

Article

Bridging Terrestrial and Marine Geoheritage: Assessing Geosites in Portofino Natural Park (Italy)

Paola Coratza ^{1,*}, Vittoria Vandelli ^{1,*} , Lara Fiorentini ², Guido Paliaga ³ and Francesco Faccini ^{3,4} 

¹ Dipartimento di Scienze Chimiche e Geologiche, Università degli Studi di Modena e Reggio Emilia, Via Campi 103, 41125 Modena, Italy; paola.coratza@unimore.it

² Settore Politiche delle Aree interne, Antincendio, Forestazione, Parchi e Biodiversità, Regione Liguria, Via D'Annunzio 111, 16121 Genova, Italy; lara.fiorentini@regione.liguria.it

³ CNR Istituto di Ricerca per la Protezione Idrogeologica, sede di Torino, Strada delle Cacce 73, 10135 Torino, Italy; guido.paliaga@irpi.cnr.it (G.P.); faccini@unige.it (F.F.)

⁴ Dipartimento di Scienze della Terra, dell'Ambiente e della Vita, Università degli Studi di Genova, Corso Europa 26, 16132 Genova, Italy

* Correspondence: vittoria.vandelli@unimore.it

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Abstract: Interest in geoheritage research has grown over the past 25 years and several countries have issued laws to encourage improvement and conservation. Investigations on geosites are prevalently carried out on land environments, although the study of underwater marine environments is also of paramount scientific importance. Nevertheless, due to the constraints of underwater environments, these sites have been little explored, also on account of the higher costs and difficulties of surveying. This research has identified and assessed the terrestrial and marine geosites of the Portofino Natural Park and Protected Marine Area, which are internationally famous owing to both the land scenic features and the quality of the marine ecosystem. The goal was to pinpoint the most suitable sites for tourist improvement and fruition and identify possible connections between the two environments. In all, 28 terrestrial sites and 27 marine sites have been identified and their scientific value as well as their ecological, cultural, and aesthetic importance has been assessed. In addition, accessibility, services, and economic potential of geosites has also been taken into account. Both the updated database of terrestrial and marine geosites in the Portofino protected areas and the assessment procedure adopted can become useful tools for the managers of these sites and provide decision-makers with possible strategies for tourist development.

Keywords: underwater geoheritage; geosites; geomorphological survey; geotourism; Portofino Park; Italy

1. Introduction

Geoheritage and geosite studies have assumed growing scientific importance in the past 25 years, and territorial legislative initiatives have emerged all around the world. Geoheritage studies have usually been carried out in terrestrial environments: Mountain areas (e.g., [1–6]), coastal areas (e.g., [7–11]), karst areas (e.g., [12–16]), fluvial areas (e.g., [17–19]), and volcanic areas ([20–23]). Recently, a great deal of interest has concerned also geoheritage in urban areas (e.g., [24–30]).

For what concerns the definition of geosites and their different types of values, they have been much debated within the scientific community (cfr., [31,32] and reference therein). Up to now, two main approaches can be distinguished for defining what geosites are: A restrictive and a broader definition.

According to the restrictive definition, geosites are in situ elements with high scientific value [33], i.e., sites “having particular importance for the comprehension of the history of the Earth and of its

present and future evolution” [34,35]. According the broader definition, geosites—or geodiversity sites (*sensu* [33])—are defined as geological elements that present a certain value due to human perception or exploitation, e.g., elements with high scientific, educational, aesthetic, and cultural value. Often, geosites are included in protected areas even if their institution is, in most countries, related to the biological aspects more than the geological ones. In fact, geology has often been inadequately accounted for in parks creation, planning and management. Nevertheless, after decades of focus on the protection of biological heritage, a great deal of progress has been made in the last 20 years (cf., [36] and reference therein). In this respect, particularly notable is the UNESCO Global Programme, which intends to “promote a global network of geoparks safeguarding and developing selected areas having significant geological features” [31,37,38]. Moreover, natural disasters and their tangible evidence in landscape may be important geosites, ideal to promote geological education [39] and geotourism [40,41].

In Italy as elsewhere, the nature conservation in coastal and marine environment is provided by marine protected areas whose nature conservation policy primarily addresses the biodiversity, often underestimating or nearly neglecting abiotic features. Among the European legislative framework worthy of note are the EU Birds Directive (1979), the Habitats Directive (1992), the OSPAR Convention (1992), and the EU Marine Strategy Framework Directive (2008), which have focused the attention towards the marine environment.

Concerning underwater geoheritage and marine geosites [42], despite their importance, only few studies have been developed; this is particularly true when compared with studies on marine biotic heritage ([43] and references therein). This is mainly due to the physical constraints of the marine environment that influence the high costs of underwater surveys and the difficulty of investigating near shore areas, where navigation is not possible. In addition, as highlighted by Burek et al. [44], there are general differences in attributes related to sites of geological and geomorphological interest in terrestrial and marine environments. In a marine environment, geological heritage is largely invisible, except in clear and shallow water, and hardly accessible. These characteristics have reduced the opportunities for promotion, education, and interpretation activities for the public, but at the same time, they have also reduced vulnerability to man-made damage. Furthermore, the different perception and enjoyment of abiotic features of the aquatic environment by tourists has led to a delay in developing common schemes and approaches to the identification, assessment, and improvement of submarine geosites [43].

While many studies have dealt with emerged shorelines [45–47], geoheritage research in underwater environments still lacks common investigation schemes and approaches, again especially in comparison to studies on marine biotic features [48,49]. Specific studies on submerged geoheritage are few and were developed mainly by Italian researchers [43,50–55]. In particular, in Orrù et al. [52], the selection of sites of geomorphological interest was carried out by considering several significant valences as: (i) Model of geomorphological evolution; (ii) exemplarity; (iii) paleo-geomorphological testimonial; and (iv) ecological valence. In the same work, the geosite assessment was carried out considering their scientific interest and other types of interest such as cultural, educational, and historical interests. Similar to this approach was the one used by Rovere et al. [43]; in fact, they evaluated underwater geomorphological heritage in two Mediterranean marine areas by considering two sets of values, that were the scientific and the additional values. The two sets were further divided in subcategories inspired by those proposed for terrestrial environment (e.g., [47,56,57]). Recently, Flores-de la Hoya et al. [58] proposed a method to rapidly assess coastal underwater spots to be used as recreational scuba diving sites. In the latter work, the assessment was based on several criteria inspired by the methodology provided by Ramos [59] for the evaluation of diving site attractiveness in the Algarve region.

As regards marine geoconservation, a growing interest has been recently observed, especially in the UK, where geoheritage has started to be integrated in the management of protected areas ([44,60,61]) and a methodology to assess geodiversity key areas on the seabed has been developed.

From a geoheritage viewpoint, submerged areas are particularly interesting for several reasons:

- Relict landforms, testifying past geological and geomorphological events or paleo-environments, and direct consequences of human interaction are usually better preserved than in a continental environment [52]. In particular, research on climate change occurring in the past 22 ka BP has allowed sea-level fluctuations to be identified up to about −120 m with respect to present levels. The numerous marine markers identifiable in the submerged strip of present-day Mediterranean coasts constitute exceptional archives of long-term paleo-environmental change, with particular reference to climate and sea-level changes (e.g., [62–64]).
- Abiotic heritage has strong interconnections with human life and marine biodiversity, since it plays an important role in providing benefits through the functioning of ecosystems (cf., [65]). The benefits include ecological benefits, such as habitat provision and improvement of fish stocks, social and cultural benefits related to nature appreciation, economic benefits of tourism, and recreational enjoyment of the marine environment.
- Submerged areas are often tourist destinations, with a potential for geotourist popularization of their geological and geomorphological heritage. Enjoyment of the underwater environment focuses mainly on biological attractions, such as marine biota and habitats [51] or cultural elements, such as archeological remnants (e.g., [66,67]) or shipwrecks (e.g., [68,69]) whilst the importance of natural abiotic features is often underestimated [55]. The submerged environments are also used for tourist activities, especially for cultural, historical, and religious purposes. Examples of links between submerged cultural heritage and submerged geoheritage in the Mediterranean have been developed in marine protected areas in Liguria [43,53–55], in the Greek Islands [47], in Sardinia [50,52], and in Malta [70].

According to Rovere et al. ([43] and references therein), a complete approach in the studies of geoheritage in coastal zones should necessarily include the description of both the shore and inner continental shelf, according to the fact that two environments showing common processes and landforms must be considered as a single feature [71]. The need for integrating terrestrial and submerged datasets in geomorphological studies is not new. Examples of studies coupling land and sea data available in literature have considered several aspects, such as: (i) Archaeological investigations (e.g., for the northern coast of Ireland by Westley et al. [72] and Harff et al., [73]); (ii) paleo-environmental reconstruction (e.g., Quaternary geomorphological evolution of the Tremiti Islands, southern Italy [74,75])—especially in fluvial environments; (iii) marine spatial planning [76]; (iv) coastal hazards assessment and risk reduction (e.g., mitigation of the risk due to tropical cyclones, tsunamis, floods, and sea-level rise along the Mozambique coasts [77,78]); (v) integrated geomorphological mapping of emerged and submerged areas (e.g., [79] in the Netherlands; [80] in the Tremiti Islands, southern Italy; [70,81] in the Maltese Archipelago).

The goal of this study is to identify and assess terrestrial and marine geosites—intended, in a broad sense, as component of the cultural heritage of a territory [82,83]—in the Portofino Natural Park (Liguria Region, northern Italy), in order to select sites more suitable for a geotourism exploitation, pinpointing a potential morphogenetic bridge between terrestrial and marine features. These latter are poorly known by the general public especially from geological and geomorphological perspectives. The Portofino Natural Park, which comprises a terrestrial protected area, established in 1935, and a marine protected area, established in 1999, is well known at an international level thanks to its landscape, environmental, and cultural characteristics (Figure 1). Over 1 million people a year visit the sea hamlets of Portofino and Camogli, as well as the coast between Rapallo and Portofino, whereas the 80 km long footpath network is trodden throughout the year by over 100,000 hikers [11]. In recent times, scuba diving activities, managed by the protected marine area administration, have significantly increased. Scuba divers arrive at properly chosen buoys starting from the diving centers of Santa Margherita, Camogli, and San Michele di Pagana (located between Santa Margherita Ligure and Rapallo). The remarkable environmental and cultural features conserved both in terrestrial and marine areas of the Portofino Natural Park led the study area to become an ideal site for the development of geotourism, defined according to the broader approach of the National Geographic in the United States as “tourism that

sustains or enhances the geographical character of the place being visited, including its environment, culture, aesthetics, heritage and the well-being of its residents” [84].



Figure 1. Location map of the study area (modified from [11]).

2. Geographical Setting

The Promontory of Portofino breaks the continuity of the coastline between Genoa and La Spezia, along a perimeter of 13 km and an area of 18 km². The orography is characterized by rather high peaks, considering the short distance from the sea [85]. There is a WNW–ESE oriented relief, the culmination of which corresponds to the Mount of Portofino (610 m). Hydrographic catchments are less than 1 km² wide, with channels of the second order at the most [86]. Among the most important catchments of the southern slope, the following can be quoted: Cala dell’Oro catchment, located west of San Fruttuoso bay; San Fruttuoso catchment; Ruffinale and Vessinaro catchments, both located between San Fruttuoso Bay and Portofino promontory. Whereas, on the eastern side, the Rio del Fondaco at Portofino and Fosso dell’Acquaviva at Paraggi are found [87,88].

Due to the torrential regime, the flow rates of watercourses are substantially nil for most of the year; in the case of heavy rainfall of short duration (not infrequent in the area), the maximum flow rates, for return times of 200 years, range between 20 and 40 m³/sec (flow rate unit contribution of 40 m³/sec/km² for catchment areas of less than 1 km²).

The Portofino Park protects the area of the promontory bearing the same name, which is located less than 20 km away to the east of Genoa. To date, the protected area is 1056.26 ha, out of which 58.61 ha make up the integral reserve, 597.31 ha are the general reserve area, and 362.50 ha are the protection area. The remaining 37.84 ha belong to the economic promotion area [11]. The contiguous territory adds an extra 932 ha to the Park (Figure 2).

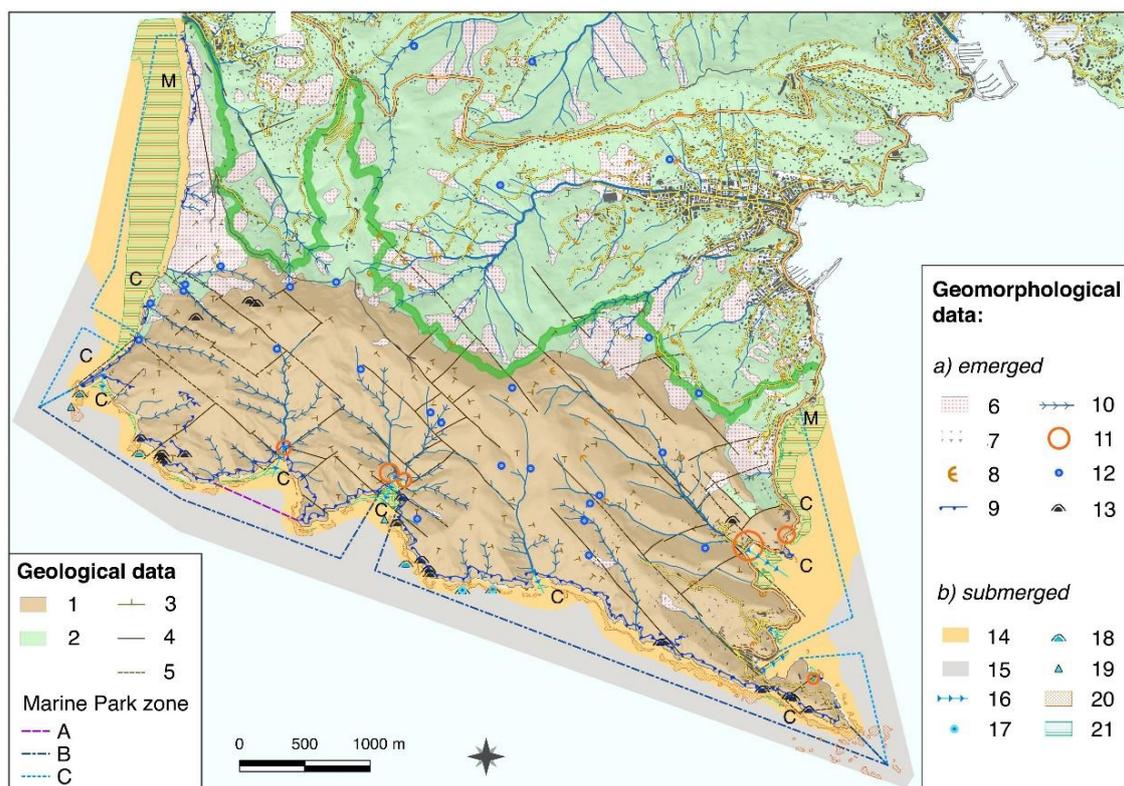


Figure 2. Geological and geomorphological sketch of the study area (modified from [11,86–88]): (1) Conglomerate; (2) marly limestone flysch; (3) bed attitude; (4) fault; (5) tectonic lineament; (6) landslide and debris covers; (7) anthropic fill; (8) soil slip; (9) edge of sea cliff scarp; (10) incising channel; (11) pocket beach; (12) spring; (13) cave; (14) submerged cliff with boulders, sands in the small bays (San Fruttuoso, Portofino and Paraggi); (15) sea bottom with sands and muddy sands; (16) submerged channel; (17) submerged spring; (18) submerged cave; (19) submerged peak; (20) coralligenous reef; (21) seagrass meadow.

The area of the Park stretches over the municipal territories of Camogli, Portofino, and Santa Margherita Ligure, whereas the contiguous area is part of the municipal territory of Rapallo. The residing population of the Park is around 750 inhabitants. The presence of tourists is high throughout the year: At the village of Portofino, there are over 1 million tourists per year, whereas at San Fruttuoso, tourist boats carry some 400,000 tourists/year around the Gulfs of Tigullio and Paradiso [11,86]. Apart from seaside tourism, there is also a high presence of hikers along the over 80 km long footpaths: Just the stretch from Portofino Vetta to Pietre Strette is trodden by over 70,000 hikers per year.

Thanks to its landscape, natural, and cultural values [89,90], the Promontory of Portofino has been protected since 1935 by Italian Law no. 1251 (Establishment of the local authority of Mount of Portofino). Since 1995, it has been managed as ‘Ente Parco’, established by Ligurian Regional Law no. 12/95 (Reorganization of protected areas), which redefined the borders of the protected area with Regional Law no. 29/2001 (Identification of the perimeter of the Portofino Natural Regional Park).

The Marine Protected Area of Portofino, established by the Italian Ministry for the Environment, was added to the Park with the Decree of 26/04/1999, which implemented the Italian Law no. 979/1982 (Measures for the Sea Protection). The marine area is subdivided into three zones of safeguard (A, B, and C), in which free navigation, hunting or catching of fauna, underwater fishing, and diving are forbidden. In addition, all underwater activities that require contact with the seabed are forbidden, as well as the anchoring of any boat [91]. Zone A (Integral Reserve) comprises the sea area of Cala dell’Oro bay (west of San Fruttuoso bay). Access to this area is permitted only for emergency rescue and authorized scientific research. Zone B (General Reserve) stretches from the Portofino lighthouse

point to Punta Chiappa, excluding the access corridor to the harbor of San Fruttuoso. Less restraining issues characterize this zone: Authorized sport fishing is allowed for residents, scuba diving is allowed for diving centers and authorized private subjects, whereas bathing is free. This marine area is very popular among scuba divers, who are attracted by the considerable natural beauty of the seabed and, in particular, by the great number of violescent sea-whips (*Paramuricea clavata*) and the richness of sea fauna. Zone C (Partial Reserve) stretches between the two sides of the Promontory of Portofino and owes its fame to the vast prairies of Mediterranean tapeweed (*Posidonia oceanica*). Bathing, scuba diving, and sport fishing are allowed. On the whole, over 70,000 scuba divers per year plunge into the water of the Portofino Protected Marine Area [92].

Recently, in December 2017, the Portofino National Park was established. It comprises both the terrestrial area and the protected marine area. By the end of 2019, the Italian Ministry for the Environment will establish the new borders of this National Park with a specific law.

3. Geological, Geomorphological, and Hydrogeological Setting

The geology of the Portofino National Park is known at an international level owing to the presence of Portofino Conglomerate, whose lithological nature and geological and geomorphological significance have in fact been widely studied (e.g., [93–95] and references therein) as well as its geomechanical behavior (e.g., [88,96]). The conglomerate forms the trapezoid-shaped promontory between Punta Chiappa to the West and the Portofino lighthouse to the East. The geological root of the Portofino Mount, between Camogli and Rapallo, is characterized by a marly-calcareous flysch (Mt. Antola Flysch). The boundary between these two geological formations (pudding stone and flysch) is partially ascribable to tectonic causes and shows a WNW–ESE trend (Figure 2). The Promontory morphology is derived from a structure bounded by normal faults, typical of a continental margin subject to disjunctive tectonics [97,98].

The Portofino Conglomerate is made up of marly-calcareous clasts and, to a lesser degree, sandstones, ranging in size from centimeters to meters, arranged in several-meter thick layers with rare sandstone intervals, often accompanied by thin coal layers. Ophiolite, limestone, cherts, and gneiss clasts are also found, although less frequently. This conglomerate, which lacks a fossil record, was dated doubtfully to the Oligocene due to the scarcity of biostratigraphic records [97,98].

On the whole, the structural setting of the Conglomerate shows a SE to SW dip, with a less than 20° inclination. The rock mass is affected by various joint systems, easily identifiable at a meso- and macro-scale. The NW–SE and NE–SW oriented systems, which are ascribable to normal faults, are the most important. At a slope scale, the intersection between the various joint systems produces the subdivision of the conglomerate into several decameter-thick blocks [99].

Mt. Antola Flysch, dating to the Cretaceous, is made up of calcareous marls and marly limestones, marls with argillite levels, siltites, and calcarenites. The structural setting of the flysch is constrained by diverse deformation phases, both ductile and brittle, which affected this rock mass. An isoclinal-fold arrangement was identified in this formation; it shows a SSW vergence with a WNW–ESE oriented axis [95].

Landforms in the study area are controlled by geological-tectonic setting and conditioned by meteo-climate conditions [87,88]. Rocky cliffs up to 200 m high, the highest of the Mediterranean coast, characterize the southern slope of the Promontory of Portofino [93]. The average inclination of the slope is 45° to 65°, although many are the coastal stretches characterized by vertical cliffs [94]. The action due to swell is important and is determined by both SE wind ('Scirocco', dominant wind), and SW wind ('Libeccio', prevailing wind). Sea storms are rather frequent, with wave heights exceeding 5 m; they can cause serious damage to buildings and infrastructures, as in the event of 27–29 October 2018, which affected the Promontory eastern coast, between Rapallo and Portofino.

The profile of the emerged cliff continues underwater up to a depth of some 70 m. Up to the margin of the shelf, some 140 m deep, the inclination of the seabed is rather homogeneous and gentle.

The margin of the shelf, which is not influenced by the presence of the promontory, is found at a distance of 3.5 to 4 km from the coast [100].

The base of the narrow continental slope is found at a depth of 0.6 to 1 km, in correspondence with a furrow named ‘Canyon della Riviera di Levante’, which stretches in an E–W direction, with the confluence of a small canyon formed in the West front of the Promontory of Portofino [85,100].

The morphologically significant tectonic alignments, which contour Mount Portofino with landforms such as saddles, towers, and triangular facets, continue in the submerged portion. Some of the faults are considered active, since they disrupt the seabed in their underwater part.

In the high conglomerate cliffs of the southern slope, there are often rock falls, even along very steep fluvial channels, mostly of the first order, as in the case of the torrents Ruffinale and Vessinaro [96]. On the western slope, the cliff has been prevalently modelled in Mt. Antola Flysch, attaining heights exceeding 100 m. This stretch of coast is subject to a SW swell, which is one of the main causes for occurrence of rapid slope movements, such as debris/mud flows and rock avalanches, which often have a high destructive power [94]. There are also slow slope movements with surface of rupture in the marly-calcareous bedrock. In this case, numerous morphotectonic clues suggest a process of the mountain slope deformation type [101]. Along the boundary between the conglomerate and flysch, there are landslides of diverse origin and state of activity owing to the contrast of resistance and deformability between adjacent rock masses [11]. Among the landslide bodies surveyed, worthy of note is the accumulation found at Sotto Le Gave, on the eastern slope, which is partially due to mountain slope deformation and has affected buildings and infrastructures even in the recent past.

In the submerged area comprised within 200 m from the coastline, morphological rises linked to neotectonic modelling are found, as South of Punta Chiappa (*Secca dell’Isuela*), E of San Fruttuoso (*Secca Gonzatti*), and SE of Punta Portofino. This portion of the seabed reveals exceptional biodiversity [91], also resulting from geomorphological features. The widespread coralline biocoenosis and tapeweed prairies, which characterize most of the seabed near the coast, are developed on large rock blocks (>1 m).

The meteo-climatic characteristics of this area are linked to the cyclogenesis of the Gulf of Genoa, which causes events of short but intense precipitation (less than 6 h, with rain peaks exceeding 50 mm/h) between mid-summer and mid-autumn [93,102,103]. Consequently, the most common effects at ground level are flash floods, hyper-concentrated fluxes, and debris/mud flows. Among the most significant and destructive events in living memory, those of 1915, 1961, and 1995/1996 should be mentioned. Also, in the 2000–2018 period, many extreme hydro-meteorological events occurred on Portofino Promontory, causing important effects at ground level with considerable damage to buildings and infrastructures: The average, on a historical basis, is over one event per year [11].

The Ligurian Speleological Registry lists 20 caves in the Portofino Conglomerate [104]. Their origin is prevalently tectonic although, to a much lesser extent, is due to chemical–physical dissolution or processes linked to the sea wave action. In addition, several natural caves have been surveyed in the submerged portion of the cliff, up to a depth of 60 to 70 m; also, their genesis is a result of tectonic modelling.

The intense joint network of the conglomerate, the contrast of hydraulic conductivity with the marly-calcareous flysch, and the climate characteristics of the territory cause significant effective infiltration with widespread presence of groundwater and springs [99]. Effective infiltration ranges from 350 mm/y at sea level up to over 500 mm/y at higher elevations. The water springs are located either along the contact between the Conglomerate and the marly-limestone Flysch, or in the Conglomerate rock mass, along tectonic lineation, or along the interface with the sandy interlayers. Underground aquifers are extremely fragmented, with annual intermittent flow rates ranging from less than 1 L/min in dry summer to over 10 L/s in late autumn. Some of these springs have been used for a long time and today still feed local water-supply systems [93]. There are also significant springs underwater, along the submerged cliffs, and at the connection with the shelf. The latter is an important morphological element indicating the position of the sea-level at the end of the Würm regression. Furthermore, these features

bear witness to the neotectonic activity taking place in the Plio-Quaternary, with uplifting and lowering phenomena affecting the seabed.

Among anthropic forms, drywall slope terracing is a very common farming technique, which dates back to ancient times. Terracing has deeply modified the geomorphological, vegetation, and dwelling landscape at a slope scale. Well-preserved examples of slope terracing are found in the Valloni di Paraggi, Portofino, and San Fruttuoso; they make up an important cultural and landscape asset.

4. Materials and Methods

The increasing interest in the promotion of geotourism requires the selection and assessment of geosites in order to determine priorities in site management and geoconservation strategies. Based on these premises, a research program for the identification and assessment of geosites at the Portofino Natural Park has been developed.

4.1. Geosites Identification

Research on geosites at Portofino Natural Park has taken advantage of the numerous thematic maps and scientific publications on the geology and geomorphology of the study area, concerning both emerged and submerged areas of the Park, as well as tourist maps and guidebooks. Some milestone publications have been particularly significant for the aims of this study, such as Ristori [105] on the Conglomerate and groundwater regime at Mount Portofino and Pellati [85] on the geomorphological characteristics of the Promontory of Portofino. As for geological and petrographic features of the conglomerate, the contributions by Giammarino et al. [97] and Giammarino and Messiga [98] should be mentioned. As concerns geomorphological features, in recent times there have been contributions on geomorphological hazard and tourist vulnerability along the Park footpaths [86], on the landslides of the western slope of Mount Portofino [94], and on geomorphological mapping of San Fruttuoso and Portofino [87,88]. In addition, other publications have been taken into account: The debris flows along the coast [93], the hydrogeology of the Caselle springs [99], and the terracing of the Park considered as a cultural asset [90]. Salmona and Varardi [91] discuss the socioeconomic aspects of the protected marine area, whereas other contributions deal with underwater tourism and related impact on the ecosystem. Cerrano et al. [92] stress the importance of volunteer scuba divers for scientific activities aiming at the conservation of Mediterranean natural resources and [106] describe the success of scuba diving in the Portofino protected marine area. Furthermore, Lucrezi et al. [107] illustrate the contribution of scuba divers in the management of protected marine areas and, again, Lucrezi et al. [107] pinpoints the correct balance between scuba diving activities and environmental sustainability. Saayman and Saayman [108] discuss the economic benefits resulting from scuba diving in protected marine areas, and Di Carro [109] describes an approach for assessing human impact on the Portofino protected marine area. Finally, Markantonatou et al. [110] develops a study on social networks and the flow of information for responsible and sustainable planning in the Portofino protected marine area.

For the selection of terrestrial geosites (Table 1 and Figure 3), this study took advantage of the inventory developed by Faccini et al. [11] where geosites have been selected and classified according to their main scientific relevance in: Geological, geomorphological, mineralogical-petrographic, hydrogeological geosites, and viewpoints (*sensu* [111]).

A geoheritage inventory for the underwater part of the area investigated was lacking. Therefore, marine geosites were selected (Table 2) by combining geological and geomorphological data in strict collaboration with park managers. The sites were classified according to their main scientific relevance as geomorphological, speleological, and hydrogeological geosites (Tables 1 and 2 and Figure 3). Since geosite assessment is important for the promotion of the area from a geotourism perspective, two marine sites of cultural interest and great tourist potential have been included (*Cristo degli Abissi*—ID 21S; and *Mowak Deer shipwreck*—ID 13S). These sites show a complex relationship between the natural and/or human heritage of the Portofino Park [11]. The underwater geosites have been classified into two categories according to the skills of the visitors: (i) Snorkeling sites (more or

less available to everybody) and (ii) sites equipped for qualified scuba divers. Snorkeling sites have been classified based on direct observations and comprise practically all the free bathing sites of the Portofino Protected Marine Area. They are pocket beaches, often fed by annual beach nourishments, apart from the Punta Chiappa site, which is a rocky cliff. The scuba diving sites are managed by the Portofino protected marine area and are identified by 21 signaling buoys, where one or two boats can be moored. The diving sites have been classified into three categories, according to their technical difficulties. The scientific data reported in the cards of each diving point, which have been elaborated by the Portofino protected marine area [112], have been updated with new original observations on each diving point up to a maximum depth of 45 m.

Table 1. Terrestrial geosites.

Nr	Name/Location	Scientific Interest	Features/Description
1T	Pietre Strette	Geological	Conglomerate
2T	St George Church	Geological	Conglomerate
3T	St Rocco	Geological	Marly limestone
4T	P.ta Chiappa	Geological	Conglomerate
5T	P.ta Pedale	Geological	Marly limestone
6T	Pietre Strette	Geomorphological	Boulders
7T	Vitrале	Geomorphological	High cliffs
8T	P.ta Cervara	Geomorphological	Sea stack
9T	Mt. Campana	Geomorphological	Mass movement (lateral spread)
10T	P.ta Budego	Geomorphological	High cliffs
11T	Cala dell'Oro	Geomorphological	Inlet
12T	Pietre Strette	Minero-Petrographical	Anagenite
13T	Cala dell'Oro	Minero-Petrographical	Coal interlayers
14T	St Rocco	Minero-Petrographical	Abandoned quarry
15T	Rio Gentile	Minero-Petrographical	Abandoned quarry
16T	Coppelli	Hydrogeological	Natural springs
17T	Acquaviva	Hydrogeological	Natural springs
18T	Caselle	Hydrogeological	Natural springs
19T	Vegia	Hydrogeological	Natural springs
20T	St Rocco	Viewpoints	Viewpoints
21T	Batterie	Viewpoints	Viewpoints
22T	Toca saddle	Viewpoints	Viewpoints
23T	Castelletto	Viewpoints	Viewpoints
24T	Rocca del Falco	Viewpoints	Viewpoints
25T	Base O	Viewpoints	Viewpoints
26T	Mt Campana	Viewpoints	Viewpoints
27T	Semaforo Nuovo	Viewpoints	Viewpoints
28T	Sotto le Gave	Viewpoints	Viewpoints

4.2. Geosite Assessment

Evaluation of geosites has been developing since the 1990s (cf., [32,113–115]). In spite of many published methods about the assessment of sites, the scientific literature reveals that there is still a great debate concerning values and criteria to be used in the geosite assessment process (see [31,116] and reference therein) and there is no general accepted method. One of the most popular approaches for geosite assessment is the comparative analysis of geosites within a given area, by applying numerical evaluation of their values, based on several criteria and respective indicators (e.g., [33,56,117–121]). The aim of a quantitative assessment is to reduce subjectivity [122] associated with any evaluation procedure, since the intrinsic value of these environmental elements cannot really be measured. Indeed, the scientific quality of a geosite is a purely indicative numerical quantity, which can be subject to variations determined by the subjectivity of the operators and the general characteristics of the area under examination.

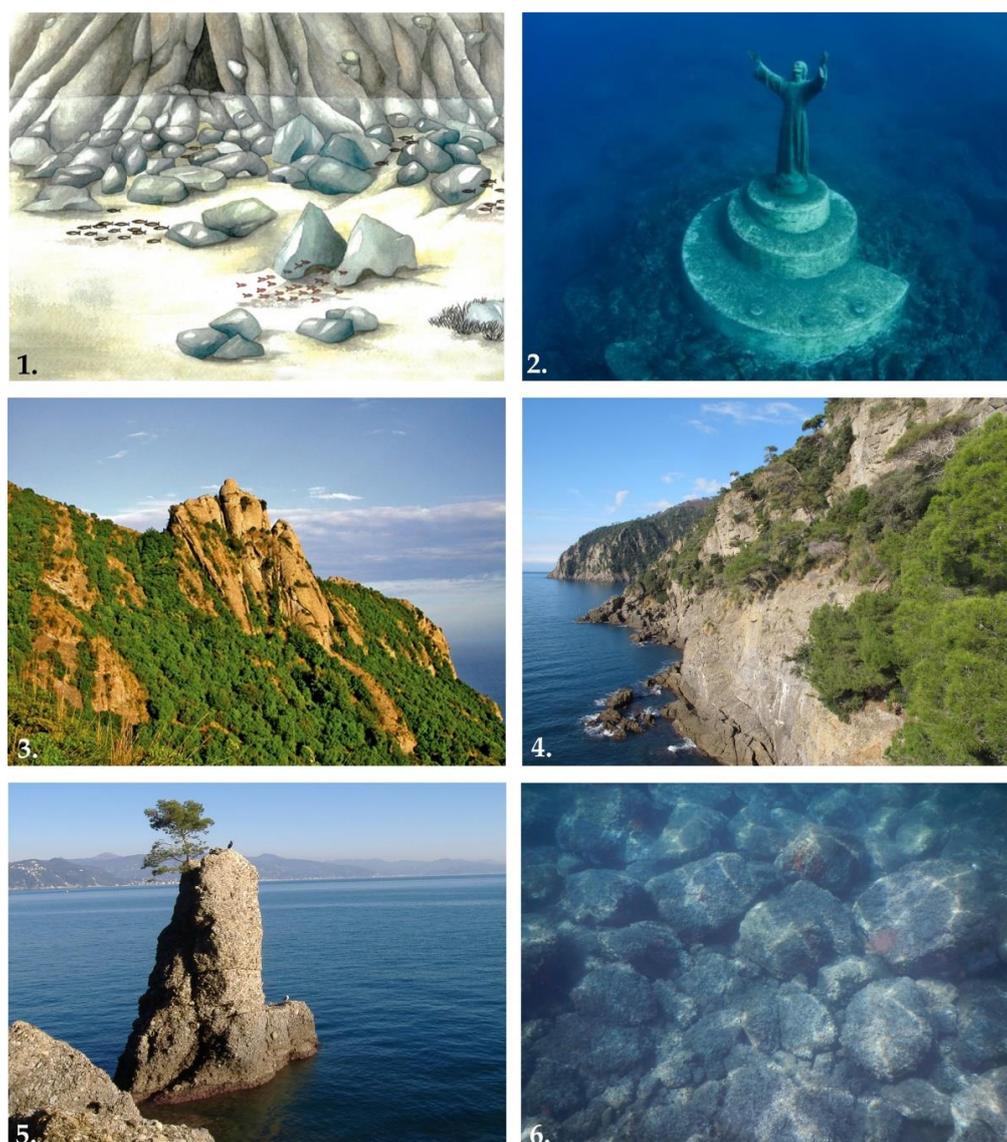


Figure 3. Examples of geosites in the Portofino Natural protected areas: (1) Grotta dell'Eremita (44.31797 N 9.15120 E, marine geosites 3S and cave on the sea cliff); (2) Cristo degli Abissi (44.314038 N 9.174979 E, marine geosites 21S); (3) Mt. Campana (44.31973 N 9.15529 E, terrestrial geosites 26T); (4) High cliffs at Vitrale (44.30389 N 9.20164 E, terrestrial geosites 7T); (5) Punta Cervara stack (44.31355 N 9.21291 E, 'lo scoglio della Carega', terrestrial geosites 8T); (6) Rock fall boulders at Castello di Paraggi (44.31112 N 9.21241 E, marine geosites 26D). Image 1 and 2 from Portofino Marine Protected Area archive [100].

Table 2. Marine geosites (minimum and maximum depth are expressed in meters). The eighth column refers to the qualitative level of difficulty to reach a certain submerged geosite through scuba diving (source: [112]).

Nr	Name/Location	Scientific Interest	Features/Description	Protection Zone	Min Depth	Max Depth	Difficulty
1S	Punta Chiappa di Levante	Speleological	Cave	B	10	40	high
2S	Punta della Targhetta	Geomorphological	Submerged cliff	B	8	20	low
3S	Grotta dell'Eremita	Geomorphological	Cave	B	5	40	low
4S	Punta della Torretta	Geomorphological	Submerged cliff	B	10	35	high
5S	Punta dell'Indiano	Geomorphological	Submerged cliff	B	16	45	high

Table 2. Cont.

Nr	Name/Location	Scientific Interest	Features/Description	Protection Zone	Min Depth	Max Depth	Difficulty
6S	Il Dragone	Geomorphological	Landslide blocks, cliff	B	5	40	high
7S	La Colombara	Speleological	Cave	B	10	30	medium
8S	Secca Gonzatti (Secca Carega)	Geomorphological	Submarine relief, shoal	B	5	30	medium
9S	Targa Gonzatti	Geomorphological	Landslide blocks	B	12	33	high
10S	Scoglio del Raviolo (Andrea Ghisotti)	Hydrogeological/ Geomorphological	Cave and submarine spring	B	10	35	medium
11S	Testa del Leone	Hydrogeological/ Geomorphological	Cave and submarine spring	B	8	35	medium
12S	Scoglio del Diamante	Geomorphological	Landslide blocks	B	10	30	low
13S	Mohawk Deer	Geomorphological/ Cultural	Landslide blocks and scarp	B	10	40	high
14S	Punta Vessinaro	Geomorphological	Landslide blocks, submarine cliff	B	10	35	high
15S	Casa del Sindaco - Vitrale	Geomorphological	Submarine cliff, landslide blocks	B	20	40	high
16S	Chiesa di San Giorgio (La Liscia)	Geomorphological	Landslide blocks, cave	B	10	40	medium
17S	Punta del Faro	Geomorphological	Landslide blocks, cliff	B	16	40	medium
18S	Secca dell'Isuela	Geomorphological	Submarine relief	B	14	40	high
19S	Punta dell'Altare	Geomorphological	Submarine cliff	B	10	35	medium
20S	Punta Chiappa ponente	Geomorphological	Cliff, debris covered sea bottom	B	5	25	low
21S	Cristo degli Abissi	Geomorphological/ Cultural	Debris covered sea bottom, rocky blocks	B	12	30	low
22D	Punta Chiappa	Geomorphological/ Geological	Cliff, submarine scarp	B/C	0	5	low
23D	Baia di San Fruttuoso	Geomorphological/ Ecological	Seabed, submarine scarp, Posidonia meadows	B	0	3	low
24D	Baia dell'Olivetta	Geomorphological	Boulders, submarine cliff	C	0	3	low
25D	Baia di Paraggi	Geomorphological/ Ecological	Seabed, submarine cliff, Posidonia meadows	C	0	3	low
26D	Castello di Paraggi	Geomorphological	High cliff, rock fall boulders	C	0	5	low
27D	Punta Cervara-Punta Pedale	Geomorphological/ Geological	Landslide boulders, Posidonia meadows	C	0	5	low

Some methods for quantitative assessment of geosites are based on combined numerical indices to obtain a final score, often named Q-value or global value (e.g., [57,123,124]). This index corresponds to the combination of three sets of criteria relevant to: (i) intrinsic characteristic of a geosite (e.g., degree of scientific knowledge), (ii) potential for use, (iii) need for protection.

Other authors preferred methodologies based on independent criteria (e.g., Brilha's [33] methodology) without the determination of a final score, but considering the results of each set of criteria relevant to a given site. This is because the criteria considered are independent of each other and because the independent numerical evaluation for each criterion enables the individual analysis of each geosite. Specific geosite assessment procedures vary in terms of both the number and type of criteria considered as well as weighing individual parameters and indicators. The criteria generally used for geosite and geomorphosite assessment can be classified into five categories as follows [120,125]:

1. Scientific/intrinsic (scientific merit) values;
2. Exemplarity and educational potential of the site;
3. Accessibility to the site and presence of tourist infrastructures;

4. Existing threats and risks;
5. Added values.

The criteria are preferably adapted to the geological and geomorphological context of the study area.

In the present study, the recognized terrestrial and marine geosites have been quantitatively assessed by applying a methodology that has been specifically set up on the basis of previous works ([47,56,57,119,126]), which concerned the evaluation of terrestrial sites of geomorphological interest and which were applied also to underwater geosites [11]. Although the coastline marks the boundary between terrestrial and marine environments, there is a continuity of geological and geomorphological features across this boundary [61]. In order to fulfil this continuity between land and sea the same assessment methodology for terrestrial and marine geosites was applied. This methodology is based on three sets of values relevant to scientific, additional, and potential for use (Tables 3–5) and the evaluation process builds on bibliographical data and on the detailed and well consolidated knowledge of the geological and geomorphological features of the study area acquired by authors. Scientific value was divided into four sub-criteria (Table 3): Integrity (INT), representativeness (REP), rareness (RAR), and paleogeographic model (PAL). Additional value was divided into three sub-criteria (Table 4): Ecological (ECOL), aesthetical (AEST), and cultural (CULT). Potential for use value was divided into three sub-criteria (Table 5): Accessibility (ACC), services (SER), and economic potential (ECON).

A score between 1 and 5 was attributed to each sub-criterion. For each geosite, the total scientific/additional/potential for use value (*Totval*) was estimated by summing the score of each sub-criterion (a_i) and dividing by the number of sub-criteria (n_a) for each set of values (cf. Equation (1)):

$$Tot\ val = \frac{\sum_i a_i}{n_a}. \quad (1)$$

The aesthetic value is the most subjective one and for the definition of criteria and its assessment, research on landscape perception (see e.g., [34,127] for a review) has been taken into account. Table 4 specifies which features are to be considered in order to assess the aesthetic value of a given geosite. According to Coratza et al. [119], these features are: (i) panoramic quality, (ii) colour diversity, (iii) vertical development, (iv) naturalness. The cultural value is the more heterogeneous sub-criterion (Reynard et al., 2007). Therefore, in order to guide the assessment procedure, the features considered to estimate the cultural value for a given geosite are specified in Table 4. Considering the tourist vocation of the area, attention was devoted to the assessment of the potential for use value. In particular, for the estimation of accessibility (ACC), two sets of sub-criteria were taken into account for terrestrial and marine geosites, as shown in Table 5. In order to estimate the economic potential of a site, the number of visitors per year has been taken into account. In fact, it can be assumed that the greater the number of visitors, the more the economic income. In particular, for the study area, two different sets of thresholds, regarding the number of visitors per year, were considered in the assessment of the economic value of terrestrial and marine geosites, respectively. An exception was made for estimating the economic value of marine geosites accessible via snorkeling. For these, the same visitor thresholds as the terrestrial geosites have been here considered, since they are comparable to terrestrial geosites in terms of number of visitors. The data on visitor influx along the footpath network across the present geosites, which have been given by the Park authority, are an indispensable element for judging the economic potential of the area. For this purpose, eco-counters aiming to monitor hikers have been installed. As for the number of visitors to marine geosites accessible with scuba diving equipment, the management is ruled by an agreement between diving centers and the administration board of the protected marine area, which has also provided us with attendance data concerning each diving point.

Table 3. Sub-criteria used for the numerical assessment of geosite scientific value.

Scientific Value	1	2	3	4	5
Integrity (INT): State of conservation of a landform	Poor conservation due to natural causes (after [43])	Poor conservation due to inadequate management inadequate management	Damage may occur in some parts of landform but landscape integrity is preserved	Good conservation due to proper management	Good conservation due to natural conditions
Representativeness (REP): exemplarity with respect to a reference space [119]	No exemplarity (after [43])	Poor example of process or landform	Fair example of process or landform	Good example of process or landform	Reference site (in scientific literature) for the description of process or landform
Rareness (RAR): rarity of the site with respect to a reference space [57]	Very common	Rare at a local scale ¹	Rare at a regional scale	Rare at a national scale	Rare at an international scale
Paleogeographical model (PAL): Importance of a site in defining processes or environments characterizing the Earth history (modified after [43])	No paleogeographic value (after [43])	Scarce paleogeographic significance	Good representation of a paleoprocess	Good representation of a paleoenvironment	Good representation of a paleoprocess and a paleoenvironment

¹ Rare at the scale of Portofino Natural Protected area.

Table 4. Sub-criteria used for the numerical assessment of geosite additional value.

Additional Value	1	2	3	4	5	
Ecological value (ECOL): presence of ecotypes and level of the site protection for its natural features [128]	No ecotypes and no site protection	Presence of ecotypes without any protection	Presence of rare ecotypes and protection at a local level	Presence of rare ecotypes and protection at a regional level	Presence of rare ecotypes and protection at a national level	
Aesthetic value (AEST): [119]	Panoramic quality	Site not visible from any viewpoint	Site visible from one viewpoint	Site visible from more than one viewpoint	Site visible from many viewpoints also at a great distance	
	Color diversity	No color diversity	Low color diversity	Moderate color diversity	High color diversity	Very high color diversity
	Vertical development	Same level as the surrounding ground	Slightly emerging from the surrounding ground	Moderately emerging from the surrounding ground	Significantly emerging from the surrounding ground	Imposing feature in the landscape
	Naturalness	Completely modified by human intervention	Strongly affected by human intervention but some natural features are still preserved	Moderately affected by human intervention but most of the natural features are preserved	Slightly affected by human intervention	No traces of human intervention
Cultural value (CULT): [119]	Religious importance	No religious importance	Religious importance but no connection to geological and geomorphological features of the site	Religious importance with connection to geological or geomorphological features of the site	Local religious importance with connection to geological and geomorphological features of the site	National religious importance with connection to geological and geomorphological features of the site
	Historical importance	No historical importance	Historical importance but no connection to geological and geomorphological features of the site	Historical importance with connection to geological or geomorphological features of the site	Local historical importance with both connections to geological and geomorphological features of the site	National historical importance with both connections to geological and geomorphological features of the site
	Artistic and/or literature importance	No artistic and literature importance	Artistic and/or literature importance but no connection to geological and geomorphological features of the site	Artistic and/or literature importance with connection to geological or geomorphological features of the site	Local artistic and/or literature importance with connections to both geological and geomorphological features of the site	National artistic and/or literature importance with connections to both geological and geomorphological features of the site

Table 5. Sub-criteria used for the numerical assessment of geosite potential for use.

Potential for Use Value		1	2	3	4	5
Accessibility (ACC): level of accessibility	Land	No access	Accessible only by experts with specific technical skills (e.g., climbers, speleologists)	Accessible by experts but no specific technical skills are required	Accessible by people with normal movement capacity	Accessible by people with limited movement capacity
	Sea [43]	No accessibility or only with indirect methods (e.g., ROV, submersible)	Accessible to expert professional divers or speleology divers	Accessible to 2nd level SCUBA divers (max depth 40 m)	Accessible to 1st level SCUBA divers (max depth 18 m)	Accessible to snorkeling
Services (SER)	Land: presence of equipment and support services in the nearby [119]	No services	Support services within a walkable distance but subject to seasonal availability	Equipment available but subject to seasonal availability	Equipment and services in the near proximity of the site subject to seasonal availability	Equipment and support services in the near proximity of the site, available 7/24 all year round
	Sea: distance from the nearest boarding dock [58]	distance from the boarding dock > 10 km	distance from the boarding dock between 10 and 7 km	distance from the boarding dock between 7 and 5 km	distance from the boarding dock between 5 and 2 km	distance from the boarding dock < 2 km
Economic potential (ECON): number of visitors per year	land	Visitors < 5000	5000 < visitors ≤ 20,000	20,000 < visitors ≤ 50,000	50,000 < visitors ≤ 70,000	visitors > 70,000
	sea	Visitors ≤ 100	100 < visitors ≤ 400	400 < visitors ≤ 700	700 < visitors ≤ 1000	Visitors > 1000

5. Results

Twenty-eight terrestrial geosites and 27 marine geosites were identified and assessed (Figure 4 and Tables 1 and 2). The terrestrial geosites are mainly sites of geomorphological interest of tectonic origin or gravity-induced slope landforms or even coastal landforms, all strictly linked to each other in terms of origin and geomorphological evolution. The footpath network follows the distribution of the terrestrial geosites, which are widespread all over Portofino Park. Marine geosites are mainly concentrated between Punta Chiappa di Levante and Punta Portofino, which is the largest outcrop area of the Portofino Conglomerate.



Figure 4. Location of terrestrial and marine geosites.

The geosites selected were evaluated considering their scientific value. Moreover, the research assessed numerically geosite additional value in terms of ecological and eventually cultural importance of the sites as well as their aesthetic quality. Additionally, the potential for use was estimated taking into account the visit conditions, proximity, and availability of services and economic potential of each site. If we compare the average scientific, additional, and potential for use values in both marine and terrestrial geosites (Figure 5), it can be noticed that these values are similar and comparable to each other and no significant variation was identified. Notwithstanding the adoption of the same assessment methodology for terrestrial and marine geosites, some sub-criteria (accessibility, services, and economic potential) have been adapted considering the different characteristics between terrestrial and marine sites. This approach has allowed a balanced evaluation of geosites between the terrestrial and marine area. Moreover, the relationships between the two environments have been better defined.

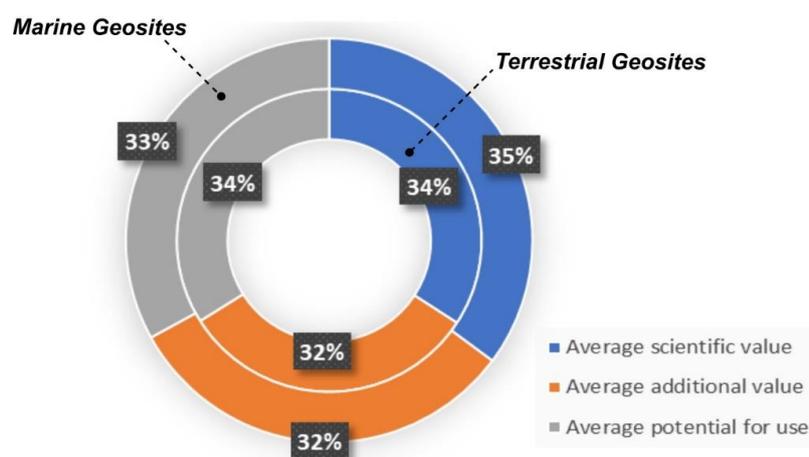


Figure 5. Compared graphs referring to the average of the scientific, additional, and potential for use total values (cf. Section 4.2), calculated considering all the assessed terrestrial (inner circle) and marine geosites (outer circle), respectively.

At the same time, the use of independent assessment criteria permitted the individual analysis of the geosites and the identification of opportunities, weaknesses, and restrictions on tourism development. Indeed, these are fundamental steps for the enforcement of Park management strategies [129].

Multivariate representation (Figures 6 and 7) allows one to compare geosites to each other. Different colors indicate the main scientific interest (geomorphological, speleological, or hydrogeological) of each geosite and the form of the cartograms indicates groups of geosites (e.g., geosites with high scientific value but low potential for use value).

Regarding the scientific value, the assessment of the sub-criteria has revealed that the majority of geosites both terrestrial and marine are well preserved. This confirms the success of conservation strategies applied in the area by the Park authorities. Moreover, most of the geosites are fair to good examples of geological/geomorphological processes and landforms, in terms of level of representativeness (REP). Both terrestrial and marine geosites can be considered as rare at a regional scale, whereas the *Cristo degli Abissi* site (ID 21S) is exceptional at an international scale. High cliffs, more than 150 m a.s.l., set up along active normal faults, continue below sea-level and evolve due to retrogressive erosion, as witnessed by submerged rock fall deposits located on the sea bottom at different distances from the cliffs. These rock fall deposits are good examples of retrogressive processes favored by intense faulting and originated by gravity-induced processes. In addition, good examples of paleo-processes are offered by submerged caverns of structural origin, which are the continuation of land caves. Terrestrial conglomerate outcrops and submarine reliefs are good representatives of past paleo-environments. In particular, submarine reliefs (e.g., the *Secca Gonzatti* geosite—ID 8S) and saddles are ascribable to deep-seated gravitational slope deformations. Many terrestrial springs gushing in the conglomerate or at the boundary between conglomerate and marly-calcareous flysch,

are found also below sea-level and witness the different uplift rate due to neotectonic activity between the emerged and submerged areas of the Park.

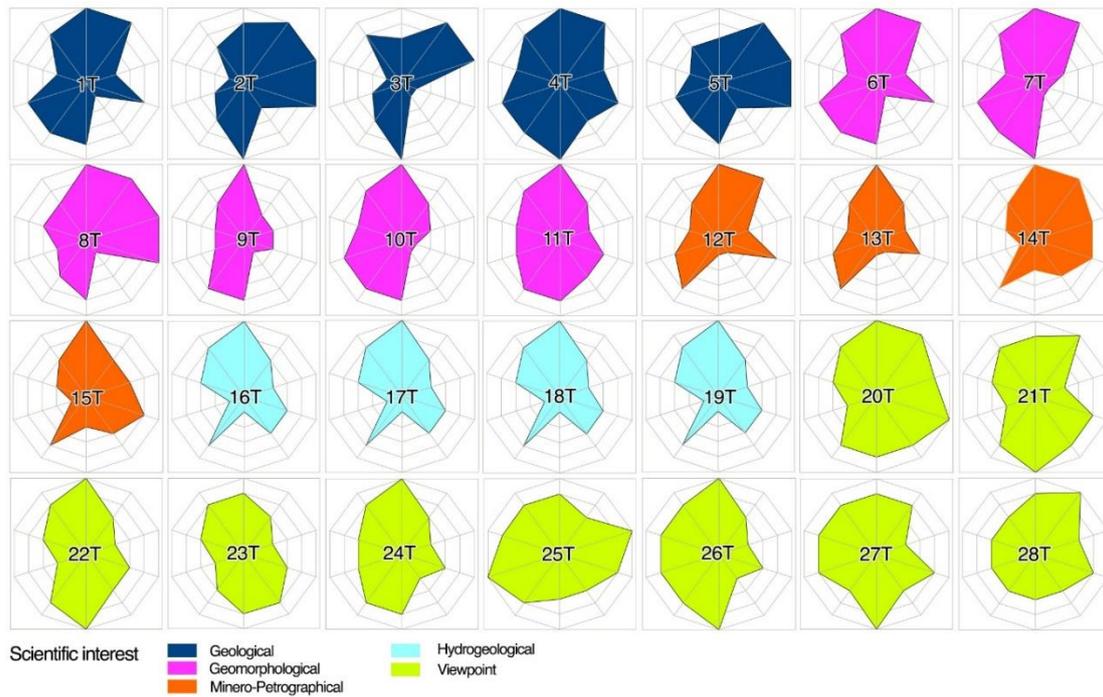


Figure 6. Multivariate representation of the results of terrestrial geosite assessment. Along the axes, the quantitative results of the assessment of the scientific, additional, and potential for use values and their sub-criteria are shown for each terrestrial geosite (for axis legend, see Figure 7). The colors represent different scientific interests, as specified in the figure legend.

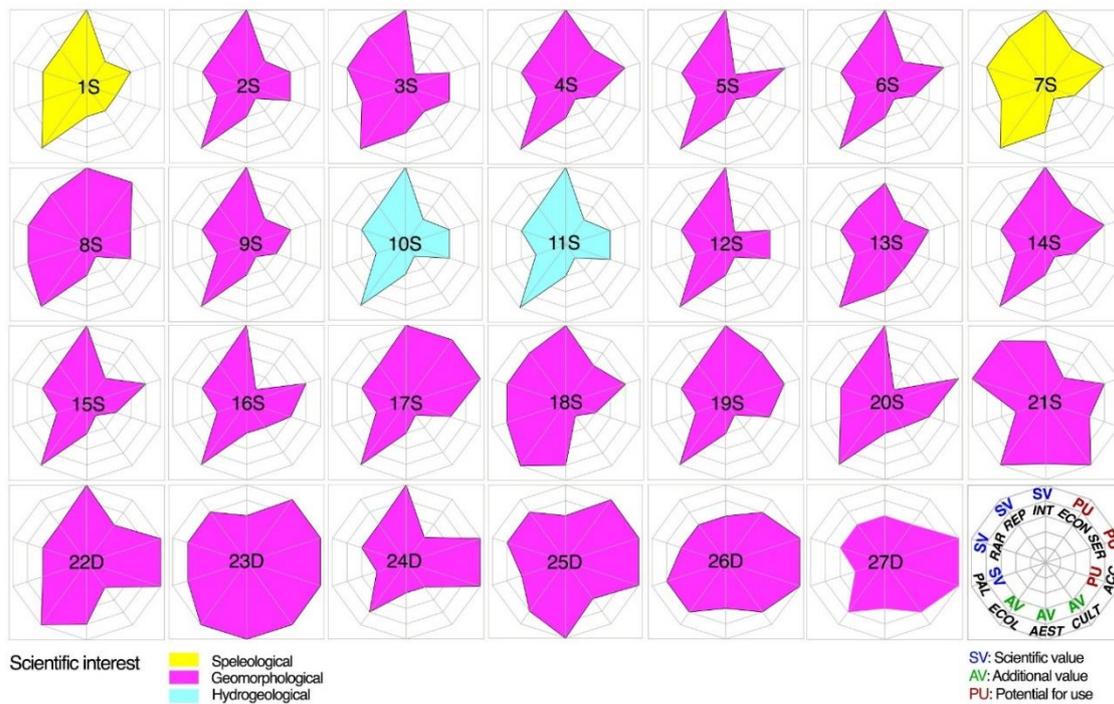


Figure 7. Multivariate representation of the results of marine geosite assessment. Along the axes, the quantitative results of the assessment of the scientific, additional, and potential for use values and their sub-criteria are shown for each marine geosite. The colors represent different scientific interests, as specified in the figure legend.

The majority of terrestrial geosites is protected at a regional level, since it is included within the Portofino Regional Natural Park. The great majority of marine geosites is characterized by high ecological value; most of them are included in the protected marine area of type B, while the others are located within the type C protected area. Marine sites have a high ecological importance owing to the presence of coralline biocoenosis and prairies of *Posidonia oceanica* both on sandy and rocky seabeds. Furthermore, the presence of rocky blocks resulting from rock falls and topples originating in the overhanging conglomerate and, to a lesser extent, marly-calcareous flysch cliffs, favors exceptional biodiversity recognized at an international level.

Viewpoints generally have the greatest additional value due to their scenic quality and color diversity (aesthetic value, AEST). Among marine geosites, the *Baia di San Fruttuoso* (ID 23D), *Baia di Paraggi* (ID 25D), and the *Cristo degli Abissi* site (ID 21S) have the highest additional value due to their aesthetic quality and cultural relevance. For instance, the *Baia di San Fruttuoso* hosts the abbey bearing the same name, which dates back to the 10th century CE, while the internationally famous *Cristo degli Abissi* statue was placed in 1954 and has now assumed historical relevance.

The assessment of the potential for use is crucial in choosing management strategies aimed at the promotion of geotourism in the area; therefore, particular attention has been devoted to choosing the most suitable sub-criteria for this evaluation. The latter revealed that terrestrial geosites are generally easily accessible except from the cliffs, of course, which require climbing skills for their fruition, while panoramic points are generally the easiest accessible terrestrial geosites. The most accessible marine geosites are the ones reachable by snorkeling, while all the other sites are accessible only to second-level certified scuba divers.

Low values are recorded for services in the proximity of terrestrial geosites. In fact, despite the support services being generally located at a walkable distance, they are subject to seasonal availability (mainly in spring and summer). For marine geosites, the services—i.e., boarding docks—are mostly located at a distance of 4 to 7 km. Every year, tens of thousands of visitors choose to hike along the footpaths of the Portofino Natural Park (from 20,000 to more than 70,000 visitors per year), making the economic value of terrestrial geosites very high. As for marine geosites, the number of visitors, in terms of scuba dives per year, is two orders of magnitude lower than the terrestrial geosite visitors, except for snorkeling sites, which are attended as much as land ones. It should be mentioned that data on scuba diving are underestimated due to the presence of illegal non-registered scuba divers.

6. Conclusions

The Portofino Natural Park boast some of the most impressive sceneries of the Mediterranean area, displaying a large variety of geological landscapes as well as unique ecological systems, both in terrestrial and marine environment.

This research has led to the identification and assessment of 28 terrestrial and 27 marine geosites of the Portofino Natural Park and protected marine area, pinpointing the most suitable sites for geotourism promotion, for both their contribution to the understanding of the geological processes acting through time on landscapes as well as their aesthetic importance.

In fact, the area is a well-known seaside resort and the present economy is almost exclusively based on onshore and offshore tourism. Nevertheless, tourism activities focus mainly on the rich marine biota and habitats and for recreational purposes while the geological and geomorphological features are usually neglected. Instead, these features, including submarine ones, could play a relevant role in developing a sustainable and safe tourism fruition, thanks to a deeper understanding of the complex geological and geomorphological contexts.

Moreover, for the first time, geosite assessment has been performed by applying a common methodology to both terrestrial and marine geosites. Some sub-criteria (accessibility, services, and economic potential) have been adapted considering the different characteristics between terrestrial and marine sites. This approach has allowed us to emphasize the relationships between the terrestrial and marine environments. The selected geosite network is meant to show common processes and

landforms between these environments creating the ground for diversified but common and more efficient management and conservation actions and policies.

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