

## Chapter 2

### Study Sites

**Abstract** This chapter describes the study sites analyzed in this book: Carchuna and Playa Granada beaches (Southern Spain). Both constitute natural examples of mixed sand and gravel coasts exhibiting the Mediterranean complexity described in the previous chapter. The former site presents complex management practices due to the location of services near the shoreline, and the latter is in a deltaic coast that is strongly affected by river regulation over recent years. Both sites are influenced by a complex narrow inner shelf that enhances the impact of the marine agents on coastal evolution.

The sites are in the southern coast of Spain and face the Mediterranean Sea (Fig. 1.1). The coastline of Carchuna is characterized by non-periodic cusped features of different dimensions (Fig. 2.1) and a shelf-indenting canyon near the western boundary. Playa Granada can be considered as a regular and quasi-rectilinear beach (Fig. 2.1), whose evolution is strongly dependent on the management of the Guadalfeo River. The sites are widely studied examples of Mediterranean mixed sand and gravel coasts where the processes detailed in this book are highlighted.

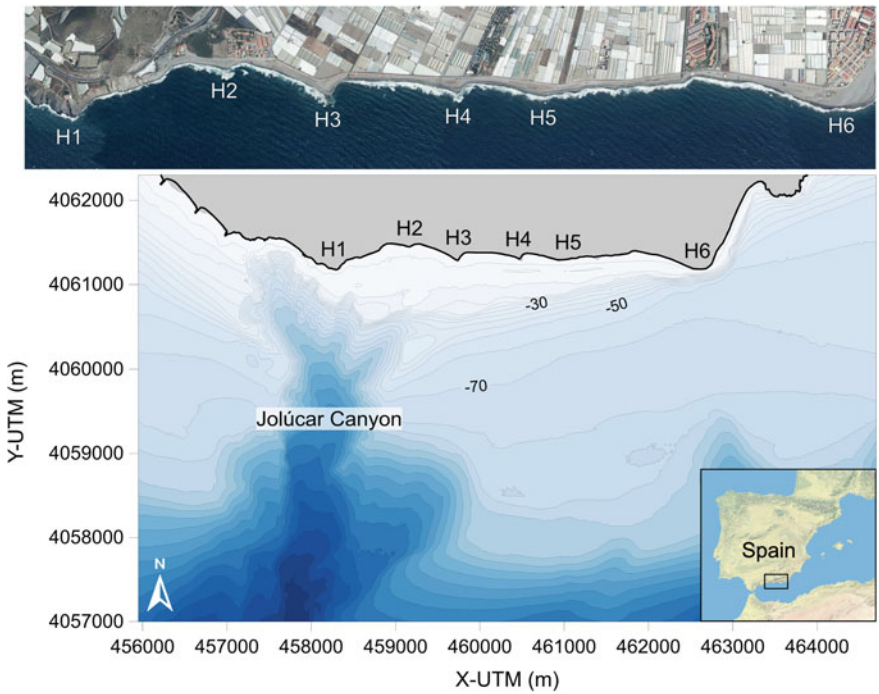
### 2.1 Carchuna Beach

Carchuna Beach is a 4 km long mixed sand and gravel beach located on the Mediterranean coast of Southern Spain and facing the Alborán Sea (Fig. 2.2). The beach is bounded to the west by Sacratif Cape (H1, Fig. 2.2) and to the east by the Punta del Llano Promontory (H6, Fig. 2.2). The beach exhibits a series of large-scale cusped features with an alongshore spacing of hundreds of meters. These features are bounded by a series of seaward-extending horns (H2–H6, Fig. 2.2).

The short streams which discharge in Carchuna Beach have their sources in the high mountainous relief of the Alpujarrian complex. The hydrological basins of these rivers are characterized by steep relief; the foothills over Carchuna Beach and neighboring areas exceed a 40% slope with non-cohesive material covering the rock substrate. The hillsides show frequent outcrops of rocks as a consequence of the high erosion rate. These streams have concave longitudinal profiles with slopes decreasing toward the mouth [24].

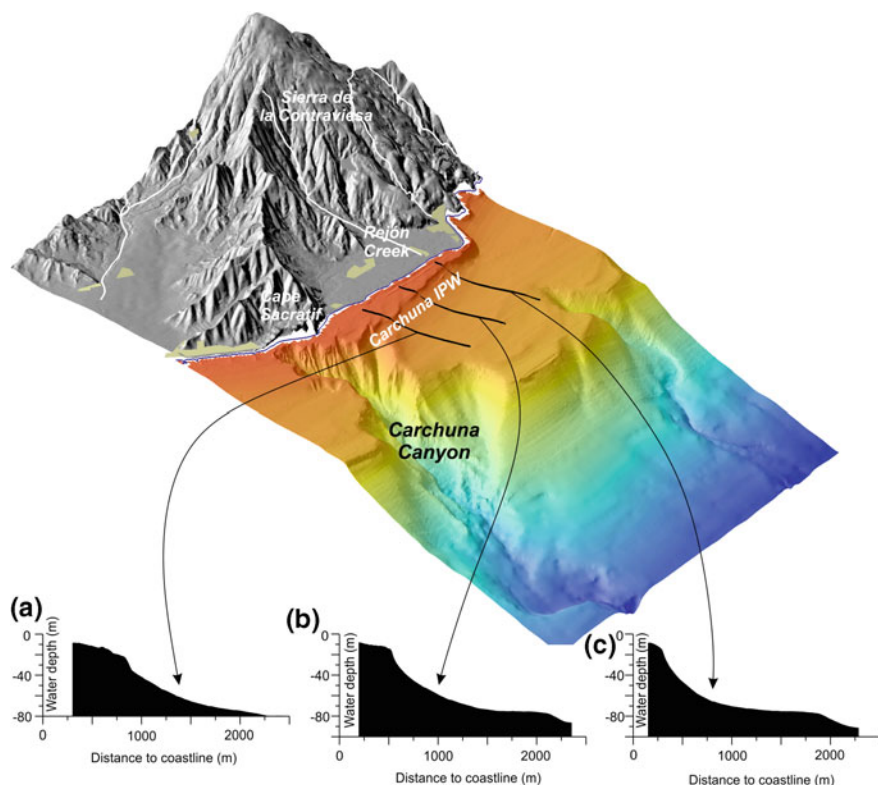


**Fig. 2.1** Photographs of Carchuna (left) and Playa Granada (right) beaches. (Source Photographs by Miguel Ortega-Sánchez and Rafael J. Bergillos)



**Fig. 2.2** Plan view of Carchuna Beach showing the location of the horns (H1–H6) and detailed bathymetric contours (in meters below the present sea level)

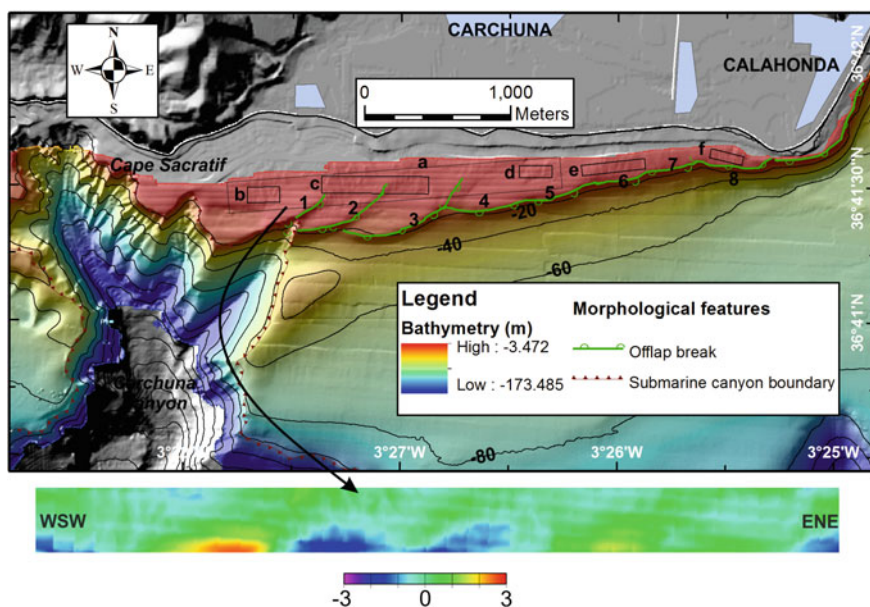
Their main courses extend below the mean sea level approximately down to 75 m depth (Fig. 2.3). These profiles show three different regions: (1) the upper region extending from 300 m altitude down to 40 m; (2) the middle region, where the stream slows down and discharges water and solids into the sea, extending to between 40 and 375 m; and (3) the offshore region where the slope is steep again [24]. As a result of



**Fig. 2.3** Three dimensional representation of the topo-bathymetric morphology of the Carchuna system. The lateral continuity of the Carchuna IPW is interrupted by the Carchuna Canyon. Its seaward extent decreases from west (up to 1.6 km in the vicinity of the Carchuna Canyon) to east (several hundreds of meters around the Punta del Llano Promontory). (Source [26]. Reproduced with permission of Elsevier)

the fluvial and marine processes, the offshore bathymetry opposite Carchuna Beach is characterized by straight and convergent contours toward Carchuna horn, furrowed transversely by several submerged valleys (Fig. 2.3). Chief among these submerged valleys is Carchuna Canyon [26].

Unlike the majority of the submarine canyons of the northern margin of the Alborán Sea [1], the head of Carchuna Canyon is located a short distance from the coastline. The Canyon trends N-S, paralleling the Motril Canyon located to the west [23]. It ends at a water depth of approximately 700 m and has a total length of approximately 5 km. Although the major part of the canyon is located in deep water, the upper part of the western and eastern tributaries cut the shelf (Fig. 2.4). These tributaries, which extend to water depths from approximately 10 m to approximately 180 m, are relatively small in comparison with the main channel of the canyon [26].



**Fig. 2.4** Geomorphological features of the Carchuna IPW, including a marked offlap break and the distal termination. The offlap break (or clinoformrollover) indicates the topset to foreset transition and is composed of a succession of individual breaks of slope, curved in the western part of the system and more rectilinear in the eastern part. The distal boundary is set at the 60 m bathymetric line, where a significant slope reduction is evidenced at the base of the foresets. (Source Adapted from [26]. Reproduced with permission of Elsevier)

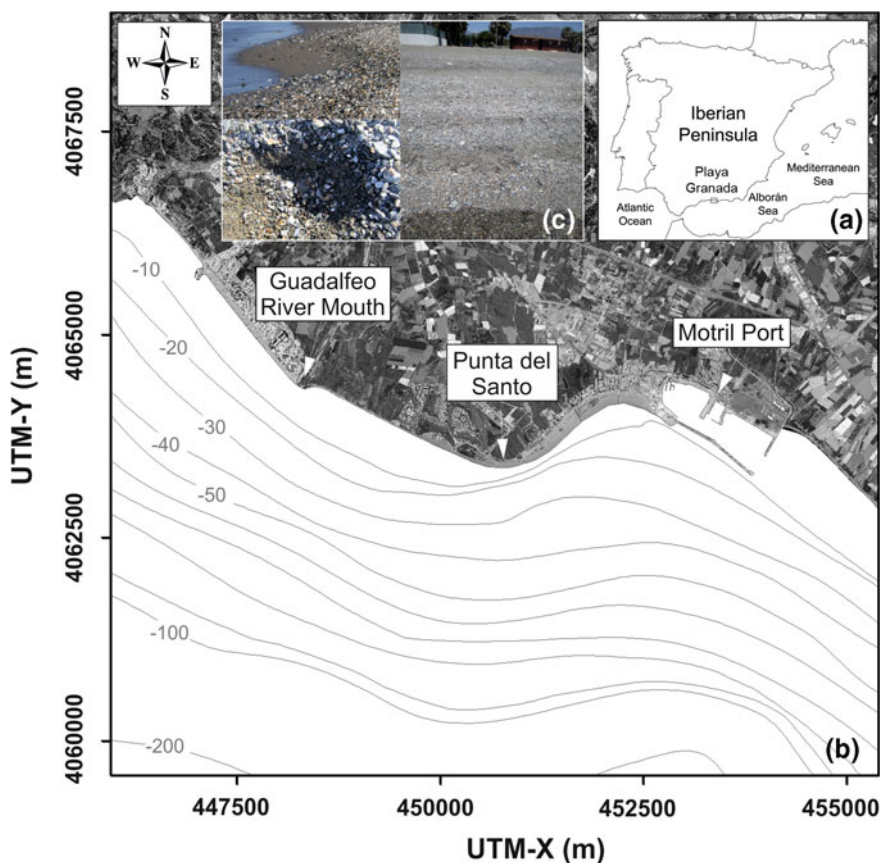
To the east of Carchuna Canyon, a wedge-shaped sedimentary body exists that has been interpreted as an infralittoral prograding wedge (IPW) in previous studies (Figs. 2.3 and 2.4). The physical continuity between the emerged beach ridge units and several marked increases in slope occurring over the Carchuna IPW has been interpreted as the result of a linked genetic mechanism with oblique or lateral progradation of successive IPWs rather than growth normal to the nearby coastline [10]. The shelf is covered by mainly gravelly sands in the vicinity of the study area. The sand content decreases steadily seaward, ranging from more than 90% at a water depth of less than 20 m (landward of the well-marked increase in slope characterizing the Carchuna IPW) to approximately 70% in the vicinity of the shelf break. In contrast, the gravel content increases steadily from less than 5% at shallow depths to as much as 25% at the distal shelf margin [8].

Analysis of aerial photographs since 1956 and images obtained from a video camera station installed at Sacratif Cape in November 2002 has not revealed significant changes in the alongshore locations of the horns [19]. The beach slope varies along the length of the embayments from  $0.04^\circ$  (in the middle) to  $0.3^\circ$  (in the horns) due to the alongshore variation in the sediment grain size. The steeper-sloping zones are related to larger proportions of coarser sediments [7]. The presence of Carchuna

Canyon and the coarse sediments at the horns suggest that the sediment exchange through the west and east boundaries of the unit is almost negligible. Moreover, the actual sediment supply from the local streams is also negligible, because of the construction of a large number of greenhouses and terraces in their beds to divert water for irrigation. Thus, it can be assumed that there is no sediment input to Carchuna Beach. Because of the large grain sizes, which armor the foreshore, as well as the mild annual wave energy flux, the beach is eroding slowly, but consistently.

## 2.2 Playa Granada

Playa Granada is a 3 km long mixed sand and beach located on the southern coast of Spain that faces the Mediterranean Sea (Fig. 2.5). The beach corresponds to the



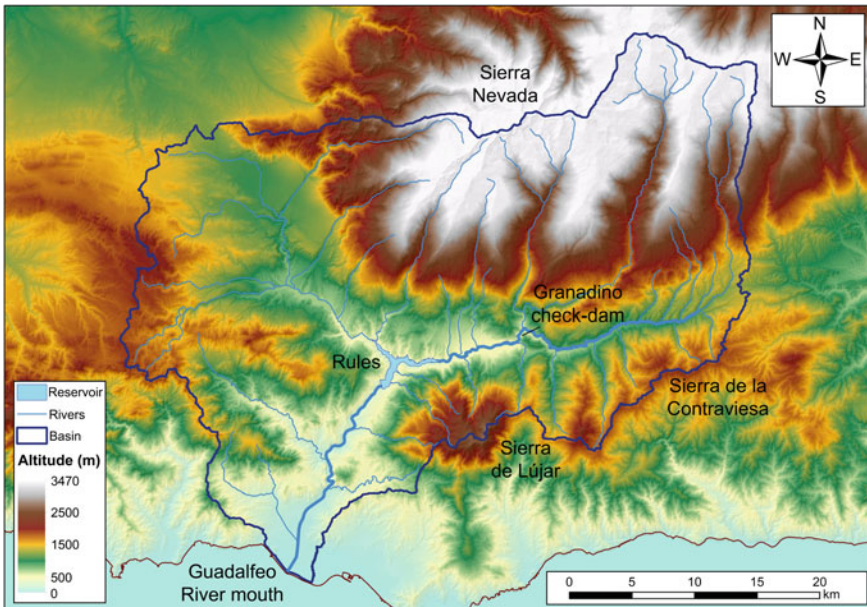
**Fig. 2.5** **a** Location of Playa Granada (Southern Spain). **b** Plan view of Playa Granada and bathymetric contours (in meters below the present sea level). **c** Sediment variability on the beach. (Source Adapted from [5]. Reproduced with permission of Elsevier)



central stretch of the Guadalfeo deltaic plain [2] and is bounded to the west by the Guadalfeo River mouth and to the east by *Punta del Santo*, the former location of the river mouth. The deltaic coast is bounded to the west by Salobreña Rock and to the east by Motril Port. This port is an artificial barrier that prevents eastward longshore sediment transport [12].

The Andalusian littoral of the Mediterranean Sea is characterized by the presence of high mountainous relief and short fluvial streams, and the main contributor of sediments to the beach is the Guadalfeo River. Its basin has an area of  $1,252 \times 10^6 \text{ m}^2$  and includes the highest peaks on the Iberian Peninsula ( $\sim 3,400 \text{ m.a.s.l.}$ ). Consequently, the river is associated with one of the most high-energy drainage systems along the Spanish Mediterranean coast. The northern catchment divide corresponds to the crest line of the Sierra Nevada, whereas the southern divide corresponds to the crest lines of the Sierra de la Contraviesa and the Sierra de Lújar (Fig. 2.6).

The mountainous influence of the Sierra Nevada conditions the hydrological dynamics and the pluvio-nival character of this semi-arid and high-mountain basin. This sub-basin is mainly composed of Nevado-Filábride complex (mica-schist and graphitic mica-schist). The high altitude guarantees the presence of snow from November to June, which allows a near-perennial flow despite its aridity [13]. The nival contributions condition this quasi-perennial flow, which allows the development of an armor layer and separates a surface layer ( $D_{50} \sim 60 \text{ mm}$ ) from a substrate layer



**Fig. 2.6** Delimitation of the basin and locations of the Rules' Reservoir, the Granadino check-dam, the Sierra Nevada, the Sierra de la Contraviesa and the Sierra de Lújar

**Table 2.1** Minimum, maximum, mean and standard deviation (SD) of the annual precipitation (in mm/y) in 11 meteorological stations of the Guadalfeo basin [21]

Station	Minimum	Maximum	Mean	SD
Albuñol	210	1026	456	179
Bérchules	301	1617	658	249
Cádiar	218	1217	429	186
Contraviesa	312	1062	627	285
Órgiva	207	1434	482	195
Poqueira	434	1485	829	379
Pórtugos	326	1719	726	286
Soportújar	336	1810	692	261
Tajos Breca	413	1474	793	381
Torvizcón	262	1265	539	188
Trevélez	307	1635	663	258

( $D_{50} \sim 2.5$  mm). The periodic occurrence of intense precipitation and snowmelt events reshape this drainage network and release a large amount of sediment [22].

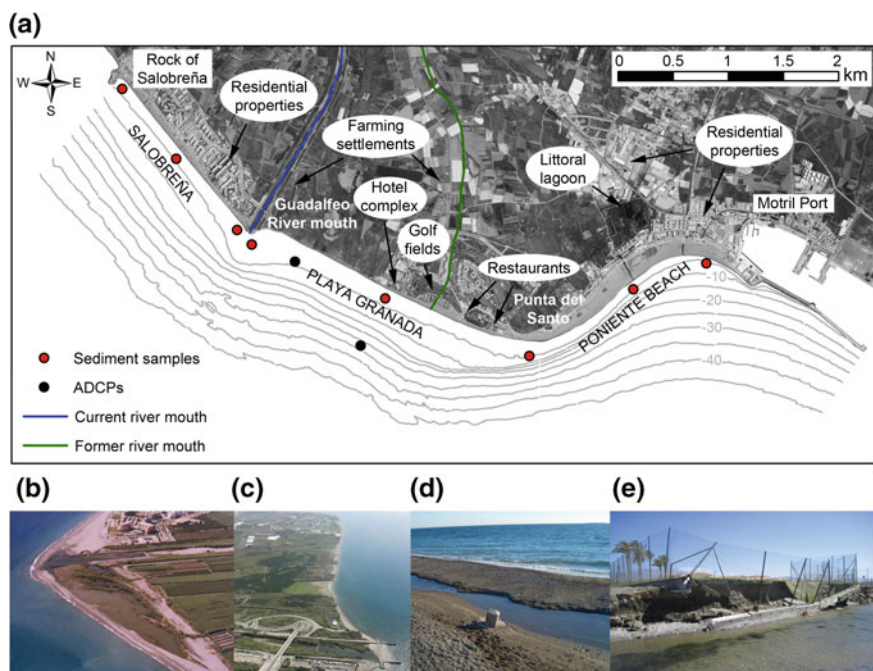
The Sierra de la Contraviesa presents a more ephemeral nature with the absence of snowmelt cycles and sub-surface storage. It is composed of Alpujárride complex (quartzites, phyllites and schists). The evolution of erosion processes is clearly influenced by changes in vegetation and land use. This area was originally dominated by forest and Mediterranean shrubs, and large areas of almond and olive orchards are currently pre-eminent [20]. This change has led to the emergence and development of different types of incisions in the form of rills, gullies and more developed channels. Here, the tributary channels lead to important bed-load contributions during intense events that accumulate in the Guadalfeo River.

The annual precipitation data show significant spatial gradients (Table 2.1) and the average annual rainfall in the basin is 586 mm, with minimum and maximum values of 500 and 1000 mm, respectively [20, 21]. The pre-regulation hydrological regime of the Guadalfeo River had peak discharges that exceeded 1,000 m<sup>3</sup>/s [9]. The river longitudinal profile is variable: the slope is greater than 2% in the Southern Sierra Nevada and Sierra de la Contraviesa, approximately 1% upstream of the Granadino check-dam, equal to 2.5% between the Órgiva's gauge station and the Rules' Reservoir, and approximately 0.9% downstream of the dam (Fig. 2.6). This relatively steep topographic gradients lead to large contributions from a wide range of sediment sizes [21]. As a result, the particle size distribution on the coast is particularly complex with varying proportions of sand and gravel (Fig. 2.5b). Three sediment fractions are predominant in the studied coastal area: sand ( $\sim 0.35$  mm), fine gravel ( $\sim 5$  mm) and coarse gravel ( $\sim 20$  mm) [4].

The river was dammed 19 km upstream from the mouth in 2004, regulating 85% of the basin runoff [18]. The total capacity of the Rules' Reservoir (117 hm<sup>3</sup>) was planned to be used for the following purposes: irrigation (40%), supplies for resi-

dential developments along the coast (19%), energy generation (9%), flood control (30%) and environmental flow (2%). However, the river damming modified the natural flow regime and altered the behavior of the system downstream. In particular, the reduction in sediment supply to the coast due to river regulation has been greater than  $74,000 \text{ m}^3/\text{y}$  since 2004 compared to the volume that would have reached the coast under natural conditions [6], contrasting with the accumulation of sediment as delta deposits in the reservoir upstream [22]. As a consequence, the deltaic coast, whose dynamics has been historically governed by the sediment supply of the river during intense events [14, 15], currently presents coastline retreat and severe erosion problems [3].

The studied stretch of beach, which is occupied by an exclusive leisure resort, golf courses, restaurants and summer homes, has been particularly affected and has presented higher levels of coastline retreat in recent years than both western and eastern stretches, known as Salobreña and Poniente Beach, respectively (Fig. 2.7). In addition, Playa Granada has urban lots, at the south of the river mouth, that have not been developed yet. In light of these facts, it is clear that the coast has a high environmental and tourist value, and its exploitation requires a large area of dry beach



**Fig. 2.7** a Locations of former and current river mouths, beach profiles where the sediment samples were taken (red circles), ADCPs (black circles), principal occupations and bathymetric contours in 1999. Plan views of the delta before (b) and after (c) the river damming. d Boundary marker of the public domain that is located few meters from the shoreline due to coastline retreat in Playa Granada. e Storm-induced erosion problems in the hotel complex indicated in panel a



**Table 2.2** Artificial replenishment projects carried out on the coast since the entry into operation of the dam

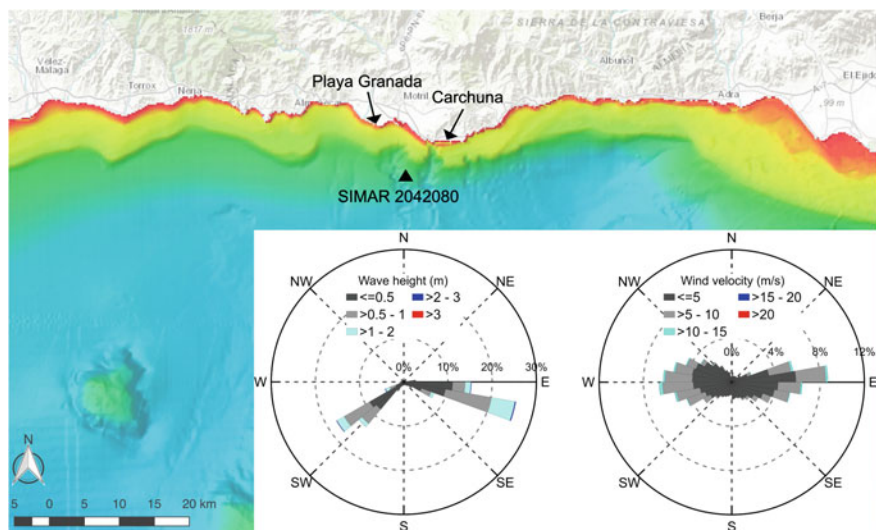
Year	2006	2009	2010	2014	2014
Volume (m <sup>3</sup> )	70,950	51,375	1,654	19,436	106,676
Purpose	Protection	Protection	Tourism	Tourism	Protection

[12]. For this reason, artificial nourishment projects in this mixed sand-gravel coastal environment have been frequent since the entry into operation of the dam (Table 2.2).

The continental shelf of the Guadalfeo River is narrow with an average width of less than 5 km. The shelf break is located at a depth of 100 m and is approximately parallel to the main coastline orientation of the delta front [17]. The shelf gradient is  $>3^\circ$  in the delta foreset region and then decreases seaward to  $<1.5^\circ$  in the bottomset region [15]. The Guadalfeo River pro-delta extends seaward almost 3.5 km and is characterised by an undulating pro-delta surface due to the presence of bedforms [17]. An off-lap break is identified proximally over the pro-delta, at water depths of 8–14 m and up to 0.5 km from the coast [11]. Medium sands with some muddy intercalations are found in the Guadalfeo pro-delta, whereas the sediment composition in shallower water across the foreset region is dominated by sandy sediments [16]. The emerged deltaic area of the fluvial system covers  $8.6 \times 10^6 \text{ m}^2$  and is composed of coarse-grained sediments ranging from medium sands to boulders [15].

## 2.3 Maritime Climate

Climatic patterns at the study sites exhibit a significant contrast between summer and winter. The region is subjected to the passage of extra-tropical Atlantic cyclones and Mediterranean storms with average wind speeds of 18–22 m/s [24, 27] which generate wind waves under fetch-limited conditions (approximately 300 km). The storm wave climate is distinctly bimodal with the prevailing west-southwest (extra-tropical cyclones) and east-southeast (Mediterranean storms) wave directions (Fig. 2.8). Peak significant wave heights during typical and extreme storm events exceed 2.1 and 3.1 m, respectively. Under South Atlantic storm conditions, swell waves generated in the Gulf of Cadiz propagate through the Strait of Gibraltar. These swell waves impinge the coast simultaneously with the local wind waves, but with slightly different angles [25]. The astronomical tidal range is  $\sim 0.6 \text{ m}$  (microtidal conditions), whereas typical storm surge levels can exceed 0.5 m [5].



**Fig. 2.8** Wave and wind roses at the study sites. Data from SIMAR XXX were provided by *Puertos del Estado*

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Ortega-Sánchez, M.; Bergillos, R.J.; López-Ruiz, A.;  
Losada, M.A.

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