed model. This has reduced the variables that describe the characteristics of these beaches to 14.

To these 14 variables, the depth of the *Posidonia oceanica* was added, previously unused in the classification of beaches. This variable has been proved important with an error of 17.6% in classification being observed in its absence.

A validation of the discriminant function has also been performed using data from five beaches obtained between the months of January and May 2014. That validation used very different values for sediment size and berm slope and still provided correct classifications, which indicate that, although these variables are dependent on the time when the data are determined, their influence within the discriminant function is not large enough to change the classification, which remains the same throughout the year.

Therefore, the method described here can be used to classify gravel beaches anywhere in the world, simply, using variables requiring basic measurements and verifying the validity of the coefficients of the canonical function that beach behaviour and its ability to absorb the energy of waves depends largely on the fraction of sand within its composition, so that the beach management of maintenance and protection are different from one type of beach to another.

Because of the complexity of these types of beaches, the number of variables used to describe them should be such that small changes do not change the model or type of beach studied, which is why the study of the number and types of variables used and their validation is important.

ACKNOWLEDGMENTS

We would like to thank the Directorate General of Coasts and, more specifically, the Provincial Services of Coasts from Alicante, as well as the University of Alicante and the Polytechnic University of Valencia for the information provided.

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