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Geomorphological analysis of San Nicola Island (Tremiti Islands, Southern Adriatic Sea). Results from the 2021 and 2022 Environmental Geomorphology field camps of the MSc in Geological Sciences and Technologies of Earth and Planets (University 'G. d'Annunzio' of Chieti-Pescara)

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ABSTRACT
This paper presents the results of the 2021 and 2022 field activities carried out at San Nicola Island (Tremiti Islands, Southern Adriatic Sea) by two groups of students as part of the Environmental Geomorphology Field Mapping course held within the Master's Degree in Geological Sciences and Technologies of Earth and Planets at University 'G. d'Annunzio' of Chieti-Pescara. Field activities were carried out following an integrated approach that involved morphometric, geological, and geomorphological analyses, supported by the combination of traditional methods with modern survey instruments and techniques. The Main Map (1:2,500 scale) comprehensively depicts the landscape of San Nicola Island, which is affected by both long- and short-term evolutionary processes, as witnessed by widespread slope landforms. The cartographic products presented in this work can represent a useful tool in territorial planning and management, as well as a valuable base for further scientific studies.

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Environmental geomorphology field camp; fieldwork; students; San Nicola Island; Tremiti Islands; Southern Adriatic Sea

1. Introduction

In the framework of academic scientific curricula well-designed field trips, comprising pre-, on-, and post-field activities and satisfying administrative-teaching and educational criteria (Orion, 1993), represent practical tools for improving students' knowledge, since experiential activities can favor the construction of abstract concepts and provide the bases for a meaningful learning (Elkins & Elkins, 2007). In this context, geosciences greatly benefit from field activities (often more than other disciplines), which are the best opportunity for having a direct contact with geological-geomorphological and environmental features, with a clear pedagogical relevance (de Barros et al., 2012).

Among geosciences sectors, geomorphology plays a pivotal role, including not only the understanding but also the mapping and the potential modeling of Earth's surface processes. Geomorphological mapping represents a useful tool for the interpretation of landforms at any spatial scale, with sketches and maps constituting the graphical inventory of landscape features, essential to visualize and analyze geomorphological data and deliver a complete view of the landscape evolution (Dramis et al., 2011; Dykes, 2008; Knight et al., 2011; Verstappen, 2011). However, teaching geomorphological mapping requires practical field activities, being most of its concepts not conveyable in a satisfying way only through in-class lessons (De Waele et al., 2012).

Over the past years, the broad deployment of Geographical Information Systems (GIS) and the use of new tools to facilitate field mapping, along with the availability of high-resolution remote sensing data and Digital Elevation Models (DEMs), improved the ability to capture and investigate surface (and subsurface) features and to produce detailed geomorphological maps (Bufalini et al., 2021; Mascioli et al., 2022;

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Szypuła, 2017). These last, consequently, represent more and more a valuable tool in support of land defence, protection, and management and provide necessary information for effective environmental research and studies (Jaboyedoff et al., 2012; Lee, 2001; Lundmark et al., 2020; Otto & Smith, 2013; Reddy, 2018).

This paper presents the results of field mapping campaigns performed at San Nicola Island (Tremiti Islands, Puglia Region, Southern Adriatic Sea), which features great historical monumental and landscape value. Activities were carried out by two groups of students as part of field activities planned in the Environmental Geomorphology Field Mapping course, held within the second year of the Master's Degree in Geological Sciences and Technologies of Earth and Planets at University 'G. d'Annunzio' of Chieti-Pescara. Activities took place over 29 September–3 October 2021, and 30 September–4 October 2022, with participants belonging to 2021/2022 and 2022/2023 academic years, respectively.

The archipelago of Tremiti Islands is considered an excellent geological and geomorphological laboratory featuring slope, marine, fluvial, and karst landforms set on Cenozoic marine and Quaternary continental successions. The area, indeed, is of crucial importance for the definition of the Late Quaternary Adriatic basin evolution, resulting from a complex landscape evolution driven by climate, tectonics, and sea-level changes and comprehensively recorded in islands peculiar geomorphological features (Mastronuzzi & Sansò, 2002; Miccadei et al., 2011b; Paglia et al., 2020).

That being stated, the purpose of this work was to enhance students' awareness on the importance of field observation and mapping in natural processes comprehension at different spatial and temporal scales through the combined use of traditional surveying methods and contemporary hardware and software tools provided by technological advancements (Miccadei et al., 2016). Achieved results confirmed the necessity of a constant effort in teaching fieldwork activities to young geologists, in order to provide them with the adequate 'sensitivity' to properly deal with geological and geomorphological processes.

2. Study area

Tremiti Islands, located in the Southern Adriatic Sea about 22 km away from the Gargano promontory's coast (Figure 1a), were established in 1989 as a Marine Protected Area (MPA) with a high scientific value, holding an incredible variety of landforms, mostly linked to marine, slope, and karst processes; furthermore, the overall setting of these landforms is related to the tectonic and lithological control. The Tremiti Archipelago is composed by San Domino, San Nicola, Capraia, and Cretaccio Islands (Figure 1b). A fifth island, Pianosa, belongs to the archipelago and is located about 17 km away from the other ones towards NE (Figure 1c).

The islands' surface has a tabular morphology, bounded by very steep to vertical cliffs. Elevation reaches the maximum value of 116 m a.s.l. at San Domino Island while San Nicola, Capraia, Cretaccio, and Pianosa Islands show moderate elevations, with altitudes up to 76, 55, 30, and 15 m a.s.l., respectively (Buccolini et al., 2020; Miccadei et al., 2012).

From a geological standpoint, the study area is characterized by a Cenozoic marine succession, arranged in a general SE-dipping homocline setting and mainly composed of limestone, dolomitic limestones, dolomites, and marls (Selli, 1971). These units are unconformably overlain by Quaternary continental deposits – breccias, conglomerates, calcretes, sands, eluvium-colluvium deposits, and soils – belonging to different depositional environments (Andriani et al., 2005; Miccadei et al., 2011a).

The tectonic framework is mainly characterized by E–W, WSW–ENE, and NE–SW strike-slip fault systems, secondarily by NW–SE to N–S oriented ones, showing strike-slip and dip-slip kinematics (Miccadei et al., 2011b). The strong seismicity of the area is well documented (Argnani et al., 1993; De Alteriis, 1995; Di Bucci et al., 2007; Del Gaudio et al., 2007). Historical earthquakes affected the islands of the archipelago, e.g. the 6 June 1892, Isole Tremiti earthquake (Mw 4.9), and the Gargano and Periadriatic areas, e.g. the 31 July 1627 Capitanata earthquake (Mw 6.7); more recent events, on the other hand, enucleated in the Adriatic sector, e.g. the 27 March 2021 Central Adriatic Sea earthquake (Mw 5.2) (Favali et al., 1993; ISIDe Working Group, 2007; Miccadei et al., 2021; Rovida et al., 2022).

The geomorphological features result from the combination of marine, coastal, and subaerial processes linked to long-term processes such as Quaternary tectonics, regional uplift, and eustatic sea-level changes (Parlagreco et al., 2011; Ridente & Trincardi, 2002). Slope, fluvial, karst, and marine landforms are widespread, with present-day morphodynamics ruled by the strong interaction between slope and marine processes (Miccadei et al., 2012). Instability processes at San Nicola Island are particularly evident and failure mechanisms of rock slopes are complex. The island features a coast almost entirely affected by landslides mainly occurring as rockfalls, topples, and lateral spreads with retrogressive evolution (Cotecchia et al., 1996; Lollino & Pagliarulo, 2008).

3. Methods

To achieve a thorough geomorphological characterization of San Nicola Island, students applied an integrated approach by combining morphometric,

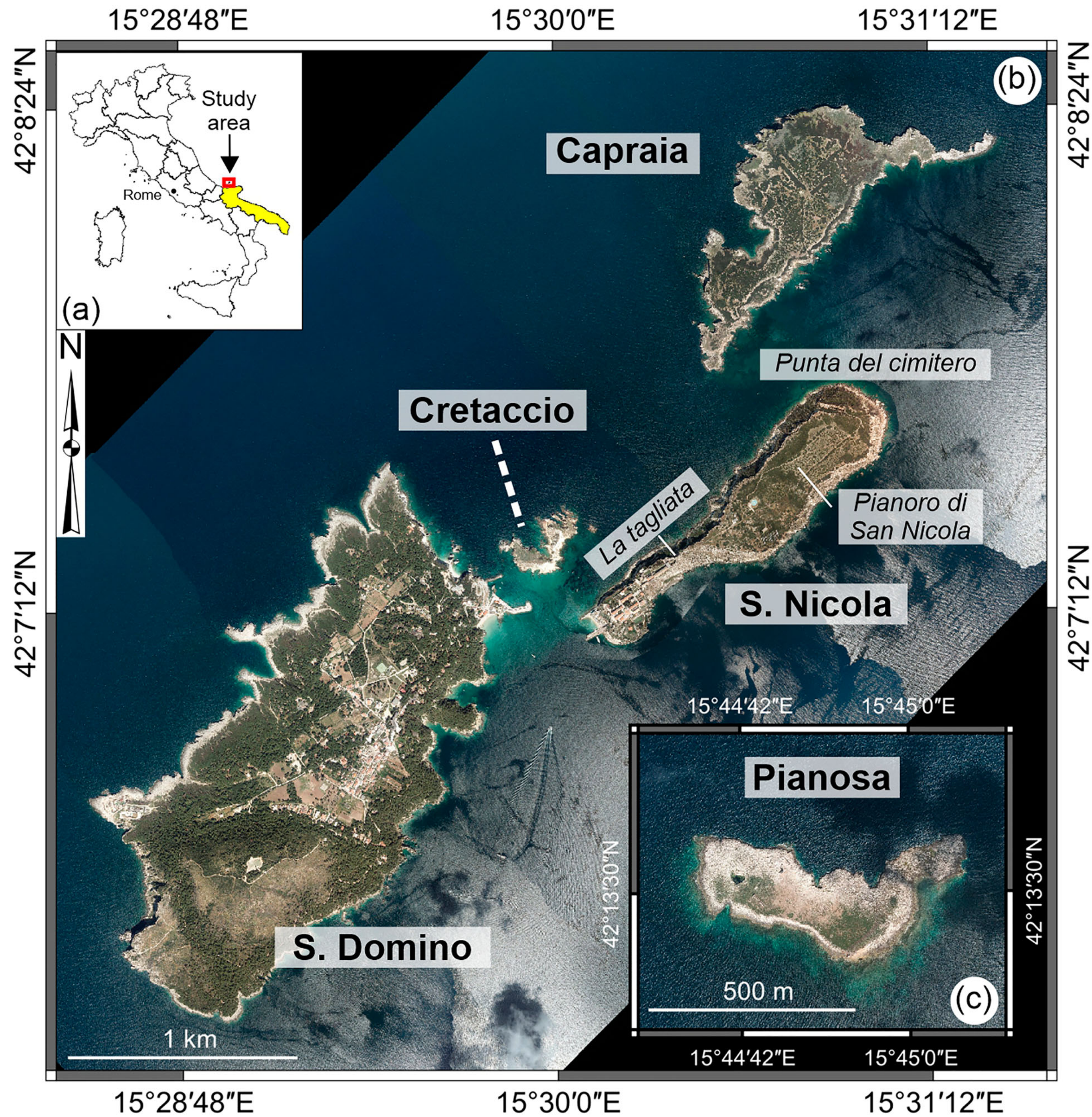

Figure 1. (a) Location map of the study area in the Southern Adriatic Sea. The red box identifies the location of Tremiti Islands; (b) 2019 orthophoto image of San Domino, San Nicola, Capraia, and Cretaccio Islands (Puglia Region, http://www.sit.puglia.it); (c) orthophoto image of Pianosa Island (Puglia Region, http://www.sit.puglia.it).

geological, and geomorphological analyses as already done in, e.g., Miccadei et al., 2016 and Buccolini et al., 2020. Activities were divided into three main phases, namely pre-field, on-field, and post-field ones. Pre-field activities comprised all preliminary steps aimed at acquiring literature data, defining the general geological and geomorphological setting of the area, and pointing out the field mapping protocol to be applied. On-field activities centered on the observation and mapping of geomorphological features of the island, mainly focusing on slope landforms and their potential evolution and interaction with other natural elements as well as with anthropic ones. Survey was carried out by integrating traditional methods with modern instruments and techniques, such as the use of devices like tablets with dedicated software for direct on-field digital mapping and georeferenced photos acquisition. In case of inaccessible investigation sites, students made use of drones equipped with high-resolution integrated cameras (De Donatis et al., 2020; Nowak et al., 2020). Post-field work, finally, consisted in the combination and interpretation of acquired data, which led to the detection of landscape features and the production of the final geomorphological map.

Topographic data and orthophoto color images were retrieved from the Cartographic Office of the Puglia Region (http://www.sit.puglia.it) and the Italian

National Geoportal (http://www.pcn.minambiente.it). Digital Elevation Models (DEMs) with a cell size of 2 × 2 m were derived from LiDAR (Light Detection and Ranging) data (1 m resolution), provided by Ministero della Transizione Ecologica (https://www.mite.gov.it/). Elevation, Slope, Aspect (sensu Strahler, 1952), and Local relief (sensu Ahnert, 1984) rasters were all extracted from the DEM by means of ESRI ArcGIS 10.6™ tools to highlight orographic features of the study area.

Field work-based geological and geomorphological analyses were conducted in conjunction with the interpretation of 2019 orthophoto images of Tremiti Islands (Puglia Region, http://www.sit.puglia.it). Mapping activities were carried out following directions proposed by the Geological Survey of Italy and the AIGeo – the Italian Association of Physical Geography and Geomorphology (ISPRA, 2007; ISPRA, 2018) and in accordance with geomorphological mapping themed literature (Demurtas et al., 2021; Gustavsson et al., 2006; Miccadei et al., 2017; Otto et al., 2011; Smith et al., 2011; Thornbush et al., 2014). Outcropping bedrock lithologies and surficial deposits, tectonic features, and geomorphological landforms were analyzed and preliminary mapped at the 1:1,000 scale; to ensure results comparability and better represent the features of the study area, a common legend was conceived and applied (GNGFG, 1994; Pisano et al., 2020).

After field activities, students produced a 1:2,500 geomorphological map of the island together with geomorphological cross-sections and the photo documentation; this material was then checked and assembled by means of CorelDRAW® 2019 tools into the Main Map. This last is here presented, including three main sections:

(1) Morphometry (in the central left part);
(2) Main geomorphological map (in the right upper part);
(3) Geomorphological cross-sections and photo documentation (in the lower part).

4. Results

4.1. Morphometric features

Morphometric analyses were performed to derive the main landscape features of San Nicola Island, as part of geomorphological mapping preliminary activities.

The island features an elongated shape in the SW-NE direction, with a length of about 1,500 m and a coastal extension of approximately 3,700 m. Elevations range between 0 and 76.5 m a.s.l. The whole area can be divided into two sectors, separated by a NW-SE directed depression and both showing an almost flat and tabular morphology: the former is localized towards SW and features heights up to 43 m a.s.l.; the latter is found towards NE, features the highest elevations – mostly of about 75 m a.s.l. (values around 76.5 m constitute local spikes) – and comprises the *Pianoro di San Nicola* area. This last is located NE of *La tagliata* (Figure 1b), another depression originated by tectonic and landslide phenomena and later artificially deepened for defense purposes (Figure 2c; Cotecchia et al., 1996). A step-like morphology is also detected in correspondence of the *Punta del Cimitero* area, with main W-E directed steps featuring a difference in altitude of about 15 m (Figure 2f; Box *a* of the attached map).

Slope values (α) range between 0 and 83°. The study area can be fairly divided into three slope classes: flat to gently sloping areas ($0 \leq \alpha < 20°$), sloping areas ($20 \leq \alpha < 60°$), and steep to very steep areas ($\alpha \geq 60°$). Flat to gently sloping areas are detected in correspondence of high flat areas as well as at the foot of slopes bordering the island. Tabular high sectors are delimited by steep to very steep sectors, which are also found in correspondence of the above-mentioned NW-SE directed depression separating high flat areas, as well as of W-E directed steps in the *Punta del Cimitero* area. Sloping zones edging almost the whole island connect these steep sectors with flat to gently sloping low ones; other sloping SW-NE directed narrow regions are visible in the south-eastern portion of high tabular areas (Box *b* of the attached map).

Slopes aspects show a well-defined distribution, with major sectors mainly SW-NE directed. Sloping areas found towards NW mostly feature a NW dipping; flat to gently sloping and sloping areas located towards SE a SE one. The northward stepped sector, on the other hand, shows a general N dipping with S or SW dipping secondary narrow sectors W-E directed. Other narrow N-to-W dipping sectors NE-SW-aligned are also detected on the *Pianoro di San Nicola* area, especially towards the SE flank (Box *c* of the attached map).

The local relief, finally, features values up to 77 m. Flat surfaces show the lowest elevation difference within set windows; highest values, conversely, are found where sloping to very steep areas occur (Box *d* of the attached map).

4.2. Geomorphological features

The geomorphological map resulting from preliminary and field activities synthesizes all gathered information on outcropping lithologies and highlighted landforms.

The bedrock of San Nicola Island is composed of a Cenozoic marine succession constituted by gently SE-dipping marls, locally with a considerable macrofossils content, and unconformably overlain by sub-horizontal dolomitic limestones (Figure 2a). Surficial deposits

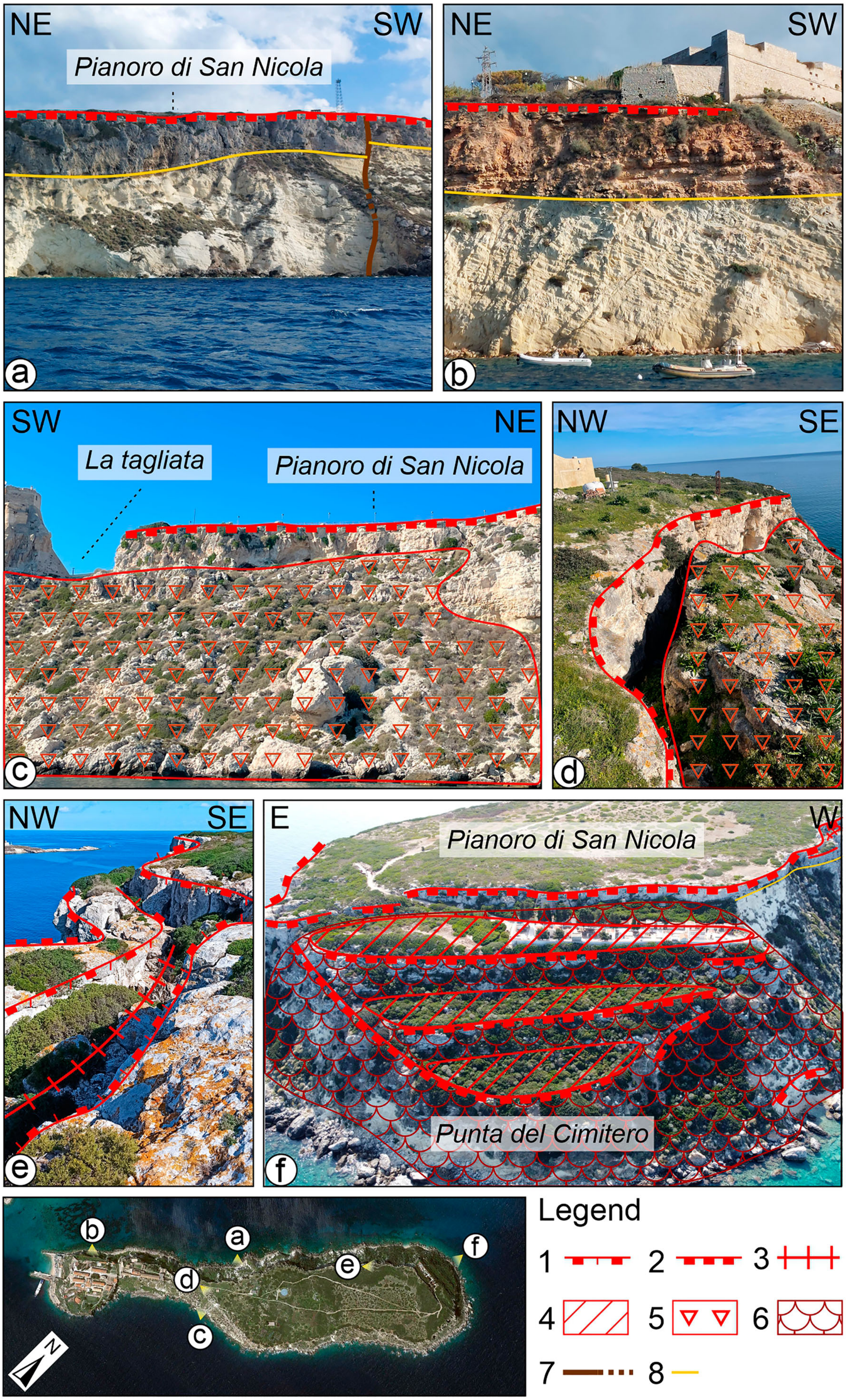

Figure 2. Photo documentation of geomorphological features of San Nicola Island. Legend: (1) slope scarp, $5 \leq$ height < 10 m, (2) slope scarp, height $\geq$ 10 m, (3) trench, (4) landslide terrace, (5) rockfalls, (6) Deep-Seated Gravitational Slope Deformation, (7) tectonic lineament, dashed if uncertain, (8) lithological boundary.

are mainly represented by eluvial-colluvial deposits, found in the flat uppermost sectors, and landslide bodies constituted by small- to medium-size block falls of marly or dolomitic lithology (Figure 2c,d). In the southern sector, furthermore, an outcrop made of gently SW dipping breccias and conglomerates, arranged in about 0.25 m thick layers, is present towards NW, lying above an erosive surface set on the marly bedrock (Figure 2b). Anthropic deposits are present in the southwestern portion and constituted by meter-sized blocks. Sandy shore deposits, finally, are present only in the port area, towards SW (Geomorphological map and geomorphological cross-sections of the attached map).

In the study area, the connection between morphological features and outcropping lithologies is striking. Summit flat to gently sloping surfaces are mostly set on dolomitic limestone deposits, locally covered by a thin layer of eluvial-colluvial deposits. Steep to very steep scarps bordering these sectors are also set on dolomitic outcrops. By the seashore, flat areas are characterized by sandy shore, anthropic, or rockfall deposits. Sloping sectors, on the other hand, mainly feature a marly lithology, often covered by meters-thick landslide bodies.

Concerning tectonic features, the main element is constituted by a high-angle NW-SE directed fault separating the two high tabular sectors. Another fault is visible along the NW flank, displacing both marly and dolomitic deposits (Figure 2a; Geomorphological map and AA' and CC' geomorphological cross-sections of the attached map). A set of sub-vertical joints and open fissures is also detected on high tabular surfaces, mainly with SW-NE direction, that is parallel to the main flanks of the island.

Identified landforms feature a structural, slope, or anthropic origin. Structural landforms are represented by the NW-SE directed structural scarp which separates high tabular surfaces and represents the morphological expression of the above-mentioned high-angle fault activity (Geomorphological map and AA′ geomorphological cross-section of the attached map).

Slope landforms are largely widespread and mainly represented by landslide deposits with associated scarps. These last, with heights generally greater than 10 m, border tabular surfaces on dolomitic limestones nearly without interruption, connecting flat summit areas with sub-vertical rocky cliffs. Other slope scarps with a lesser extension are present in the region, marking E-W steps found in the *Punta del Cimitero* area or set on marly sloping areas. Further landforms of this type with heights lower than 5 m are localized in the central-eastern part of the *Pianoro di San Nicola* area, where several counter-slopes are also detected, locally interrupting the gently SE-sloping trend. A few meters deep trench, moreover, is found in the NW sector of the same region, featuring a NE-SW direction, thus parallel to the main slope scarp system present in the area and bordered by 5–10 m high scarps (Figure 2e). Morphometric analyses and field activities allowed the detection and characterization of several slope phenomena of recent or past activation, with deposits featuring variable extension and thickness. Rockfalls and topples dominate among landslides, with major affected areas found along sloping eastern flanks and at their base, nearly completely covered by deposits (Figure 2c,d). Other noticeable events are detectable in the western sector, with deposits spatial distribution limited to flat regions located by the sea, or extended along the whole sloping area from the break of slope at the base of the dolomitic layer to the sea, as it happens below the above mentioned trench (Figure 2e). Field survey activities were limited to emerged sectors, although several submerged fallen blocks were mapped by analysing orthophoto and high-resolution drone images. Concerning the stepped sectors towards North, finally, the whole area is clearly affected by a gravity-induced process currently in a state of quiescence, likely to evolve over very long periods of time and consequently classified as a Deep-Seated Gravitational Slope Deformation (DGSD). That said, N-dipping steps are interpreted as landslide terraces set at progressively lower heights moving towards North due to differential displacement of rock blocks (Figure 2f; Geomorphological map and geomorphological cross-sections of the attached map).

Anthropic landforms are present in the south-western region hosting the urban fabric. SW-NE directed scarps are visible in the south-eastern portion and along the NW-border of the southern high tabular surface; given their location and their direction concordant with that of slope scarps found in the *Pianoro di San Nicola* area, however, a slope origin is conceivable with a later human reworking. Along the SW flank of the same sector some landslide defense works are present, built to protect underlying structures and activities. Coastal defense works, finally, are represented by anthropic deposits placed by the sea to safeguard infrastructures from its potentially disruptive action and to prevent further excavation undermining the foot of slopes.

5. Conclusions

The geomorphological mapping results presented in this work are the outcomes of the 2021 and 2022 Environmental Geomorphology field camps carried out at San Nicola Island (Tremiti Islands), held within the Master's Degree in Geological Sciences and Technologies of Earth and Planets at University 'G. d'Annunzio' of Chieti-Pescara. Students were given the opportunity to enhance their surveying abilities and acquire new skills on geomorphological processes and landforms detection and evaluation, by applying an integrated approach and combining traditional field-mapping methods with modern instruments and techniques. The presence of long- and short-term evolutionary processes and related landforms allowed all participants to acquire the awareness of the key role played by observation and on-field mapping activities in landscape analysis, thus confirming the importance of fieldwork in young geologists and geomorphologists education.

The field mapping campaign pointed out the high geomorphological dynamism of San Nicola Island. Slope landforms such as scarps, counter-slopes, and trenches represent the expression of long-term processes affecting the area. In this context, rockfalls and topples potentially occurring at any time represent a sudden expression of such processes, leading to short-term landscape evolution. At present, these events are indeed enhancing the narrowing of some portions of the island – see, for example, the sector localized immediately NE of *La tagliata* – in addition to constituting geomorphological hazards potentially threatening all socio-economic activities. In conclusion, the produced geomorphological map provides a comprehensive overview of San Nicola landscape features, thus representing a valuable tool in the context of territorial planning and management as well as a significant base for further scientific studies.

Software

Field mapping activities were carried out using the 'FieldMove' App, developed by Midland Valley & Petroleum Experts (https://www.petex.com/media/2578/fieldmove_user_guide.pdf). The vector/raster data and Main Map were managed using ESRI ArcGIS 10.6™; the final editing was realized using CorelDRAW® 2019.

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Data availability statement

The data presented in this study are available on request from the author. The data are not publicly available due to privacy. Images employed for the study will be available online for readers.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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References

Ahnert, F. (1984). Local relief and the height limits of mountain ranges. *American Journal of Science*, *284*(9), 1035–1055. https://doi.org/10.2475/ajs.284.9.1035

Andriani, G. F., Walsh, N., & Pagliarulo, R. (2005). The influence of the geological setting on the morphogenetic evolution of the Tremiti Archipelago (Apulia, Southeastern Italy). *Natural Hazards and Earth System Sciences*, *5*(1), 29–41. https://doi.org/10.5194/nhess-5-29-2005

Argnani, A., Favalli, P., Frugoni, F., Gasperini, M., Ligi, M., Marani, M., Mattietti, G., & Mele, G. (1993). Foreland deformational pattern in the Southern Adriatic Sea. *Annals of Geophysics*, *36*(2), 229–247. https://doi.org/10.4401/ag-4279

Buccolini, M., Carabella, C., Paglia, G., Cecili, A., Chiarolanza, G., Cioria, C., Conicella, C., D'Alonzo, A., De Viti, L., Di Carlo, F., Di Francesco, F., Di Luzio, M., Di Mango, C., Di Nardo, E., Di Nino, C., Di Renzo, L., Di Tollo, A., Epifani, C., Esposito, G., … Miccadei, E. (2020). Geomorphological analysis of the San Domino Island (Tremiti Islands, Southern Adriatic Sea). Results from the 2019 geomorphological field camp of the MSc in geological science and technology (University of Chieti-Pescara). *Journal of Maps*, *16*(3), 10–18. https://doi.org/10.1080/17445647.2020.1831979

Bufalini, M., Materazzi, M., De Amicis, M., & Pambianchi, G. (2021). From traditional to modern 'full coverage' geomorphological mapping: A study case in the Chienti river basin (Marche Region, Central Italy). *Journal of Maps*, *17*(3), 17–28. https://doi.org/10.1080/17445647.2021.1904020

Cotecchia, V., Guerricchio, A., & Melidoro, G. (1996). Geologia e processi di demolizione costiera dell'isola di S. Nicola (Tremiti). *Memorie della Società Geologica Italiana*, *51*, 595–606.

De Alteriis, G. (1995). Different foreland basins in Italy: Examples from the central and southern Adriatic Sea. *Tectonophysics*, *252*(1-4), 349–373. https://doi.org/10.1016/0040-1951(95)00155-7

de Barros, J. F., Almeida, P. A., & Cruz, N. (2012). Fieldwork in geology: Teachers' conceptions and practices. *Procedia - Social and Behavioral Sciences*, *47*, 829–834. https://doi.org/10.1016/j.sbspro.2012.06.743

De Donatis, M., Alberti, M., Cipicchia, M., Guerrero, N. M., Pappafico, G. F., & Susini, S. (2020). Workflow of digital field mapping and drone-aided survey for the identification and characterization of capable faults: The case of a normal fault system in the Monte Nerone Area (Northern Apennines, Italy). *ISPRS International Journal of Geo-Information*, *9*(11), 616. https://doi.org/10.3390/ijgi9110616

Del Gaudio, V., Pierri, P., Frepoli, A., Calcagnile, G., Venisti, N., & Cimini, G.B. (2007). A critical revision of the seismicity of Northern Apulia (Adriatic microplate – Southern Italy) and implications for the identification of seismogenic structures. *Tectonophysics*, *436*(1-4), 9–35. https://doi.org/10.1016/j.tecto.2007.02.013

Demurtas, V., Orrù, P. E., & Deiana, G. (2021). Deep-seated gravitational slope deformations in central Sardinia: Insights into the geomorphological evolution. *Journal of Maps*, *17*(2), 607–620. https://doi.org/10.1080/17445647.2021.1986157

De Waele, J., Anfossi, G., Campo, B., Cavalieri, F., Chiarini, V., Emanuelli, V., Grechi, U., Nanni, P., & Savorelli, F. (2012). Geomorphology of the Castel de' Britti area (Northern Apennines, Italy): An example of teaching geomorphological mapping in a traditional and practical way. *Journal of Maps*, *8*(3), 231–235. https://doi.org/10.1080/17445647.2012.707337

Di Bucci, D., Ravaglia, A., Seno, S., Toscani, G., Fracassi, U., & Valensise, G. (2007). Modes of fault reactivation from analogue modeling experiments: Implications for the seismotectonics of the Southern Adriatic foreland (Italy). *Quaternary International*, *171-172*, 2–13. https://doi.org/10.1016/j.quaint.2007.01.005

Dramis, F., Guida, D., & Cestari, A. (2011). Nature and aims of geomorphological mapping. *Developments in Earth Surface Processes*, *15*, 39–73. https://doi.org/10.1016/B978-0-444-53446-0.00003-3

Dykes, A. P. (2008). Geomorphological maps of Irish peat landslides created using hand-held GPS. *Journal of Maps*, *4*(1), 258–276. https://doi.org/10.4113/jom.2008.1029

Elkins, J. T., & Elkins, N. M. (2007). Teaching geology in the field: Significant geoscience concept gains in entirely field-based introductory geology courses. *Journal of Geoscience Education*, *55*(2), 126–132. https://doi.org/10.5408/1089-9995-55.2.126

Favali, P., Funiciello, R., Mattietti, G., Mele, G., & Salvini, F. (1993). An active margin across the Adriatic Sea (central Mediterranean Sea). *Tectonophysics*, *219*(1-3), 109–117. https://doi.org/10.1016/0040-1951(93)90290-Z

GNGFG. (1994). Proposta di legenda geomorfologica ad indirizzo applicativo. *Geografia Fisica e Dinamica Quaternaria*, *16*(2), 129–152.

Gustavsson, M., Kolstrup, E., & Seijmonsbergen, A. C. (2006). A new symbol-and-GIS based detailed geomorphological mapping system: Renewal of a scientific discipline for understanding landscape development. *Geomorphology*, *77*(1-2), 90–111. https://doi.org/10.1016/j.geomorph.2006.01.026

ISIDe Working Group. (2007). Italian seismological instrumental and parametric database (ISIDe). *Istituto Nazionale di Geofisica e Vulcanologia (INGV)*, https://doi.org/10.13127/ISIDE

ISPRA. (2007). Guida alla rappresentazione cartografica della Carta Geomorfologica d'Italia in scala 1:50,000. *Quaderni Serie III del Servizio Geologico Nazionale.*

ISPRA & A. I. G. E. O. (2018). Aggiornamento ed integrazione delle linee guida della Carta Geomorfologica d'Italia in scala 1:50,000. *Quaderni Serie III del Servizio Geologico Nazionale*.

Jaboyedoff, M., Oppikofer, T., Abellán, A., Derron, M., Loye, A., Metzger, R., & Pedrazzini, A. (2012). Use of LIDAR in landslide investigations: A review. *Natural Hazards*, *61*(1), 5–28. https://doi.org/10.1007/s11069-010-9634-2

Knight, J., Mitchell, W. A., & Rose, J. (2011). Geomorphological Field Mapping. *Developments in earth surface processes*, *15*, 151–187. https://doi.org/10.1016/B978-0-444-53446-0.00006-9.

Lee, E. M. (2001). Geomorphological mapping. *Geological Society, London, Engineering Geology Special Publications*, *18*(1), 53–56. https://doi.org/10.1144/GSL.ENG.2001.018.01.08

Lollino, P., & Pagliarulo, R. (2008). The interplay of erosion, instability processes and cultural heritage at San Nicola island (Tremiti Archipelago, Southern Italy). *Geografia Fisica e Dinamica Quaternaria*, *31*(2), 161–169.

Lundmark, A. M., Augland, L. E., & Jørgensen, S. V. (2020). Digital fieldwork with fieldmove – How do digital tools influence geoscience students' learning experience in the field? *Journal of Geography in Higher Education*, *44*(3), 427–440. https://doi.org/10.1080/03098265.2020.1712685

Mascioli, F., Piattelli, V., Cerrone, F., Cinosi, J., Kunde, T., & Miccadei, E. (2022). Sediments and bedforms of the Harle

tidal inlet (Wadden Sea, Germany). *Journal of Maps*, https://doi.org/10.1080/17445647.2022.2154175
Mastronuzzi, G., & Sansò, P. (2002). Holocene uplift rates and historical rapid sea-level changes at the gargano promontory, Italy. *Journal of Quaternary Science*, *17*(5-6), 593–606. https://doi.org/10.1002/jqs.720
Miccadei, E., Carabella, C., & Paglia, G. (2021). Morphoneotectonics of the Abruzzo Periadriatic area (central Italy): Morphometric analysis and morphological evidence of tectonics features. *Geosciences*, *11*(9), 397. https://doi.org/10.3390/geosciences11090397
Miccadei, E., Mascioli, F., Orrù, P., Piacentini, T., & Puliga, G. (2011a). Late quaternary paleolandscape of submerged inner continental shelf areas of Tremiti islands archipelago (northern Puglia). *Geografia Fisica e Dinamica Quaternaria*, *34*(2), 223–234. https://doi.org/10.4461/GFDQ.2011.34.20
Miccadei, E., Mascioli, F., & Piacentini, T. (2011b). Quaternary geomorphological evolution of the Tremiti Islands (Puglia, Italy). *Quaternary International*, *233*(1), 3–15. https://doi.org/10.1016/j.quaint.2010.04.028
Miccadei, E., Orrù, P., Piacentini, T., Mascioli, F., & Puliga, G. (2012). Geomorphological map of the Tremiti Islands (Puglia, Southern Adriatic Sea, Italy), scale 1:15,000. *Journal of Maps*, *8*(1), 74–87. https://doi.org/10.1080/17445647.2012.668765
Miccadei, E., Piacentini, T., Antoniani, F., Caporali, L., Carducci, A., Cerone, D., Cerritelli, F., D'Amico, A., De Angelis, C., De Filippis, R., De Santis, A., Di Matteo, A., Di Nicola, D., Di Pietro, I., D'Intino, N., Febo, S., Giuliani, L., Iezzi, F., Imperatore, R., … Valentini, A. (2016). Castel di sangro-scontrone field camp – Structural and applied geomorphology. *Journal of Maps*, *12*(5), 1269–1281. https://doi.org/10.1080/17445647.2015.1129994.
Miccadei, E., Piacentini, T., & Buccolini, M. (2017). Long-term geomorphological evolution in the Abruzzo area, central Italy: Twenty years of research. *Geologica Carpathica*, *68*(1), 19–28. https://doi.org/10.1515/geoca-2017-0002
Nowak, M. M., Dziób, K., Ludwisiak, L., & Chmiel, J. (2020). Mobile GIS applications for environmental field surveys: A state of the art. *Global Ecology and Conservation*, *23*, e01089. https://doi.org/10.1016/j.gecco.2020.e01089
Orion, N. (1993). A model for the development and implementation of field trips as an integral part of the science curriculum. *School Science and Mathematics*, *93* (6), 325–331. https://doi.org/10.1111/j.1949-8594.1993.tb12254.x
Otto, J. C., Gustavsson, M., & Geilhausen, M. (2011). Cartography: Design, Symbolisation and Visualisation of Geomorphological Maps. *Developments in Earth Surface Processes*, *15*, 253–295. https://doi.org/10.1016/B978-0-444-53446-0.00009-4
Otto, J. C., & Smith, M. J. (2013). Geomorphological mapping. In *Geomorphological techniques*, (6(2), 1–10). British Society for Geomorphology.
Paglia, G., Bergamin, L., Buccolini, M., Carabella, C., Cerrone, F., Chiocci, F. L., d'Arielli, R., Esposito, G., Federico, D., Mancinelli, V., Marassich, A., Mazzetti, M., Mecacci, S., Nolè, C., Piattelli, V., Romano, E., Salvati, E., & Miccadei, E. (2020). 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), ecology, and marine biology in the Tremiti Islands (Southern Adriatic Sea, Puglia, Italy). *Journal of Maps*, *16*(3), 1–9. https://doi.org/10.1080/17445647.2020.1776645
Parlagreco, L., Mascioli, F., Miccadei, E., Antonioli, F., Gianolla, D., Devoti, S., Leoni, G., & Silenzi, S. (2011). New data on Holocene relative sea level along the Abruzzo coast (central Adriatic, Italy). *Quaternary International*, *232*(1-2), 179–186. https://doi.org/10.1016/j.quaint.2010.07.021
Pisano, L., Zumpano, V., Liso, I. S., & Parise, M. (2020). Geomorphological and structural characterization of the 'Canale di Pirro' polje, Apulia (Southern Italy). *Journal of Maps*, *16*(2), 479–487. https://doi.org/10.1080/17445647.2020.1778550
Reddy, G. O. (2018). Remote sensing and GIS for geomorphological mapping. In G. Reddy, & S. Singh (Eds.), *Geospatial technologies in land resources mapping, monitoring and management. Geotechnologies and the environment* (pp. 21). Springer.
Ridente, D., & Trincardi, F. (2002). Eustatic and tectonic control on deposition and lateral variability of quaternary regressive sequences in the Adriatic basin (Italy). *Marine Geology*, *184*(3-4), 273–293. https://doi.org/10.1016/S0025-3227(01)00296-1
Rovida, A., Locati, M., Camassi, R., Lolli, B., Gasperini, P., & Antonucci, A. (2022). Catalogo Parametrico dei Terremoti Italiani (CPTI15), versione 4.0. *Istituto Nazionale di Geofisica e Vulcanologia (INGV)*, https://doi.org/10.13127/CPTI/CPTI15.4
Selli, R. (1971). Isole tremiti e pianosa. In G. Cremonini, C. Elmi, & R. Selli (Eds.), *Note illustrative della Carta Geologica d'Italia alla scala 1:100.000 Foglio 156* "*S. Marco in lamis* (pp. 49–65). Servizio Geologico d'Italia.
Smith, M. J., Paron, P., & Griffiths, J. (2011). Geomorphological mapping, methods and applications.In *Developments in earth surface processes*. (Vol. 15). Elsevier Science.
Strahler, A. N. (1952). Dynamic basis of geomorphology. *Geological Society of America Bulletin*, *63*(9), 923–938. https://doi.org/10.1130/0016-7606(1952)63[923:DBOG]2.0.CO;2
Szypuła, B. (2017). Digital elevation models in geomorphology. In: D. P. Shukla (eds.) *Hydro-Geomorphology – Models and trends*. London: IntechOpen. https://doi.org/10.5772/intechopen.68447
Thornbush, M., Allen, C., & Fitzpatrick, F. (2014). Geomorphological fieldwork. In *Developments in earth surface processes*. (Vol. 17) Elsevier Science.
Verstappen, H. T. (2011). Old and New Trends in Geomorphological and Landform Mapping. *Developments in earth surface processes*, 13–38. https://doi.org/10.1016/B978-0-444-53446-0.00002-1.