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THE IMPRESSIVE COASTAL CLIFFS OF CAPO CACCIA IN NORTH-WESTERN SARDINIA (ITALY). OUTLINES FOR LANDSLIDE RISK ASSESSMENT

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Abstract: The coast between Capo Caccia and Punta Giglio promontories in the north-west of Sardinia is characterized by high cliffs extended for more than 37 km. Here the cliffs are interrupted only by the beach of Porto Conte and small rocky coves. They are made almost entirely of Mesozoic limestone rocks, which generally give rise to high coasts with different contexts of development and risk. Only a short section in the northernmost portion is given by marly-clayey rocks of Triassic. They form a highly unstable cliff, due to the presence of interbedded gypsum. This coast is formed by the recent flooding of the bay of Porto Conte, because in the past it was a large karst valley. In fact, the landscape of this area is dominated by karst landforms and a dense underground hydrographic network. The most famous karst caves are located in the continental part but, recently, the submerged caves have become an attractive location for divers. Finally, it is clear that the whole cliff of Capo Caccia and Punta Giglio has undergone a rapid evolution, driven by intense fracturing of the limestone as well as the deep and dense karstic process. This rapid evolution is demonstrated by the numerous landslides occurred along the coast and the absence/scarcity of sea level notches. In order to identify areas at risk of landslides along this coast so impressive, moreover corresponding to a Marine Protected Area and in part to a Regional Park, was made a GIS-based map of geomorphological risk related to the instability of the cliff. Such map shows four classes of hazard determined by the detection of fractures recognized only along the face of the cliffs and landslide processes occurring along it.

Key words: Cliffed coast, Landslide Risk, GIS-based mapping, north-western Sardinia

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INTRODUCTION

In the world high and rocky coasts often represent one of the most popular tourist destinations. For this reason, some stretches of rocky coasts are protected by

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specific institutions of safeguard (natural reserves, parks and recently geoparks). However, this coastal type is subject to the convergence of continental and marine processes, which could cause changes rather quickly. In order to prevent damage and loss of this natural heritage, as well as to establish best practices for conservation and sustainable use of marine and coastal area, an assessment of the main conditions of instability is required. These conditions were evaluated along the cliffs of Capo Caccia and Punta Giglio in north-western Sardinia (Figure 1), set in the homonymous Marine Natural Reserve and in the Regional Park of Porto Conte.

Figure 1. Location of the study area

CLIFFS IN STUDY

Along the coast of Alghero municipality in north-western Sardinia develops a coastline dominated by the presence of an impressive limestone cliff. It extends for more than 37 km, interrupted only by the Mugoni beach situated in the deep bay of Porto Conte (Figure 2a) and other small rocky coves. This bay is enclosed by the promontories of Capo Caccia and Punta Giglio, which jut out into the sea, to the west and to the east respectively, making the coastal outline very suggestive (Figure 2b). This outline in plan can be considered as a ria that is a dry valley formed in karst environment (Federici et al., 1999), and then progressively flooded by the sea during the last stage of the Pleistocene climate change (Ginesu, 2004). This evolution has been confirmed by numerous archaeological findings, which have allowed us to reconstruct the ancient shorelines of the bay (Carboni & Ginesu, 2006). For example, during the Neolithic (6.000 years b.p.) the bay was a large coastal lake closed by sandy ridges. Instead, at the time of the maximum emersion, owing to the wide diffusion of limestone, the landscape was modelled by karst processes, as well as by a dense underground water flow network, made up by conduits and caves. Such network did not allowed a real surface drainage network, as can be seen even today. In fact, the Nurra, that is the Coastal Geotectonic Region where the cliff in study is located, lacks virtually of true rivers, while along its coast are well known numerous limestone springs.

The cliff (Figure 2b) is mainly made of Mesozoic carbonate rocks, which are in the immediate hinterland in tectonic contact with the Palaeozoic crystalline basement that is extensively exhibited on the Argentiera massif. Such massif forms the northern boundary of the area. In particular, the eastern side of the promontory of Capo Caccia is mostly given by dolomitic limestone of the Lower Cretaceous, while the western side is formed of dolomitic limestone of the Jurassic (Cherchi et al., 2010). In the northern section of the same headland marl, clay and gypsum of the Middle Triassic outcrop on the cliff (Posenato, 2002). Instead, the coast of the promontory of Punta Giglio, further to the east of the former cape, is exclusively formed of dolomitic limestone of the Jurassic (Cherchi et al., 2010).

Figure 2a. The inner part of the bay of Porto Conte between Capo Caccia and Punta Giglio

Figure 2b. The long promontory of Capo Caccia characterized by a continuous cliff mainly formed of Mesozoic limestone

Both promontories are affected by large faults with prevailingly orientation N-S and E-W, this makes their rock mass particularly rough. However, the greater fragility is found in the section in which outcrop middle Triassic deposits, not only for the intrinsic geomechanical characteristics, but for the proximity to the faults zone, that distinguish the contact with the Palaeozoic basement.

The height of the cliff is highly variable in the investigated coast between 320 m at Punta Cristallo (Figure 3) where middle Triassic rocks outcrop, and 200 m in front of the islands of Piana and Foradada. Continuing the analysis along the headland, the cliff rises up to 250 m at Punta della Pegna and then around Capo Caccia reduces to only 100 m. On the eastern side of the head, at the mouth of the bay of Porto Conte, it is much lower with values of about 50-60 m, while into the bay it rapidly decrease markedly in height and slope. Finally, the cliff at Punta Giglio, which close the bay to the east, does not exceed 100 m. Further to the east towards Alghero, the coastline became rapidly low. In the bay of Porto Conte the shore platform gently slope into the sea and join the base of the cliff, contrarily on the cliff, outer of the bay, where the deeper isobaths rapidly reach the cliff.

According to the characteristics recognized inside the bay of Porto Conte the presence of a shore platform adjacent to the cliffs permit to classify them as the type A of Sunamura (1992). Instead, most of the cliffs, exposed to the west and hence out of the bay, show a vertical walls like to the plunging type of Sunamura (1992), which continue below the sea level up to an average depth of 20 m. Because of this depth, the origin of most of these cliffs is due to tectonics, instead the other ones is attributed to the modelling in continental environment that occurred during the last lowering of the sea level of the Pleistocene.

At the base of these cliffs, as can be observed in underwater surveys, there are blocks of limestone, sometimes of considerable size. These blocks confirm the various phenomena of falling and toppling occurred along the western cliff. Such phenomena are classified as single event, easily defined in its shape, or as a multitude of events, complex expression of a widespread instability. The rock falls and topples are favoured by both the considerable fracturing and the prevailing waves from NW.

However, the erosion of the cliff, rather than being imputed to the energy of waves, must be attributed to the effectiveness of the karst processes. Such processes are mainly developed along the layer discontinuities or along the fractures, especially if open. This determines the isolation of blocks with the consequent collapse of large portions of the cliff. The rate of retreat of the cliffs of Capo Caccia is estimated at an average of few centimetres per century (4-5 cm/century), even if the northernmost area close to Punta Cristallo (Figure 3) the rate can be considered triple.

Figure 3. The cliff of Punta Cristallo more than 300 m high

In different rock promontory almost exclusively inside the bay of Porto Conte a sea-level indicator, as a notch, has been found recurrently at some 3.8 m a.s.l. More precisely its altitude decreases from east (Punta Giglio) to west (Capo Caccia) across different rock promontories isolating little coves from an eustatic elevation of 5.5 to 3.45 m. According to several authors these differences is related to the accommodation by faults occurred along this continental margin (Antonioli et al., 2007).

Also in the western side of the promontory of Capo Caccia the +3,8 notch is preserved (Figure 4), but only inside the Neptune cave. Therefore, the preservation of such marker is due to the protection to the erosion as well as to the decreasing energy of waves inside the bay of Porto Conte. Such notch was formed during interglacial conditions, as witness the associated deposits, and is broadly comparable to the eustatic sea-level height reached during the substage 5e (Eutyrrhenian: 125 Ky b.p.) of the oxygen-isotope curve (Antonioli et al., 1998).

Close to the Grotta Verde this notch and the associated fringe of lithodomes was re-exhumed after the erosion of a landslide that covered it. According to the archaeological finds the age of the landslide is the Neolithic (Tanda, 1976). In fact, at the bottom of this cave, at present submerged by the sea, several human bones are found in some graves. This find, which look like a necropolis, permit to hypothesize that the coastline 7300 years ago was about 8.5 m below the sea level (Antonioli et al., 1998).

Figure 4. The Tyrrhenian notch "*survived*" in this protected stretches near Capo Caccia; a holocenic landslide buried and preserved this form subsequently re-exhumed by erosion of the foot of the landslide.

Along the cliff in study it is possible to follow continuously the present notch, even 1 m deep and 0,50 m high on average. This is likely due to the continuous action of the chemical dissolution of submarine springs (Cigna et al., 2003). Other palaeo-sea level marks can be seen only by divers' survey, as sea notches at the depth of 10 and 20 m. The submerged parts of the cliffs reveal widespread karst forms (Chessa et al., 1999; Orrù et al., 2005; Ginesu & Fasano, 2oo8), like the numerous underwater caves and conduits, partially altered by the marine current dynamics. The deepest forms are usually preserved worse.

CLIFFS AS GEOMORPHOSITES

Among the different aspects of the coastal landscape, cliffs have always been a matter of interest and appeal, especially for the scenic component. However, in order to ensure their efficient protection you need to give them a scientific validation that is their consideration as geomorphosites. According to the original definition by Panizza (2001) a geomorphological landform (and process) that have acquired a scientific, cultural/historical, aesthetic and/or social/economic value is a geomorphosite. In order to this acquisition is therefore necessary to evaluate some parameters such as the knowledge of the site by experts, its representative in the area, its rarity in the considered geological asset, the degree of conservation, its exposure and ultimately its value added, i.e. its ability to have a further relevance to different aspects of the environment (ecological and/or naturalistic value, touristic and/or economic value, historical and or cultural value, protected area) (Coratza & Giusti, 2005). In the case of the cliffs of Capo Caccia and Punta Giglio each of these parameters is plentifully verified.

In particular, these cliffs are highly representative of the geomorphological evolution of the north-western coast of Sardinia. Such representativeness is confirmed by numerous research (see the reference list) also enlarged to the submerged part and to the caves. The modelling of the promontory of Capo Caccia occurred along NW-SE trending normal faults, which displace the carbonate sequence toward sea in the western side and toward mainland in eastern side.

The former side shows a plunging profile (Sunamura, 1992) with a face 300 m high that continues underwater down to depths of 50 m b.s.l., whereas the latter side is less steep and its sea-bottom does not reach great depths. Such eastern side, moreover, represent also the flank of a valley incised by a river in the maximum glacial time and then submerged by sea (Ginesu, 2004).

Punta Giglio represents the western flank of the valley, at present Porto Conte bay. The structural discontinuity, which affected the carbonate sequences, favoured an important karst system (Chessa et al., 1999; Cigna et al., 2003; Tuccimei et al., 2003; Ginesu & Fasano, 2008), better preserved in the side of bay than the western side. This fact put in evidence the retreat of the western cliff by waves and subaerial processes quicker than the cliffs inside the bay.

In this coastal environment there are also ecological aspects of primary importance both terrestrial and marine (Farris et al., 2007). In the first a large number of flower species endemic to Sardinia, attributed to a small areal extent or even that they have in the area of Capo Caccia-Punta Giglio the only world-wide distribution must be considered (Valsecchi, 1976). Within seconds the submarine biological community, quite heterogeneous, finds its maximum expression in the many ravines that are in the sea bottom and in the submerged part of the cliffs. Finally, as already mentioned, the peninsula of Capo Caccia preserves sites of archaeological interest. These sites from the early Neolithic may represent an added value to geomorphosite of Capo Caccia.

Such aspects, visible in a circumscribed territory, have become one of the major tourist attractions for the north-western Sardinia. Hence it could be considered an original offer for tourist in the sense of Pralong & Reynard (2005). This condition is evidenced by the 150,000 tourists who visit these places every year (Carboni et al., 2010). They exploit the easy accessibility to these cliffs (i.e. the Escala del Cabirol in Figure 5) and the opportunity to see the cliffs from different panoramic points, even from the boat; however in this case it has to sail at a safe distance.

Figure 5. Neptune Cave (photo on the right) accessible with the "*Escala del Cabirol*" (photo on the left), a straight ramp of about 660 steps "*carved*" on the ridge of the promontory

In reality the visit permit to see also the other environmental aspects, equally fascinating, as the caves, including that of Neptune, a true geological wonder (Figure 5), the sea-bottom so valuable for divers and the Mediterranean macchia with an impressive variety of plants to consider unique in the world. This multiplicity of issues has encouraged the establishment of the Marine Protected Area of Capo Caccia and Porto Conte, however being the coastal landscape affected by a series of morphogenetic processes that can make this vulnerable area and even put to risk the safety of visitors, it is necessary invest in interventions and protective measures.

RISK ANALYSIS

In order to identify the risk areas of the studied coast, that also correspond to a Marine Protected Area and partially to a Regional Park, was made a map of geomorphological risk related to the instability of the cliff. This map at scale 1:25000 was carried out in a GIS environment. Its database was constructed in basis to the survey of the main fault lines, which are identified inland, and the detection of fractures recognized exclusively along the face of the cliff. This work has processed in various stages:

• Analysis of aerial photos;

• Image processing with AutoCad for the identification of homogeneous areas of cliff;

• Acquisition of raster data related to the different stretch of the cliff, and measurement of fractures;

• Implementation of the acquired data: number of fractures, type of fracture and relative measures and orientation;

• Calculation of the factor Danger Index by setting the function performed in a GIS environment.

Previously a geological survey integrated to the aerial photo analysis was executed in the coastal zone with aim to map the different lithology and the main tectonic lines, thus to make easy the distinction in homogeneous areas identified with AutoCad.

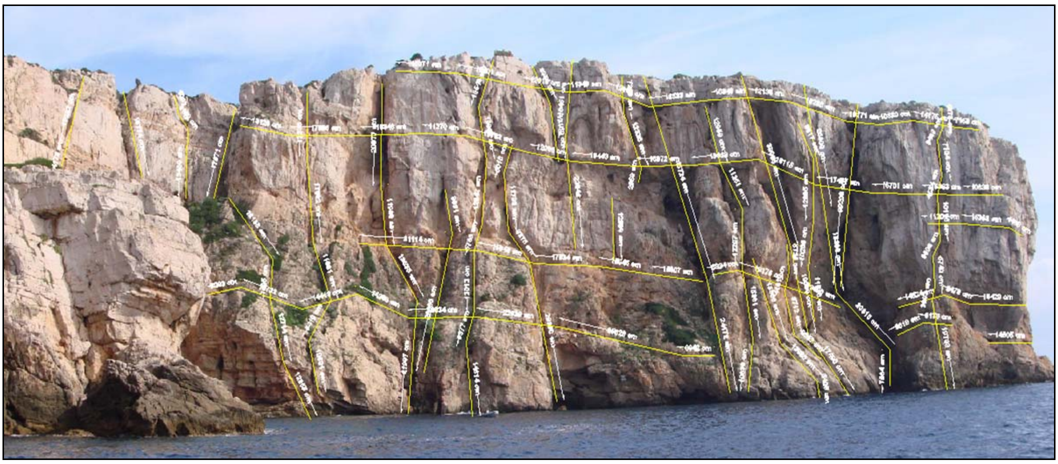

Figure 6. In the framework of the GIS, more than 3000 fracture orientation measurements were made on the cliffs of Capo Caccia and Punta Giglio (in the photo). Such measurements were made on the vertical cliff face through analysis photographs of the coastline, previously, along the wall, a graduate bar was placed that allowed in image processing to detect the length of the fractures

The method of investigation was carried out by acquiring photographic images of the cliff with an observer equipped with measurement bar (Figure 6). Subsequently the images were processed through a software that allowed the measurement of fractures as well as the height and the length of the cliffs. The fractures identified were classified into three types:

a. large cracks running through the entire cliff face;

b. fractures along layer stratification;

c. joints and minor fractures related to gravitational stress (Mortimore & Duperret, 2004).

Each area of the coast, identified in GIS, are linked to the available data (morphological parameters and type of fracture) measured in that area. The representation of the data in the layer RIL_FALESIA of the GIS system containing all the survey data indicated in three levels as "*Fractures*", "*Landslides*" and "*Elaborated Fractures*". The level "*Fractures*" contains the set of information obtained through the processing of data on the software "*Fotus*" by ACCA. Such software, moreover, allowed to obtain the data relating to the length of the fractures, after calibration and measurement on the ground. Each fracture was measured with an angle to the plane of the cliff and then with the program "*stereoNet*" has been made a "*Rose diagram*" to represent its orientation and direction. Such diagram was used to identify every fracture plane and compare it in terms of frequency over the entire area of competence.

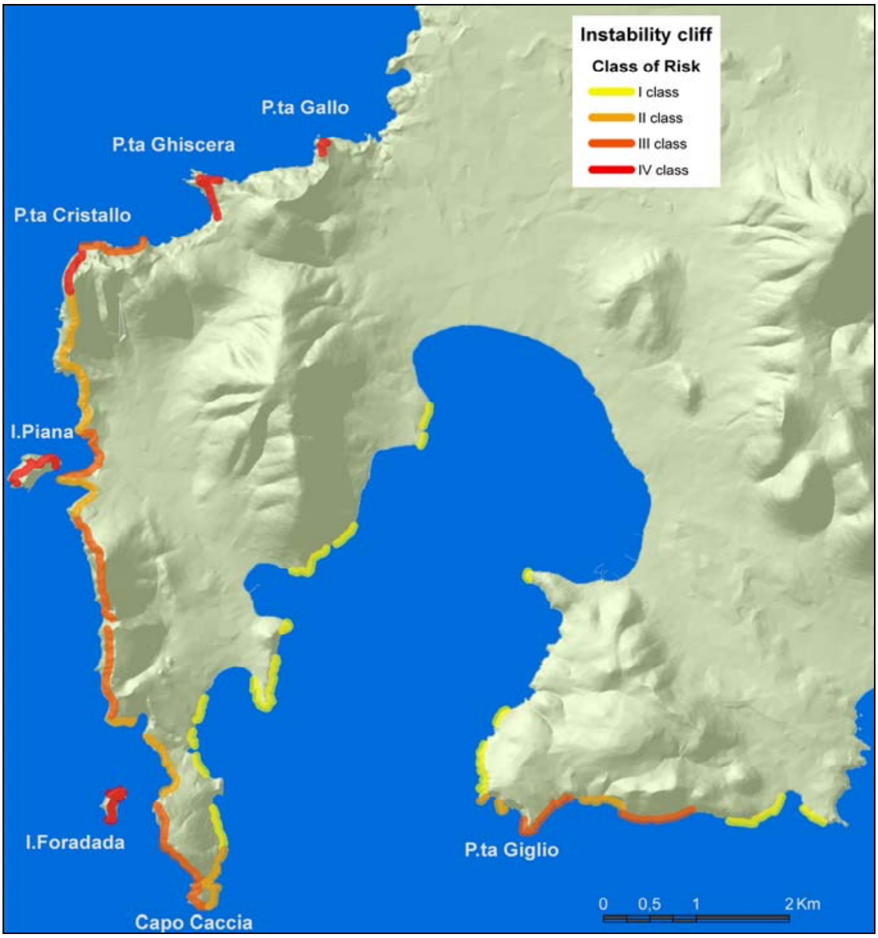

Figure 7. These 4 classes are mapped onto the coastline in a GIS format and the data related to the hazards is held in a GIS database developed by the authors and now held by the local authorities

In order to develop the formulas for assessing the risk (R) has assumed H as an index of the landslide hazard cliff highlighted on the cliff (H_I) and V as an index of environmental vulnerability of the coastal zone arranged by the use of the cliff. The former index was calculated by processing the data collected from the survey carried out along the cliffs. The intensity of H_I is mainly defined by the frequency of fractures measured in the surface unit on the cliff as well as by the number of landslides. Whereas the second index takes into account the position of fractures and landslides in basis to the function played in the Marine Reserve Area. Through the processing of data in a GIS environment we obtained indices that have allowed us to quantify the susceptibility to landslides and therefore the risk to lose this tourist resource in 4 classes (Figure 7).

Such classes has mapped, and that makes particularly perceptible the high risk present along the whole stretch of cliff on the northern coast of Alghero, where the cliffs show one of the higher coastal risk of Sardinia for the greater speed of retreat. This is evident by the lack of presence of notches and other paleo-sea level marks referable to the Tyrrhenian or previous stages. In addition, evidences of the erosive processes are evident by the numerous landslides that have been detected along the coast, both historical and recent. The sections with a higher instability, as it is noted from the map in Figure 7, are those exposed to the west (classes III and IV). These stretches are in fact subjected to the strong influence of the prevailing waves from the north-west. Moreover, in the northernmost stretch the risk are emphasized because of outcrops of gypsum and clays, Triassic in age. Much lower instability, which also corresponds to a lower risk, is attributed to the cliffs inside the bay of Porto Conte.

CONCLUSION

The text and photos relative to the geomorphosite of Capo Caccia, presented in this paper, can only minimally to highlight the geological, cultural and economic heritage (Reynard et al., 2009) preserved in this place for its many visitors. Not only the cliffs, but also the bay which lies between them, beautifully represent the geological history of north - western Sardinia and testify with its emerged and submerged landforms the dynamic interaction over time between the sea and the island. In this dynamic is well integrated a remarkably diverse plant and animal population in both emerged and underwater habitat.

This has encouraged the establishment of a Marine Protected Area, and also the promotion of a series of measures to safeguard the entire coast. Such measures are necessary for the great number of visitors, coming in this site every year, attracted by the suggestive landscape, but also by the opportunity to dive in fascinating submerged areas, to bathe inside a spectacular bay, to enter into wonderful caves. However they can determine directly and indirectly with the activities they induce significant impacts (Agardy, 1993).

Therefore, public and private institutions have developed an integrated system capable of offering tourists goods and services of high quality, and avoid compromising the environment as a whole. However, they cannot overlook a fundamental natural look: the high and rocky coasts are inevitably subject to erosion, whose phenomena can cause a risk to those who use the site (Coratza & De Waele, 2012). To this end it is necessary to assess the level of risk to which they may be subject to the tourists, so as to help the institutions to intervene mitigating it with specific and appropriate interventions (Coratza et al., 2008; Poch and Llordes, 2011). The approach presented in this paper is in this direction and can be applied in other coastal areas where you want to ensure a sustainable and responsible tourism in areas with natural resources of great value.

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REFERENCES

Agardy, M., (1993), *Accomodating ecotourism in multiple use planning of coastal and protected areas*, Ocean and Coastal Management, 20, p. 219-239.

Antonioli, F., Ferranti, L., Lo Schiavo F., (1998), *The submerged Neolithic burials of Grotta Verde at Capo Caccia (Sardinia, Italy). Implication of sea-level rise,* Mem. Descr. Serv. Geol. Naz., 52, p. 290-312.

Antonioli, F., Anzidei, M., Lambeck, K., Auriemma, R., Gaddi, D., Furlani, S., Orrù, P., Gaspari, A., Karinja, S., Kovacic, V., Surace, L., (2007), *Sea-level change during the Holocene in Sardinia and in the northeastern Adriatic (central Mediterranean Sea) from archaeological and geomorphological data,* Quat. Sci. Rev., 26, p. 2463-2486.

Carboni, D., Ginesu, S., (2006), *Evoluzione della linea di costa in alcuni siti archeologici della Sardegna nord – occidentale,* Atti del Simposio Il monitoraggio costiero mediterraneo. Sassari, ottobre 2006, p. 301 - 309.

Carboni, S., Russino, H., Russino, M., (2010), *Monitoraggio del carico antropico nel litorale della Baia di Porto Conte*, Archivio Studi e Ricerche Area Marina Protetta Capo Caccia – Isola Piana.

Cherchi, A., Simone, L., Schroeder, R., Carannante, G., Ibba, A., (2010), *I sistemi carbonatici giurassico-cretacei della Nurra (Sardegna settentrionale),* Geological Field Trips, 84 Congresso Soc. Geol. It., Sassari 2008, vol.2, p. 55-122.

Chessa, L., A., Vitale, L., Scardi, M., (1999), *Descrizione dell'ambiente sommerso con censimento e studio delle grotte sottomarine,* in M. Gutierrez (a cura di), Protezione dell'ambiente e gestione delle risorse naturali, Q. Ist. Studi Pol. Giuridici, p. 167 - 197.

Cigna, A., Forti, P., Nike Bianchi, C., (2003), *Geologia e genesi delle grotte marine,* in AA.VV., Grotte marine: cinquant'anni di ricerca in Italia'', Ed. CLEM, Ministero dell'Ambiente, Sezione Difesa Mare, p. 505

Coratza, P., Giusti, C., (2005), *Methodological proposal for the assessment of the scientific quality of geomorphosites,* Il Quaternario, Italian Journ. of Quat. Sciences, 18(1), p. 307-313.

Coratza, P., Ghinoi, A., Piacentini, Daniela, Valdati J., (2008), *Management of geomorphosites in high tourist vocation area: an example of Geo-hiking maps in the Alpe di Fanes (Natural Park of Fanes-Senes-Braies, Italian Dolomites),* GeoJournal of Tourism and Geosites, 2, p. 106-117.

Coratza, P., De Waele, J., (2012), *Geomorphosites and Natural Hazard. Teaching the importance of Geomorphology in Society*, Geoheritage, 4(3), p. 195-203.

Farris, E., Pisanu, S., Secchi, Z., Bagella, S., Urbani, M., Filigheddu R., (2007), *Gli habitat terrestri costieri e litorali della Sardegna settentrionale: verifica della loro attribuzione sintassonomica ai sensi della Diretti*va 43/92/CEE "Habitat", Fitosociologia, 44(1), p. 165-180.

Federici, P.,R., Ginesu, S., Sias, S. (1999), *Lineamenti geomorfologici ed evoluzione recente del paesaggio nella Nurra occidentale (Sardegna N.W.), La fascia costiera di Porto Conte – Porto Ferro,* in M. Gutierrez .(a cura di) Protezione dell'ambiente e gestione delle risorse naturali, Q. Ist. Studi Pol.-Giuridici, p. 95-136.

Ginesu, S., (2004), *Coste di sommersione: rias,* in Italia: Atlante dei tipi geografici, Istituto Geografico Militare, Firenze, p. 189-201

Ginesu, S., Fasano (2008), *Le grotte sommerse lungo le falesie di Capo Caccia e Punta Giglio (Alghero, Sardegna nord-occidentale),* Atti Simposio Il monitoraggio costiero mediterraneo, Napoli, 4-6 giugno 2008, p. 533-536.

Mortimore, R.,N., Duperret, A., (2004), *Coastal chalk cliff instability,* Geological Society Engineering Society, Spec. Pubbl., 20.

Orrù, P., Panizza, V., Ulzega, A., (2005), *Submerged Geomorphosites in the marine protected areas of Sardinia (Italy): assessment and improvement,* Il Quaternario, Italian Journ. of Quat. Sciences, 18(1), p. 167-174.

Panizza, M., (2001), *Geomorphosites: concepts, methods and examples of geomorphological survey*, Chinese Science Bulletin, 46, p. 4-6.

Poch, J., Llordes, J.P., (2011), *The Basque Coast Geopark: support for good practices in geotourism*, GeoJournal of Tourism and Geosites, 8, p. 272-280

Posenato, R., (2002), *The Triassic of the Nurra region (Northwestern Sardinia, Italy),* Rend. Soc. Paleont. Ital., 1, p. 111-118.

Pralong, J.P, Reynard, E., (2005), *A proposal for a classification of geomorphological sites depending on their tourist value*, Il Quaternario, Italian Journ. of Quat. Sciences, 18(1), p. 315-321.

Reynard, E., Coratza, P., Regolini Bissig, G., (2009), *Geomorphosites,* Verlag Dr. Friedrich Pfeill, Munchen.

Sunamura, T., (1992), *Geomorphology of Rocky Coasts*, Oxford University Press.

Sias, S., Russino, G., (2007), *La Carta del Rischio Geomorfologico. Il S.I.T. dell'Area Marina Protetta di Capo Caccia - Isola Piana,* G.I.S. Day 2007.

Tanda, G., (1976), *Grotta Verde (Alghero, Sassari),* Nuove testimonianze archeologiche della Sardegna Centro-Settentrionale, ed. Dessì, Sassari.

Tuccimei, P., Fornós J.J., Ginés À., Ginés J., Gràcia F., Mucedda M., (2003), *Sea level change at Capo Caccia (Sardinia) and Mallorca (Balearic Islands) during oxygen isotope substage 5e, based on Th/U datings of phreatic overgrowths on speleothems*, Puglia 2003 Final Conference Project IGCP 437 Coastal Environmental Change During Sea-Level Highstands: A Global Synthesis with implications for management of future coastal change, p. 235-238.

Valsecchi, F., (1976), *Sui principali aspetti della vegetazione costiera della Nurra Nord-occidentale (Sardegna settentrionale)*, Giorn. Bot. Ital., 110, p. 21-63.

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