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OSTENDE AND ARRIGUNAGA BEACHES, TWO DIFFERENT INTERVENTIONS AND SUBSEQUENT GEOMORPHOLOGICAL CHANGES IN NORTHERN SPAIN: AN APPROPRIATE POLICY TO FOLLOW?

Las playas de Ostende y Arrigunaga, dos intervenciones diferentes y cambios geomorfológicos sufridos en el norte de España:¿una apropiada política a seguir?

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Abstract: *The small towns of the Basque-Cantabrian coast (Spain) suffer from strong demographic pressure in summer time that has made it necessary to develop new beach areas suitable for bathing. In 1991 in Castro Urdiales (Cantabria), gravel was dumped in Urdiales cove (350,000 m^3) to create the Ostende artificial beach. In Getxo (Bizkaia), the regeneration of Arrigunaga urban beach involved a complex intervention between 1995 and 1999, with the construction of groynes, the removal of sands and conglomerates of cemented cast iron slag (beachrock), the subsequent deposition of natural bioclastic sand (213,000 m^3) and the complete urbanization of the beach. Several decades having now elapsed, the present work analyses how the two interventions have evolved, whether the migration of sand-gravel, with losses and accumulations in different areas, poses a risk for the proper use of the beaches, and whether the groynes meet their original objectives and maintain themselves despite the numerous sea storms to which they are subject. As a new feature, the rapid formation of new geomorphological aquafact structures on the rocky protrusions generated by the mechanical abrasion of water/sand-gravel. Finally, the question is raised whether this type of intervention is appropriate in the current context of environmental conservation.*

Keywords: *coastal dynamics, beach regeneration, blast furnace slag, beachrock, aquafacts, Basque-Cantabrian coast.*

Resumen: *El bienestar económico producido en el último tercio del siglo XX lleva consigo el disfrute, en la época estival, de una segunda vivienda situada en la costa. Las pequeñas localidades costeras sufren una fuerte presión demográfica que obliga a acondicionar nuevos espacios de esparcimiento playeros. En Castro Urdiales (Cantabria) en 1991 se realizó un vertido de gravilla (350.000 m^3) en la Ensenada de Urdiales, para pasar a convertirse en la playa artificial de Ostende. En Getxo (Bizkaia), la regeneración de la playa urbana de Arrigunaga conllevó una intervención compleja entre los años 1995 y 1999, con la construcción de espigones, retirada de arenas y conglomerados de escorias de fundición cementados (beachrock), el vertido de arena bioclástica natural (213.000 m^3) y la completa urbanización de la playa. Una vez que han pasado varias décadas, en este trabajo se analiza cómo han evolucionado ambas intervenciones, si la migración de la arena-gravilla, con pérdidas y acumulaciones en diferentes zonas, supone un riesgo para el pleno uso de las playas, y si los espigones cumplen los objetivos iniciales y se mantienen a pesar* *de los numerosos temporales marítimos sufridos. Como novedad, se constata la rápida formación de acuafactos como nuevas estructuras geomorfológicas sobre las protusiones rocosas por la abrasión mecánica de agua/arena-gravilla. Por último, surge la pregunta sobre si este tipo de intervención resulta adecuado en el actual contexto de conservación ambiental.*

Palabras clave: *dinámica costera, regeneración de playas, escorias alto horno, beachrock, acuafactos, costa Vasco-Cantábrica.*

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Introduction

The last third of the 20th century saw a certain economic boom in Basque society, which allowed the most fortunate to acquire a second residence in small coastal towns along the Basque-Cantabrian coast (Bizkaia, Cantabria) (Fig. 1A). This led to a major increase in population in these small towns during the summer period, with the consequent demand for public assistance services and recreational spaces. In this sense, according to 2019 data, the municipality of Castro Urdiales (Cantabria) went from a stable census population of 32,069 inhabitants to more than 70,000 inhabitants during the summer season, whereas in the municipality of Getxo (Bizkaia) the population surveyed in 2019 reached 79,946 inhabitants.

One of the most frequently requested services during the summer season was for new beaches to be developed as recreation areas, forcing the responsible administrations (municipal, provincial, and the Coastal Demarcation Office) to coordinate and undertake specific projects to satisfy the growing demand. In 1991, the municipality of Castro Urdiales undertake a work on the Urdiales cove, initially without sand and with a small marsh area, that was to become the so-called artificial beach of Ostende (around 750 m in length, Fig. 1B). In the municipality of Getxo, by contrast, the work was undertaken on the Arrigunaga urban beach (around 630 m in length, Fig. 1C) that due to its deep anthropic footprint was practically in disuse and was not recommended for bathing. This situation was mended by a complex intervention in the area, with the construction of three groynes and a large breakwater (associated with Punta San Ignacio). It was completed in 1999 with the addition of bioclastic natural sand to the beach.

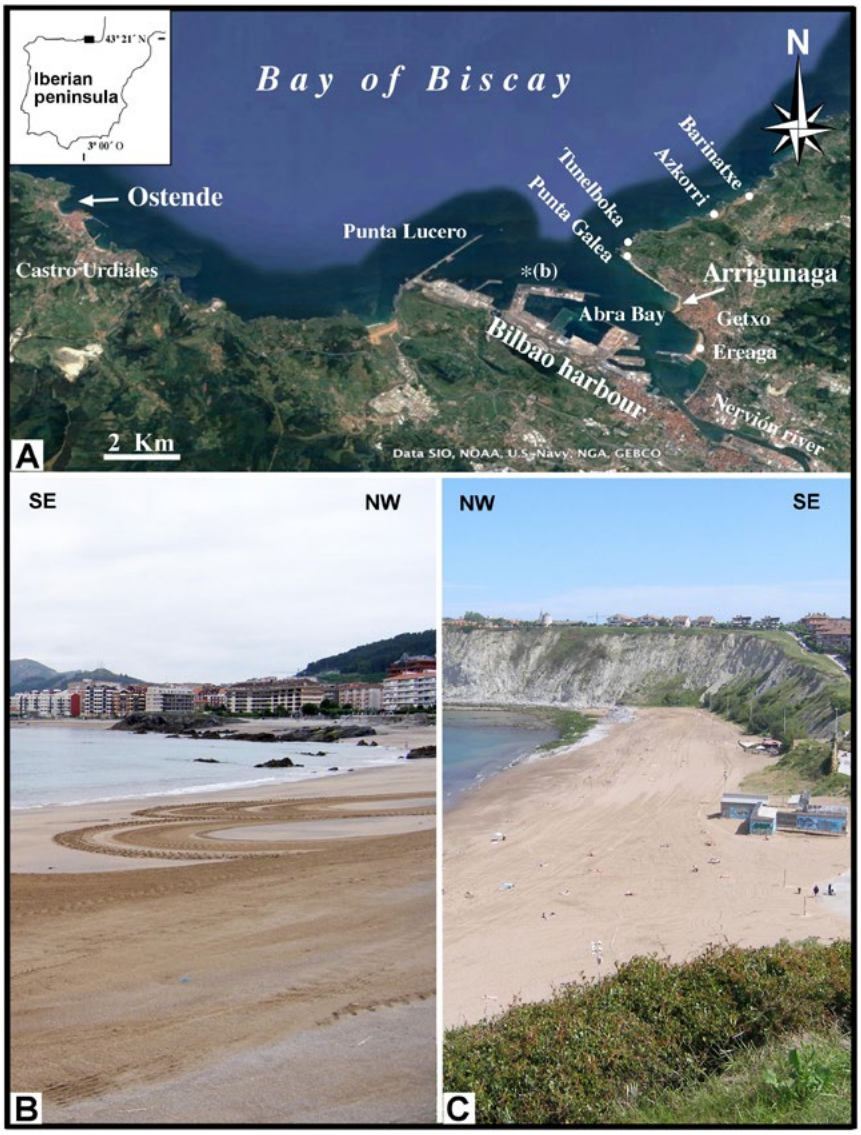

Fig. 1.- A: Geographical location of the Ostende artificial beach (Castro Urdiales, Cantabria) and the Arrigunaga beach (Getxo, Bizkaia) along the Basque-Cantabrian coast. *(b) Location of the Abra-Ciervana buoy. B: View from the northern part of the current Ostende artificial beach (750 m in length), showing the tracks from the mechanical levelling that is carried out daily. C: General view of the current Arrigunaga beach from its western part (630 m in length).

More than two decades after these interventions (30 and 21 years, respectively), it seems appropriate to review how the processes of coastal dynamics have acted upon them. In this sense, this study aims to inquire whether the behaviour has been as theoretically predicted or whether there have been substantial changes in the profiles of each beach. The loss and/or migration of the sands concentrated in certain areas may have modified the expected beach half-life. As regards the groynes and the breakwater built on Arrigunaga beach, the question is whether they have been effective or been overcome by the coastal dynamics. Additionally, this study also deals with how the interaction of tides and sediments has promoted an abrasive process producing new geomorphological structures in the natural rocky protrusions and in the breakwater blocks that stand out in the foreshore.

Geological context and characteristics of the interventions

Ostende beach (Urdiales Cove)

The Ostende artificial beach (43º 23' 21" N and 3º 13' 33" W, Fig. 1A) belongs to the municipality of Castro Urdiales (Cantabria). From a geological point of view, the beach substrate is composed of limestones from the so-called "Planar-parallel limestone of the Urdiales Cove Formation" (Rosales, 1995, 1999). Dated to the lower Albian, it is composed of 200 m-thick rhythmic alternations of marls, marly limestones and limestones in decimetre-thick beds. Rosales (1995) suggested that this formation belongs to a hemipelagic platform related to the distal part of a carbonate ramp-type shelf. Westwards the unit grades laterally to shallow shelf limestones (Oriñon Limestone Formation).

Refurbishment works were carried out in a short period of time (from 29/12/1988 to 02/01/1991) and consisted of the modification of Urdiales cove by the deposition and levelling of crushed gravel (6-8 mm in diameter) along a coastal strip around 750 m in length, using a total volume of 330,580 m^3 to this end (data provided by the Cantabrian Coastal Demarcation Office) (Figs. 1B, 2A-C). Currently, the sediments found on the artificial beach correspond to two types: a) a minor part of fine-medium bioclastic natural sands (0.2-0.3 mm) typical of the beaches of the Cantabrian coast; and b) a majority of limestone gravels (6-8 mm) that corresponds to the artificial crushed deposit, extracted from the Santullán quarry, currently showing a clear increase in the roundness index (Figs. 2D-F).

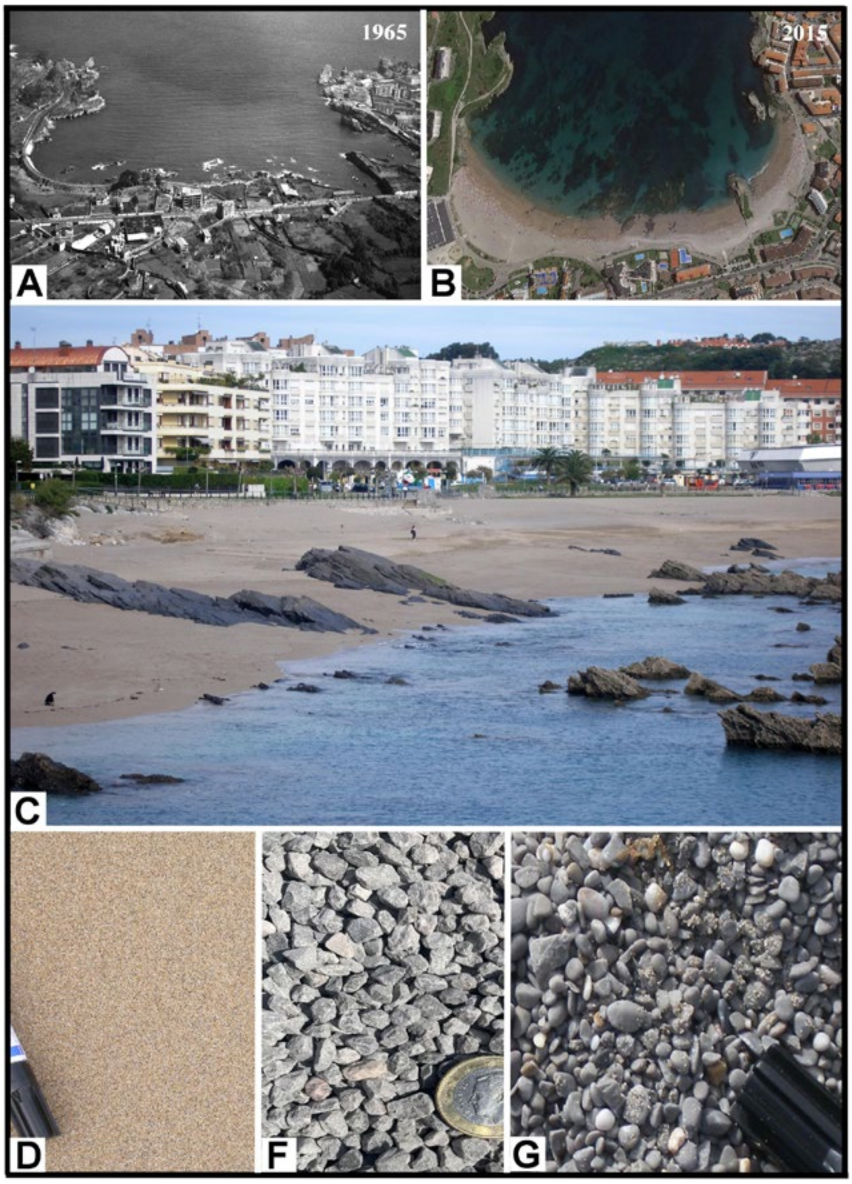

Fig. 2.- Ostende beach, Castro Urdiales. A: Aerial view of Urdiales cove, dating from 1965. B: Aerial image similar to the previous one, taken in 2015, with evidence of the sand-gravel spill creating the recreation area (750 m in length). C: Current picture of the artificial beach from the southeast, where the protrusions of Urgonian limestone can be observed. D: Detail of the fine bioclastic sands that make up a small part of the sandbank. E-F: Appearance of the artificial angular gravels (E), now notably rounded (F) by the abrasive effect exerted over three decades. Marker and coin are 2 cm and 2.2 cm in diameter, respectively.

Arrigunaga beach

Three sectors bounded by faults can be distinguished in the cliffs bordering the Arrigunaga beach (43º 21' 22.0" N and 3º 01' 10.00" W, Fig. 1A), Getxo (Bizkaia) (Rodríguez-Lázaro *et al.*, 1989). The northeastern sector comprises turbidite sediments that belong to the middle Eocene and consist of an alternation of calcarenites and coarse calcisiltites with marls. The central sector, in mechanical contact (thrust sheet) with the former sediments of lower-middle Maastrichtian age crop out, being predominantly composed of marls and marly limestones without calcarenitic beds. The macro-palaeontological content includes ichnofossils, internal moulds of inoceramids and ammonoid impressions. These materials form a small synclinal structure in mechanical contact to the west with sediments from the middle Eocene to the lower Eocene. The outcrops at the centre of the cliff are mostly marls, except at some points where turbidite beds with nummulitid fossils occur. Further west, the Algorta-Azkorri sandstones crop out significantly; these rocks are quartz-feldspathic turbidites (Payros *et al.*, 2006, 2009). Ostracod associations indicating increasingly deep marine depositional environments from the Maastrichtian to the middle Eocene (Rodríguez-Lázaro *et al.*, 1989).

The Arrigunaga beach can be classified morphodynamically as reflective to intermediate depending on the season of the year, as well as corresponding to the approximately marginal beach type (Gutiérrez Elorza, 2008), within the Abra Bay (Fig. 1A). This beach has gone through different phases of use throughout the 20th century. As a place name in Basque, "Arrigunaga" denotes a place of stones ("arrigun-aga") (Goikoetxea Araluce, 1984), as it is graphically reflected in a nautical chart entitled "Plano de la Barra de Bilbao (1806)" (Martin-Merás and Rivera, 1990), which reveals that the present-day Arrigunaga beach consisted of cobbles-boulders. This situation changed when a major accumulation of coarse sand, granules, pebbles and cobbles (1 mm-120 mm in diameter) was deposited on the beach. These new sediments, which were poorly sorted, came from industrial waste (mainly slag from an iron blast furnace) and were discharged onto the coastal platform by the blast furnace company "Altos Hornos de Vizcaya" between 1902 and 1966, with a calculated volume of about 25 million tons (Aizpiri, 1983; Astibia, 2012; Pujalte *et al.*, 2015).

In a first phase, between the years 1940-1960, Arrigunaga was a family beach with limited use, little recommended for bathing owing to the polluted waters from its confluence with the still untreated freshwaters of the Nervión River (Figs. 1A, 3A). Notably, most of the industries located on the estuary dumped their waste into this river without prior treatment. Coastal drift, wave currents and storm waves led to the accumulation of part of this industrial discharge in the eastern area of the Nervión river mouth, specifically on Arrigunaga, Azkorri and Barinatxe beaches, in addition to

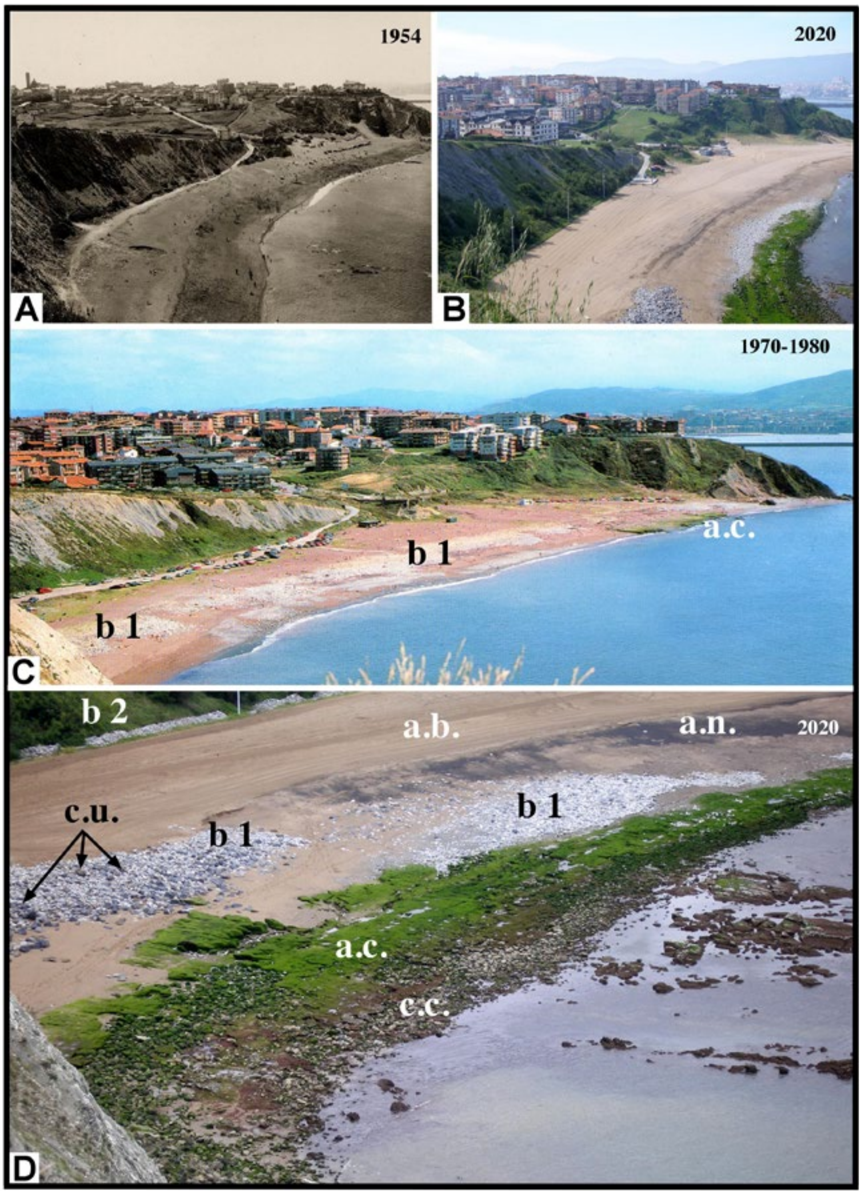

Fig. 3.- Arrigunaga beach, Getxo. A: General view of the beach from around 1954. B: Current picture with an orientation similar to the previous one (630 m in length). C: Image from about 1970-1980, where turbidite blocks (b1) and cemented sands (a.c.) are present as a beachrock. Note the general reddish colour of the sands. D: Detail of the current beach where boulders (c.c.) and cemented sands (a.c.) from the discharge of slag into the sea by the iron blast furnace (Altos Hornos de Vizcaya) can be seen at low tide. The bioclastic sands (a.b.) collected by dredging are mixed with a fine metallic mineral component detached from the blast furnace slag, producing the blackened appearance of the sands (a.n.). The natural accumulation of turbidite blocks (b1) is evident; these come from the cliff along with other blocks of Urgonian limestone (c.u.) eroded from the groynes. Recently, some of these boulders (b2) have been mechanically transported and accumulated at the contact between the high backshore and the cliff.

other cliff areas such as Tunelboka (Fig. 1A). Its rapid, *in situ*, cementation caused the formation of large, sub-horizontal sediment beds that reached variable thicknesses of 3-9 m with parallel and cross stratifications with a slight inclination towards the sea (García-Garmilla, 1990). Aerial photos from 1956-57 (http://centrodedescargas.cnig.es/CentroDescargas/index.jsp#) show the presence of these cemented beds at their maximum development. They are regarded as a beachrock formed on temperate shorelines, where the basal part is mostly conglomeratic, meanwhile very coarse sandstones dominate the upper part. Their detrital components of anthropogenic origin are considered as human ichnofossils of the so called Anthropocene time period (Astibia, 2012). Subsequent works have analysed their benthic foraminiferal associations (Martínez García *et al.*, 2013), their geomorphological evolution (Pujalte *et al.*, 2015) and their geochemical composition (Arrieta *et al.*, 2011; Iturregui *et al.*, 2014; Arrieta *et al.*, 2017).

A second phase began between the years 1972-75 with the construction of the Punta Lucero dyke-dock (2,750 m long) and the unfinished Punta Galea dyke (projected length of 3,400 m; 250 m completed), which modified the usual coastal current regime and led to an intense erosive activity that dismantled the beachrock in the most heavily eroded areas. This erosive activity, together with the cessation of industrial discharges in 1966, is confirmed by aerial orthophotos dating from 1983 onwards. Nevertheless, the Arrigunaga beach continued to deteriorate, and was not recommended for swimming and/or sunbathing (Fig. 3C).

The third phase corresponds to its regeneration. This phase began in 1995, when an attempt to control the landslides off the Punta Galea cliff was made by building a barrier of three groynes to prevent the migration of blocks and gravel towards the beach (Losada and Medina, 1993). These groynes were built with large limestone blocks (Urgonian facies, Aptian-Albian), being the closest to the beach the longest one (80 m long), followed 200 m away by another groyne (60 m long), and finishing 190 m away with the shortest one (50 m long). Due to their location, these groynes are faced to the usual northwesterly storms from the sea that directly impacting on them. The data collected by the Abra-Ciervana buoy installed very close to the cliff (Fig. 1A) provide the average values of maximum wave height, significant wave height, peak period and average peak direction on a monthly basis during the time series from 2001 to 2020 (Table 1; data obtained at Puertos del Estado; www.puertos.es/en-us/oceanografia/Pages/portus.aspx).

It was from 1998 that the recovery project of the beach itself was undertaken, with the removal of the cemented cast slag blocks (16,000 m^3) and their replacement by bioclastic sands (213,000 m^3) composed of bivalve remains, echinoderms, calcareous algae, and fragments of quartz and feldspars, from a sandbar near the small town of Bakio (43º 26' 40.18" N; 2º 48' 37" W). These sands were extracted at a depth of more than 20 m by means of several suction dredgers (Iria Flavia and Atlántida Primera dredgers). The intervention was completed with the urbanization of the beach and the creation of the corresponding accesses, now providing a 630 m-long beach suitable for swimming, with a surface area greater than 51,000 m^2 at low tide and 35,000 m^2 at high tide (data obtained from Bizkaia Provincial Council). Arrigunaga beach has been frequently used since its establishment until the present day, although it has undergone modifications that will be further commented below (Figs. 3B, D).

Effects of the deposits and new geoforms

Ostende artificial beach, 30 years later

The most notable geomorphological changes that can be observed in the Ostende beach are the following.

(a) It can be currently considered as a pocket beach (Davies, 1980) limited by headlands of compact Urgonian limestones, where theoretically the volume of sediment remains constant. The beach has maintained itself, despite not receiving new contributions of natural, bioclastic or river sands from longshore drift currents. However, the action of the tides (mesotidal, i.e., 2-5 m) and storm wa-

Abra-Ciervana buoy (2001-2020)

Months	Hmax.	Tp.	Dir.	Year	Day	Hour
January	11.9	9.1	346	2003	31	6
February	9.5	10.0	340	2005	14	0
March	9.3	16.6	333	2008	11	2
April	7.1	14.3	334	2012	18	18
May	6.7	13.3	336	2004	5	11
June	4.9	8.00	348	2010	16	15
July	5.0	10.1	334	2001	18	19
August	5.0	10.0	338	2007	21	6
September	6.1	13.4	330	2017	12	0
October	6.3	8.7	356	2012	27	20
November	8.4	11.1	333	2009	8	11
December	8.8	14.3	334	2007	10	2

Hmax: Maximum Wave Height (meters)
Tp: Peak Period (seconds)
Dir: Peak Direction, "coming from"(degrees)

Abra-Ciervana buoy (2001-2020)

Months	Hs Max.	Tp.	Dir.	Year	Day	Hour
January	5.5	12.5	333	2005	18	21
February	5.4	14.3	336	2013	6	21
March	6.7	16.6	333	2008	11	2
April	4.8	14.3	334	2012	18	18
May	4.7	12.5	333	2004	5	10
June	2.7	8.00	346	2010	16	18
July	3.0	11.1	331	2001	18	17
August	3.1	9.1	342	2007	21	7
September	3.5	11.7	333	2017	11	22
October	3.5	9.5	335	2003	23	15
November	5.1	14.3	331	2010	9	9
December	6.0	16.6	342	2007	10	1

Hs: Significant Wave Height (meters)
Tp: Peak Period (seconds)
Dir: Peak Direction, "coming from" (degrees)

Table 1.- Monthly mean values of maximum wave height, significant wave height, peak period, and average peak direction during the period 2001-2020, at the Abra-Ciervena buoy (Puertos del Estado).

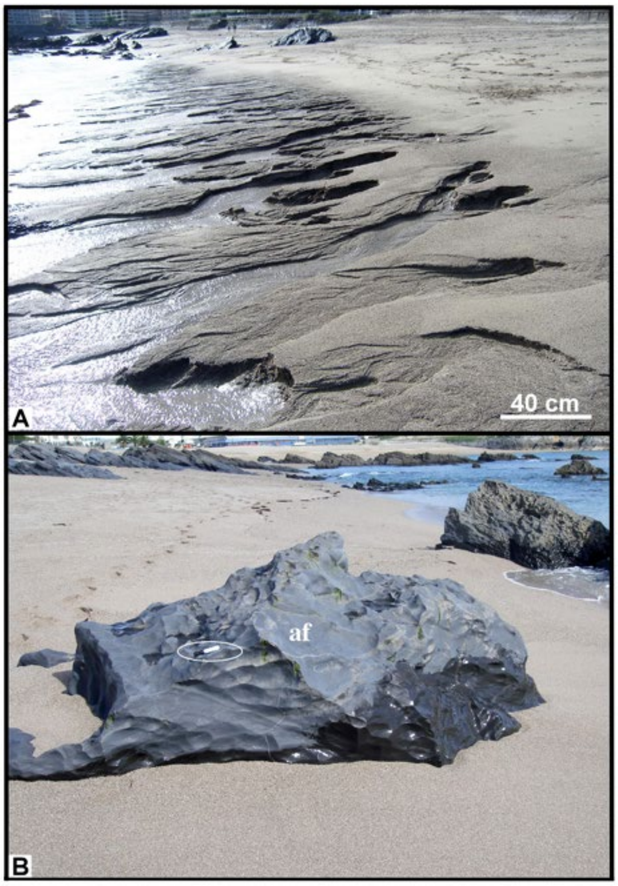

Fig. 4.- Ostende beach, Castro Urdiales. A: Low tide view, with the formation of return channels or rill marks. B: Outcrop belonging to the “Planar-parallel limestone of the Urdiales Cove Formation” (lower Albian), affected by water/sand-gravel abrasion, which originates marine aquafacts (af). The marker is 13 cm in length.

ves causes a significant accumulation of gravel-sand in the high backshore, with a variable steep slope depending on the area (> 10º) as far as the foreshore. Thus, it can be considered as a reflective-type beach, although it may become intermediate-type at quiet times, depending on the season (Figs. 2B-C). Continuous levelling out with machinery makes the slope reduced, and small return channels or rill marks start to develop when water pouring from the water table at low tide conditions (Fig. 4A).

(b) By contrast with the much finer bioclastic sands (Fig. 2D), the higher index of roundness (rounded/well-rounded) and low sphericity of the angular gravels, artificially dumped on the cove, compared to the original deposits are particularly noteworthy (Figs. 2E-F).

(c) After 30 years, the permanence of the beach is ensured, if considering that the average life of a regenerated beach is measured by the time that elapses from the intervention to the loss of at least 50% of the volume of the beach (Leonard *et al.*, 1990).

(d) The current morphology of the beach preserves a significant number of limestone (Urgonian facies) protrusions in the foreshore zone, which favours the generation of new geoforms considered marine aquafacts (af), already mentioned by Elorza and Higuera-Ruiz (2016). Strongly polished surfaces with vertical zoning and fine keel morphologies and wide grooves are characteristic, as well as bows perpendicular to the direction of the waves (Figs. 4B, 5A-B).

(e) Taken into account the time elapsed, analysis of these geoforms makes it possible to establish the approximate speed of reduction undergone by the protrusions due to mechanical abrasion. Our estimation was that the alveoli initially formed by echinoderms, calcareous algae activity (Fig. 5A) have been lowered by 1-2 cm, so the abrasion rate may be between 0.3-0.6 mm/year (Elorza and Higuera-Ruiz, 2016).

Regenerated Arrigunaga beach, 20 years later

The most relevant geomorphological modifications at the Arrigunaga beach are as follows.

(a) In the eastern part of the beach, a marked loss of the bioclastic sand provided during the intervention carried out in 1999 and an accumulation of boulder blocks (0.5-1 m^3) from different sources occurred. The turbidite blocks (b1) of light grey tones coming from the cliff are associated with the notable presence of blocks of darker tones of Urgonian limestone (c.u.), originally from the partially dismantled groynes (Figs. 3 B-D).

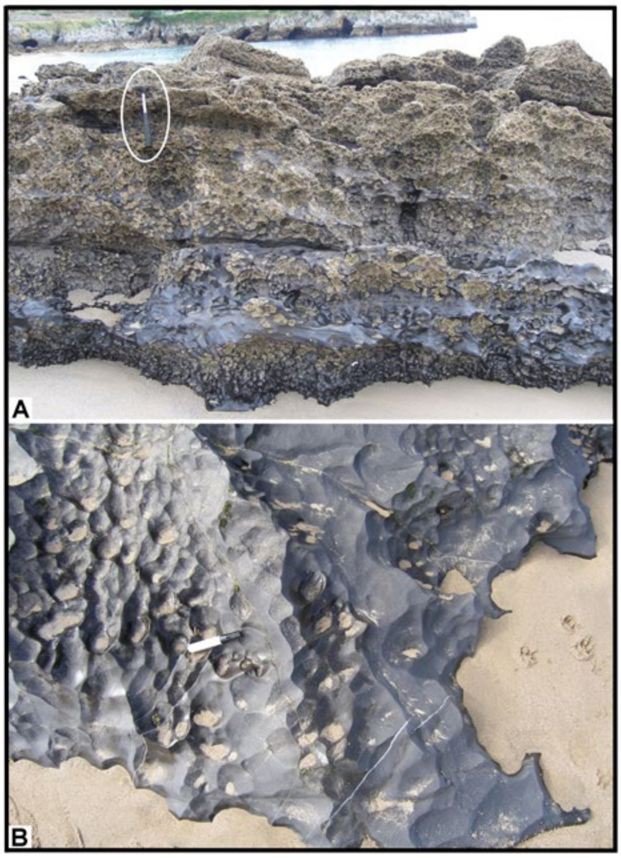

Fig. 5.- Ostende beach, Castro Urdiales. A: View of a black limestone protrusion intensely affected by basal abrasion, showing a strong polish and wet luster, already above small alveoli formed by bioerosion (echinoderms, calcareous algae, limpets, sea acorns). B: Detail of wide grooves and fine keels morphologies characteristic of aquafacts. Hammer and marker are 28 cm and 13 cm in length, respectively.

(b) The three groynes (1, 2 and 3) built in the eastern zone in 1995 were affected by waves impact in a few years (Fig. 6A), and since 2018 the aerial photographic evidence of their destruction is conclusive. Furthermore, in the distal groyne 1 an erosive action (flanking effect) in the leeward area is a recognizable case of "terminal groyne syndrome" (Valsamidis and Reeve, 2020), which reaches the beach itself (Figs. 6B, D). Currently, the presence of large immobile turbidite blocks (b), is noticeable over the abrasion platform (Fig. 6C). The longest, terminal groyne of 80 metres (groyne 3) has kept in good condition, whereas the smallest (groyne 1) of 50 m is practically dismantled. The intermediate groyne (groyne 2) is being overcome in the windward zone by an accumulation of boulder blocks (b1) from the nearby cliff (Figs. 6B, D-F, 7A-B). The accumulation of turbidite blocks (b1) of considerable sizes (50-100 cm by 20-40 cm) is notable in groynes 2 and 3; these were colonized long time ago by lithophagous bivalves, mainly *Lithophaga lithophaga* (Fig. 6F). Lithophagous bivalves are long-lived and can reach ages of up to 50 years (Peharda *et al.*, 2015), so continued stability is required in the shoreface. This suggests that there has been a reactivation of the nearshore currents energy since 1975, favoured by the storms that moved these blocks from the quiet shoreface zone, fostering the colonization and development of the bivalves, towards the foreshore and backshore zones. Finally, just in this final area of the cliff-beach, in relation with a regional major fault (Rodríguez-Lázaro *et al.*, 1989), continuous loosening of sharp-edged blocks (b) occurs from the cliff (Fig. 7C).

(c) The loss of sand also reveals the presence of sub-horizontal beachrock slag beds, which were not removed during the intervention and are now colonized by green algal mats. The beds mainly consist of slag from the iron blast furnace, and carbonate turbidite blocks, but they never contain blocks of the Urgonian limestone used in the 1995 intervention. The beacrock unconformably overlie the marine abrasion platform (Figs. 3D, 7D-F).

(d) Sandy sediments stay in the central area of the beach, although with a trend to accumulate in the upper backshore zone, covering the entire urbanized area showing a steep, but variable slope depending on the section (≈ 20º, 3 m high, 75 m long) as far as the foreshore. Daily mechanical levelling (Fig. 7F) mitigates the steep slope produced by tides and storms. As a result of sand movements, blackened sandy areas appear occasionally due to the mixing of bioclastic

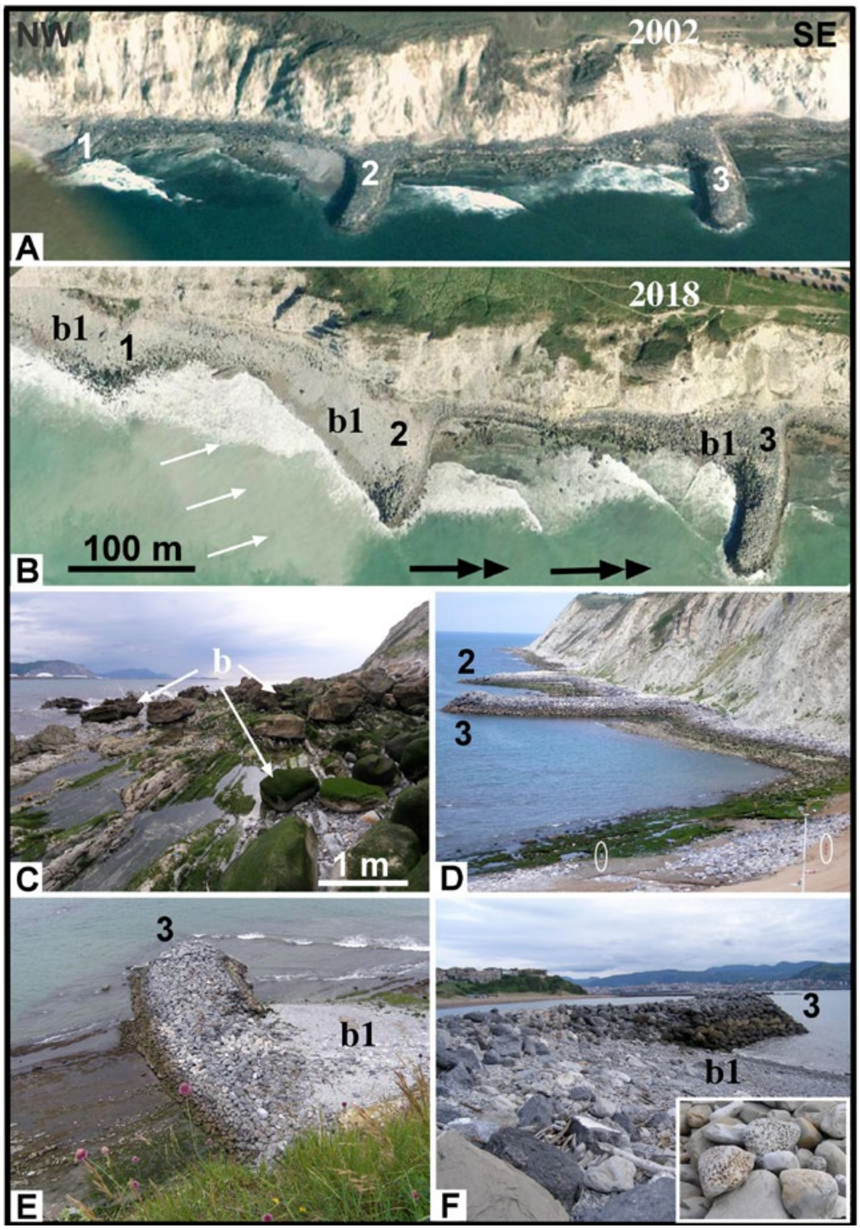

Fig. 6.- Arrigunaga beach, Getxo. A: Aerial view of the Punta Galea cliff in 2002, with the three groynes (1, 2 and 3) built in 1995, slightly affected on their windward sides by the impact of the tidal and storm waves. B: Approximately the same aerial view obtained in 2018. Fallen down blocks from the cliff (b1), are destroying groynes 1 and 2, filling the inter-groyne areas, mainly in the leeward zones. Groyne 3 is the least affected groyne, although the intense erosion of the cliff is visible in its leeward area. White arrows mark the usual NW direction of the waves. Black arrows indicate the longshore drift current along the beach. C: Accumulation of large, recently eroded, angular turbidite blocks (b) on the abrasion platform. D: Lateral view of groynes 2 and 3 and the eastern part of the beach at low tide. White ellipses show human beings for scale. E: View of groyne 3, showing the windward accumulation of rounded turbidite blocks (b1) and how they bypass the highest part of the groyne. F: Detail of the windward area of groyne 3 with blocks partially covering the groyne, with an inset of the boulders with lithophagous bivalves.

sand with fine remains of dark minerals segregated from the slag (Figs. 3D, 7G-H). The composition of these sands, determined by DRX analysis, corresponds to quartz (SiO_2), calcite ($CaCO_3$), magnetite (Fe_3O_4), goethite (FeOOH) and haematite (Fe_2O_3). Opaque ores such as magnetite, haematite and wüstite (FeO) can be observed by magnetic separation (Fig. 7H). This latter mineral is characteristic of high temperatures (> 570 ºC) in a reducing environment of anthropogenic slag, meteorites and basalts (Cornell and Schwertmann, 2003; Gil *et al.*, 2008).

(e) In the western zone, the breakwater (210 m) built perpendicular to the beach line and associated with the thick-bedded turbidite cliffs of the Algorta-Azkorri sandstones maintains the large blocks of Urgonian limestone (c.u.) stable, without producing any modification in its structure (Figs. 8A-B).

(f) The sediment in the foreshore zone of the western area ranges from sand to gravel (Fig. 8C), whereas in the backshore zone the accumulation of sand is more noticeable (> 3-4 m), almost totally covering the existing protrusions of siliciclastic turbidite sandstones (Algorta-Azkorri sandstones) (Fig. 8D). There are ascending-dune deposits (climbing dunes) of finer grain-size sands (0.1-0.2 mm), which adapt to the rocky slope of the cliff (Fig. 8E). The slope increasing in the shoreface zone (> 10º) is daily mechanically levelled (Fig. 8F) and it is noteworthy the presence at low tide of small return channels due to the outflow from the water table at the contact with the abrasion platform (Fig. 8G).

(g) As stable morphological structures, the incipient polishing of the initially irregular and rough surface is detected in some blocks of the breakwater. This polishing leads to the consequent formation of aquafacts (af), despite the fact that their orientation does not offer favourable conditions for intense abrasion (Figs. 8H).

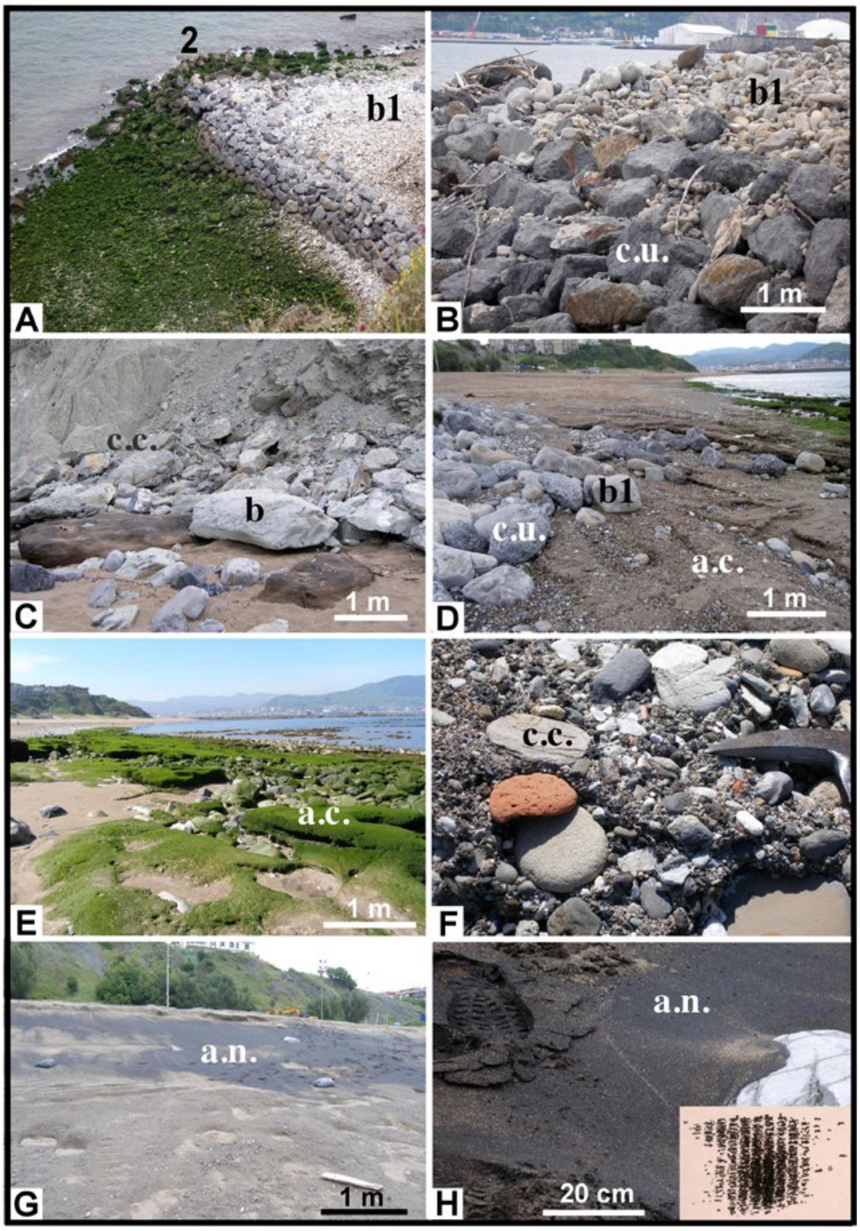

Fig. 7.- Arrigunaga beach, Getxo. A: View of groyne 2, with a large number of turbidite blocks (b1) from the cliff that goes beyond the groyne. On the leeward side, the large number of blocks covered with green algal mats is indicative of their lack of movement as they are protected from the waves impact. B: Detail of the leeward area with small, light colour, rounded turbidite blocks (b1) over the large, darker, blocks of Urgonian limestone (c.u.). Trunk remains are also deposited. C: Marly limestone blocks (b), eroded from the cliff; the lack of resistant turbidite beds causes them to decompose easily over time. D: Blocks of turbidite beds, already rounded (b1), from the cliff mixed with blocks of darker Urgonian limestone (c.u.) detached from the groyne. These loose blocks overlay the cemented sands (a.c.) from the blast furnace slag. E: General appearance at low tide of the cemented sands (a.c.), now colonized by green algal mats. F: Rounded cemented blocks (c.c.) such as bricks, slag and limestones. G: View of the bioclastic sands mixed with metallic particles, eroded from the slag, producing an overall dark effect (a.n.). H: Detail of the black sands (a.n.) of metallic composition (magnetite, haematite and wüstite) with magnetic properties.

Suggested measures as conclusions

On the Ostende beach, more intense levelling activity seems necessary to mitigate the steep slopes (> 10º) that are established between the shoreface zone and the high backshore zone. Taking into account the established half-life values for a standard beach, the permanence of this sandy-gravel artificial beach is assured for a long period of time. The continuous and rapid abrasion of the gravel will produce greater roundness and a decrease in its grain-size, improving the recreational quality of the beach. In our opinion, the intervention carried out in 1990 has maintained itself and meets the social and recreational objectives for which it was conceived.

The Arrigunaga beach poses a more complex problem due to the continued contribution of the Punta Galea cliff blocks to the northeastern part of the beach. If the intention is to maintain the entire useful surface of the beach as a recreational area, the question is whether it is advisable to remove the still-existing cemented conglomerate-sand bed fragments (beachrock), given their very high heritage value as a geological witness of the Industrial Revolution in northern Spain (Astibia, 2012). The large, well-rounded blocks that accumulate in the eastern zone can be redistributed in the upper backshore zone (b2), a task already started in 2020 (Fig. 3D). The progressive erosion of groynes 1 and 2, indicative of the impact of storm waves and the high block accumulation from nearby cliffs, suggests the need to reinforce and periodically maintain these groynes, evaluating the possible incorporation of larger blocks among the current ones. For these future maintenance interventions, the monthly mean values of the maximum wave height (5-12 m), the peak period (9-16 seconds) and the peak direction "coming from" (330-356 degrees) provided by the Abra-Ciervana buoy during the years 2001-2020 (Table 1), may help to design the most appropriate action. Also, an updated study of the coastal currents is required to adjust the spacing and length of the groynes in order to avoid the flanking effect. The presence of turbidite blocks colonized by lithophagous bivalves, mostly *Lithophaga lithophaga*, confirms the idea that marine currents have been reactivated and have changed in direction since 1975. Regarding sand movements, it seems that the mechanical levelling that is carried out on a daily basis is not enough to maintain the beach profile (Fig. 8F). The continuous levelling of the profiles in the central and western zones is a weak response to the natural movements of the sand, with slopes between 10-15º. There is an incipient formation of aquafacts in the blocks of the breakwater in response to water/sand-gravel abrasion during storms (Fig. 8H). This complex intervention seems to have been successful for the purposes originally pursued as recreation areas recommended for bathing, but a continuous maintenance is required to avoid the dismantling of the groynes.

Once the evolution of these two beaches is known, the question is whether this type of regeneration is appropriate

Fig. 8.- Arrigunaga beach, Getxo. A: View of the Punta de San Ignacio breakwater associated with large turbidite beds, in the western part of the beach. B: View of the large Urgonian limestone breakwater blocks (c.u.), preserved since they were built, without further modification by storms. C: Bioclastic sand added to the beach in 1999 and round-edged gravel from the natural cliff. D: Northwestern storm waves generate cup shapes on the beach; the white arrow points to partially covered protrusions. E: View of a small berm (b) after a spring tide, the climbing dunes are visible in the distance, marked by the white arrows. F: Daily mechanical levelling mitigates the steep slope of the beach. G: Southwestern foreshore zone with the presence of an erosion surface made up of thin folded beds from the lower Eocene sediments. Inset shows a detail of return channels or rill marks. H: Urgonian limestone breakwater blocks showing the onset of aquafacts (af) formation due to abrasion by sand-loaded waves. The luster and smooth polishing surface is characteristic. The hammer for scale is 32 cm in length.

on the Basque-Cantabrian coast, where the need for beach areas is still high, particularly in the vicinity of large urban cities (Pilkey and Cooper, 2014). It is beyond the scope of the present work to give a conclusive answer that allows the most suitable policy to be decided upon both cases (MOPU, 1985, 1991; Canteras *et al.*, 1995; París Solas *et al.*, 1995). However, with a full knowledge of the environmental impacts that may occur (Finkl and Walker, 2005), these actions may be acceptable if all the requirements stipulated both in the European Legislation (85/377/EEC) and at a national level (Royal Legislative Decree 1302/86, evaluation of environmental impact; Royal Decree 1131/88, regulation for the execution of Royal Legislative Decree 1302/86) are fulfilled. In addition, the currently in force new Spanish Coastal Law (i.e., "Ley 2/2013, de 29 de mayo, de protección y uso sostenible del litoral y de modificación de la Ley 22/1988, de 28 de Julio, de Costas"), published in May 2013, involves the first major change in the last 25 years since the previous 1988 Spanish Coastal Law (Negro *et al.*, 2014).

The most obvious benefits may be to reduce the high occupation of traditional beaches as well as to have well known spaces for their recent interventions. These places function as open laboratories where it is possible to compare the response of coastal dynamics in the face of the climate change that is already threatening the coastal and populated areas.

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