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ORIGINAL ARTICLE

Conservation Status of the Listed Marine Fossil Sites in the Macizo de Anaga Biosphere Reserve (Tenerife, Canary Islands, Spain)

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Abstract
Owing to their characteristics and origins, palaeontological objects should indeed be considered within the scope of natural heritage, since they are natural items not arising from human action. However, in the Canary Islands, they are dependent on historical heritage legislation. The fossil record of the Canaries is exceptional and important, since it has been preserved in the context of active oceanic volcanic islands. The first fossils found in the archipelago are marine, belonging to the Jurassic period and they extend up to the Holocene. These fossil sites can be considered a non-renewable resource with a high risk of disappearance, which we should know how to conserve and protect. To this effect, the marine palaeontological sites of Anaga were assessed. Each of the sites were therefore rated in terms of scientific, sociocultural and socioeconomic value, as well as the damage risks, as part of the goal of documenting their exact present state. The heritage assessment applied 26 criteria, to maintain objectivity. Results show the high-risk level the palaeontological sites are under, as well as its general importance (they scored more than 1.9 out of 3 points). The fossil site of Tachero has the highest heritage value and stands out in most of the applied parameters. Results also contribute to the idea that palaeobiological conservation is useful to preserve current biodiversity. Aided by this assessment, the value of the palaeontological resources of the Canary Islands will help diversifying tourism and enhancing the sustainable economic growth of the archipelago.

Keywords Canarian fossils · Palaeontological heritage · Valuation · Cultural property · Fossil record

Introduction

The duality of natural heritage was approved at the General Conference of the United Nations Educational, Scientific and Cultural Organization (UNESCO) in its 1972 Paris meeting. This is formed of two highly related concepts: biodiversity (biotic component) and geodiversity (abiotic component). Both have been developing naturally through time, which lends them outstanding scientific and aesthetic value (Nieto et al. 2006). Thus, highly diverse areas are conserved for future generations to be able to enjoy and benefit from. In Spain, natural heritage is regulated by Law 42/2007 governing Natural Heritage and Biodiversity, a framework to which the regional autonomous and local administrations must adhere. However, Law 33/2015 has taken effect since 2015, modifying the previous one to improve some aspects of its application, especially regarding management of those protected areas.

Since fossils are evidence of past life forms registered in rocks, palaeontological heritage is normally included under geological heritage. Nevertheless, in Spain, it is classified as historical heritage, and though some autonomous governments have decided to legislate palaeontological activities much more specifically, in the Canary Islands, regulation of the legal system of palaeontological assets is framed within the Law 4/1999, 15th March, on the Historical Heritage of the Canary Islands (Article 2; http://www.gobiernodecanarias.

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org/libroazul/pdf/29052.pdf). The Canarian fossil record can be considered of great importance and exceptional value, since its fossils have been laid down in a context of active volcanic oceanic islands. In consequence, the heritage deserving inclusion in this record must take into account the growth and development processes of each volcanic complex.

The earliest known fossils of the Canary Islands are marine and belong to the Jurassic, they extend discontinuously up to the Holocene. Even though the fossil record is different on each of the islands, the oldest fossils on the island of Tenerife belong to the Pleistocene (Martín González 2009). Sand-dune palaeoenvironments contain the most continuous fossil record, but mostly consisting of terrestrial fauna like gastropods (Castillo et al. 2006) and insect trace fossils (La Roche et al. 2014; De León Hernández 2018), together with reptiles, mammals and birds (García-Talavera Casañas et al. 1989). Our study area lies in the Macizo (massif) de Anaga, a peninsula constituting the northeast end of Tenerife, where there are a great variety of palaeontological sites along the coastline (García-Talavera Casañas et al. 1989; Castillo et al. 1999).

The first inventory of Canary palaeontological sites was published by Francisco García-Talavera Casañas and collaborators in 1989, who compiled all the known information for Tenerife. Later, Castillo et al. (2001) carried out a heritage assessment of every site known up to then and proposed 41 of them as points of special interest (‘Puntos de Especial Interés Paleontológico’ or PEIP). Two of these are located in Anaga: Tachero and Igueste de San Andrés, the latter also being recently proposed as a Site of Cultural Interest (BIC; Padrón 2015). Besides its geological history, Anaga stands out for its ratio of endemic flora, for instance the laurel forest plant communities, which appeared in the Mediterranean basin before the Quaternary Glaciations. It is the only place in the Canaries where every tree species of this formation is represented (Rivas Martínez et al. 1993). In addition, there is a great diversity of fauna including fishes, reptiles, birds and mammals (Martín et al. 1998). However, the most numerous and noteworthy animals in Anaga are the insects: more than 1910 inventoried species, 512 of which live exclusively in the archipelago, about 329 species are endemic to the island and 95 of them are exclusive to this area of Tenerife (Canarian Biodiversity Data bank; http://www.biodiversidadcanarias.es/atlantis/common/index.jsf). On 9th, June 2015, the Macizo de Anaga was declared a Biosphere Reserve during the annual UNESCO meeting, further protecting a total of 48,727 ha.

Management of the palaeontological heritage in the Autonomous Community of the Canary Islands is framed under two laws: Law 4/1999, 15th March, on the Historical Heritage of the Canary Islands, where this heritage is recognised as special (Chapter II, Article 72), though its protection regime is not specified. According to this law, the palaeontological heritage of the Canaries consists of moveable and immovable assets (fossils and sites, respectively) that include representative elements of the evolution of all living beings, as well as geological and palaeoenvironmental components related to human culture. Due to their value, the conservation concept of Palaeontological Zone was proposed, to preserve the most important heritage assets. These would be fossil sites or places with a fossil record of irreplaceable or outstanding materials related to chronology or palaeoenvironment. They should be declared as Bienes de Interés Cultural (BIC, Cultural Property, CP from now on), while the rest of the assets would be classified in other CP categories (movable property, monuments, etc.). It is also contemplated that the palaeontological sites of the Canaries must be identified and located by means of island palaeontological charts. Moreover, Chapter I, Articles 18–24, discusses immovable ‘bound-in’ property (fossils). When a property or plot of land has collections or movable heritage highly related to its own history, it is also at the same time legally implicated by its declaration as CP. Said movable property is indivisible from the immovable property, it can thus only be transferred or alienated together with the latter. And Law 12/1994, 19th December, on Natural Areas of the Canary Islands (Chapter II, Article 12), valid until 15th May, 2000, and currently regulated by the Legislative Decree 1/2000, 8th May, in which the ‘combined text of the spatial planning laws of the Canary Islands and natural areas’ was approved, where the concept of Natural Monument is defined. Nowadays, it is also regulated by Law 4/2017, 13th July, on the Soil and Protected Natural Areas of the Canary Islands. It was declared binding by the Canary Government, following an application for public information and exposure in the municipalities involved, with a previous report from the Island Board of Protected Natural Areas.

Knowing the palaeobiological information of a region is essential to understand long-term dynamics in its ecosystems (Barnosky et al. 2017), and it is also essential in conservation planning, from a species level to an ecosystem level, as it is a unique and direct source of information (Jablonski and Shubin 2015).

The main aim of this paper is to evaluate and assess the conservation state of the palaeontological marine fossil sites in the Macizo de Anaga Biosphere Reserve, as an initiative to encourage knowledge of the palaeontological heritage of the Canary Islands, as well as its preservation of unique palaeobiological information and social use.

Geographical and Geological Context

Six palaeontological sites located in the Macizo de Anaga Biosphere Reserve have been analysed (Fig. 1a, b, Table 1): (1) Punta del Hidalgo, (2) Tachero, (3) El Draguillo and (4) Las Palmas de Anaga on the northern coast of the mountain range; and (5) Las Teresitas and (6) Igueste de San Andrés on the southern face.

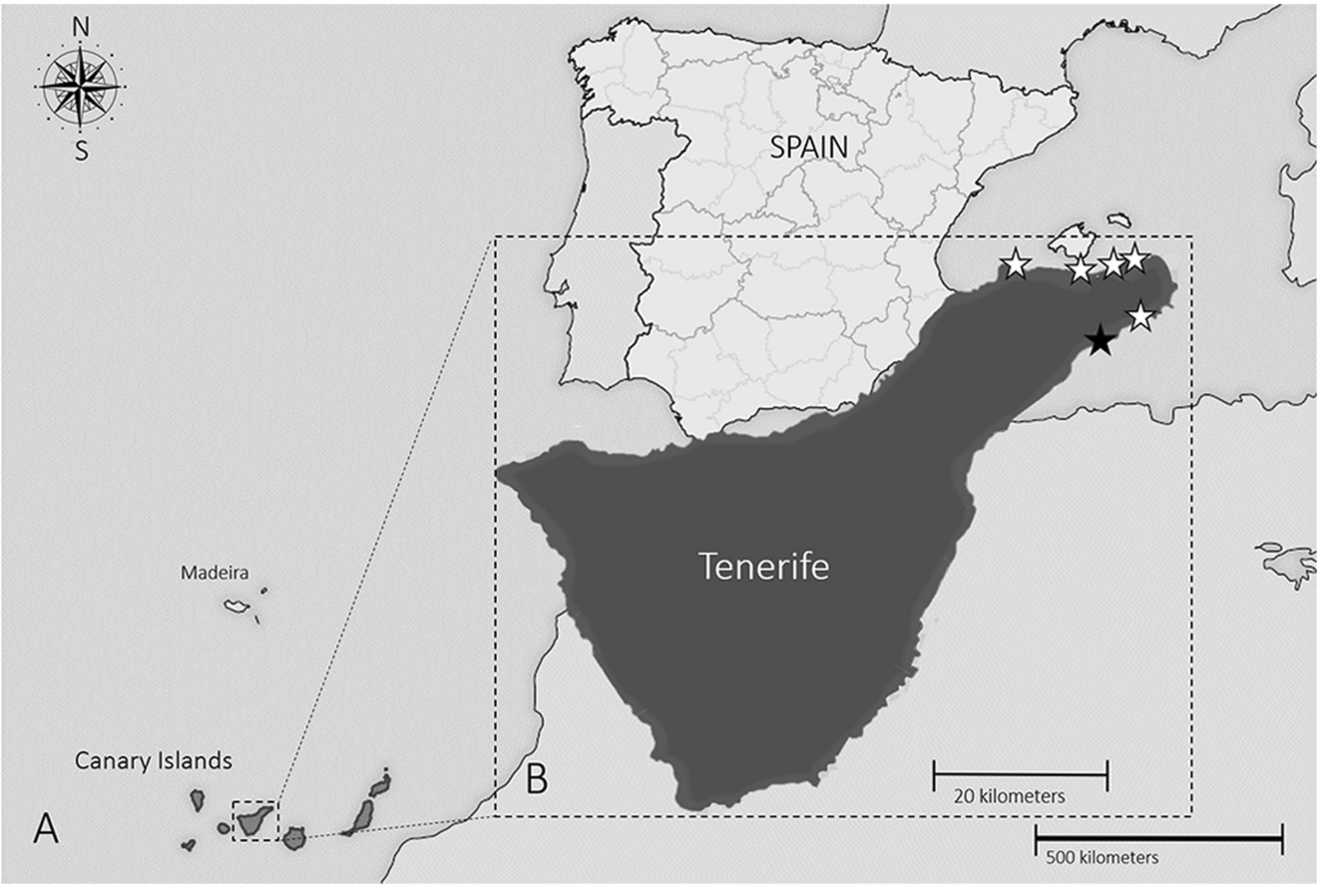

Fig. 1 Geographic location of the Canary Islands (**a**) and the relative position of the Anaga fossil sites (**b**)

They are located in two municipalities, San Cristóbal de La Laguna and Santa Cruz de Tenerife. Areas immediately surrounding the palaeontological sites have been inhabited since aboriginal times but nowadays only sparsely.

Anaga's palaeontological sites belong to a geological context of oceanic islands seemingly bound to a volcanic hot spot (Carracedo et al. 1998; Carracedo and Troll 2016). The volcanic complex of Tenerife rose from the ocean floor at more than 3000 m below sea level, through three types of activity (Seisdedos Santos 2008) (Fig. 2):

1. The mountain ranges of Anaga, Teno and Adeje are the oldest structures of the island (Miocene-Pliocene).
2. The mountain systems, which are linear rift edifices as result of multiple eruptions that form three major ridges

Table 1 Palaeontological fossil sites analysed in this study

Name	Locality	Age	Height	Type	Marine fauna
La Punta del Hidalgo	La Punta del Hidalgo	Upper Pleistocene	0–1 m	Coastal marine deposits	Warm water fauna
Tachero	Taganana	Neo-Tyrrhenian	1–2 m	Raised beach	Warm water fauna
Costa del Draguillo	El Draguillo	Pleistocene	3–10 m	Coastal marine deposits	Warm water fauna
Playa de Las Palmas	Las Palmas de Anaga	Neo-Tyrrhenian	1–2 m	Raised beach	No presence of warm water fauna
Igueste de San Andrés	Igueste de San Andrés, Santa Cruz	Tyrrhenian	0.5 m	Coastal marine deposits with continental materials	Warm water fauna
Las Teresitas	San Andrés	Tyrrhenian	2 m	Pebble and black sand raised beach	Warm water fauna

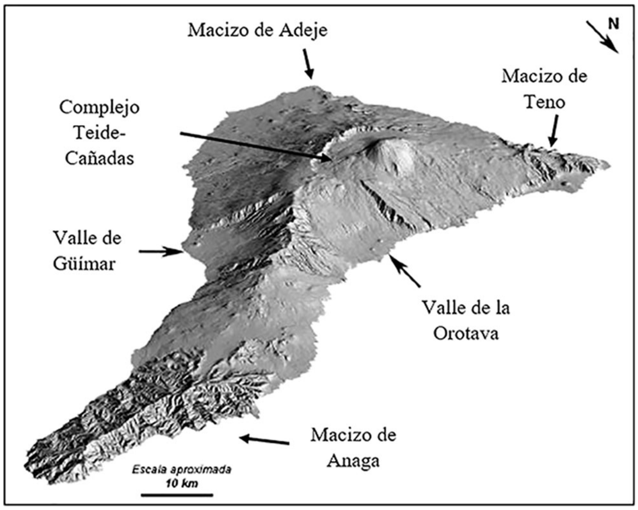

Fig. 2 The main geological features of Tenerife. Modified from Seisdedos Santos 2008

connecting the ancient mountain ranges with the more recent central edifice (Pliocene).

3. The Teide-Cañadas complex, which is the most complicated structure in the archipelago, located in the middle of the island, as a result of the successive spatial and temporal overlap of cones, stratovolcanoes, tephra, domes and lava flows (Pliocene–present).

The first phase of Tenerife's volcanic activity resulted in three independent small islands, which would now be the southern mountain range of Adeje and Torre del Conde (the oldest rocks, 8–12 My), followed by that of Teno in the northwest (formed between 5 and 7 My) and lastly, Anaga (around 3–6 My), where the fossil sites are situated (Punta Anaga geological sheet: 1097a; 1:50,000). The second formation phase is characterised by a pause in Anaga's volcanic activity for approximately 1 million years. Around 3.5 My after the agents of erosion modified the area, the activity in the central part of the island became reactivated, resulting in the Cañadas complex. In this area, another even higher stratovolcano would later be formed (2500 m high approx.; the Cañadas II complex). That volcanic activity was very explosive, and all the rest of the island was affected by it. Finally, around 170,000 years ago, the Cañadas II volcanic complex underwent a series of massive landslides that resulted in two semi-calderas, the Orotava and Güímar valleys. Not long after, the present Teide-Pico Viejo complex erupted, at present reaching 3718 m.

The fossil sites can be found in the Anaga massif, a shield-like mountain range at the northeast end of Tenerife. It was formed in at least two phases, one older and of indeterminate age that formed the Taganana arc where diverse fragmentary materials appear, crossed by dikes and plutonic rocks (Fig. 3). The second phase was the shield phase, in which lavas and basaltic tephra became stacked up in a 100-m succession crossed by dikes and phonolitic domes, nowadays highly eroded. Recently, some authors consider the Taganana arc as an amphitheatre-like remnant originated by the landslide of part of the material from Anaga northwards into the sea (Guillou et al. 2004).

The fossil sites studied show the following sedimentary and palaeontological characteristics:

- Punta del Hidalgo. 28R371032E 3161894N (Fig. 4a)

Sea-eroded platform from the upper Pleistocene with sand-like sediments interpreted as a sedimentary beach. Shells and marine gastropod fossils of extant species can be found (Fig. 5e, f).

- Tachero. 28R380276E 3160462N (Fig. 4b)

Outstanding fossil site, with gravel-like sediments of a shallow marine environment from the upper Pleistocene. Earlier studies (García-Talavera Casañas et al. 1978) identified more than 100 species of molluscs, characterised by 20% Senegalese fauna that no longer live in the Canary Islands.

- El Draguillo. 28R384745E 3162118N (Fig. 4c)

At the base of this fossil site, there is a level made up of a marine platform sediment. There is an erosive discontinuity in the upper part of this level, over which there are gravel and sand-like sediments that aid in identifying the sedimentary environments of the ancient beaches. There are varied shell and marine gastropod remains and echinoderms (Fig. 5c), as well as serpulids, which are evidence of a high-energy depositional environment (Kröchert et al. 2008) (Fig. 5d).

- Playa de Las Palmas de Anaga. 28R385896E 3162540N (Fig. 4d)

It shows a 2-m thick layer with rounded pebbles and boulders of various sizes and black sand from the Neo-Tyrrhenian (García-Talavera Casañas et al. 1989). We found warm climate marine fossils with a high percentage of species that no longer live in the Canary Islands, among which the following stand out: *Nucella plessisi* (Lecointre, 1852), *Planaxis lineatus* (da Costa, 1778), *Brachidontes puniceus* (Gmelin, 1791), *Codokia eburnean* (Gmelin, 1791) and *Patella candei* (D'Orbigny, 1840) (García-Talavera Casañas et al. 1989).

- Igueste de San Andrés. 28R387756E 3155593N (Fig. 4e)

Located on the southeastern coast of Anaga, it is the first case of marine deposits from the Pleistocene of

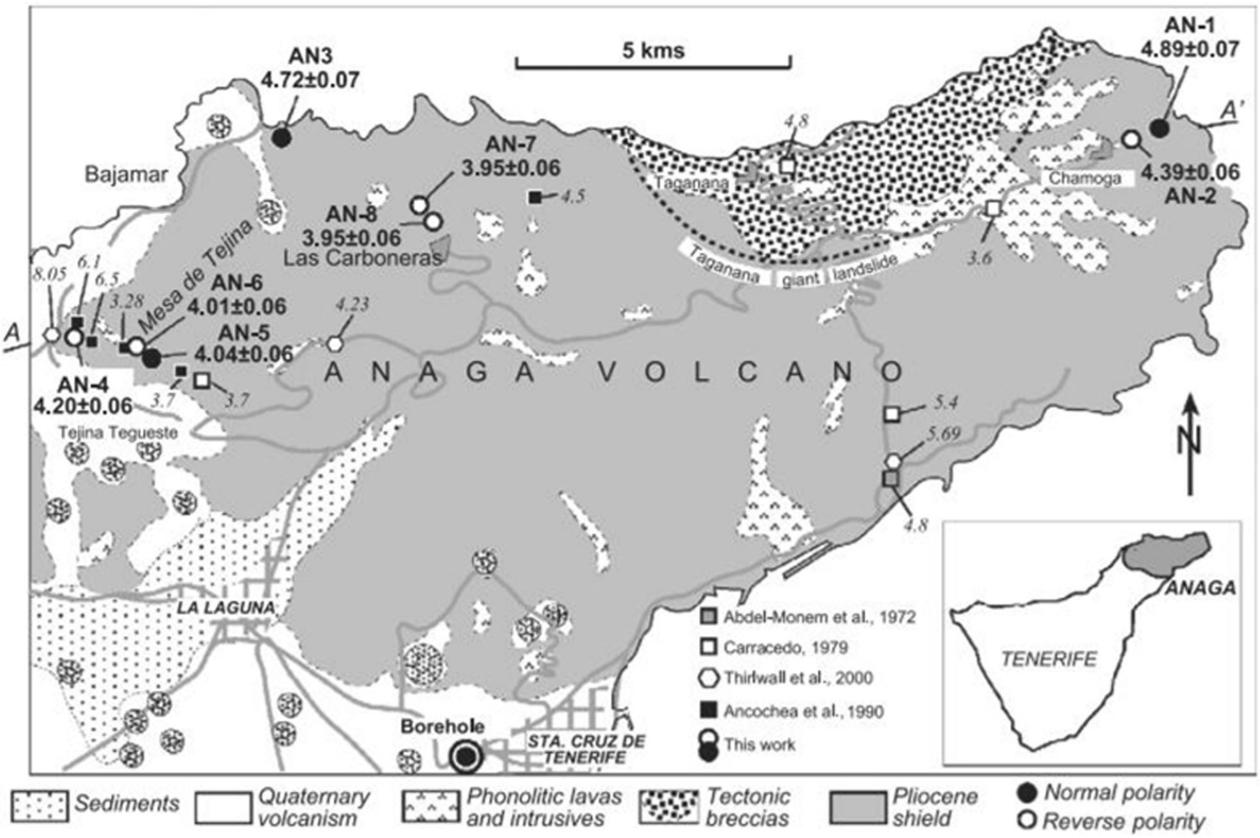

Fig. 3 Geological map of Anaga. From Guillou et al. 2004

Tenerife that contain warm water fauna (Fig. 5a). The basaltic volcanic levels from the older Anaga complex are covered by terrestrial deposits (Fig. 5b). Fragments of different bivalve species and marine gastropods were found between the conglomerates. The quantity of marine organism fossils proves the high-energy depositional conditions of the environment (Zazo et al. 2003a, b; Kröchert et al. 2008).

- Las Teresitas*. 28R384448E 3154237N

This fossil site is nowadays destroyed. It was a pebble and black sand raised beach assigned to the Tyrrhenian (Quaternary). García-Talavera Casañas et al. (1989) suggested it was an accumulation of dead molluscs after storms. The species he found there were *Persististrombus latus* (Gmelin, 1791), *Conus pulcher* (Lightfoot, 1786), *P. candei* (D'Orbigny, 1840), *Patella ulyssiponensis aspera* (Röding, 1798), *Cardium tuberculatum* (Linnaeus, 1758), *Callista chione* (Linnaeus, 1758), *Vermetus* spp. (Daudin, 1800), *Charonia variegata* (Lamarck, 1816), *Bolinus cornutus* (Linnaeus, 1758), *Stramonita haemastoma* (Linnaeus, 1767), *Pecten jacobeus* (Linnaeus, 1758) and *Lithophaga aristata* (Dillwyn, 1817) (Fig. 4f).

Materials and Methods

The digital practical guide for assessment of the Canary Island Palaeontological Heritage was followed, as elaborated by the Animal Biology Department of the University of La Laguna (from the work of Morales 1996; Castillo et al. 1999, 2000 and 2001; Cendrero 2000, Meléndez and Molina 2001, and the IGME's IELIG (Inventario Español de Lugares de Interés Geológico). This heritage assessment applied 26 valorisation standards, for each island, in order to establish their level of interest or importance by comparison with the other marine deposits on Tenerife catalogued by García-Talavera Casañas et al. (1989).

A summary sheet was compiled with the criteria applied (Table 2). Some were redefined because most of the fossils found were marine in origin. The data used to complete the summary came from a literature search of books and papers, visits to the Museum of Natural Sciences of Tenerife: 'Museo de la Naturaleza y el Hombre', and field work at the studied fossil sites.

The weighting of each different criteria was established on a scale of values from 0 to 3 as follows: 0, no interest (or non-existent risk of damage); 1, low

Fig. 4 Images of the palaeontological fossil sites studied in this work. **a** La Punta del Hidalgo, visible fossil site in light colour over basaltic flow. **b** Tachero, with high rhodolith concentration. **c** El Draguillo, thin layer of the fossil site. **d** Las Palmas de Anaga, aerial view of the fossil site. **e** Igueste de San Andrés, landslides covering part of the fossil site. **f** Las Teresitas (currently destroyed; left; before the touristic development plans; right; after)

interest (or low risk of damage); 2, high interest (or moderate risk of damage); and 3, exceptional interest (or high risk of damage); see the matrix included.

Nevertheless, there are other methodologies in order to assess the heritage of a specific area. Most of them follow the same principles: a series of parameters, which are given a score depending on its value, belonging to different categories based on the purpose of the assessment (scientific, educational, touristic or cultural value). The methodology designed by the Geological and Mining Institute of Spain (IGME), although it focuses on the selection of the most significant geosites in Spain, is based on eighteen different parameters with different weights, which then they are given a score based on a scale from 0 to 4. These criteria are split up in three categories, scientific interest, educational interest and tourist interest (García-Cortés et al. 2014). Another methodology, very similar to the last one, was developed by the Palaeontological Museum of Elche (MUPE), but in this case, the parameters are equally weighted (Corbí et al. 2018). Other methodologies use a GIS-based project, to represent and manage the detailed spatial data and associated databases of such sites (Mampel et al. 2009). As mentioned before, the

Fig. 5 Some fossils found in the Biosphere Reserve of Anaga. **a** *Persististrombus latus* enables correlation between Atlantic-Mediterranean basin (Igueste de San Andrés). **b** Land snails (*Hemicycla* sp.) found between two marine deposits from Igueste de San Andrés. **c** Sea urchin (Costa del Draguillo) with colour evidences. **d** *Patella* sp. in stacking pattern (Costa del Draguillo). **e** Articulate bivalve (Punta del Hidalgo). **f** Diverse marine gastropods in nesting pattern (Punta del Hidalgo)

assessment of this project was conducted at island level, so the relevance of these criteria was established in comparison with other marine deposits on Tenerife.

Results

The results of the heritage assessment are described below and summarised in Table 2. Scientific, socioeconomic and sociocultural criteria were evaluated, along with the damage risks, describing the final status of each of the sites.

Scientific Assessment

Type of Fossils

The presence of unusual or rare fossil species was evaluated, in addition to those that are endemic. Among the fossils found, there are algae, rhodophytes, and bivalve and gastropod molluscs. A detailed list of the species found at every palaeontological site can be found in Tables 4 to 8 in the supplementary data. There are a large number of important species such as the marine gastropod *Persististrombus latus* (Gmelin, 1792), a warm water gastropod (Fig. 5a), typical of Jandían deposits on Fuerteventura (Castillo et al. 2001). This species was only found in the nowadays destroyed deposit at Las Teresitas (García-Talavera Casañas et al. 1989) and at Igueste de San Andrés.

Taxa Diversity

Bibliographic information on every palaeontological site has been compiled (García-Talavera Casañas et al. 1989; Zazo et al. 2003a, b; Kröchert et al. 2008; Padrón 2015; Martín-González et al. 2016) in order to establish this parameter. Additionally, the database of the Museo de la Naturaleza y el Hombre de Tenerife was consulted, as well as the online database WoRMs. Some of these fossils can be seen in Fig. 5 (see Tables 4 to 8 in the supplementary data).

Table 2 Results for each criterion or parameter assessed. Red is for the lowest value (0), orange and yellow mean intermediate values (1; orange, 2; yellow) and green is to indicate the highest value (3)

	Punta del Hidalgo	Tachero	El Draguillo	Las Palmas de Anaga	Igueste de San Andrés
			Scientific assessment		
Types of fossil	2	3	2	2	2
Taxa diversity	2	3	3	2	3
Fossil condition	1	1	1	1	1
Taphonomic information	2	3	2	2	2
Biostratigraphic information	1	1	2	3	3
Type locality	0	3	0	0	0
Geological interest	2	3	2	3	2
Palaeoclimatological interest	1	3	2	2	2
Geomorphological value	3	3	3	3	3
Palaeontological site abundance	2	3	2	2	3
			Socioeconomic assessment		
Touristic potential	1	3	2	2	2
			Sociocultural assessment		
Educational interest	3	3	3	3	3
Geographic situation	3	2	2	2	3
Historical value	2	2	2	2	1
Level of knowledge	3	3	3	2	3
Complementary value	3	3	3	3	3
Mean	1.93	2.5	2.125	2.125	2.25
			Damage risk		
Site length or fragility	3	3	3	2	2
Accessibility	3	3	2	2	3
Buildings	3	2	0	0	3
Mining value	0	0	0	0	0
Roads and tracks	3	0	0	0	3
Landfills	3	3	0	0	3
Collecting/trading/plundering	2	2	1	1	1
Natural erosion	3	3	3	3	3
Mean	2.5	2	1.125	1	2.25

Fossil Condition

Due to the location of all the palaeontological sites (near the coast, most of them between 0 and 2 m, see Table 1), almost all of the fossils suffer taphonomic alteration processes like abrasion and are highly eroded (Fig. 5a, b). This means that during the biostratinomic phase, they underwent taphonomic alterations such as bioerosion, bioimmuration or disarticulation. The remains have therefore become resedimentated. Those sites with every fossil fragmented receive a lower rating, and those with no taphonomic alterations whatsoever, a higher one.

Taphonomic Information

Most specimens identified at the sites and those conserved in the museum are not from methodical stratigraphic excavations, but the exact locations are known, allowing retrospective identification of their respective layer. The justification for this criterion is that the better we know how the fossils were gathered and preserved at the site, the more complete the palaeoenvironmental reconstructions will be (Fig. 5c–f).

Biostratigraphic Information

Those sites that contain guide fossils that permit greater geographical and chronological correlations receive the highest ratings, even at an overall level. Among Anaga sites, there are a few fossils that correlate with other palaeontological sites from the Upper Pleistocene of the Canary Islands and the Mediterranean Basin (Fig. 5a), justifying the highest ratings.

Type Locality

This parameter has the lowest rating possible at every site because no new species to science have been described in any of them except Tachero. There are only two possible points to be awarded: either there have been new species described there, or not.

Geological Interest

The Anaga palaeontological sites are very important geologically speaking, they thus receive the two highest ratings. This parameter was defined bearing in mind three traits: volcanic stratigraphy, tectonics and geodiversity. The sites are located on the basal remains of a volcanic edifice, and a wide range of geological formations can be recognised. Consequently, the sites in which these three traits are most outstanding receive the highest ratings.

Palaeoclimatological Interest

This refers to climate events belonging to one particular cycle, which is in turn recognised by identifying a fossil or group of fossils acting as indicator of some palaeoclimatological trait. For example, the presence of *Conus ermineus* (Born, 1778), *Spondylus senegalesis* (Schreibers, 1793) and *Strombus bubonius* = *Persististrombus latus* indicates warm water conditions. Therefore, the more events detected, the higher the rating. Owing to this information and previous studies, three climatic events can be reconstructed in the Quaternary of Tenerife. In fact, five marine levels can be observed on the island, which represent six glacial-interglacial transitions during the middle Pleistocene and Holocene (Zazo et al. 2003a).

Geomorphological Value

This criterion is defined as the importance of the geological processes that acted upon the palaeontological site materials. Three types of geomorphology are highlighted: (a) dynamic, (b) climatic, and (c) structural. Those sites in which all three traits are present are rated higher than those that have only two or one.

Palaeontological Site Abundance

The main goal of applying this criterion is to guarantee the conservation of at least one site representative of each type in the archipelago, because the geological history of each one of them is unique and independent. Bearing this in mind, this criterion will give more importance to sites that are unique on the island, since they will be the only evidence of that specific ecosystem there.

Socioeconomic Assessment

Touristic Potential

Tourism is the most important source of permanent income in the Canary Islands. Therefore, this rating is defined by the type of visitors the palaeontological site may have, since not all will find such a visit interesting. This in turn also depends on their cultural level, since interpreting fossils and sedimentary deposits is so not easy for the general public. Thus, the rating will be higher when a site can be visited and understood by the people with an average cultural level, and lower when only specialists would be interested.

Sociocultural Assessment

Educational Interest

This criterion is defined by whether the site could be used as a tool for teaching science subjects, specifically Biology and Geology. For a high rating, the different fossils and sediments have to be easily recognisable.

Geographic Location

This refers to the distance from urban centres to the sites. The higher ratings are for closeness to towns or villages, to allow easier access to the site for everyone interested.

Historical Value

This rating is governed by whether the site has been referred to in chronicles of scientific and natural history. The first palaeontological records for Tenerife are from the twentieth century, when Óscar Burchard identified tortoise remains on the southern slope of the island as chelonian, described beforehand by Ahl in 1926 (Martín González 2009). Only the Igueste de San Andrés site was studied by Zazo et al. after 2000 (Zazo et al. 2003a, b), so the remaining sites get the second highest rating.

Level of Current Knowledge About the Sites

This is rated on the number of bibliographical references to each palaeontological site and/or fossil collections assembled from them. A higher number of scientific papers indicates more importance at a scientific or educational level, providing more information to interpret and disseminate.

Complementary Value

All of the sites in this study are located in a Biosphere Reserve zone (June 2015), which adds to their high value in a complementary sense. The palaeontological information from these sites will in turn increase the value of the protected area.

Damage Risks

Certain of the above parameters fall within this concept, however, they will be analysed from the perspective of the risk they involve for each site. These are necessary to plan a possible intervention or to set up conservation measures.

Site Length or Fragility

The shorter the size/length of the site, the higher will be the risk of it disappearing. These sites vary between small areas (such as Tachero, measuring only a few metres, see Fig. 4) and average-sized areas (such as Igueste, 100 m long). However, none of them can be seen entirely at once due to frequent cliff landslides or wave action covering them with pebbles.

Accessibility

Sites with easy access have a higher risk of damage. Particularly, those located near any settlement are constantly visited by many people, so if they are unaware of its presence, they will probably not take care of the place as they should. Four categories were used in this criterion: not located, inaccessible, difficult access and accessible.

Buildings

As in Accessibility, sites with a large number of buildings will have higher risks. To evaluate this, four categories were used: no building(s), building(s) planned or developable, building(s) in process or building(s) established.

Mining Value

The palaeontological sites are not located in suitable terrain for these practices, so all sites receive the minimum rating.

Communication Routes

Only the most inaccessible sites are free of this danger (El Draguillo, Las Palmas de Anaga). In this case, four categories were used, but only two of them were observed (non-existent or affected).

Landfills

None of the sites has ever been used as a legal landfill. However, there is a great deal of rubbish along their length. Besides this, the sites located near villages (La Punta del Hidalgo and Igueste de San Andrés) have sewage outfalls a few metres from the shore (Fig. 6), which worsen the conservation of the palaeontological sites. Like the previous criteria, only two categories were observed (non-existent or affected).

Collecting/Trading/Plundering

There was no evidence of site-robbing during the fieldwork. However, this is not easy to identify because most remains are in small-sized rocks (50–200 mm) and anyone could take them without others noticing. Sites with the easiest access are more vulnerable to this kind of behaviour.

Natural Erosion

Erosion has affected and currently affects all the palaeontological sites. Closeness to the shore and the periodically torrential rainfall typical of Anaga increase this rating for all of them.

Discussion

Considering the origin and character of fossils and palaeontological sites, their protection should be included within the concept of Natural Heritage. Regulating such palaeontological objects as Historical Heritage causes many problems in the Canary Islands. Although the regional legislation does separate palaeontological heritage, it does not specify special articles for its management. In general, it could be said to be ambiguous and contradictory, and does not contemplate entrusting palaeontology specialists with the guardianship of this heritage, but archaeologists.

The use of heritage assessment criteria, as used in this study, is useful to apply for various actions from the administration regarding palaeontological resources, to ensure their conservation and the progress of scientific knowledge

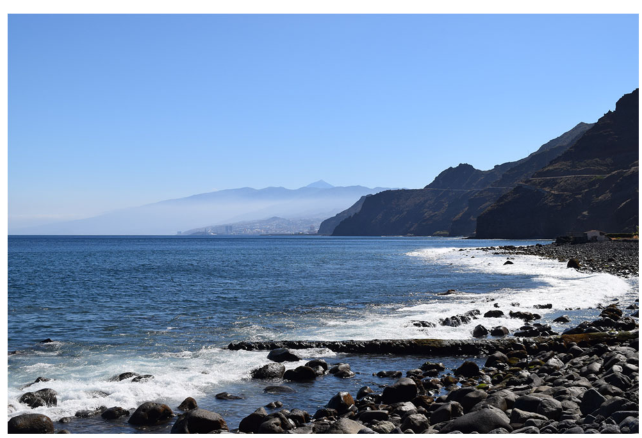

Fig. 6 View from Igueste de San Andrés fossil site where a sewage outfall can be seen, an important damage risk. Also, the Teide can be seen from the fossil site, so the touristic value of the site is increased

(Castillo et al. 1999; Alcalá 2002; Martín González 2009; Cobos 2004; Jablonski and Shubin 2015; among others). According to these criteria, the importance of the Anaga palaeontological sites is evident not only regionally, but at national and international level. Regarding scientific criteria, the number of endemic species (more than 60%) of different phyla, classes and orders are striking and the fossils are mostly conserved complete with some taphonomic alterations. Furthermore, each site belongs to different time periods (García-Talavera Casañas et al. 1989), they contain guide fossils that permit local chronological correlations (García-Talavera Casañas et al. 1989; Zazo et al. 2003a) and they are of great geological, palaeoclimatological and geomorphological importance. The Canaries only have one type of palaeontological site per island, although these do not seem so important compared to other sites nationally or globally, the volcanic origin of the islands cannot be forgotten. This lends a particularly high value to any kind of fossil site found on them, due to the rarity of sedimentary rocks there.

With respect to sociocultural and socioeconomic criteria, the closeness to the population, accessibility and precise knowledge of the sites would make them perfect places for the application and interpretation of palaeontological information. This can and must be conveyed to the population, who are mostly unaware of the great variety of fossils on the islands, in particular the Canary Islanders themselves. Moreover, being situated in such a protected area as a Biosphere Reserve should facilitate their management and conservation. We cannot forget that the archipelago is visited by more than 12 million tourists per year (Padrón 2015).

Unfortunately, as seen in the damage risks, Anaga's sites are subject to a huge risk of demise. Their surrounding area, geographical situation, buildings, expoliation, use as rubble tips and especially the erosion to which they are increasingly exposed from storms and rising sea levels, all put them in a dangerous situation. Without prompt action, they will disappear forever. For this reason, it is extremely urgent to take action to at least record this heritage, with measures such as photogrammetry. Not every site is the same, and obviously, not all are subjected to the same dangers (Tables 2 and 3). The Tachero and Igueste sites have the same vulnerability level because their situations are very similar. Easy access, buildings, road access and sea erosion have led these sites very close to disappearing. Sadly, the Las Teresitas site aptly serves as an example of mismanagement; we can only learn from previous mistakes and try not to cause or permit other similar losses.

The palaeontological heritage in the Canary Islands constitutes a very important part of the fossil record, not only due to the recent origin of the archipelago, but because of its importance at an international level. It holds in its record every vertebrate group except for amphibians (Castillo et al. 1996), and so, the study of this fossil record will answer questions such as colonisation, evolution and extinction events on islands where the ecosystems have suffered rapid changes.

Similar fossil sites to those assessed in this work (fauna and climatic conditions) have been published (Ávila et al. 2015, 2016, 2018), achieving the definition of Paleopark, as is the case of the volcanic island of Santa María, Azores.

In the United States of America, it has been many years since they consider the palaeobiological information in order to take conservation decisions in any ecosystem (Barnosky et al. 2017), and it is not any less important in an island ecosystem (Nogué et al. 2017). It is clear that palaeontological records should be used to apply any management and conservation strategies, whether focused on recovering, eliminating or accepting novel ecosystems. The results in this work will help improve the knowledge of the Anaga Biosphere Reserve area and, thus, supply more palaeontological information in order to make decisions in the reserve.

As explained before, most of Anaga's sites have great tourist potential, because they can generally be visited by any type of public. However, before anyone could visit them, it is necessary to follow some basic requirements. They can include ensuring safe access for visitors, signs warning them of possible landslides, and cleaning the sites to make the visit a pleasant experience. Information panels explaining each site and its surroundings could be installed. The cost of such infrastructure should be assimilated by local administrations in collaboration with the Man and Biosphere programme (UNESCO), which designates and manages biosphere reserves.

Conclusions

Every palaeontological site in the Macizo de Anaga Biosphere Reserve is a non-renewable resource in great risk of disappearing. We must discover more about each site to preserve and protect them, since they are part of the Earth's

Table 3 Fossil site vulnerability, from lowest (left) to highest (right)

Fossil site vulnerability				
Lowest vulnerability		Highest vulnerability		
El Draguillo	Tachero	Igueste de San Andrés	La Punta del Hidalgo	Las Palmas de Anaga

history about which we still have so much to learn. The information obtained from heritage assessment constitutes a starting point to propose these palaeontological fossil sites should be classified as cultural property ('Bien de Interés Cultural'). Action is necessary at each site, prioritised according to its vulnerability.

The results presented in this work show the high damage risk each fossil site is under, as well as the great palaeontological information that can be extracted from them, thus, making them, important fossil sites among the island of Tenerife. However, there is still a lot of work to do in those fossil sites.

The scientific, sociocultural, socioeconomic and damage-risk assessments for each of the sites with palaeontological resources of marine origin in Anaga have thus been presented, also recording their current state. Conservation of such resources will aid in diversification of tourism towards quality and thus contribute to sustainable economic growth in the archipelago.

The unique fossil record of the Canary Islands (including palaeobiological, taphonomic, biostratigraphic and cultural information) should be used to take decisions about biodiversity conservation in a global context and apply protection figures such as 'PaleoParks'.

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References

Alcalá L (2002) Valoración patrimonial de los yacimientos de vertebrados de la Fosa de Teruel. In: El patrimonio paleontológico de Teruel (G. Meléndez Hevia & E. Peñalver Mollá, Coords.). Instituto de Estudios Turolenses, pp 227–242

Ávila SP, Melo C, Silva L, Ramalho RS, Quartau R, Hipólito A, Cordeiro R, Rebelo AC, Madeira P, Rovere A, Hearty PJ, Henriques D, Marques da Silva C, de Frias Martins AM, Zazo C (2015) A review of the MIS 5e highstand deposits from Santa Maria Island (Azores, NE Atlantic): palaeobiodiversity, palaeoecology and palaeobiogeography. Quat Sci Rev 114:126–148. https://doi.org/10.1016/j.quascirev.2015.02.012

Ávila SP, Melo C, Berning B, Cordeiro R, Landau B, da Silva CM (2016) Persististrombus coronatus (Mollusca: Strombidae) in the lower Pliocene of Santa Maria Island (Azores, NE Atlantic): paleoecology, paleoclimatology and paleobiogeographic implications. Palaeogeogr Palaeoclimatol Palaeoecol 441:912–923

Ávila SP, Ramalho RS, Habermann JM, Titschack J (2018) The marine fossil record at Santa Maria Island (Azores). In: Volcanoes of the Azores. Springer, Berlin, pp 155–196

Barnosky AD, Hadly EA, Gonzalez P, Head J, Polly PD, Lawing AM, Eronen JT, Ackerly DD, Alex K, Biber E, Blois J, Brashares J, Ceballos G, Davis E, Dietl GP, Dirzo R, Doremus H, Fortelius M, Greene HW, Hellman J, Hickler T, Jackson ST, Kemp M, Koch PL, Kremen C, Lindsey EL, Looy C, Marshall CR, Mendenhall C, Mulch A, Mychajliw AM, Nowak C, Ramakrishnan U, Schnitzler J, Das Shrestha K, Solari K, Stegner L, Allison Stegner M, Chr Stenseth N, Wake MH, Zhang Z (2017) Merging paleobiology with conservation biology to guide the future of terrestrial ecosystems. Science 355:eaah4787

Carracedo JC, Day S, Guillou H, Badiola ER, Canas JA, Torrado FP (1998) Hotspot volcanism close to a passive continental margin: the Canary Islands. Geological Magazine, 135(5), 591–604.

Carracedo JC, Troll VR (2016) The geology of the Canary Islands. Elsevier, Amsterdam

Castillo C, López M, Martín M, Rando JC (1996) La paleontología de vertebrados en Canarias. Rev Esp Palentol N° Extraordinario, 237–247. ISSN 0213-6937

Castillo C, Castillo J, Coello JJ, Martín E, Martín M, Méndez A (2009) La Tutela del Patrimonio Paleontológico en Canarias. Valoración general. Coloquios de Paleontología, Universidad Complutense, Madrid 50:9–21

Castillo C, Martín González E, Hernández Z (2000) Criterios para la valoración del patrimonio paleontológico de Canarias. Geotemas 1(2):305–308

Castillo C, Martín-González E, Martín Oval M (2001) Valoración del patrimonio paleontológico de Canarias: propuesta de Puntos de Especial Interés Paleontológico. Rev Esp Paleont n° extr, 105–115

Castillo C, Yanes Y, Alonso MR, Ibañez M (2006) Napaeus lajaensis sp. nov.(Gastropoda: Pulmonata: Enidae) from a quaternary Aeolian deposit of northeast Tenerife, Canary Islands. Zootaxa 1307(1): 41–53

Cendrero A (2000) Patrimonio geológico; diagnóstico, clasificación y valoración. Jornadas sobre patrimonio geológico y desarrollo sostenible, pp 23–37

Cobos A (2004) Valoración patrimonial de los yacimientos de icnitas de dinosaurio de la provincia de Teruel. Geogaceta 36:191–194

Corbí H, Fierro I, Aberasturi A, Sánchez Ferris EJ (2018) Potential use of a significant scientific geosite: the Messinian coral reef of Santa Pola (SE Spain). Geoheritage 10(3):427–441

De León Hernández V (2018) Paleobiología de trazas fósiles de insecto en Tenerife. Trabajo de Fin de Grado de la Facultad de Biología de la Universidad de La Laguna. 31pp

García-Cortés A, Carcavilla L, 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 Madrid, version, 12, 61.

García-Talavera Casañas F, Kardas SJ, Richards HG (1978) Quaternary marine mollusks from Tenerife, Canary Islands. The Nautilus (3): 97–102

García-Talavera Casañas F, Paredes Gíl R, Martín Oval M (1989) Catálogo Inventario de Yacimientos Paleontológicos. Provincia de Santa Cruz de Tenerife. In. Est. Canarios, La Laguna, Tenerife 76 pp

Guillou H, Carracedo JC, Paris R, Torrado FJP (2004) Implications for the early shield-stage evolution of Tenerife from K/Ar ages and magnetic stratigraphy. Earth Planet Sci Lett 222(2):599–614

Jablonski D, Shubin NH (2015) The future of the fossil record: paleontology in the 21st century. Proc Natl Acad Sci 112(16):4852–4858

Kröchert J, Maurer H, Buchner E (2008) Fossil beaches as evidence for significant uplift of Tenerife, Canary Islands. J Afr Earth Sci 51(4): 220–234

La Roche F, Genise JF, Castillo C, Quesada ML, García-Gotera CM, De la Nuez J (2014) Fossil bee cells from the Canary Islands. Ichnotaxonomy, palaeobiology and palaeoenvironments of Palmiraichnus castellanosi. Palaeogeogr Palaeoclimatol Palaeoecol 409:249–264

Mampel L, Cobos A, Alcalá L, Luque L, Royo-Torres R (2009) An integrated system of heritage management applied to dinosaur sites in Teruel (Aragón, Spain). Geoheritage 1(2–4):53–73

Martín M, Atoche P, Castillo C, Criado C (1998) La microfauna del yacimiento de 'El Bebedero'(Teguise, Lanzarote): implicaciones

paleobiológicas, históricas y medioambientales. XIV Jornadas de Paleontología, 121–124.
Martín González E (2009) El legado paleontológico de nuestras islas: un patrimonio a conservar. En: Misterios de la Gea: descifrando los enigmas ocultos en rocas, gases, agua y fuego. In: Afonso-Carrillo J (ed) Actas IV Semana Científica Telesforo Bravo. Instituto de Estudios Hispánicos de Canarias, Tenerife, pp 99–124
Martín-González E, González-Rodríguez A, Vera-Peláez JL, Francisco Lozano MC, Castillo Ruiz C (2016) Asociaciones de moluscos de los depósitos litorales de Pleistoceno superior de Tenerife (Islas Canarias, España). Vieraea: Folia Scientarum Biologicarum Canariensium, (44):87–106
Meléndez G, Molina A (2001) Patrimonio paleontológico en España: una aproximación somera, El. Enseñanza de las Ciencias de la Tierra, 9(2):160–172.
Morales J (1996) El Patrimonio Paleontológico. Bases para su definición, estado actual y perspectivas futuras. MOPTMA. Serie Monografías: El Patrimonio Geológico. Bases para su valoración, protección, conservación y utilización, págs, pp 39–52
Nieto L, Pérez-Lorente F, Guillén-Mondejar F, Díaz-Martínez E (2006) ¿Es necesaria una ley para la protección de la Geodiversidad y el Patrimonio Geológico? Algunas consideraciones. In: García-Ramos J, Jiménez-Sánchez M, Piñuela-Domínguez M, Fernández C (eds) 35 págsResúmenes de la VII Reunión de la Comisión de Patrimonio Geológico. Museo del Jurásico de Asturias, Colunga
Nogué S, de Nascimento L, Froyd CA, Wilmshurst JM, de Boer EJ, Coffey EE, ... Willis KJ (2017) Island biodiversity conservation needs palaeoecology. Nature ecology & evolution, 1(7):181.
Padrón E (2015) Valoración Patrimonial de los recursos paleontológicos de Tenerife: Yacimiento de Igueste de San Andrés. Trabajo de Fin de Grado de la Facultad de Biología de la Universidad de La Laguna, San Cristóbal de La Laguna
Rivas Martínez S, dela Torre W, Del Arco Aguilar MJ, Rodríguez Delgado O, de Paz PLP, García Gallo A, Acebes Ginovés JR, Díaz González TE, Fernández González F (1993) Las comunidades vegetales de la Isla de Tenerife (Islas Canarias). Itinera Geobotanica 7:169–374
Seisdedos Santos J (2008) Los grandes paleo-deslizamientos de Güimar y La Orotava (Tenerife): análisis geológico, mecanismos de inestabilidad y modelización geomecánica. Tesis doctoral, Universidad Complutense de Madrid, 521 pp
Zazo C, Goy JL, Hillaire-Marcel C, González Delgado JA, Soler V, Ghaleb B, Dabrio CJ (2003a) Registro de los cambios del nivel del mar durante el Cuaternario en las Islas Canarias Occidentales (Tenerife y La Palma). Estud Geol 59:133–144
Zazo C, Goy JL, Dabrio CJ, Bardají T, Hillaire-Marcel C, Ghaleb B, González Delgado JA, Soler V (2003b) Pleistocene raised marine terraces of Spanish Mediterranean and Atlantic coasts: records of coastal uplift, sea-level highstands and climate changes. Mar Geol 194:103–133

Further reading

http://visor.grafcan.es/visorweb_v3/
http://www.gobiernodecanarias.org/istac/
Guía práctica digital para la gestión del patrimonio cultural y natural. Universidad de La Laguna (contenido del aula virtual de la asignatura de Paleontología)
http://www.idecanarias.es/resources/GEOLOGICO/TF_LITO_unidades_geologicas.pdf
http://www.marinespecies.org/