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A multidisciplinary approach to the study of insular environments: the 1st Summer School on Geomorphology, Ecology, and Marine Biology in the Tremiti Islands (Southern Adriatic Sea, Puglia, Italy)

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A multidisciplinary approach to the study of insular environments: the 1st Summer School on Geomorphology, Ecology, and Marine Biology in the Tremiti Islands (Southern Adriatic Sea, Puglia, Italy)

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ABSTRACT
This paper is the outcome of the 1st Summer School on Geomorphology, Ecology, and Marine Biology in insular environments, focused on the advanced and multidisciplinary methods for the scientific investigation of marine coastal areas. It was held at Tremiti Islands, a significant laboratory for geomorphological, biological, and ecological studies because of its dynamic interaction between geodiversity and biodiversity, which makes it an ideal place for scientific research and geotourism. Landscape information was collected during field trips, while practical activities were finalized to sampling sediments and data collection of hard bottom assemblages. The map is the result of a multidisciplinary analysis incorporating geomorphological field observations and advanced methods applicable for ecological and environmental research, supported by scientific diving. This work represents a useful tool for the dissemination of environmental knowledge of the area and for understanding the relationships between landscape and natural heritage through modern and environmentally aware tourism.

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1. Introduction

The 1st Summer School on Geomorphology, Ecology, and Marine Biology in insular environment, held on 30 June–3 July 2019, at Tremiti Islands (southern Adriatic Sea, Puglia Region), aimed at promoting a multidisciplinary scientific approach for the study of the interactions between physical and biological characteristics of emerged and submerged marine coastal areas. A specific focus was given to the scientific diving and its capacity to collect information for supporting science allowing for the non-invasive observations of habitats, fauna, and flora of aquatic ecosystems in their natural environment. Insular systems, like Tremiti Islands, are ideal sites for the development of integrated environmental studies because they are generally characterized, in small spaces, by a wide variety of emerged and submerged landscapes that support very diverse habitats and organisms. At the same time, they are very vulnerable systems which require the development of new research approaches aimed at the knowledge and protection, especially concerning the effects of global changes, by the scientific community (Bellard et al., 2014). Tremiti islands, established in 1989 as Marine Protected Area (MPA), were an ideal site for the summer school because of their high scientific value, derived from the dynamic interaction between geodiversity and biodiversity, and the presence of coastal marine caves of particular interest from a geomorphological and ecological viewpoint (Gallo D'Addabbo et al., 2001; Miccadei et al., 2011b; Pignatti et al., 1967); besides, the cultural importance, linked to the presence of one the most important monasteries of the Adriatic coast of Italy, should be seen in a context of site conservation, management, and land planning (Pagliarulo, 2015). In addition to a strictly scientific purpose, the school also played a role in integrating aspects of scientific dissemination and tourism; through this type of events, the activity of geotourism on the territory becomes an opportunity for tourism, cultural activities and a powerful tool in education for young people, adults, local citizens, and observers/geotourists. Geotourism is a type of sustainable tourism developed in the last few decades in the broad field of geoheritage

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enhancement focusing on geosites, geomorphosites, physical landscape management and geopark/natural park management (Piacentini et al., 2019; Reynard & Brilha, 2017). Tremiti Archipelago can be considered an important laboratory for geological, geomorphological, and ecological studies, being at the same time renowned for tourism, recreation, educational, and scientific diving activities. The school was addressed to undergraduates, PhD students and researchers of geological, biological and natural sciences, but also technicians engaged in the environmental field. The educational activities, which were mostly focused on methods for surveying, sampling and data acquisition in the field of geomorphology, marine geology, sedimentology, foraminiferal ecology, and marine biology, were organized in morning lessons and practical activities. Scientific diving was also considered as a fundamental tool for the acquisition of data in marine coastal environment with a description of the main methods for surveying and sampling marine caves. The acquisition of data and samples for scientific research in underwater conditions requires a specific methodological approach, and this is more demanding when the object of the study are extreme environments such as marine caves (Caramanna et al., 2012); in this context, it is necessary the involvement of specifically trained divers and the application of suitable protocols. The underwater activity, carried out during the school, was finalized by surveying and sampling of two marine caves at Cala Sorrentino and Cala Caffè (Capraia Island) in order to outline the geomorphological and ecological features of marine caves. New methods, which took into account the fragility and logistic constraints of these environments, for the hard-bottom assemblages' characterization inside and outside the caves were also applied. Hard substrates host a rich biodiversity whose description is a valuable element for the characterization and comparison of these environmental domains (Gerovasileiou et al., 2017).

2. Geological and geomorphological framework of Tremiti islands

The Tremiti Archipelago is located in the southern Adriatic Sea, north of the Gargano promontory, and it is made up of San Domino, San Nicola, Capraia, Cretaccio islands, and Scoglio la Vecchia rock (Figure 1). The islands are aligned in an SW-NE direction and cover an area of about 3 km^2. The topography rises from a gentle underwater slope that reaches about 70 m b.s.l.

The islands are composed of a carbonate bedrock, constituted by limestone, dolomitic limestone, and marls, overlaid, on the mainland of the islands, by

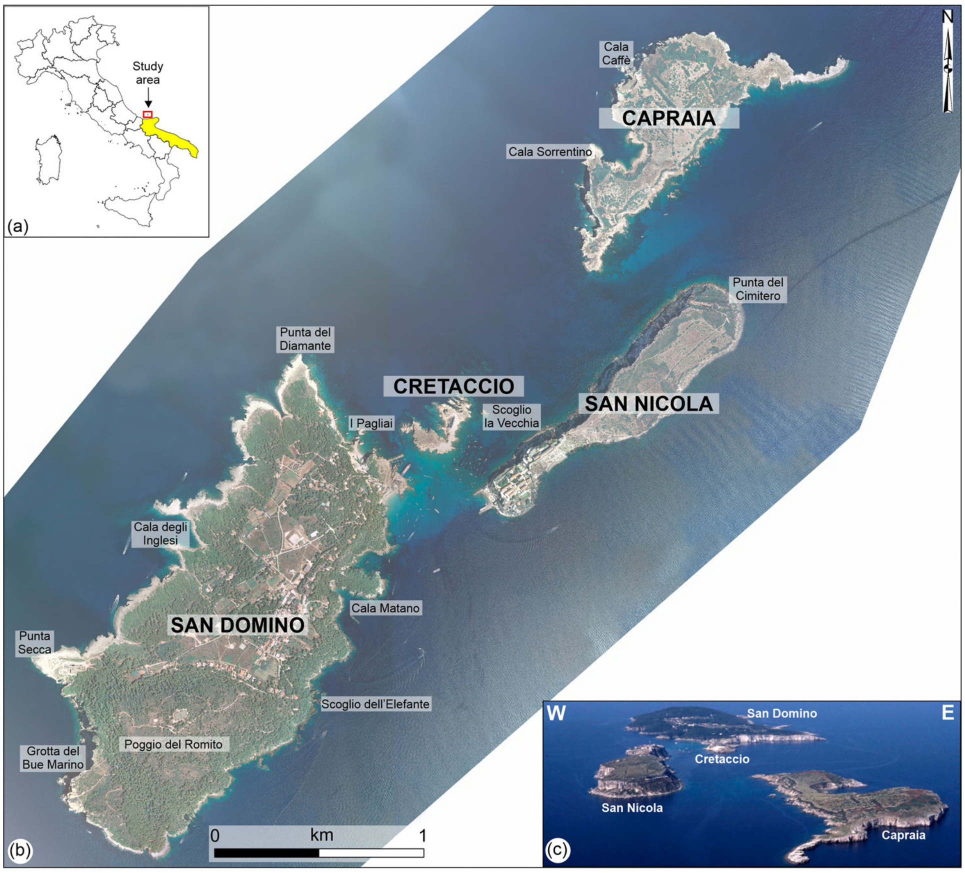

Figure 1. (a) Location map of the Puglia Region in Southern Italy. The red box identifies the location of the islands; (b) orthophoto images of Tremiti Islands (Puglia Region, http://www.sit.puglia.it); (c) landscape photo.

conglomerates, paleosoils, calcretes, aeolian sands, eluvial-colluvial deposits, and soils referable to a Quaternary continental succession (Figure 2). Marine submerged areas are developed on carbonate bedrock with seabed deposits made up by gravel, sand, and silt (Lirer et al., 2002; Miccadei et al., 2011a; Selli, 1971). The main tectonic discontinuities, E-W, WSW-ENE, and NE-SW oriented, are characterized by strike-slip kinematics and can be associated with regional discontinuities. The study area is affected by strong seismicity with earthquakes along E-W to SW-NE tectonic discontinuities, associated with strike-slip and transpressive focal mechanism and magnitude up to 4.0 (Argnani et al., 1993; De Alteriis, 1995; Del Gaudio et al., 2007; Favalli et al., 1993). The present-day landscape setting is the result of a complex relationship among long-term geomorphological evolution, Late Quaternary tectonics, with the major control coming from coastline variations due to both regional uplift and Pleistocene-Holocene eustatic sea-level changes (Antonioli & Vai, 2004; Chiocci et al., 2004; Mastronuzzi & Sansò, 2002; Parlagreco et al., 2011; Ridente & Trincardi, 2002). The geomorphological features are characterized by landforms referable to slope, karst, coastal and marine environments. In detail, karst processes are widespread on emerged and submerged areas and determine, in combination with pre-existing tectonic features and wave erosion processes, the distribution, genesis, and growth of several coastal caves, partly or completely submerged by seawater, such as Cala Caffè and Cala Sorrentino marine caves (Miccadei et al., 2012a).

3. Methods

The present work was based on an integrated methodological approach that incorporates the morphometric analysis, the geomorphological field observations and the scientific diving techniques. The morphometric analysis, as well as the landscape mapping, was carried out with GIS software (ArcMap® 10.6). The analysis of the main orographic features, such as elevation analysis and slope analysis, was performed on the basis of a LiDAR digital elevation model (DEM) with a raster resolution of 1 m, provided by Ministero dell'Ambiente e della Tutela del Territorio e del Mare. Bathymetric analysis was performed by processing and interpolating data from Istituto Idrografico Militare, Piano Nautico n. 204 'Isole Tremiti e Pianosa' (1:15,000 scale). Geomorphological field observations were based on field mapping, carried out at an appropriate scale (1:5,000–1:10,000) on printed topographical maps, in order to investigate the landscape features and to discriminate the main geomorphological elements. All mapped features were digitized by means the GIS software and then assembled to form the final map. The mapping was performed according to the guidelines of the Geological Survey of Italy (ISPRA, 2007; ISPRA & AIGEO, 2018) and thematic literature concerning geomorphological and landscape analysis (Calista et al., 2016; Miccadei et al., 2012a, 2012b; Piacentini et al., 2018). The main features of the marine caves were investigated by means of scientific diving including activities of underwater survey and characterization of sediment and hard bottom assemblages. The survey was carried out by Global Underwater Explorers (GUE) divers and ISPRA researchers according to GUE procedures. The GPS position of the starting point at the entrance of the cave was taken through a Surface Marker Buoy (SMB) on the surface; a guideline, considered as a series of consecutive segments, each of them being connected to the next, was positioned by the divers from the entrance to the inner part of the cave. Then, the guideline was used as a reference for taking measures (length, direction, and depth) and for a preliminary mapping of the cave, using the Mnemo device (see Scientific Section's box on the Main Map). On the same line, labeled cookies were positioned at a regular distance for identification of the sampling stations for ecological purposes. Divers manually collected a total of 5 water and sediment samples for each cave according to Romano et al., 2018a. Three aliquots of sediment were used for the analysis of grain size, Total Organic Carbon (TOC) (De Falco et al., 2004; Romano et al., 2018b), and benthic foraminifera (BF), the last one previously stained with a Rose Bengal /ethanol solution for the recognition of living specimens (Walton, 1952). Water samples, collected close to the sediment/water interface, were used for measuring temperature, salinity, pH and Dissolved Oxygen (DO) by means a multiparametric probe. For the investigation of hard bottom benthic communities, carried out only for educational purposes, a non-destructive protocol was used. A collection of 20 photographs with a surface area of 0.25 m^2, radially distributed with respect to the entrance to the cave, was carried out, together with the measurement of the inclination of the substrate. The photographic sampling was also replicated in the first part of the cave, positioning the square on the walls inside an imaginary buffer which from the opening of the cave extends up to 1.5 m inside.

4. Results

The map presented in this paper illustrates the results of the landscape analysis of emerged and submerged marine coastal areas. It includes two different sections which are described in the following paragraphs:

(1) Morphometry section (on the upper right part);
(2) Landscape map section (on the central part).

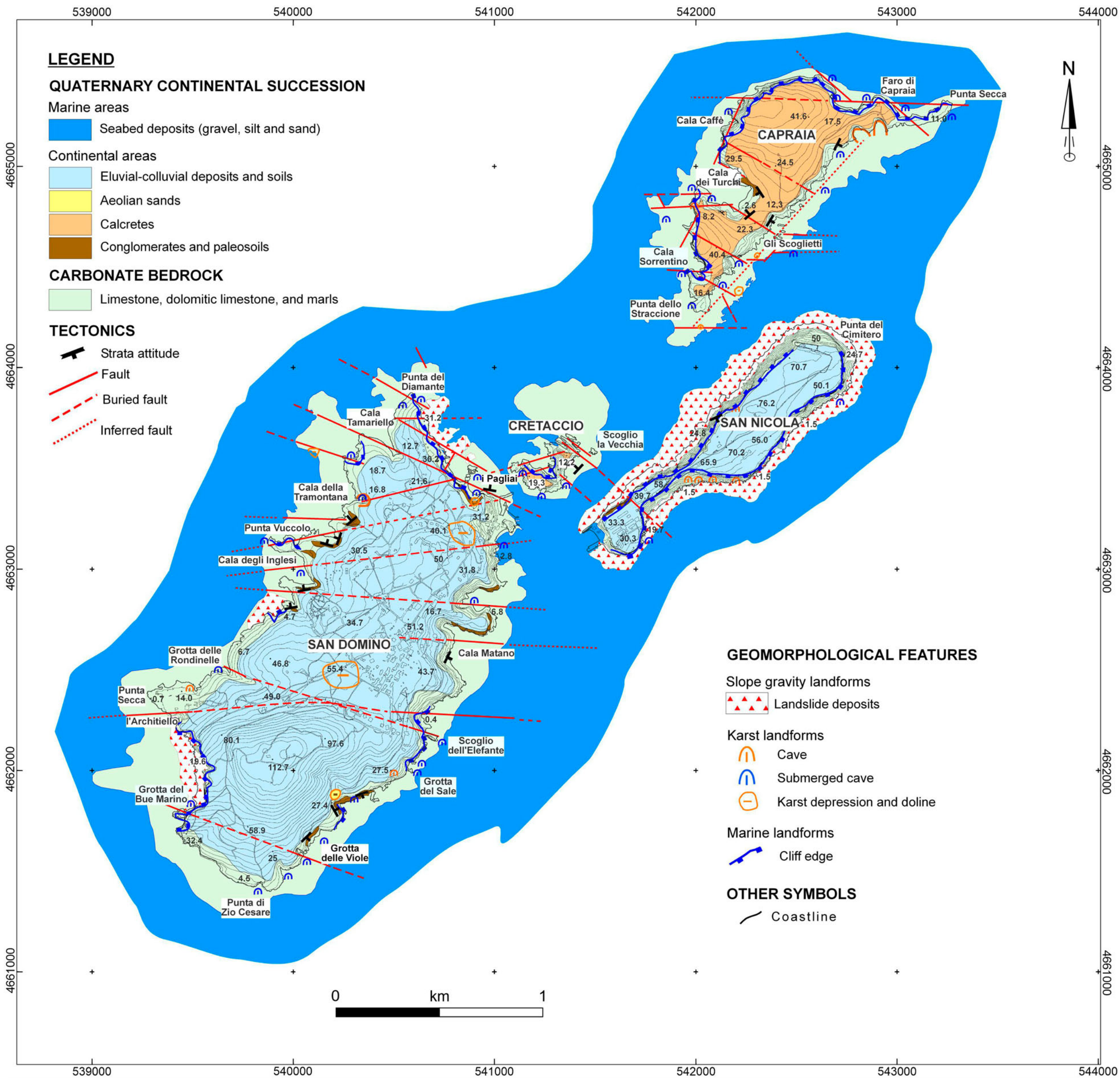

Figure 2. Geological scheme of Tremiti Islands (modified from Andriani et al., 2005; Miccadei et al., 2012a).

An additional scientific diving section, located in the lower part of the map, is presented to describe the advanced ecological and biological methodologies, illustrated during the summer school, for the scientific investigation of underwater site investigations.

4.1. Morphometry section

The overall topography is characterized by a slightly rough morphology with a landscape showing very steep or vertical cliffs and a tabular summit. San Domino island reaches the maximum altitude (Poggio del Romito, 119 m a.s.l.) located in the SW sector of the island and is characterized by an irregular and wavy morphology with elevation ranging from 20 to 40 m a.s.l., bordered by vertical cliffs. It shows a homogeneous slope distribution (values between 0° and 10°) with the highest values (>50°) along the cliffs. San Nicola island shows a tabular morphology with elevation ranging from 55 to 75 m a.s.l., bordered by high rock cliffs (up to about 60 m high). It reaches the highest altitude (76 m a.s.l.) in the NW sector. Slope values range from 0° to 5° on the summit tabular surface with high values (>60°) along the surrounding sub-vertical cliffs. Capraia island shows a cuesta morphology, characterized by a steep cliff on one side and a gentle back slope on the other. The elevation ranges from 20 to 55 m a.s.l. with maximum altitudes of about 55 m a.s.l. in the NW sector bordered towards W by cliffs up to 20 m high. It shows a homogeneous slope distribution (values between 0° and 15°) with the highest values (>50°). The bathymetry presents a step-like morphology ranging from sea level to >70 m b.s.l., with three main homogeneous sectors at 5–40 m b.s.l., 40–60 m b.s.l., and 60 – >70 m b.s.l.

4.2. Landscape map section

On the main map, the distribution of landscape features of the main islands is represented at a 1:5,000 scale. They are listed and briefly described in the following paragraphs (numbers refer to the map and its corresponding visual legend).

4.2.1. Tabular landscape (1)

This landscape is characterized by tabular areas with a flat morphology set on eluvial-colluvial deposits, mainly consisting of loose argillaceous, dark reddish-brown deposits. It is present on the summit areas of San Domino at an elevation of about 100 m a.s.l., and on San Nicola at an elevation from 40 to 75 m a.s.l. It also characterizes a small sector of Cretaccio at heights of about 20 m a.s.l. It, generally, shows a homogenous slope distribution with values ranging between 0° and 5°.

4.2.2. Cuesta landscape (2)

This landscape characterizes the morphology of Capraia island and presents steep cliffs on calcareous bedrock along with the western sector of the island and a gentle slope dipping towards east. It is set on breccia, paleosols, and calcretes deposits. The elevation ranges from 20 to 50 m a.s.l. with slope values ranging from 0° to 10°, located especially in the northernmost sector of the island, with sub-vertical scarps showing the highest slope values (>50°) near Cala Caffè and Cala Sorrentino.

4.2.3. Slope landscape (3)

This landscape is mostly present on San Domino island on eluvial–colluvial deposits and shows a wavy and irregular morphology highlighting the junction areas between the tabular surfaces and the vertical coastline. The elevation rises from 5 to 40 m a.s.l. in the central sector of the island, with higher values (up to 90 m a.s.l.) in the southernmost sector between Punta di Zio Cesare and Poggio del Romito. This landscape unit is characterized by slope values from 5° to 30°, heterogeneously distributed in areas of slight incline.

4.2.4. Cliff landscape (4,5)

This landscape is characterized by the presence of vertical cliffs and very steep coastal slopes showing slope values >60°. Much of the coast of San Nicola, Capraia and Cretaccio and part of San Domino are characterized by steep, vertical, >80 m high cliffs descending precipitously into the sea. San Nicola is totally bordered by sub-vertical cliffs with overhanging blocks and slope values ranging from 50° to 75°. In some cases (e.g. I Pagliai, San Domino Island) where the calcareous bedrock is made up of highly fractured limestone, cliffs are controlled by faults and related fracturation giving rise to a landscape developed over a large cataclastic area and strictly controlled by the lithological and tectonic features of the island. Cliff edges are present at San Nicola and in some sectors of San Domino and Capraia. Emerged rock and sea stacks are also widespread next to this landscape, with significant examples at I Pagliai and Scoglio dell'Elefante.

4.2.5. Landslide landscape (6)

This landscape is generally associated with the cliff landscape. The present-day morphology of the islands is characterized by the complex interaction of gravitational and marine processes that induce the instability, retreat, and evolution of the vertical cliffs. Inactive and relict landforms are represented by palaeolandslides, located below sea level and made of decametric calcareous blocks; active landslides significantly affect the whole present-day coastline. Most of the present cliffs are characterized by different types of mass movements such as rockfalls and topples, slides, and lateral spreads. They consist of small- to medium-size block falls due to undercutting by waves whose steady impact forms a horizontal notch in the cliff at the mean sea level. They are present along almost the whole coast of San Nicola and locally the coast of Capraia and San Domino.

4.2.6. Karst landscape (7,8)

This landscape is widespread both on emerged and submerged areas of the archipelago, strictly linked to the lithological features of the calcareous bedrock. It is characterized by low relief flat coasts with elevation ranging from 0 to 20 m a.s.l. and gently dipping convex slopes. The submerged karst landscape is highlighted by the presence of about 50 caves scattered throughout the archipelago and located between the sea level and 50 m b.s.l. Walking on the islands or sailing around them, the effects of karst processes are clearly evident; exemplary karst landforms are represented by sub-circular dolines on San Domino island, at an elevation between 40 and 50 m a.s.l., with diameter varying from some decimeters to over one meter, and doline edges widespread along the coastline (i.e. Faro di Capraia and Cala della Tramontana).

4.2.7. Submarine landscape (9)

This landscape characterizes the seabed developed in the marine areas around the islands. It represents a karst landscape, developed under aerial conditions and, then, sealed with coastal and marine deposits. It is characterized by the presence of several marine caves (such as Cala Sorrentino and Cala Caffè caves) showing different extent according to the site-specific geomorphological setting.

The bathymetry presents three main flat surfaces at 8–10 m b.s.l., at 20–25 m b.s.l., and at 50–55 m b.s.l., more evident on the northwestern side of the archipelago. They are bounded by scarps and sub-vertical slopes and can be described as marine erosion surfaces related to different past sea levels, lower than the present one.

4.3. Scientific diving section

Tremiti Islands, due to the high frequency of marine caves along their coast, represent a key point for the application of underwater techniques finalized to scientific research. Scientific diving is increasingly being used for numerous studies allowing at the same time the application of interdisciplinary research (Bałazy et al., 2014; Iliffe & Bowen, 2001; Lang, 2007) but, even if flexible, it requires a standardized approach and systematization, depending on the type of research conducted, especially if carried out in overhead environments like as marine caves (Exley, 1986). It is particularly important in the natural sciences where it allows for the non-invasive observations of habitats, fauna, and flora of aquatic ecosystems in their natural environment (Kur & Mioduchowska, 2018; Marassich, 2019).

4.3.1. Description and survey of the marine cave

There are several methods to carry out a survey of a cave; the most commonly used is the placement of a polygon line, marked by stations located at each change of direction, on which depth, direction, and the inclination are recorded for obtaining a profile of the cave. Additional data can be taken for a 3D reconstruction. In this paper, mainly due to the small extent of the two caves, only the polygon line based on depth, compass direction and distance was considered for the survey, which was also used for the location of the sampling stations. In both caves a general direction E-SE (90°—100°) and an average depth of 20 m (ranging from 19 to 25) was recognized. Visibility was about 15 m and in line with the conditions of the facing open sea area. Both caves had relatively high ceilings and significant organic deposits on the bottom but maintained a very simple morphology without secondary passages and relatively short distances from the entrances of the cave at the end of the passage.

4.3.2. Ecology of benthic foraminifera

Marine caves may be considered as natural laboratories to study the effects of environmental changes because they are affected by wide and fast changes of environmental parameters in short times and small spaces; moreover, the effects of seasonal and global environmental changes are amplified in these habitats, being located at the boundary between the marine and continental domain. The study of confined domains may be helpful for the comprehension of mechanisms that regulate the response of benthic foraminifera to environmental variability at a global scale. In particular, the identification of the effects of temperature and pH on foraminiferal assemblages in cave environment may supply preliminary information on the effects of climate changes and anthropogenic impact, especially in terms of sea-level changes and water contamination. In this context, the identification of reliable and easily applicable ecological indicators is of particular importance. Benthic Foraminifera (BF) are a group of eukaryotic protozoa, mostly bearing a mineralized shell called 'test', very abundant in sediments of marine and transitional environments where, since the last decades of the twentieth century, they have been recognized as effective environmental indicators for both natural and anthropogenic changes (Jorissen et al., 2018). The study of BF in marine caves started in the 2000s in tropical karst systems of Yucatan peninsula (van Hengstum et al., 2008) and Bermuda (Little & van Hengstum, 2019: van Hengstum & Scott, 2011), while only later it has been applied in the Mediterranean which is, until now, the only temperate region where this research was developed (Bergamin et al., 2018; Romano et al., 2018a, 2020). These studies, carried out in the Gulf of Orosei (Sardinia, Italy) karst system, recorded the presence of BF not only close to the cave entrance, where assemblages similar to the marine ones were present, but up to several hundred meters inside the tunnels, where they constituted peculiar assemblages characterized by decreasing diversity and density from the cave entrance to the inner parts as a response to increasing stressed conditions. The environmental stress was attributed to the gradient, from marine to continental conditions, of water parameters such as salinity, pH, and DO. Also, sediment texture and nutrient availability played an important role in the distribution of BF in marine caves. A succession of different foraminiferal assemblages, corresponding to specific ecozones, was recognized along the cave tunnels, as a response to the change of environmental conditions. The same behavior is recognizable in both studied caves, in spite of their short extension, where the preliminary results indicated abundant living and dead BF, well-distinct assemblages from those found outside the cave, specimens generally small and fragile and, as dominant taxa, *Patellina corrugata* and *Spirillina vivipara* characterized by epifaunal attached or clinging lifestyle.

4.3.3. The marine biology of hard bottom

Marine caves are acknowledged as 'refuge habitats' or 'biodiversity reservoirs' of great conservation value, harboring a rich biodiversity (40–65% of the Mediterranean sponge, bryozoan, tardigrade and brachiopod diversity), including a considerable number of rare, cave-exclusive, endangered, protected, and deep-sea species (Gerovasileiou & Voultsiadou, 2012, 2014). The description of the benthic populations of the caves provides a valuable additional element for the characterization and comparison of these environments. The biodiversity inside the caves is not comparable with that present outside; however, a characteristic of the benthic populations in the vicinity of the cave is of interest in the comparative study between caves. The photographic sampling can allow to recognize the natural gradient outside/inside the cave and provide information about the type of species and richness of the hard-bottom assemblages immediately outside the cave, close to the entrance, in the semi-dark and dark section of the cave.

5. Conclusion

This paper is the outcome of the 1st Summer School on Geomorphology, Ecology, and Marine Biology, held at the archipelago of Tremiti Islands. The emerged and submerged landforms of the study area provide a fascinating key to improve the reading and understanding of the landscape and the natural and human history of the southern Adriatic Sea. These landforms preserve the record of a landscape evolution connected to geomorphological processes driven by the interaction between climate, tectonics and sea level changes. The strongest cultural impact on the area is due to the settlement of Benedictine monks who built the Abbey of Santa Maria, which subsequently became the historical, religious, and administrative center of the Tremiti Islands (Pagliarulo, 2015). The main aim of the paper was to present an innovative methodological approach for the analysis of insular environments, incorporating geomorphological field observations, ecological and environmental analyses of underwater habitats supported by scientific diving. The map presents the results of the morphometric and landscape analysis of emerged and submerged marine coastal areas, with a brief description of preliminary results about physical and biological characteristics of underwater site investigations (Cala Caffè and Cala Sorrentino marine caves). The main map is designed to establish an easy and guided visual connection between the observers/geotourists and the landscape and natural heritage of the Tremiti Islands. It incorporates long-term (geological) and short term (historical) memories of the landscape shaping and of the present geological-geomorphological hazards. The geomorphological significance of the archipelago is enhanced by its considerable ease of access and by its protection within the Gargano National Park. Such a small archipelago holds an incredible variety of landforms, mostly due to marine, slope and karst processes; moreover, the overall setting of these landforms is related to tectonic and lithological control (Miccadei et al., 2012a). In detail, marine caves, widespread in the area, shows karst habitats that may be considered as natural laboratories for studying environmental variability, recorded by benthic foraminifera which may live in these restricted environment, not only close to the entrance, but even at considerable distance from it, and respond to changes of environmental parameters (Romano et al., 2018a). In conclusion, this work represents a useful tool for describing the interaction between geodiversity and biodiversity and for understanding the relationships between landscape and natural heritage through a modern and environmentally aware tourism.

Software

The vector/raster data and main map were managed using Esri ArcGIS ® 10.6, with final editing performed using Corel DRAW 2019 ®.

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Peer-Review Information

Unlike regular articles, submissions to the Journal of Maps Student Section do not undergo a comprehensive open-peer-review process. All submissions to the Student Section are reviewed internally by one subject specialist and one cartographer, and the focus is to provide constructive, actionable comments that facilitate an encouraging experience of the publishing process and an outlet for the work of research students.

Disclosure statement

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