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ORIGINAL ARTICLE

Potential Use of a Significant Scientific Geosite: the Messinian Coral Reef of Santa Pola (SE Spain)

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Abstract The Messinian coral reef of Santa Pola, one of the most relevant geosites in the geological heritage of the western Mediterranean, is quantitatively assessed in terms of geoscience and features of potential use. Two different methodologies are used, one developed by the Geological and Mining Institute of Spain (IGME) for the Spanish Geosite Inventory (IELIG) and the other prepared by the Paleontological Museum of Elche (MUPE) for the Fossils and Heritage Project of Alicante (FOPALI). Santa Pola scores very high with both methods, which is a clear indication that this exceptionally relevant scientific geosite (included in the Spanish Geosite Inventory) also has a high didactic and tourism-recreational potential. In addition, the paper compares and discusses the two different methodologies, concluding that the selection of a model depends on the purpose of the evaluation (representativeness of the geosite in the Spanish territory associated to the Spanish Geological Inventory (IELIG) and a comparison of palaeontological and geological features (FOPALI) between different geosites). This work is a starting point to develop a specially designed management plan and geoconservation strategy for this exceptional geosite of the western Mediterranean.

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Introduction

The Messinian coral reef (atoll type) of Santa Pola cape (province of Alicante, SE Spain; Fig. 1) is one of the most significant geo-sedimentary enclaves from the Neogene record of southeastern Spain (e.g. Esteban 1979; Esteban et al. 1996; Calvet et al. 1996; Feldmann and McKenzie 1997; Soria et al. 2008a, b; Corbí and Yébenes 2010, 2012; Corbí and Soria 2016). Its scientific and didactic value has been recognized by various institutions that have included Santa Pola mountain, where the Messinian coral reef is located, in various inventories and catalogues on specific topics: (a) geosite (Spanish Geosite Inventory (LIG) carried out by the Geological and Mining Institute of Spain); (b) geo-scientific map of the province of Alicante (Auernheimer 1989); (c) palaeontological catalogue of the Community of Valencia; and (d) the geological context of international value associated with the Global Geosites project (García-Cortés et al. 2008; Carcavilla and Palacio 2010). In addition, this singular geosite has been included in the didactic guidebook *Geological Walks of the Province of Alicante* (GeoAlicante Research Team 2010). Moreover, the notable geological and palaeontological heritage of Santa Pola mountain, of great interest to the general public, is evidenced by the selection of this geosite to hold the 2013 Alicante "Geolodía" public field day (Crespo-Blanc et al. 2011, 2016; Aberasturi et al. 2013). Finally, its didactic and outreach potential is also reflected in various chapters in books on the geology of the province of Alicante (Alfaro et al. 2004a, 2004b; Corbí and Yébenes 2012). All these recognitions are combined with remarkable geo-scientific interest as, since the 1970s, this fossil coral reef has been studied by

Fig. 1 Geographic location of the geosite (figure courtesy of Francisco Asensio-Montesinos)

numerous researchers and by petroleum companies that have organized specialized geosedimentary field trips (Montenat, 1977, 1990; Esteban and Giner 1977; Esteban, 1977, Esteban and Giner, 1977, Esteban et al., 1978, Esteban, 1979, Esteban et al., 1996, Esteban, 1997; Vallés 1985, 1986; Montenat 1990; Calvet et al. 1991, 1994, 1996; Feldmann 1995; Feldmann and Mackenzie 1997; Sáez-Martínez et al. 2008; Soria et al. 2005, 2008a, b; Corbí 2010; Corbí and Soria 2016).

Geological heritage today is a specialized scientific discipline and professional development field that has been gaining importance in recent years (e.g. Wimbledon et al. 1995; Lapo et al. 1993; Alexandrowicz and Kozlowski 1999; Grandgirard 1999; García-Cortés et al. 2001; Carcavilla et al. 2007, 2009; Brilha et al., 2005, 2010, Brilha, 2016; Henriques et al. 2011; Wimbledon and Smith-Meyer 2012; Vegas et al., 2013; Fierro 2015; Hilario et al. 2015; Sánchez-Ferris 2015). The geoheritage quantitative assessment models currently in use are based on three groups of criteria or parameters (e.g. Carcavilla et al. 2007; Sánchez-Ferris et al. 2008; García Cortés et al. 2014; Brilha 2016): scientific interest, potential use, and degradation risk. Of these, not surprisingly, only the scientific criteria provide significant information about the intrinsic scientific value of the area that is intended to be evaluated in terms of geological heritage. The other two criteria (potential use and degradation risk) are particularly interesting as regards proper geosite management and must be used jointly with the former. Therefore, quantitative assessment (considering these three criteria), together with the identification and characterization of the geosite inventory, is the first essential step in a geo-conservation strategy (García-Cortés et al. 2001; Brilha et al., 2005; Brilha, 2016 Carcavilla et al. 2009; Henriques et al. 2011). This first phase brings us to the next steps related to the conservation, interpretation, promotion, and finally monitoring of geosites (e.g. Brilha 2016). Taking as a point of reference these general guidelines in geo-conservatory strategy, the profuse scientific and outreach literature on the Santa Pola atoll coral reef provides an essential starting point for the in-depth investigation of the geological heritage of this exceptional enclave, which is the purpose of this paper.

In order to analyse the quantitative assessment, in particular the scientific and potential use of the Messinian atoll coral reef of Santa Pola, we have used two different geological quantitative assessment models: (a) the model developed by the Geological and Mining Institute of Spain (IGME) for the Spanish Geosite Inventory (IELIG) (García-Cortés et al., 2014) and (b) the model prepared by the Paleontological Museum of Elche (MUPE) for the Fossils and Heritage Project of Alicante (FOPALI) (Sánchez-Ferris et al. 2008; Fierro 2015; Sánchez-Ferris 2015). This approach allows us to compare the two methodologies by discussing the applicability of the results. In short, this work represents the stepping-off point to develop a geo-conservation strategy leading to a specifically designed tool to endorse the geo-scientific interest of the site, which would enable appropriate management and conservation of this exceptional site in the western Mediterranean.

Geological Context of the Geosite

Santa Pola mountain comprises a calcareous platform 5 km in diameter, isolated and elevated above the surrounding area (Fig. 2). It is an exceptionally preserved coral reef that is one of the best examples of a Mediterranean atoll-type reef. This atoll formed during the Messinian, developing close to the outer margin of the continental shelf, about 20 km northeast of the Messinian palaeocoast, which corresponds to the current Los Colmenares mountain (south of Alicante city). After burial with more recent (Pliocene) sediments, the atoll was exhumed due to Quaternary erosion and neotectonic activity. Consequently, the current relief shows the original morphology of the atoll, providing excellent outcrops where the three-dimensional geometry of the different parts of the coral reef can be recognized. It was precisely during the formation of this coral reef structure that the Mediterranean Sea was subjected to dramatic changes related to the Messinian Salinity Crisis. Therefore, Santa Pola not only records the Messinian atoll coral reef but also evidences the profound transformations that the Mediterranean basin underwent during this period (Esteban 1979; Calvet et al. 1994, 1996; Soria et al. 2008a, b; Corbí and Soria 2016).

Santa Pola mountain lies in the northern Bajo Segura basin, a western Mediterranean Neogene basin of the eastern Betic Cordillera (Fig. 3) (Montenat 1977, 1990; Soria et al. 2005, 2008a, b, 2014; Corbí 2010, 2017; Caracuel et al. 2011; Corbí et al. 2016; Corbí and Soria 2016). By examining the general stratigraphic architecture of the above authors and incorporating the information of other investigations and our own field observations (Calvet et al. 1996; Esteban et al., 1996; Feldmann and Mackenzie 1997; Goy and Zazo 1988), the following units have been differentiated (in stratigraphic order): (a) Tortonian yellowish calcarenites with rhodoliths equivalent to the Tabarca Unit defined in nearby Tabarca island by Calvet et al. (1996) (see Martínez-Martínet et al. 2017 for a detailed description of the unit); (b) the reef complex, the Messinian atoll coral reef, which constitutes the basic framework of the mountain; (c) the terminal carbonate complex (TCC of Esteban 1979), an upper-Messinian marine unit characterized by predominantly stromatolite (mainly dome-shaped) and oolite facies; (d) Pliocene marine marls and fossiliferous sandy limestones related to the Pliocene reflooding of the Mediterranean (Corbí and Soria 2016); (e) upper Pliocene–Pleistocene continental red claystones and limestones (Sucina Formation of Montenat 1990); (f) the pre-Tyrrhenian marine terrace (middle Pleistocene), which occurs above an abrasion surface carved in materials of the marine reef slope from the reef complex (Goy and Zazo 1988); (g) breccias of the subaerial slope, a deposit of the continental bottom ledge formed by fragments of the exhumed reef front; and (h) Tyrrhenian marine terraces (upper Pleistocene) carved in the distal sectors of the colluvial border, where three levels of marine beaches and eolian dunes can be differentiated (Goy and Zazo 1988).

Methodology

For the quantitative assessment (scientific and potential use), two different methodologies have been used. One was developed by the Geological and Mining Institute of Spain (IGME) for the Spanish Geosite Inventory (IELIG). The other one was designed by the Paleontological Museum of Elche (MUPE) for the Fossils and Heritage Project of Alicante (FOPALI).

The IELIG methodology focuses on establishing a criteria to select the most significant geosites in Spain (Spanish Geosite Inventory by García-Cortés et al. 2014). As established by these authors, the proposed model is based on seven parameters: representativeness, key locality, scientific knowledge, state of preservation, observational conditions, rarity, and geological diversity, which are scored with different weights (from 10 to 30). The score of each parameter is based on a scale of 0 to 4 (excluding a score of 3). It should be noted that this model provides a high weight to the representativeness parameter (30%). On the other hand, in this methodology the potential use assessment is based on separately analysing the didactic and the tourism-recreational parameters based on 13 and 11 parameters, respectively (see García-Cortés et al. 2014 for the description of these criteria and the quantification of each parameter; see Table 3). Note that six of these didactic parameters are also considered in the scientific assessment (only the scientific knowledge criterion is not included), although the weight of each parameter is different. Therefore, seven additional parameters have been included (didactic content, logistics, population density, accessibility, geosite size, other heritage elements, and spectacular or beautiful landscape). As shown in Table 3, geological diversity, didactic content, and logistics have a high weight in the quantitative assessment (10, 20 and 15% in the final numerical value, respectively). Eleven parameters are used to calculate the tourism-recreational value (Table 3; García-Cortés et al. 2014 for the description of the numerical criteria used). In this case, one of the scientific parameters (observational conditions) and six of the didactic parameters (logistics, density of population, accessibility, geosite size, presence of other heritage elements, and spectacular or beautiful landscape) remain, although the weight is different. Additionally, four other parameters have also been included (outreach content, potential to develop tourism and recreational

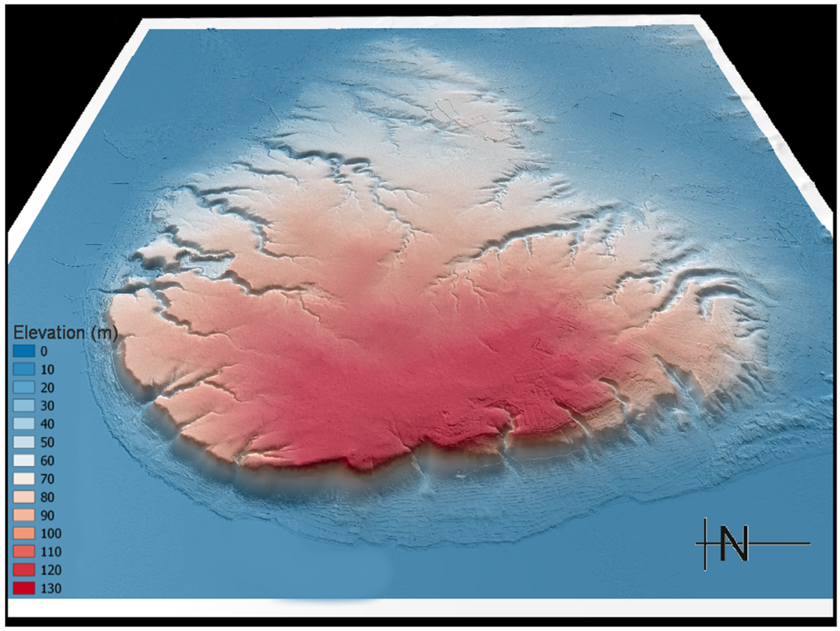

Fig. 2 Digital elevation model (DEM) combined with hillshade map (implemented with QSIG) of the study area (figure courtesy of Francisco Asensio-Montesinos)

activities, proximity to recreational zones, and socio-economic context). Note that, in this model, the parameters with the greatest weight are spectacular or beautiful landscape (20%), geosite size (15%) and outreach content (15%).

In contrast, the FOPALI methodology for scientific assessment (Sánchez-Ferris et al. 2008; Fierro 2015; Sánchez-Ferris 2015) is based on ten criteria or parameters (abundance of similar outcrops, key locality, palaeodiversity-geodiversity,

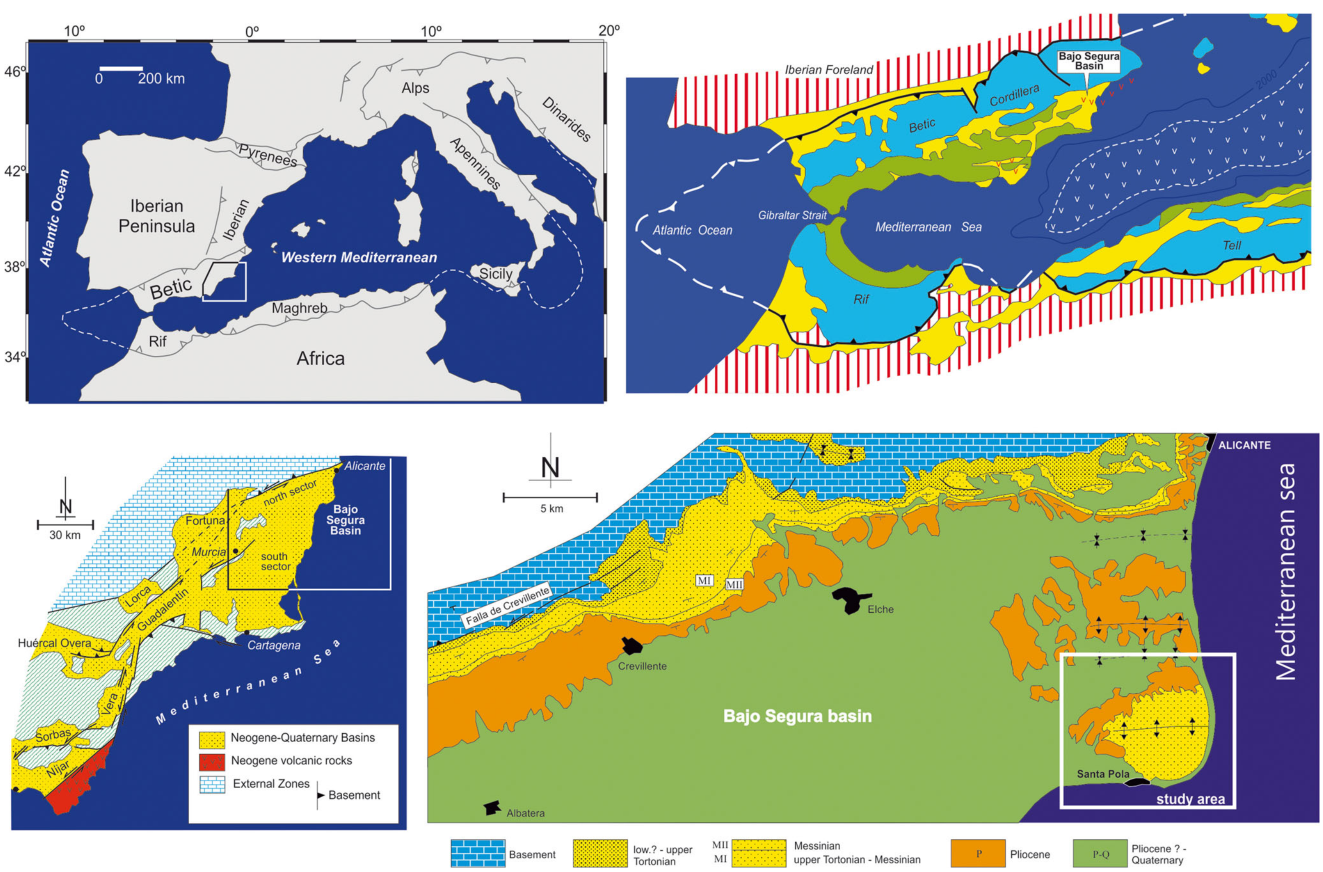

Fig. 3 Geological context of the geosite in the northern Bajo Segura basin (figures courtesy of Dr. Jesús M. Soria)

palaeodisparity, conservation status of the immovable and movable property, taphonomic-genetic interest, geological interest (including biostratigraphy, lithostratigraphy, tectonics, and geomorphology), utility to illustrate processes, and scientific potential) equally weighted and ranked from 0 to 4 (Table 1). Table 1 displays the scores to quantify each of the parameters or criteria. As can be seen, the maximum scientific value of a site or area is 40 points, which can be normalized to a scale of 0 to 10. In the FOPALI model, the potential use assessment is based on eight parameters or criteria with the same weight: degree of knowledge or investigation, historical value, didactic interest, complementary value, proximity to populations, number of inhabitants in the surrounding area, visibility, and accessibility (Table 2). Note that, unlike the IELIG model, there are no scientific parameters included in this list. Moreover, each of the proposed parameters (ranked on a numerical scale from 0 to 5) has the same weight in the final score of the site. Finally, in this model the maximum potential use score of a site or area is 40 points, which can be normalized to a scale of 0 to 10.

Results

Sedimentary Environments Recorded

This section summarizes the main features of the sedimentary environments and facies distribution in the Messinian atoll of Santa Pola (reef complex). The sedimentary facies characterization based on the review of the literature and our own field observations is one of the starting points to the clear scientific and potential use assessment provided in the paper's next section.

In the reef complex, three sedimentary environments can be distinguished (Fig. 4):

(a) The reef front, which corresponds to the semi-circular ledge defining Santa Pola mountain, reaching a height of more than 40 m close to the lighthouse (Figs. 4 and 5). The reef front has notable regularly spaced channels (gullies up to 30 m wide) with an average separation of 490 m, as well as regularly distributed buttresses along the entire reef crest (Fig. 4). These singular geomorphological characteristics are probably directly related to the spur and groove system (SAG formations; see Blanchon, 2011for a review) of the atoll during its formation during the Messinian. Parallel ridges of coral and algal material (spurs) separated by regularly spaced channels (grooves) form a characteristic toothcomb pattern (Gischer 2010) that is one of the most prominent features of fore reefs worldwide. Related to erosional and construction processes (Duce et al. 2016), such formations regulate the hydrodynamic energy and nutrients received by reef platforms by acting as natural breakwaters (Munk and Sargent 1954). The reef front of Santa Pola is almost exclusively dominated by *Porites* genera (Esteban, 1979) (Fig. 6). This singular feature, together with the size and morphology of the *Porites* colonies, made Esteban et al. (1978) consider Santa Pola to be an "aberrant" or "anomalous" type of coral reef. In the reef front, the *Porites* assemblages show clear morphological zoning, with three zones distinguishable in the reef wall (from lower to upper): (a) dishes or plate-like zone; (b) branching zone of finger-like morphologies more or less branched, constituting the main section of reef wall; and (c) a massive coral zone, cropping out in the upper part of the reef crest. It is especially noticeable that fan-shaped *Halimeda* packstones and grainstones and yellowish calcarenites developed in front of the channels (Fig. 4).

(b) The reef slope, which spreads from the reef front to the ancient open platform. Fragments from the coral reef were deposited in this zone. It coincides with the current slope, and thus the deposits are partially covered by rocks fallen in more recent times in subaerial conditions. A large number of these fallen blocks (of metric scale) can be observed near the Marine Research Centre of Santa Pola (CIMAR, Santa Pola municipality, University of Alicante) (Fig. 7). Therefore, this area is the ideal didactic and outreach site to recognize different *Porites* coral assemblages. In fact, one of these blocks is part of the rock garden of the University of Alicante (Fig. 8), a didactic space inside the university, where a selection of the different rock types from the Betic Cordillera are represented.

(c) Lagoon or back reef zone. It is formed mostly by reef patches (of metric scale) and calcarenites with *Halimeda* and bivalves. Unfortunately, not too many outcrops have been preserved since the lagoon sediments were mostly eroded before sedimentation of the newest, Pliocene–Pleistocene materials, which comprise the upper part of Santa Pola mountain.

Scientific Assessment

In this section, the scientific assessment parameters are characterized considering the two methodologies described, discussing their proposed scores (expressed in Table 3). As shown in Table 3, the two methodologies yielded the same score (8 on a scale of 10), which will be further analysed in the "Discussion" section. In the next section, all the parameters considered from both methodologies are examined.

The Santa Pola coral reef receives the maximum score in the *Representativeness* parameter (Model IELIG, Table 3) since its formation is directly related to the Messinian

Table 1 Scientific criteria and scores in the FOPALI model

Scientific parameters	Weight/points		Weight/points
Abundance of similar outcrops	×10	Key locality	×10
Present in more than one place in the municipality	0	No	0
Unique in the municipality	1	Specific level/one geological unit	2
Unique in the community	2	Generic level/more than one geological unit	4
Unique in Spain	3		
Unique in the world	4		
Palaeodiversity/geodiversity	×10	Palaeodisparity	×10
1–5 species/geological elements	0	1 phylum	0
6–10 species/geological elements	1	2 phyla	1
11–15 species/geological elements	2	3 phyla	2
16–20 species/geological elements	3	4 phyla	3
>20 species/geological elements	4	> 4 phyla	4
Status of preservation (immovable property)	×10	Status of preservation (movable property)	×10
Heavily deteriorated	0	Very bad	0
Key characteristics deteriorated	1	Bad	1
Affected but the key characteristics can be recognized	2	Average	2
Some deterioration	3	Good	3
Perfectly preserved	4	Very good	4
Taphonomic/genetic interest	×10	Geological interest	×10
Very low	0	Very low	0
Low	1	Low	1
Medium	2	Medium	2
High	3	High	3
Very high	4	Very high	4
Utility to illustrate processes	×10	Scientific potential	×10
Very low	0	Very low	0
Low	1	Low	1
Medium	2	Medium	2
High	3	High	3
Very high	4	Very high	4

Salinity Crisis, one of the most significant palaeoceanographic events in the geological history of the Mediterranean (see Corbí et al. 2016; Corbí and Soria 2016 for references). Moreover, Messinian coral reefs such as the one recorded in the Sorbas basin (similar to the one analysed in this work) were the last to appear in the geological history of the Mediterranean (Martín et al. 1997). Therefore, there are numerous published scientific works on the Santa Pola coral reef, which can be summarized in five doctoral, master's, and undergraduate theses, 11 papers in international journals referenced in the Journal Citation Reports (2 papers in unindexed peer-reviewed journals), 10 congress communications, and 10 outreach and didactic publications. Consequently, the site has the maximum score in the *Scientific knowledge* parameter (Table 3). Additionally, if we take into account the units (or geological contexts or domains) defined by the Geological and Mining Institute of Spain (García-Cortés et al. 2001), the Santa Pola coral reef belongs to contexts 12 "Messinian evaporitic episodes" and 3 "Structures and singular geological formation of the continental and marine Cenozoic basins from Spain". Furthermore, due to its dimensions, state of preservation, type of coral reef, and the associated stratigraphic record, the Santa Pola coral reef is the best known example of this type of carbonate systems, in particular atoll-type coral reefs from the Messinian in the Bajo Segura basin. Finally, in the Santa Pola and Sorbas basins, a regional reference locality crops out containing a regional geological unit (*key locality* parameter, Table 3), the Terminal Carbonate

Table 2 Potential use criteria and scores in the FOPALI model

Potential use	
Degree of knowledge or investigation	×12.5
Unpublished	0
1–2 publications	1
3–5 publications	2
6–10 publications	3
11–15 publications	4
> 15 publications	5
Historic value	×12.5
After 1990	1
1990–1936	2
1935–1900	3
19th C.	4
17th C. or earlier	5
Didactic interest	×12.5
Fossils/geological elements or levels	1
Above items and palaeoenvironments/sedimentary environments or processes recorded	3
All of the above	5
Complementary value	×12.5
One element	1
2 elements	2
3 elements	3
4 elements	4
5 elements	5
Proximity to populations	×12.5
> 50 km	1
26–50 km	2
11–25 km	3
5–10 km	4
< 5 km	5
Number of inhabitants in the surrounding area	×12.5
< 10,000 (25 km ratio)	1
10,000–25,000	2
25,000–50,000	3
50,000–100,000	4
> 100,000	5
Visibility	×12.5
Nil	0
Levels or movable property	1
Levels and movable property	3
Levels, movable property, and signage	5
Accessibility	×12.5
Hard to access on foot	1
Hard to access by vehicle	2
Accessible by jeep	3
Accessible by car	4
Accessible by bus	5

Complex, a terminal Messinian unit on a Mediterranean scale, which records oolite and stromatolite facies (Esteban 1979; Roveri et al. 2009).

In the study area, the outcrops have suffered deterioration, with almost 15% (Corbí and Fierro 2016) of the geosite perimeter affected by human activities (mainly urbanized areas, industrial parks, mining sites), natural erosion (strong incised by the water network on the western side), and the widespread Quaternary development of carbonate crusts over the various geological units that constitute the coral reef. Thus, the *stage of preservation* can be considered positive with alterations (Table 3) since the sporadic deterioration does not decisively impact the site's value and interest. Nevertheless, the geo/sedimentary interpretation of the coral reef (as a large geological structure) has been affected in some places that could be considered representative viewpoints. It is worth mentioning that, in the FOPALI model, the *preservation status* parameter is divided into the *immovable property*, being the entire geological structure (the coral framework), and the *movable property*, the fossils (mainly corals of *Porites* genera, *Halimeda*, molds of gastropods and bivalves), and geological elements such as different types of sedimentary structures and representative stratigraphic levels. Therefore, the geosite's fossil content is in a good state of preservation (Table 3) since, although slightly deteriorated (the *Porites* assemblages are partially dissolved), their taxonomic characteristics are perfectly recognizable. Moreover, the site is a representative example of a large geosite where the main geological and palaeontological characteristics (sedimentary environments of a coral reef, megastructure of the crest, and fossil assemblages of the reef wall) are entirely interpretable at different scales of observation, especially emphasizing the panoramic views at a certain distance from the coast (excellent *Observational conditions*, Table 3).

Coral reef formations are relatively frequent in Neogene basins from the Betic Cordillera, such as the Bajo Segura basin (Soria et al. 2008a, b). However, in most cases, the carbonate systems recorded are fringing reefs close to the Messinian palaeocoast. The peculiarity of Santa Pola is that it records an atoll-type coral reef, and it is the only known example at a regional scale, in particular in the Valencian community (*Rarity* parameter IELIG model, Table 3). Note that the *rarity* parameter, which considers the "geological peculiarity" of the geosite according to the IELIG model, is reported (differing little in meaning) in the FOPALI model as *Abundance of similar outcrops*, in this case referring to the number of sites of the same age, fossil content, and/or geological characteristics with regard to a particular geographic setting.

Apart from the coral reef system itself, there are other geological and environmental elements of great interest

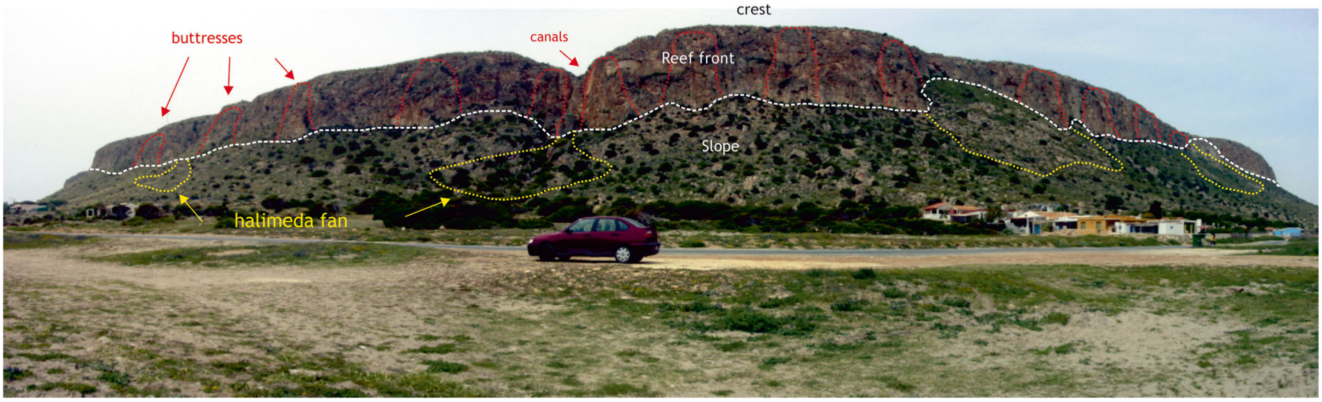

Fig. 4 Sedimentary environments of the reef complex

associated with and inside the perimeter of the geosite. These elements support the consideration of the setting surrounding the site as an area of great geodiversity with high geological interest from the point of view of biostratigraphy, lithostratigraphy, tectonics, and geomorphology (*Geological diversity* parameter: IELIG model; *Geological interest* parameter: FOPALI model). In this regard, the following considerations in the quantitative assessment should be noted: (a) the majority of the litostratigraphic units recorded at this geosite can be correlated with other sectors of the Bajo Segura basin; (b) the evolution of the Mediterranean sea-level during the Messinian and Pliocene constrains the evolution of the landscape; (c) the exceptionally well-preserved original geomorphology of the coral reef system; (d) the oolite and stromatolite facies (Terminal Carbonate Complex recording different sedimentary cycles; Esteban 1979) with levels containing particular euxinic fauna and small gastropods and bivalves of a certain biostratigraphic interest; (e) the Pliocene unit with abundant marine fossil content, rich in biostratigraphic markers of planktonic foraminifera (Lancis et al. 2004; Corbí and Soria 2016) in a stratigraphic section inside the Clot de Galvany area; (f) Pleistocene marine terraces or beaches (Goy and Zazo 1988) and their possible correlation with other coastal deposits of the Spanish coastline; (g) the Quaternary water network of geomorphological interest; (h) the wetlands of great environmental interest surrounding the geosite (e.g. Aymerich et al. 1991); (i) the sedimentary fill of Elche hollow by the Vinalopó and Segura sedimentary river

Fig. 5 Panoramic views of the reef wall in the foreground and the Alicante coastline in the background

Fig. 6 Branch-like morphologies of *Porites* in the reef wall

Fig. 7 Fallen blocks from the reef wall near the Marine Research Centre of Santa Pola (CIMAR, Santa Pola municipality, University of Alicante)

inputs; (j) the compressive tectonics (expressed by neotectonic activity, Alfaro et al. 2002), folding the terrain, which has had a significant role in shaping the landscape; (k) the marine oscillations of the Quaternary, conditioning the evolution of the landscape; and (l) the current and dune formations, starting at Carabassi beach (Arenales del Sol area) and extending northwards for several kilometres.

The *Paleodiversity* and *Paleodisparity* of the analysed site, parameters contemplated in the FOPALI model in terms of number of taxa and phyla recorded, is quite significant. This is evidenced by: (a) the abundant rhodophyta algal content in the oldest unit (Tortonian) recorded in the area; (b) the *Porites* colonies of different morphologies recorded (plate, branching, and massive), which are crusted by the activity of heterotrophic bacteria in certain parts of the reef complex, as described by Riding (2011) in similar Messinian coral reefs; (c) the thrombolite colonies cited by several authors in the reef complex (e.g. Feldmann and Mckenzie, 1997); (d) the *Halimeda* fans deposited under the slope reef (Esteban 1979); (e) red algae, vermetids, bryozooa, serpulids,

Fig. 8 Rock garden of the University of Alicante, where a representative block of the Santa Pola coral reef wall can be observed

decapod crustaceans, together with bivalves and gastropods cited by several authors in different parts of the geosite (e.g. Esteban et al., 1978; Müller 1984). Additionally, other geological units associated to the perimeter of the geosite record different taxons such as: (a) stromatolites of the Terminal Carbonate Complex (Esteban et al., 1978), with at least one genera, *Conophyton* (Feldmann and McKenzie 1997); (b) lumachella with a high diversity of mollusks in the Pliocene unit; and (c) a monospecific assemblage of *Glycimeris* recorded in the Quaternary marine terraces. Given this abundant palaeontological record, and based on our personal field data observations, certain specific interesting aspects regarding the taphonomic-genetic significance of the geosite can be listed: (a) the *Halimeda* deposits and their specific morphology in a context of fans deposited at the bottom of the reef slope; (b) the reef breccias recorded in the reef slope; (c) the relation between the *Porites* growth and the encrusted carbonate laminate; and (d) variations in the coral reef assemblages recorded related to depth, energy, and lighting conditions.

Finally, the FOPALI model also contemplates the *Utility of the outcrop to illustrate processes* and the *Scientific potential* (Table 3). The first parameter addresses whether a geosite can illustrate a particular geological process since this possible characteristic can involve added scientific value. In the case of the Santa Pola reef, the sedimentary process represented is a singularity in the context of the basin—an atoll-type coral reef. Only one equivalent example occurs inside the same basin, but it does not crop out, and is identified only in seismic lines (Torrevieja C-1 drill, Martínez del Olmo 2011). The second criteria (scientific potential) is given a maximum score (Table 3) since, despite the large number of researchers who have worked on the Santa Pola coral reef, much scientific work remains to be done. Most papers centre on sedimentology and petrology but, as Santisteban (1991) states, from the palaeontological point of view, there is still much to learn, in particular about the systematics and palaeoecology of the different fossil groups recorded (corals, algae, mollusk, foraminifera, etc.). The official palaeontological museums in the area that are permitted to hold and conserve the movable property lack significant collections from this geosite. The size of the outcrop is large, and the quantity of events and processes recorded will permit scientific research far into the future.

Potential Use Assessment

As presented in the "Methodology" section in the IELIG model, the potential use assessment comprises didactic and tourism-recreational criteria (see García-Cortés et al. 2014 for a detailed description of the methodology). According to these authors, the first six parameters of the didactic assessment correspond to the same ones used in the scientific assessment (Table 4). Consequently, there is no justification for

Table 3 Scientific assessment (score) of the Messinian atoll coral reef of Santa Pola, according to the Geological and Mining Institute of Spain (IELIG model: García Cortés et al. 2014) and the Paleontology Museum of Elche (FOPALI: Fierro 2015; Sánchez-Ferris 2015)

IELIG model (IGME)			FOPALI model (MUPE)		
Parameter/weight	Points	Partial value	Parameter (all the same weight)	Points	Average score (0–4)
Representativeness (30%)	4	120			3.2
Type locality (10%)	1	10	Type locality	2	
Scientific knowledge (15%)	4	60			
Preservation status (10%)	2	20	Preservation status of the immovable property	3	
			Preservation status of the movable property	3	
Observational conditions (10%)	4	40			
Rarity (15%)	2	30	Abundance of similar outcrops	2	
Geological diversity (10%)	4	40	Palaeodiversity/geodiversity	4	
			Palaeodisparity	4	
			Taphonomic/genetic interest	4	
			Geological interest	3	
			Utility to illustrate processes	3	
			Scientific potential	4	
Total	21	320	Total	32	
Normalized score (0–10)	8		Normalized score (0–10)	8	

using these parameters again since they have already been ranked in the previous section. As shown in Table 4, the study area receives the maximum score in most of the parameters for the IELIG model. Consequently, the *didactic assessment* has a high score (8.875 on a scale of 10).

The geosite is circular on a kilometric scale (north-south axis of 5 km and east-west axis of 6 km); therefore, it has the maximum score in the *Geosite size* parameter (Table 4). Santa Pola mountain is a natural promontory more than 140 m high directly in contact with the coastline, with numerous outcrops representative of the different sedimentary environments of the coral reef structure, especially the fossil record (mainly corals), some in life position. Therefore, it also receives the maximum score in the *Spectacular and beautiful landscape* parameter (Table 4). Santa Pola mountain is a common destination for didactic field trips in the undergraduate and graduate programs of various universities. In fact, there are several outreach papers published on the area (Estévez et al., 2004; Corbí and Yébenes 2012). The site is associated with other natural and cultural heritage places, which have interpretation centres offering field trips in the area. This proximity to protected environmental enclaves such as Tabarca island, Santa Pola, and the Clot de Galvany salt marshes illustrates its exceptional nature with a high *Didactic content* (Table 4). Among these three sites, Tabarca island deserves special mention for its excellent cultural and natural offering, including an exceptional landscape, diving, archaeology, gastronomy, and more (maximum score in the *Other heritage elements* parameter, Table 4). Additionally, the geosite has good logistics with good accessibility (*Logistics* and *Accessibility* parameters; Table 4) since it is in a geographic area that represents one of the most significant coastal settings in the province of Alicante. Moreover, even though the oriental domain is limited by the Mediterranean Sea, the area exceeds the 100,000 inhabitants per 50 km ratio (maximum value in the *Density of population* parameter; Table 4), determined by the presence of the sizable towns of Alicante, Elche, Santa Pola, Torrevieja, Orihuela, Elda, Petrel, and so on.

With regard to the tourism-recreational assessment of the IELIG methodology, seven of the total parameters have been used before, one of them in the scientific quantitative assessment and six in the didactic quantitative assessment. Thus, only four new parameters have been justified below. As shown in Table 4, the normalized score is 8.25, which is high but a little lower compared to the didactic score. The Santa Pola coral reef clearly illustrates the importance of geology to any audience, ranging from scientific experts to the general public. Consequently, this excellently preserved reef structure has a high *Outreach content* since the interpretation does not need any previous specialized knowledge, as evidenced by the numerous outreach activities in recent years. The most significant activity is the Geolodía initiative promoted by the Geological Society of Spain, for which the 2013 edition was on Santa Pola mountain (Aberasturi et al., 2013). Although

Table 4 Summary of the didactic and tourism-recreational assessment using the IELIG model

Potential use IELIG model					
Parameter/weight Didactic valuation	Points	Partial score	Parameter/weight Tourism-recreational valuation	Points	Partial score
Representativeness (5%)	4	20	Observational conditions (5%)	4	20
Key locality (5%)	1	5	Logistics (5%)	4	20
Observational conditions (5%)	2	10	Density of population (5%)	4	20
Status of preservation (5%)	4	20	Accessibility (10%)	4	40
Rarity (5%)	2	10	Size of geosite (15%)	4	60
Geological diversity (10%)	4	40	Other heritage elements (5%)	4	20
Didactic content (20%)	4	80	Spectacular or beautiful landscape (20%)	2	40
Logistics (15%)	4	60	Outreach content (15%)	4	60
Density of population (5%)	4	20	Potential to develop tourism and recreational activities (5%)	2	10
Accessibility (10%)	4	40	Proximity to recreational areas (5%)	4	20
Size of geosite (5%)	4	20	Socio-economic environment (10%)	2	20
Other heritage elements (5%)	4	20			
Spectacular or beautiful landscape (5%)	2	10			
Total	43	355	Total	38	330
Normalized score (0–10)		8.875	Normalized score (0–10)	8.25	

there are no tourism activities offered by specialized companies in the area, the place has tourism and recreational possibilities (*Potential to develop tourism and recreational activities* parameter; Table 4) since it has good logistics, accessibility, and number of inhabitants. The site has an exceptional location less than 500 m from various recreational spots such as beaches with infrastructure, camping grounds, and the downtown area of the tourist-destination city of Santa Pola (*Proximity to recreational areas* parameter; Table 4). Additionally, the *Socioeconomic context* is framed in the Comarca del Baix Vinalopó, an area with high unemployment and per capita incomes below the Valencian Community average, which is in turn lower than the overall average in Spain.

On the other hand, the FOPALI model considers (as shown in Table 2) that the *Degree of knowledge or research* is a parameter of socio-cultural interest, as pointed out by Morales (1996) and Castillo et al. (2001). Therefore, better scientific knowledge of a site involves more information and a higher potential use. As mentioned above, the degree of knowledge of the Santa Pola Messinian coral reef is very high (more than 15 publications). Moreover, the older geological publications correspond to the MAGNA geological map (Pignatelli et al. 1972), and to Dumas (1977), Esteban (1977), Esteban and Giner (1977), and Montenat (1977). Therefore, the *Historical value* parameter has a medium score (Table 5). Note that, in the FOPALI model, this parameter considers that a site has a higher potential use when it has more older publications or more older knowledge about the site. This model deems that any geological element can have didactic interest, and this interest is related to the presence of fossils, geological elements or levels, and the record of sedimentary environments and processes. In consequence, as argued above, the geological and sedimentary record of this geosite achieves the maximum score for the *Didactic interest* parameter.

The FOPALI model also contemplates the *Complementary value* of the site in the sense that the potential use is directly related to the presence of other significant sites of interest due to palaeontology, archaeology, landscape, geology, and logistics in the immediate setting. North of the site, on Los Colmenares mountain, there are significant outcrops scientifically studied that have served as a practice area for several undergraduate and graduate programs from the University of Alicante (eg Soria et al. 2005; Gamonal et al. 2017). In addition, close to the site, it is worth noting the El Cabezó Pliocene stratigraphic section, with abundant Pliocene marine fossils. Moreover, in the Santa Pola area, there are several archaeological sites, museums, and other locations of historical interest. Santa Pola mountain is surrounded by several nature parks with varying levels of protection, including the municipal nature area of Clot de Galvany, the Salinas de Santa Pola Nature Park (salt marshes), and Tabarca island with a marine reserve protected area. Finally, as mentioned above, the surrounding geology is of notable interest since the northern sector of the Bajo Segura basin records the palaeoceanographic changes related to the Messinian Salinity Crisis and current sedimentary environments of notable interest, such as Santa Pola salt marshes and El Hondo Nature Park. Consequently, the *Complementary value* parameter receives the maximum score in the FOPALI model (Table 5).

The next two parameters of the FOPALI model (*Proximity to populations* and *Number of inhabitants in the area*) also receive the maximum scores. The outcrop is less than 5 km from Santa Pola city, and the geographic area (25 km radius) has more than 100,000 inhabitants (Santa Pola, Elche, and Alicante towns).

Finally, the last parameters (*Visibility* and *Accessibility*) also receive the highest score (Table 5). The reef structure and the fossil content are perfectly visible and interpretable from different outcrops and panoramic views. Notably, interpretation to a non-specialized public requires the support of a geological guide and interpretative panels. In fact, some initiatives have already taken place (see Aberasturi et al., 2013, and interpretative panels in the lighthouse area), so the *Visibility* parameter has the maximum score (Table 5). Furthermore, accessibility is excellent (Table 5) since, as noted above, the area is a coastal tourism zone.

Table 5 Score for potential use considering the FOPALI model

Potential use (FOPALI model)		
Parameter	Points	Average value (0–5)
Degree of knowledge or investigation	5	4.6
Historic value	2	
Didactic interest	5	
Complementary value	5	
Proximity to populations	5	
Number of inhabitants in surrounding area	5	
Visibility	5	
Accessibility	5	
Total	37	
Normalized score (0–10)	9.2	

Discussion

This paper presents the quantitative assessment of the potential use of a geosite of high scientific relevance, using and testing two methodologies (IELIG and FOPALI). First, both methodologies have a high score for scientific assessment (8 out of a maximum of 10). This indicates, without a doubt, that the Santa Pola Messinian atoll coral reef (included in the Spanish Geosite Inventory of the Geological and Mining Institute of Spain) is a geosite of great scientific significance in the western Mediterranean. It is worth mentioning that the IELIG methodology for the scientific assessment considers "representativeness" to have a high weight in the scoring. Moreover, this methodology deems that a geosite with a score higher than 6.65 ("very high scientific level") must be included in the Spanish Geosite Inventory. Therefore, the main objective of the IELIG methodology is to find and complete the most significant geosites, which must include representative Spanish geological domains. In this regard, the FOPALI model for scientific assessment does not propose a specific score to establish the greater or lesser significance of a site. This is because the FOPALI model was developed to compare the results of different geo/palaeosites with each other, which allows the order of importance for subsequent management to be established. Therefore, although the final scores of the scientific assessment are exactly the same (8 using the two different methodologies), this does not imply that the models can be used interchangeably. Another point of difference between these models is the consideration of the fossil record in the scientific scoring. In terms of fossil content, the FOPALI model has considerably more scientific parameters (palaeodiversity, palaeodisparity, status of preservation of the movable property, taphonomic-genetic interest, and biostratigraphic interest). Consequently, the selection of a model also depends on the purpose of the assessment (finding and completing the Spanish Geosite Inventory versus comparing different sites with a significant fossil record in order to establish a ranking for their subsequent management). It is worth noting that, in the FOPALI model, approximately 50% of the parameters are assessed relatively (very low to very high), without establishing concrete data to justify the proposed score. This inevitably leads to an in-depth discussion justifying the proposed score. This could mean that the FOPALI model would demand better training and knowledge of the geological region on the part the team that is performing the quantitative assessment. Note that the FOPALI model was designed to be used in a shared subjectivity context, where different local sites must be assessed by a multidisciplinary team of specialists.

On the other hand, the results of the potential use assessment indicate that the Santa Pola Messinian coral reef is a geosite with significant features for social and cultural use. Both methodologies offer high scores (didactic score: 8.875 and tourism-recreational score: 8.25 in the IELIG model, and potential use score: 9.2 in the FOPALI model). The scant difference between the didactic and tourism-recreational scores (using the IELIG model) does not allow the preferential scoring of didactic use over tourism-recreational use in the geosite. Furthermore, although the differences in the scores using the two methodologies is low (6.4% between FOPALI and the average in the IELIG model), there are considerable differences between the two. The FOPALI model uses only eight parameters of the same weight, whereas the IELIG model uses 13 didactic parameters and 11 tourism-recreational parameters with different weights. Therefore, the IELIG model could be considered more exhaustive in terms of the number of parameters analysed, but this might lead to greater delays in completing the model. On the order hand, the FOPALI model, with less parameters to consider, seems to be more synthetic and consequently more efficient. In this regard, consider that this study reveals that, although the number of parameters are quite different in the two models, the final scores for the potential use assessment are practically the same.

The results of the quantitative assessment evidence the need to establish a series of management measures intended to preserve the geosite. The results show a significant, but not predominant, area (15%) of the geological structure affected by urban development and other anthropic impacts. To promote these management actions, it is also necessary to address the quantitative assessment of *Degradation risk* and the local geosite inventory, which are of crucial importance for the implementation of an integrated management plan, the next step in geoconservation strategy (Brilha 2016). The results also reveal that, although sporadic geological outreach activities and didactic texts have been carried out on the geosite (e.g. Aberasturi et al. 2013; Corbí and Yébenes, 2012), the geosite has more tourism and recreational potential to develop a broader outreach strategy. This outreach plan could contemplate establishing and promoting regular didactic field trips at different learning levels, interpretative panels at the significant panoramic views, and establishing an interpretative centre for the geosite.

Conclusions

From the research that has been performed, it is possible to conclude the following:

The first scientific quantitative assessment of the Messinian atoll coral reef of Santa Pola has been carried out based on two different methodologies, revealing, first, that the study area represents a significant geosite of scientific interest in SE Spain. Second, the quantitative assessment of potential use shows that the area offers significant opportunities for recreation in a coastal tourism area in the western Mediterranean. In addition, and considering the IELIG methodology, this geosite is representative of Spanish geoheritage since the scientific score obtained exceeds the specific score proposed to view it as representative of Spanish geological domains.

The two different methodologies (IELIG and FOPALI) used for the scientific quantitative assessment and potential use provide somewhat different perspectives. The IELIG model scientific assessment provides a high weight to the representativeness parameter as the goal of that model is to select the most representative geosites in Spain. In turn, the FOPALI model is designed to be used in a shared subjectivity context where the order of importance of different geosites in a territory with potential palaeontological content has to be established. Consequently, model selection depends on the objective and characteristics of the valuation. On the other hand, and considering the potential use assessment, the FOPALI model covers few criteria, which makes this model more synthetic and quicker to implement compared to the IELIG, which also separates the didactic evaluation from the tourism and recreational evaluation.

Further research is necessary on this geosite to extend our knowledge in order to establish the degradation risk and the inventory of local geosites of special relevance, which will constitute a solid base to develop a possible management strategy.

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References

Aberasturi A, Aguilera JC, Alfaro P, Amorós F, Andreu JM, Antón I, Ayanz J, Baeza JF, Belda A, Benavente D, Campos A, Cano M, Cañaveras JC, Castaneda R, Cerdán M, Corbí H, Cuevas J, de la Riva M, Díez D, Domènech C, Durá R, Espinosa C, Espinosa J, Estévez A, Falcés S, Fierro I, García-Sánchez E, García del Cura MA, Giannetti A, González A, González J, González M, Hernández JA, Izquierdo A, Jaúregui P, Jordá J, López-Cortés M, Macone L, Marín, JM, Martín Rojas I, Martínez Martínez J, Martínez MF, Martínez Y, Mas A, Meléndez I, Monteagudo F, Montiel V, Monzó JC, Navarro J, Oliver L, Ordóñez S, Ortega JM, Pacheco J, Palomo M, Parrés J, Pedauyé R, Piedecausa J, Pina JA, Pla C, Ramón J, Ramos A, Rodes JJ, Romero J, Rosa Cintas S, Sáez JF, Sánchez A, Sánchez-Fernández A, Sánchez MJ, Santos J, Soler JL, Soria JM, Tomás R, Vives F, Yébenes A (2013) Geolodía Alicante. Arrecife fósil de Santa Pola. Universidad de Alicante

Alexandrowicz Z, Kozlowski S (1999) From selected geosites to geodiversity conservation—Polish example of modern framework. In: Barettino D, Vallejo M, Gallego E (eds) Towards the balanced management and conservation of the geological heritage in the new millenium. Sociedad Geológica de España, Madrid, Spain, pp 40–44

Alfaro P, Delgado J, Estévez A, Soria JM, Yébenes A (2002) Onshore and offshore compressional tectonics in the eastern Betic Cordillera (SE Spain). Mar Geol 186:337–349

Alfaro P, Andreu JM, Estévez A, Tent-Manclús JE, Yébenes A (2004a) Geología de Alicante. AEPECT—University of Alicante

Alfaro P, Andreu JM, Estévez A, Pina JA., Yébenes A (2004b) Itinerarios geológicos por la provincia de Alicante para su utilización en Bachillerato. ICE—University of Alicante

Auernheimer C (1989) Mapa Geocientífico de la Provincia de Alicante. Generalitat Valenciana. Conselleria d'Administracó Pública

Aymerich FR et al (1991) Estudios ecológicos de los humedales costeros del sudeste Español. L. Inventario y Tipificación. In: Anales de Biología, vol 17, pp 153–163

Blanchon P (2011) Geomorphic zonation. In: Springer Netherlands (ed) Encyclopedia of modern coral reefs, pp 469–486

Brilha J (2016) Inventory and quantitative assessment of geosites and geodiversity sites: a review. Geoheritage 8(2):119–134

Brilha J, Andrade C, Azerêdo A, Barriga FJ, Cachão M, Couto H, Cunha PP, Crispim JA, Dantas P, Duarte LV, Freitas MC, Granja MH, Henriques MH, Henriques P, Lopes L, Madeira J, Matos JMX, Noronha F, Pais J, Piçarra J, Ramalho MM, Relvas JMRS, Ribeiro A, Santos A, Santos V, Terrinha P (2005) Definition of the Portuguese frameworks with international relevance as an input for the European geological heritage characterisation. Episodes 28(3): 177–186

Brilha J, Alcala L, Almeida A, Araújo A, Azerêdo A, Azevedo MR, Barriga F, Brum da Silveira A, Cabral J, Cachão M, Caetano P, Cobos A, Coke C, Couto H, Crispim J, Cunha PP, Dias R, Duarte LV, Dória A, Falé P, Ferreira N, Ferreira Soares A, Fonseca P, Galopim de Carvalho A, Gonçalves R, Granja H, Henriques MH, Kullberg JC, Kullberg MC, Legoinha P, Lima A, Lima E, Lopes L, Madeira J, Marques JF, Martins A, Martins R, Matos J, Medina J, Miranda R, Monteiro C, Moreira M, Moura D, Neto de Carvalho C, Noronha F, Nunes JC, Oliveira JT, Pais J, Pena dos Reis R, Pereira D, Pereira P, Pereira Z, Piçarra J, Pimentel N, Pinto de Jesus A, Prada S, Prego A, Ramalho L, Ramalho M, Ramalho R, Relvas J, Ribeiro A, Ribeiro MA, Rocha R, Sá A, Santos V, Sant'ovaia H, Sequeira A, Sousa M, Terrinha P, Valle Aguado B, Vaz N (2010) O inventário nacional do património geológico: abordagem metodológica e resultados. e-Terra 18(1):4

Calvet F, Zamarreño I, Trave A (1991) Los sistemas arrecifales del Mioceno superior en la cuenca de Alacant-Elche. Vic, I Congreso del Grupo Español del Terciario, Comunicaciones, pp. 52–54

Calvet F, Zamarreño I, Trave A (1994) The Upper Miocene reef system of the Alicante-Elche Basin (southeast Spain). Miocene reefs and carbonate platforms of the Mediterranean: Marseille, Interim Colloquium Regional Committee on Mediterranean Neogene Stratigraphy, p. 11

Calvet F, Zamarreño I, Vallés D (1996) Late Miocene reefs of the Alicante-Elche basin, southeast Spain. In: Models for carbonate stratigraphy from Miocene reef complexes of Mediterranean regions. Franseen EK, Esteban M, Ward WC, Rouchy JM. (eds.). Soc. Econ. Paleont. Mineral: 177–190

Caracuel JE, Corbí H, Giannetti A, Monaco P, Soria JM, Tent-Manclús JE, Yébenes A (2011) Paleoenvironmental changes during the late Miocene (Messinian)–Pliocene transition (Bajo Segura Basin, southeastern Spain): sedimentological and ichnological evidence. PALAIOS 26(12):754–766

Carcavilla L, Palacio J (2010) Geosites. Aportación española al patrimonio geológico mundial. Instituto Geológico y Minero de España, Madrid

Carcavilla L, López Martínez J, Durán Valsero JJ (2007) Patrimonio geológico y geodiversidad: investigación, conservación, gestión y relación con los espacios naturales protegidos. Cuadernos del Museo Geominero, No. 7. IGME, Madrid

Carcavilla L, Durán JJ, Garcia-Cortés A, López-Martinez J (2009) Geological heritage and geoconservation in Spain: past, present, and future. Geoheritage 1(2–4):75–91

Castillo C, Martín González E, Martín Oval M (2001) Valoración del Patrimonio Paleontológico de Canarias: propuesta de Puntos de Especial Interés Paleontológico. Revista Española de Paleontología, N° Extra XIV Jornadas de Paleontología, 105–115

Corbí H (2010) Los foraminíferos de la cuenca neógena del Bajo Segura (sureste de España): bioestratigrafía y cambios paleoambientales en relación con la crisis de salinidad del Mediterráneo. PhD Dissertation. University of Alicante

Corbí H (2017) El registro sedimentario de la Cuenca del Bajo Segura (SE España) a través del análisis de correspondencia: implicaciones paleoambientales. Estud Geol 73(2). https://doi.org/10.3989/egeol.42908.459

Corbí H, Fierro I (2016) El patrimonio geocientífico del arrecife Messiniense de Santa Pola (sureste de España: comparación entre dos modelos de valoración patrimonial). Geotemas 16

Corbí H, Soria JM (2016) Late Miocene–early Pliocene planktonic foraminifer event-stratigraphy of the Bajo Segura basin: a complete record of the western Mediterranean. Mar Pet Geol 77:1010–1027

Corbí H, Yébenes A (2010) El Arrecife fósil de Santa Pola. In: Senderos Geológicos: Guía de Lugares de Interés Geológico de la Provincia de Alicante, Diputación de Alicante

Corbí H, Yébenes A (2012) El arrecife de coral messiniense de Santa Pola, un lugar geológico de interés excepcional. In Santa Pola, arqueología y museo: Museos municipales en el MARQ, Fundación MARQ. pp. 96–101

Corbí H, Soria JM, Lancis C, Giannetti A, Tent-Manclús JE, Dinarès-Turell J (2016) Sedimentological and paleoenvironmental scenario before, during, and after the Messinian Salinity Crisis: the San Miguel de Salinas composite section (western Mediterranean). Mar Geol 379:246–266

Crespo-Blanc A, Urquí LC, Gómez JLS (2011) Geolodía: origen, presente y futuro. Enseñanza de las ciencias de la tierra: Revista de la Asociación Española para la Enseñanza de las Ciencias de la Tierra 19(1):95–103

Crespo-Blanc A, Alfaro P, Alonso-Zarza AM, Aurell M, Calonge A, Carcavilla L, Corral I (2016) Geolodía para un público numeroso: claves para su organización. Geogaceta 59:91–94

Duce S, Vila-Concejo A, Hamylton SM, Webster JM, Bruce E, Beaman RJ (2016) A morphometric assessment and classification of coral reef spur and groove morphology. Geomorphology 265:68–83

Dumas B (1977) Le Levant Espagnol. La genèse du relief. Tesis, Univ. Paris XII, C.N.R.S. pp. 520

Esteban M (1977) El arrecife de Santa Pola. In: 1er Seminario Práctico de Asociaciones Arrecifales Evaporíticas, Barcelona-Alacant. University of Barcelona, Faculty of Science, Department of Petrology and Geochemistry

Esteban M (1979) Significance of the Upper Miocene coral reefs of the western Mediterranean. Palaeogeogr Palaeoclimatol Palaeoecol 29: 169–188

Esteban M (1997) Guía de Campo del Arrecife Messiniense de Santa Pola. Ramón Salas y Mateu Esteban Barcelona.

Esteban MY, Giner J (1977) Field-guide to Santa Pola Reef. Messinian Seminar No. 3, Messinian Seminar, 3, Field Trip No. 5, pp. 23–30

Esteban M, Calvet F, Dabrio C, Barón A, Giner J, Pomar L, Salas R, Permanyer A (1978) Aberrant features of the Messinian coral reefs, Spain. Acta geológica hispánica 13(1):20–22

Esteban M, Braga JC, Martín JM, Santisteban C (1996) Western Mediterranean reef complexes. In: Franseen EK, Esteban M, Ward WC, Rouchy JM (eds) Models carbonate stratigraphy from Miocene reef complexes of Mediterranean regions, vol 5. Conc. Sediment. Paleont. Series, S.E.P.M., Tulsa, OK, USA, pp 55–72

Estévez A, Renard P, Yébenes A (2004) Itinerarios Geológicos por la Provincia de Alicante. 5. Cabo de Santa Pola e isla de Tabarca. In: Geología de Alicante, Alfaro, P. et al. (Eds), AEPCT and University of Alicante, Alicante, pp. 161–177

Feldmann M (1995) Controls on stromatolite formation: a comparative study of modern stromatolites from the Bahamas with Messinian examples from southeast Spain. Dissertation, Doktorat der

Naturwissenschaften, Zürich: Eidgenössischen Technischen Hochschule

Feldmann M, Mckenzie JA (1997) Messinian stromatolite-thrombolite associations, Santa Pola, SE Spain: an analogue for the Palaeozoic? Sedimentology 44:893–914

Fierro I (2015) Caracterización patrimonial de los depósitos laminados de la cuencas de Lorca. PhD dissertation, University of Miguel Hernández de Elche.

Gamonal A, Mansino S, Ruiz-Sánchez FJ, Crespo VD, Corbí H, Montoya P (2017) Sierra del Colmenar 1A, a new late Messinian (Late Miocene) locality in the Bajo Segura Basin (SE Spain): biostratigraphic and palaeoenvironmental implications. Hist Biol 1–12. https://doi.org/10.1080/08912963.2017.1297991

García-Cortés A, Rábano I, Locutura J, Bellido F, Fernández-Gianotti J, Martín-Serrano A, Quesada C, Barnolas A, Durán JJ (2001) First Spanish contribution to the Geosites Project list of the geological frameworks established by consensus. Episodes 24(2):79–92

García-Cortés A, Águeda Villar J, Palacio Suárez-Valgrande J, Salvador González CI (eds) (2008) Contextos geológicos españoles. Una aproximación al patrimonio geológico español de relevancia internacional. Instituto Geológico y Minero de España, Madrid

García-Cortés A, Carcavilla, Díaz-Martínez E, Vegas J (2014) Documento metodológico para la elaboración del inventario español de Lugares de Interés Geológico (IELIG). Instituto Geológico y Minero de España

GeoAlicante Research Team (2010) Senderos geológicos: Guía de lugares de interés geológico de la provincia de Alicante. In: Diputación de Alicante

Gischler E (2010) Indo-Pacific and Atlantic spurs and grooves revisited: the possible effects of different Holocene sea-level history, exposure, and reef accretion rate in the shallow fore reef. Facies 56(2):173–177

Goy JL, Zazo C (1988) Sequences of Quaternary marine levels in Elche Basin (eastern Betic Cordillera, Spain). Palaeogeogr Palaeoclimatol Palaeoecol 68(2):301–310

Grandgirard V (1999) Switzerland—the inventory of geotopes of national significance. In: Barettino D, Vallejo M, Gallego E (eds) Towards the balanced management and conservation of the geological heritage in the new millennium. Spain, Sociedad Geológica de España, Madrid, pp 234–236

Henriques MH, Pena dos Reis R, Brilha J, Mota TS (2011) Geoconservation as an emerging geoscience. Geoheritage 3(2):117–128

Hilario A, Mendia M, Monge-Ganuzas M, Fernández E, Vegas J, Belmonte A (2015) Patrimonio geológico y geoparques, avances de un camino para todos. Cuadernos del Museo Geominero 18. IGME, Madrid

Lancis C, Yébenes A, Flores JA, Tent-Manclús JE (2004) Precisiones bioestratigráficas y sedimentológicas sobre el Plioceno del norte de la Sierra de Santa Pola (Alicante). Geo-Temas 7:143–147

Lapo AV, Davydov VI, Pashkevich NG, Petrov VV, Vdovets MS (1993) Methodic principles of study of geological monuments of nature in Russia. Stratigraphy and Geological Correlations I(6):636–664

Martín JM, Braga JC, Riding R (1997) Late Miocene Halimeda algal-microbial segment reefs in the marginal Mediterranean Sorbas Basin, Spain. Sedimentology 44:441–456

Martínez del Olmo W (2011) El arrecife Messiniense del sondeo Torrevieja Marino C-1 desde las líneas sísmicas (SE de Epaña). Rev Soc Geol Esp 24(3–4):173–185

Martínez-Martínez J, Corbí H, Martin-Rojas I, Baeza-Carratalá JF, Giannetti A (2017) Stratigraphy, petrophysical characterization and 3D geological modelling of the historical quarry of Nueva Tabarca island (western Mediterranean): Implications on heritage conservation. Eng Geol https://doi.org/10.1016/j.enggeo.2017.10.014

Montenat M (1977) Les bassins néogènes et quaternaires du Levant d' Alicante à Murcie (Cordillères Bétiques orientales, Espagne). Stratigraphie, paléontologie et évolution dynamique. Docum. Lab. Géol. Fac. Sci. Lyon. 69

Montenat C (1990) Les bassins nèogenes du domaine bètique oriental (Espagne). Tectonique et sèdimentation dans un couloir de décrochement. Premiere partie: Ètude règionale. Documents et Travaux I.G.A.L. 12–13:1–392

Morales J (1996) El Patrimonio Paleontológico. Bases para su definición, estado actual y perspectivas futuras. In: El Patrimonio Geológico. Bases para su valoración, protección, conservación y utilización. Series Monográficas. Ministerio de Obras Públicas, Transporte y Medio Ambiente, pp. 39–51

Müller P (1984) Messinian and older decapods from the Mediterranean with description of two new species. Ann Géol Pays Hellén 32:25–34

Munk WH, Sargent MC (1954) Adjustment of Bikini Atoll to ocean waves. U.S. Geological Survey Professional Paper 260 C:275–280

Pignatelli R, Espejo JA, Crespo A (1972) Elche. Memoria y mapa geológico. Serie Magna. 1:50000. IGME, Madrid

Riding R (2011) Microbialites, stromatolites, and thrombolites. In Encyclopedia of Geobiology (pp. 635–654). Springer, Netherlands

Roveri M, Gennari R, Lugli S, Manzi V (2009) The terminal carbonate complex: the record of sea-level changes during the Messinian salinity crisis. GeoActa 8(63):63–67

Sáez Martínez P, Tent-Manclús JE, Jáuregui Eslava PJ, Estévez Rubio A, Benabdeloued NYB, Soler Llorens JL (2008) Aplicación de la sísmica de reflexión de alta resolución en el cabo de Santa Pola (Alicante). Geo-Temas 10:307–310

Sánchez-Ferris EJ (2015) Patrimonio geológico y paleontológico del término municipal de Elche: el Clot de Galvany y el Pantano. PhD dissertation, Cavanilles Institute of Biodiverstity and Evolutionary Biology, University of Valencia

Sánchez-Ferris EJ, Fierro I, Caracuel J, Marín Ferrer JM (2008) El modelo de valoración patrimonial del Proyecto FOPALI (Fósiles y Patrimonio de Alicante), Resúmenes de Comunicaciones XXIV Jornadas de Paleontología, 196

Santisteban C (1991) Guía de los arrecifes tortonienses de la cuenca de Fortuna (Murcia). Arrecife Víctor y Complejo de El Puerto. Revista Española de Paleontología :217–222

Soria JM, Caracuel JE, Yébenes A, Fernández J, Viseras C (2005) The stratigraphic record of the Messinian salinity crisis in the northern margin of the Bajo Segura Basin (SE Spain). Sediment Geol 179(3):225–247

Soria JM, Caracuel JE, Corbí H, Dinarès-Turell J, Lancis C, Tent-Manclús JE, Viseras C, Yébenes A (2008a) The Messinian–Early Pliocene stratigraphic record in the southern Bajo Segura Basin (Betic Cordillera, Spain). Implications for the Mediterranean salinity crisis. Sediment Geol 203:267–288

Soria JM, Caracuel JE, Corbí H, Dinarès-Turell J, Lancis C, Tent-Manclús JE, Yébenes A (2008b) The Bajo Segura Basin (SE Spain): implications for the Messinian salinity crisis in the Mediterranean margins. Stratigraphy 5:259–265

Soria JM, Giannetti A, Monaco P, Corbí H, García-Ramos D, Viseras C (2014) Cyclically-arranged, storm-controlled, prograding lithosomes in Messinian terrigenous shelves (Bajo Segura Basin, western Mediterranean). Sediment Geol 310:1–15

Vallés D (1985) Sedimentologia dels materials carbonatats del Miocè Superior a l'àrea de Sta. Pola (Alacant). M.S. Dissertation Thesis, University of Barcelona.

Vallés D (1986) Carbonate facies and depositional cycles in the upper Miocene of Santa Pola (Alicante, SE Spain). Rev Inv Geol: 45–66

Vegas J, Salazar A, Díaz-Martínez E, Marchán C (eds) (2013) Patrimonio geológico, un recurso para el desarrollo. Cuadernos del Museo Geominero, 15. IGME, Madrid

Wimbledon WA, Smith-Meyer S (2012) Geoheritage in Europe and its conservation. ProGEO, Oslo

Wimbledon WA, Benton MJ, Bevins RE, Black GP, Bridgland DR, Cleal CJ, Cooper RG, May VJ (1995) The development of a methodology for the selection of British geological sites for geoconservation: part 1. Mod Geol 20:159–202