

HISTORY AND HERITAGE OF COASTAL PROTECTION IN THE SOUTHERN TYRRHENIAN AREA

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EXTENDED ABSTRACT

Il crescente interesse per lo sviluppo di un'economia del mare più sostenibile ha recentemente coinvolto in modo proattivo le comunità costiere in un sistema di politiche di gestione e sviluppo del territorio incentrato sulla valorizzazione dell'ambiente, ovvero su una "crescita blu" (Blue Growth), che rappresenta un'opportunità di crescita per tutte le attività connesse all'uso del mare.

La comunità europea ha varato diversi piani a supporto della Blue Growth individuando percorsi di studio e sviluppo specifici per il territorio, volti a realizzare una crescita armonica e lungimirante in un contesto di condivisione di visioni e progetti fra gli stati membri. Fra le varie tematiche proposte, assumono particolare importanza la realizzazione di sistemi per la captazione di energia dal mare, lo sviluppo e la gestione di una pesca sostenibile, e l'individuazione di un comparto di attività legate al turismo costiero, a supporto di un'economia integrata, che si occupi non soltanto di offrire servizi ma anche di preservare e valorizzare le risorse locali.

In questo contesto, risulta pertanto fondamentale perseguire una politica integrata con lo scopo di coordinare le strategie economiche e sociali che coinvolgono i diversi settori dell'ambiente marino e costiero. Tali strategie sono inevitabilmente vincolate all'urbanizzazione incontrollata che ha interessato i territori negli ultimi decenni; all'inquinamento dell'aria, del mare e del suolo; all'erosione della costa e alle inondazioni dovute non solo alle più importanti mareggiate, ma anche a esondazioni fluviali dovute a precipitazioni concentrate in intervalli di tempo sempre più brevi, fenomeni che si presentano con frequenza e pericolosità sempre maggiori a causa dei cambiamenti climatici.

Opportunità di sviluppo così vincolate presentano sfide importanti per la pianificazione e la gestione degli interventi sulle aree costiere, con particolare riferimento all'ottimizzazione delle scelte che rendono compatibili la tutela ambientale con le esigenze di sviluppo urbanistico ed economico. Gli insediamenti costieri sono caratterizzati da un processo di organizzazione territoriale che risente della stratificazione delle realtà storiche, sociali, culturali, monumentali e artistiche che nel tempo hanno segnato l'urbanistica, l'uso del suolo e, di conseguenza, il paesaggio. Lo studio degli interventi a supporto della Blue Growth non può prescindere da un'attenta analisi della storia e del patrimonio del territorio e da una ricerca scientifica volta a riprodurre i fenomeni e i processi evolutivi per supportare i modelli di sviluppo economico.

Questo articolo è incentrato sulla regione costiera tirrenica meridionale, ove si caratterizza il territorio dal punto di vista storico e ambientale, con particolare riferimento ai recenti interventi antropici e al loro impatto. In particolare, l'evoluzione del territorio è stata analizzata nei suoi diversi processi urbanistici, morfologici e idrogeologici, strettamente interconnessi fra loro e al sistema di aree protette ivi istituito.

L'idrodinamica costiera, l'erosione delle coste e l'analisi critica delle opere di difesa realizzate in passato e programmate per il futuro, è stata approfondita attraverso la rivisitazione degli studi specialistici sviluppati nel recente passato.

L'obiettivo del presente lavoro consiste nel sensibilizzare l'ambiente accademico, le autorità e la popolazione, dei pericoli che minacciano le aree costiere, con particolare riferimento alla regione tirrenica meridionale, identificando le strategie, le scelte e gli interventi che hanno determinato la storia, lo sviluppo e le prospettive del territorio.

Una particolare menzione è rivolta alla Stazione Sperimentale Marina di Capo Tirone, istituita di recente nel comune di Belvedere Marittimo (CS), una struttura scientifica strategica in grado di ospitare e supportare numerosi filoni di ricerca, come l'esplorazione delle problematiche ambientali che affliggono le aree costiere; lo sviluppo di nuove tecnologie e strutture, sia nautiche che subacquee; la valorizzazione in loco dei patrimoni archeologici subacquei; il coinvolgimento consapevole della popolazione e la promozione della Blue Growth.

La stazione sperimentale si candida a diventare un Hub di dati e modelli ambientali in cui sviluppare una cooperazione scientifica interdisciplinare attraverso la ricerca sperimentale di campo, in ambito sia accademico che industriale, con impatti positivi anche sul turismo scientifico.

ABSTRACT

The development of the sea economy (Blue Growth) represents an opportunity for worldwide coastal communities, which are increasingly threatened by urban pressure, sea pollution, erosion processes and flooding events due to enhancing rate of relative sea level rise and storminess driven by climate change. These hazards pose several planning and management challenges to the stakeholders, often constrained in finding a compromise between flooding protection of the urban settlements, economic needs of the land and the health of the environment.

Since historical and cultural stratification affected the landscape and the development of coastal urban areas, the Blue Growth involves the analysis of the history and heritage of the land, based on a scientific research capable to promote a sustainable economic development of the area.

This manuscript focuses on the southern Tyrrhenian coast (Italy), first describing the historical and environmental features of the area and then focalizing on the impact of the anthropic interventions, with particular reference to the shoreline of Belvedere Marittimo (CS), where it is located the Marine Experimental Station of Capo Tirone, a strategic scientific hub that serves multiple research activities related to the marine environment, as the study of the hazards threatening the environmental and cultural heritage, the development of new nautical and subsea technologies, and the dissemination of citizen-science into the Blue Growth framework.

KEYWORDS: *Marine environment history, Coastal hazards, Erosion process, Marine heritage, Tyrrhenian Sea, Harbours, Marine Experimental Station*

INTRODUCTION

Marine areas are strategic environmental and economic resources, which provide multiple services for social and economic development. An integrated policy is thus fundamental in supporting social and economic management strategies linked to coastal environments. The development of a sustainable sea economy (Blue Growth) is supported by several Europe initiatives (MSFD, 2008), following the targets of the 2030 Agenda for a sustainable development of the United Nations (OECD, 2016).

Worldwide coastal and intertidal areas are fragile ecosystems which are threatened by sea level rise driven by climate change (DAVIES & FLATHER, 1977; WOTH *et alii*, 2006; LOWE & GREGORY, 2008; KIRWAN *et alii*, 2010; MEL *et alii*, 2013), which enhances flooding and erosion processes (PRANZINI *et alii*, 2015; BENDONI *et alii*, 2016; DREJZA *et alii*, 2019; MEL *et alii*, 2019; IPCC 2013). These hazards threaten coastal urban areas, with particular reference to the settlements located near the shoreline, causing significant damages to the economy, the environment and the

ecosystem (LIONELLO *et alii*, 2005; DE ZOLT *et alii*, 2006; GEDAN *et alii*, 2009; BARBIER *et alii*, 2011; MEL & LIONELLO, 2014; MEL & LIONELLO, 2016; ZARZUELO *et alii*, 2016; TOMMASINI *et alii*, 2019). In the past centuries sea-defence structures focused only on flooding protection. At present, some European countries are pursuing a global approach through actions aimed at reducing flood impact on population, economic activities, cultural heritage, environment and ecosystem. The Flooding Directive adopted by the European Commission in 2007 (2007/60/EC) encourages the Member States to map the flooding risk of river and coastal regions, evaluating human and asset exposure and taking actions to manage and reduce the global risk. In this context, the Italian legislation deals with the protection of human life, cultural heritage, economy and environment, including the sea-wave hazard into the flood list (see the Legislative Decree 23 February 2010, n. 49, "Implementation of Directive 2007/60/EC relating to the assessment and management of flood risks").

Coastal protection is widely addressed in the scientific literature (WIEGEL, 1964; CORTEMIGLIA, 1981; CERC, 1984; BENASSAI, 1998; U.S. ACE, 2000; ZHANG *et alii*, 2004; PRANZINI *et alii*, 2015; WILLIAMS *et alii*, 2018), not involving only scientists, engineers, legislators and stakeholders, but the whole population. In addition, a close collaboration between the authorities is fundamental to safeguard the environmental, social and economic needs of the land. In the last decades, coastal protection actions performed in Italy were mainly linked to the national ministerial program, only supporting the local needs and without promoting a global coordination, being still affected by financial constraints. Since several local sea-defence interventions have significantly altered the environment and have enhanced the global erosion process of the area, it is fundamental to design effective sea-defence structures aimed at protecting the urban settlements and restoring the environment.

Here we describe the physical, socio-economic and cultural characteristics of the southern Tyrrhenian coast, whose problems and potential demand special attention in Community policies. We then remark the impact of actions and interventions carried out in the southern Tyrrhenian coast in the last decades, with particular reference to the municipality of Belvedere Marittimo, where it is located the Experimental Marine station of Capo Tirone, a scientific hub multiple services to the land and to the population. A set of conclusions closes the paper.

THE SOUTHERN TYRRHENIAN COAST BELONGING TO THE PROVINCE OF COSENZA

Calabria is one of the 20 regions of Italy, located in the southern part of the country (Fig. 1). The region owns more than 700 km of densely populated coastline, part located in the Ionian Sea and part in the Tyrrhenian Sea. Coastal areas are of paramount importance for the economy of the region, which is mostly based on fishing,

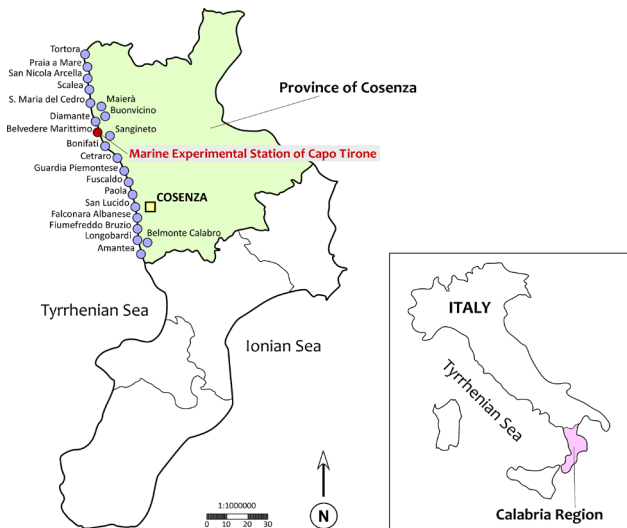


Fig. 1 - Calabria and the coastal municipalities belonging to the province of Cosenza

tourism and leisure activities. The Tyrrhenian coast belonging to the province of Cosenza is about 110 km long and includes 21 municipalities (Tortora, Praia a Mare, San Nicola Arcella, Scalea, Santa Maria del Cedro, Maierà, Buonvicino, Diamante, Belvedere Marittimo, Sanginetto, Bonifati, Cetraro, Guardia Piemontese, Fuscaldo, Paola, San Lucido, Falconara Albanese, Fiumefreddo Bruzio, Longobardi, Belmonte Calabro, Amantea, see Fig. 1).

The whole coastline has a great tourism potential, since the resident population is 117,500 inhabitants while the floating population is about 420,000 inhabitants (ISTAT, 2020). However, the shoreline is significantly affected by erosion processes which cause the retreat of the beachfront, threatening the coastal assets (FOTI *et alii*, 2019).

As concerning the geological evolution of the western Mediterranean area, during the Cenozoic era it was mainly related to the sliding of the Adriatic-Ionian plate below the Euro-Asian plate (DE RITIS *et alii*, 2019). In the southern Tyrrhenian Sea, close to the edge of the Adriatic-Ionian plate, the subduction produced a rise of magma and the building of a volcano chain.

The volcano chain can be classified into a western area, located far from the coast, where the volcanos buildings show an irregular morphology, shaped by tectonic motion, and an eastern area, located close to the coast, showing rounded volcanic buildings with a flat top, due to the interaction between volcano activity and changes in sea level that produced multiple erosion and sedimentation cycles. DE RITIS *et alii*, 2019, identified, 15 km west from the Calabrian coast located between Scalea and Guardia Piemontese, one of the largest Italian submarine volcanic structure, originated from the fusion of the material coming from the Earth's mantle and, in particular, from a deep fracture of the crust (Fig. 2).

The Calabria plaque is part of the continental shelf of the Western Mediterranean, which split from the southern edge of the European plate and collided with the African platform (CORTESE, 1895; ARGNANI & TRINCARDI, 1993; CRITELLI & LE PERA, 1998). The Tyrrhenian coast belonging to Calabria is characterized by four geological zones (BARONE *et alii*, 1982, see Fig. 3):

- the Coastal Chain (i.e. the Coastal Range), characterized by a very high chain of primary metamorphic rocks;
- the narrow Coastal Plain, broken by plateaus and mountains extended to the sea;
- the narrow Continental Cliff;
- the basin of Paola, 70 km long and characterized by a maximum depth of 1000 m.

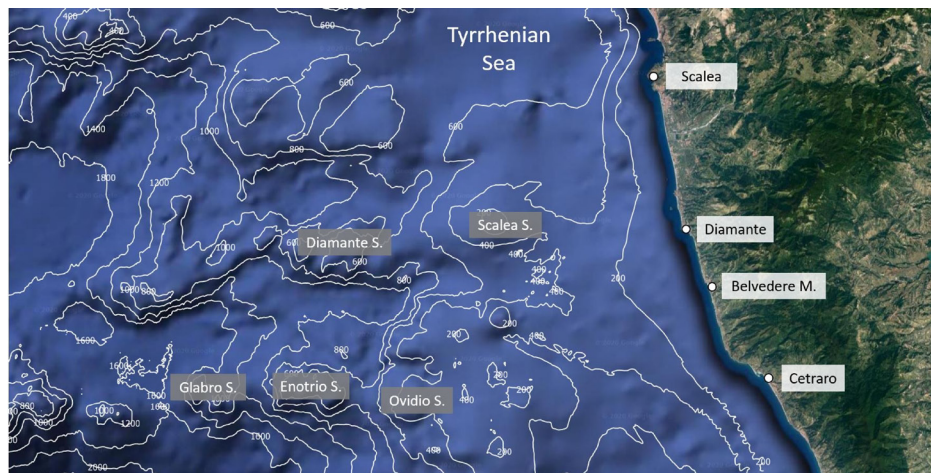


Fig. 2 - Bathymetry of the Tyrrhenian Sea between Scalea and Cetraro (see Fig. 1). The seamounts (S.) of the volcanic complexes of Diamante, Scalea, Glabro, Enotrio and Ovidio are highlighted with grey labels

Orography and climate

The coastline of the province of Cosenza (AAVV, 2004) is surrounded by highlands that reach the sea with large slopes. The orography of the area is delineated to the north by the Pollino massif, which extends across the south-west side of the Noce Valley and the east side of the Lao Valley, to the towns of Tortora and Belvedere Marittimo through the Scalone Pass (744 m. asl). South of Belvedere Marittimo, the Coastal Chain

to the sea. However, the most important historical settlements of the southern Tyrrhenian Sea were located near the Lao, Noce-Castrocucco and Savuto Rivers, the most important watercourses of the province of Cosenza, characterized by a mild bottom slope.

The Noce River originates from the mountains of Lagonegro and develops between Basilicata and Calabria. The Battindiero and the Argentino Rivers are the main tributaries of Lao River, which is mostly navigable due to its almost steady flow. The Savuto River originates in the Sila range and it flows into the Gulf of Sant'Eufemia, few kilometers north of Capo Suvero. Minor watercourses are the Abatamarco River north of Cirella, the Fiumarello River between Praia and Tortora, the Corvino River at Diamante, the Vallecupo and Soleo Rivers at Belvedere Marittimo, the Sangineto River at Bonifati and the Triolo, the Aron, the S. Giacomo, the S. Nicola, the Fiumarella and the Bagni Rivers between Cetraro and Acquappesa. The climate of Calabria is heterogeneous due to the coexistence of mountain ranges, highlands and coastal plains extended up to the sea (COSCARELLI & CALOIERO, 2012; CAPRA *et alii*, 2013). It belongs to the Mediterranean climate, with dry subtropical summers, when rare convective rainfalls occur, and temperate winters (CALOIERO *et alii*, 2015), according to the Köppen's classification (BECK *et alii*, 2018). Rain occurs with a medium-low intensity in coastal areas, with particular reference to the Ionian coastline. Medium-heavy orographic precipitations can affect the Tyrrhenian coastline (TERRANOVA *et alii*, 2014; CALOIERO *et alii*, 2015). Heavy rain events characterize the mountain ranges, where the winters are frigid and snowbound. CALOIERO *et alii*, 2016, divided Calabria into four areas following the De Martonne index: semi-arid, sub-humid, humid and hyper-humid. The Tyrrhenian coast is mostly classified as humid and sub-humid. The average annual temperature of the region is 17.9°C, with an average maximum of 26°C in July and a minimum of 9.6°C in January (PULICE *et alii*, 2013). The prevailing wind is eastward directed.

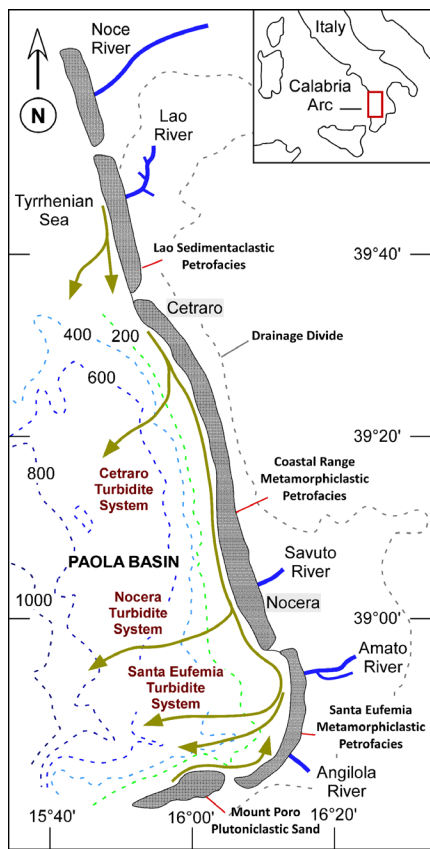


Fig. 3 - Geological structure of the coastal area belonging to the province of Cosenza

is the last ridge of the Apennine system, extended for about 73 km from Belvedere Marittimo to Amantea. The Coastal Chain is characterized by a crystalline-schistose material, modest altitudes (the maximum elevation is 1987 asl at Cozzo del Pellegrino, located south of the Argentino River) and large steeps. Between Cetraro and Guardia Piemontese, the Coastal Chain reaches the coast, conveying the alluvial gravelly sediments to the sea. The Coastal Chain is one of the rainiest areas in Italy, with an average annual precipitation of 2000 mm due to the orographic condensation of moist air masses coming from the western Mediterranean Sea. The hydrographic system is heterogeneous with several debris cones extended up

Historical land use

From the II century. B.C. to the III-IV century A.D., some residential settlements, named *villae*, provided not only the agricultural needs of the land but also an exportable surplus (Liv., XXXII, 29,3-4). In the *Historia Naturalis*, liber LII, Plinio il Vecchio (23-79 A.D.) describes the southern Tyrrhenian coast: *Proximum autem flumen Melpes, oppidum Buxentum, Graeciae Pyxus, Laus amnis. Fuit et oppidum eodem nomine. Ab eo Bruttium litus, oppidum Blanda, flumen Baletum, portus Parthenius Phocensium et sinus Vibonensis, locus Clampetiae, oppidum Tempsa, a Graecis Temese dictum, et Crotoniensium Terina sinusque ingens Terinaeus. Oppidum Consentia intus.* The portus Parthenius Phocensium is probably referred to the

natural port of Capo Tirone. The port met several needs of Roman people, such as the construction of naval fleets for the Carthaginian wars. The inland woods were easily accessible from Belvedere and the Breton pitch was used as glue. The word Tirone, as is currently named the cliff, meant the place of recruitment of young soldier to be employed in the *oppidum praesidio* (Ti-rò-ne, a military recruit of the Roman army,

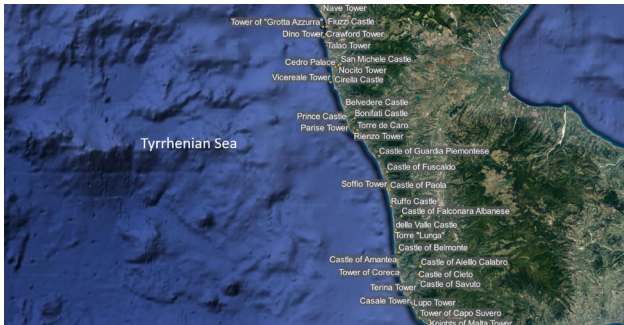


Fig. 4 - Towers, castles and fortifications along the Tyrrhenian coast of the province of Cosenza

becoming a miles after a year of training).

After the Roman era, the cultural heritage of the coastline originated from the historical events that characterized the southern Tyrrhenian coast from the 11th century (PLACANICA, 1994). Muslim raids constantly threatened the coastal villages, modelling the development of urban settlements (SAVAGLIO & CAPALBO, 2004). Several fortifications (e.g. Amantea, Cetraro, Belvedere Marittimo and Scalea buildings) and marine towers (Fig. 4) characterize the coastline (SAVAGLIO & CAPALBO, 2003). The coastal villages, were progressively abandoned leading to the depopulation of Sangineto and Belvedere Marittimo areas.

The northern part of the Tyrrhenian coast of the province

of Cosenza is named Riviera dei Cedri, extended for about 80 km from Tortora to Paola. The name originates from the local cultivation of citron (ATTLEE, 2015; MARUCA *et alii*, 2015), defined by the Bible as the fruit of the most beautiful tree, due to the unique characteristics of the fruit. The feast of Sukkòth represents for the Jews the most important religious event that celebrates the liberation of the Jews from slavery in Egypt (LEIBOWITZ, 2010) and consists in the selection of the best citron by the rabbis himself. The citron, due to its good flavour and smell, represents the elite of the Jewish people, hardworking and faithful to the Torah. Along the Riviera dei Cedri there also are some Christian buildings as the sanctuary of San Francesco da Paola, the fulcrum of many religious pilgrimages (BENVENUTO, 2019).

Until the 19th century, the Calabrian coast was mainly used for agricultural purposes. The shoreline was sparsely populated and the sediment supply was not significantly affected by the human activities. The building of the Reggio Calabria - Naples railway caused three permanent changes in the coastal geomorphology:

- a) interruption of the sediment supply to the shoreline, affecting the Holocene dunes and triggering a global erosion process in the area;
- b) interruption of the material conveyance of the colluvial debris from the Pleistocene alluvial terraces to the sea;
- c) establishment of a permanent location of the coastline.

In addition, in the last decades of the previous century, the major rivers that convey coarse and fine sediment to the coast were affected by quarrying activities for building purposes. Nowadays, riverbed excavation is prohibited, limiting the lateral retreat of the shoreline.

An example of the evolution of the shoreline located in the municipality of Belvedere Marittimo is shown in Fig. 5.



Fig. 5 - Belvedere Marittimo. (a) overview of the beach (BOSSOLASCO, 1939); (b) the heavy urbanization of the area caused the insulation of the Pleistocene terrace from the coast and the need to protect the shoreline arises. Notably, the picture highlights the different erosion process occurred with and without the sea barriers

Site of community interest

The southern Tyrrhenian coast has a valuable natural heritage, which is protected by the current legislation (PAN Life, 2016). It is included in the Natura 2000, an ecological network widespread in the European Union. In Calabria, Natura 2000 includes 178 Sites of Community Interest (SIC), for a total area of 90,650 ha. 69 habitats (priority and 49 non-priority areas) are listed in Calabria, based on the classifications identified in Annex I of Directive 92/43 / EEC, 20. The most important protected areas are the Pollino National Park, the Argentino Valley Nature Reserve, Lao Valley Nature Reserve and the Riviera dei Cedri Marine Park, which includes several sites SIC (SIC IT9310034 Isola di Dino, SIC IT9310035 Fondali Isola di Dino-Capo Scalea, SIC IT9310025 Valle del Fiume Lao, SIC IT9310037 Isola di Cirella, SIC IT931 0036 Fondali Isola di Cirella-Diamante, SIC IT9310038 Scogliera dei Rizzi, SIC IT9310039 Fondali Scogli di Isca, SIC IT9310033 Fondali di Capo Tirone, Fig. 6, where several meadows of *Posidonia Oceanica* characterize the seabed). *Posidonia oceanica* meadows sustain the environment and the ecosystem by reducing the wave energy and the erosion process (MAIOLO *et alii*, 2020b). In the last decades, the area SIC IT9310033 has been affected by the anthropic action driven by an increasing tourism demand, such as the building of road and rail networks, and abusive building and trawling, leading to an environmental degradation of the land, with particular reference to the health of *Posidonia oceanica*. In addition, high touristic and environmental value are increasingly threatened by winter storms, which triggered a significant erosion process (MAIOLO *et alii*, 2020a).

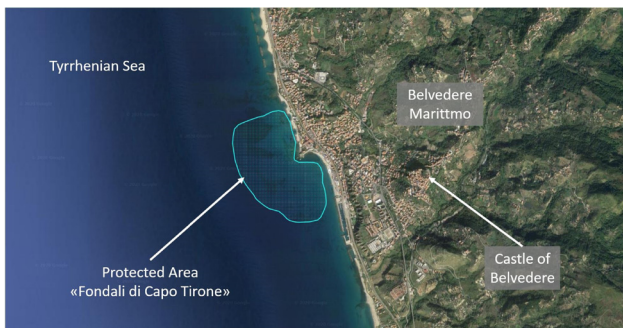


Fig. 6 - Capo Tirone SIC area located in the municipality of Belvedere Marittimo

HISTORY OF THE INTERVENTIONS

In the last decades, the Calabria Region and the Province of Cosenza authorities supported a multidisciplinary approach focused on the protection of the shoreline belonging to the province of Cosenza, by promoting several actions aimed at improving the knowledge of the needs of the land (MAIOLO *et alii*, 2000). Several studies have been performed on the former sea-defences in

order to assess their structural and operating shortcomings. These studies have been supported by the Department of Soil Defence of the University of Calabria (DSD), the Environmental Engineering Study Centre of Pavia (CSDIA) and the US Coastal & Hydraulics Laboratory of the Army Corps of Engineers (CHL). The main topics of the studies were:

- development of a risk forecasting and prevention plan in the province of Cosenza;
- preliminary analysis of the coastal erosion of the southern Tyrrhenian coast through topo-bathymetric surveys;
- approval of the executive project for the defence and the restoration of the shoreline located in the municipalities of Bonifati, Sangineto and Belvedere.

In addition, the Calabria Region and the Province of Cosenza, supported by departments of environment, public and marine works, developed:

- a preliminary basin plan for the evaluation of the hydrogeological risk;
- a master plan aimed at mitigating the coastal erosion;
- the Regional Operation Program (POR) Calabria 2000-2006 – Low environmental impact interventions for the protection of the coasts;
- the Regional Operation Program (POR) Calabria 2014-2020 – TEMAR project: techniques and devices for analysis and assessment of the water pollution.

Risk forecasting and prevention plan in the province of Cosenza

The risk prediction and prevention plan in the province of Cosenza had been developed in 1996 with the support of the DSD of the University of Calabria. The activities, ended in 2004, focused on the evaluation of the hydrogeological risk of the area, by the population of a database of the issues that affect the land and a cost-benefit analysis of structural and non-structural measures.

Preliminary analysis of the coastal erosion of the southern tyrrhenian coast through topo-bathymetric surveys

The protected areas were defined by the CHL and the CSDIA through a regional analysis to support the protection plan of the Tyrrhenian coast belonging to the province of Cosenza. The “surveying campaign” and the “executive design” were supported by the Civil Protection and Soil Defence Authority of the Province of Cosenza authority. The evaluation of the erosion process of the southern Tyrrhenian coast, carried out by the CHL and the CSDIA, consisted in three phases:

- preliminary site survey to monitor the geological, geographic and hydrodynamic parameters and the operation of the former sea-defences;

- evaluation of the sediment balance and the erosion process affecting the area by defining 11 coastal cells (KANA & MOHAN, 1997; MAIOLO *et alii*, 2020b). The retreat of the beachfront had been analysed from 1954 to 1978 and from 1978 to 1987, by applying the sediment balance equation to each cell (DEAN & DIRAMPLE, 2001). The study accounted for the contribution of bathymetric changes, shoreline transport, river sediment supply, beach nourishment or artificial excavation, rock erosion and offshore sediment loss. Results indicated a significant lateral retreat (Fig. 7). Several sea defences were built, mostly seawalls and breakwaters, without taking into account the maintenance cost and their impact on the environment;
- support the development of the general plan of the interventions of the Tyrrhenian Coast belonging to the province of Cosenza. CHL identified several structures which affected the environment and suggested their replacement with artificial sand nourishments and by fixing the sediment cells.

Approval of the executive project for the defence and the restoration of the shoreline located in the municipalities of Bonifati, Sangineto and Belvedere Marittimo

According to the studies performed by the CHL and the CSDIA, the Province of Cosenza authority promoted a set of

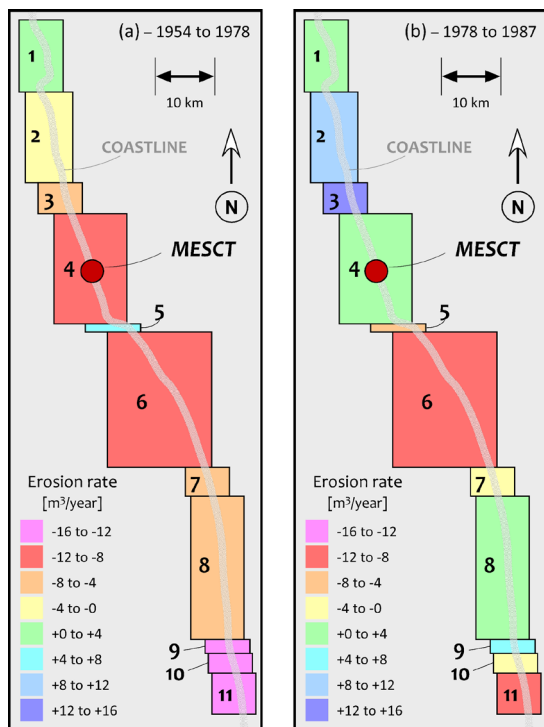


Fig. 7 - Sediment balance in the period 1954 – 1978 (a) and 1978 – 1987 (b) in the 11 cells. The Marine Experimental Station of Capo Tirone (MESCT) belongs to cell number 4

interventions to protect and restore the shoreline, focusing on the municipalities of Bonifati, Sangineto and Belvedere Marittimo, which have been particularly subjected to environmental degradation, reduction of *Posidonia oceanica* meadows and an enhanced erosion process driven by anthropic interventions and climate change. The executive project concerning the defence and the restoration of the shoreline located in the municipalities of Bonifati, Sangineto and Belvedere Marittimo includes the building of a submerged breakwater, some semi-submerged cross groins and the nourishment of the beach. In 2004 the works started in a section 700 m long located south of the port of Belvedere Marittimo in the area of Calabaia beach. In this section, the assets were threatened by flooding and the former seawalls were ineffective to counteract the major storms. The intervention consisted in an artificial nourishment cell supported by a submerged breakwater. In particular:

- a submerged breakwater 700 m long and 10 m wide, with the ridge located 2.5 m sea deep;
- groins defining the nourishment cell emerging 1 m, joined with the submerged breakwater;
- a filter made of small stones located behind the submerged breakwater, supporting the retention of fine material;
- an artificial nourishment of the cell, by using inert material derived from quarries, rivers or beaches.

Figure 8 illustrates the artificial nourishment at Calabaia beach.

Preliminary basin plan for the evaluation of the hydrogeological risk

The Basin Plan developed in 2001 produced a first dossier that defined the coastal erosion risk classes (Fig. 9), on the basis of the evolution of the shoreline in the years 1958, 1978 and 1998, and the vulnerability classes, on the basis of the damages caused by the storms.

Master plan aimed at mitigating the coastal erosion

The Calabria Region between the years 2005 and 2006 had defined the Integrated Coastal Management Plan and the Program of Agreement with the Ministry of the Economic Development and the Ministry of the Environment and Protection of the Territory and the Sea. 47 interventions, aimed at safeguarding and restoring the coast, were carried out with the support of the main municipal administrations.

In 2013, further interventions were planned in the areas subjected to higher hydraulic and environmental risk, with particular reference to the Belvedere Marittimo municipality. The study highlighted the need to counteract the sediment loss by integrating the former T-barriers with sand nourishments, submerged breakwaters and small groins located near the shoreline, aimed at fixing the sediment cell located between Capo Tirone and the port of Belvedere Marittimo.

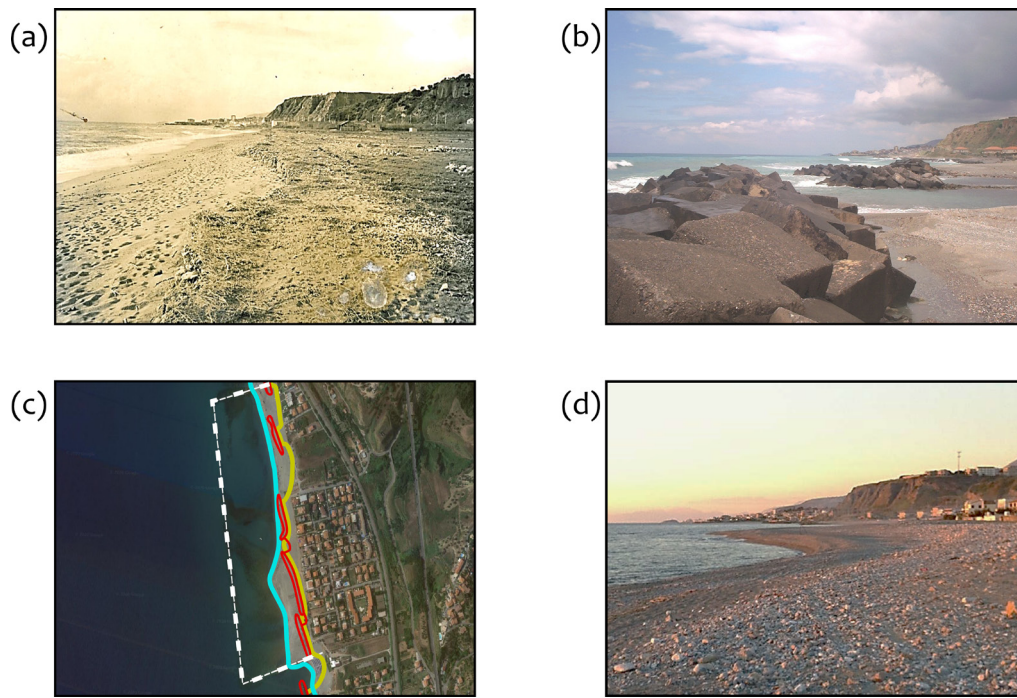


Fig. 8 - Artificial protected nourishment at Calabaia beach. (a) the area in 1967; (b) the seawalls in 2002; (c) the area where the works were performed (2006): yellow line indicates the shoreline in 2002, red line the former sea defences, blue line the present shoreline fixed by the intervention, white line the submerged breakwaters protecting the artificial nourishment; (d) the present condition of Calabaia beach

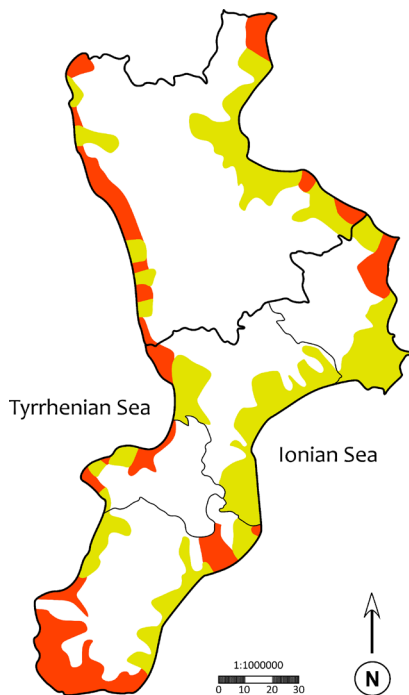


Fig. 9 - Risk of erosion of the coastal areas of Calabria. Municipalities with risk class "R2" are highlighted in yellow, Municipalities with risk class R3 in red

Regional operation program (POR) Calabria 2000-2006 - Low environmental impact interventions for the protection of the coasts

The project involved six Italian universities: University of Calabria, Mediterranean University of Reggio Calabria, Polytechnic of Bari, University of Salento, University of Salerno, University of Catania. The research focused on field and laboratory monitoring campaigns; mathematical modelling and dissemination activities, concerning the management and the protection of coastal areas, with particular reference to Belvedere Marittimo, where topo-bathymetric data had been collected and the performance of the former sea-defence system had been assessed.

Regional operation program (POR) Calabria 2014-2020 - Temar Project: techniques and devices for the analysis and assessment of water pollution

The project was carried out by the Research Group of Sustainable Management of Water Resources of the Department of Environmental Engineering of the University of Calabria (DIAM), on the coastal area belonging the municipality of Belvedere Marittimo, with the aim to investigate the water pollution. The study was carried out by means of an underwater drone, capable to collect biochemical and physical data, supported by satellite imaging for the validation process.

RESEARCH DEVELOPMENTS: THE MARINE EXPERIMENTAL STATION OF CAPO TIRONE

The coastal area of Belvedere Marittimo can support several scientific activities aimed at promoting the Blue Growth. In particular, the activities should focus on the development of a sustainable tourism, by promoting the environmental, monumental, artistic and marine heritages of the land, and by facing the erosion process and the dispersion of pollutants. The recent establishment of the MESCT aims to create a multidisciplinary hub for in situ data collection supporting the mathematical modelling (Fig. 10). In 2017, the municipality

of Belvedere Marittimo and the (DIAM) signed a framework agreement, aimed at promoting research activities related to the coastal area belonging the MESCT, formally recognized as institution in 2019 with the support of the Province of Cosenza, the DIAM, the local Environment Protection Agency (ARPACAL), the Institute of Atmospheric and Climate Sciences of the National Research Council (CNR-ISAC) and the Regional Marine Parks Authority. Furthermore, the MESCT is a crucial hub of the Integrated System of Laboratories for the Environment (SILA), founded by the Calabria Region authority. Further opportunities consist in the engagement into international research projects,

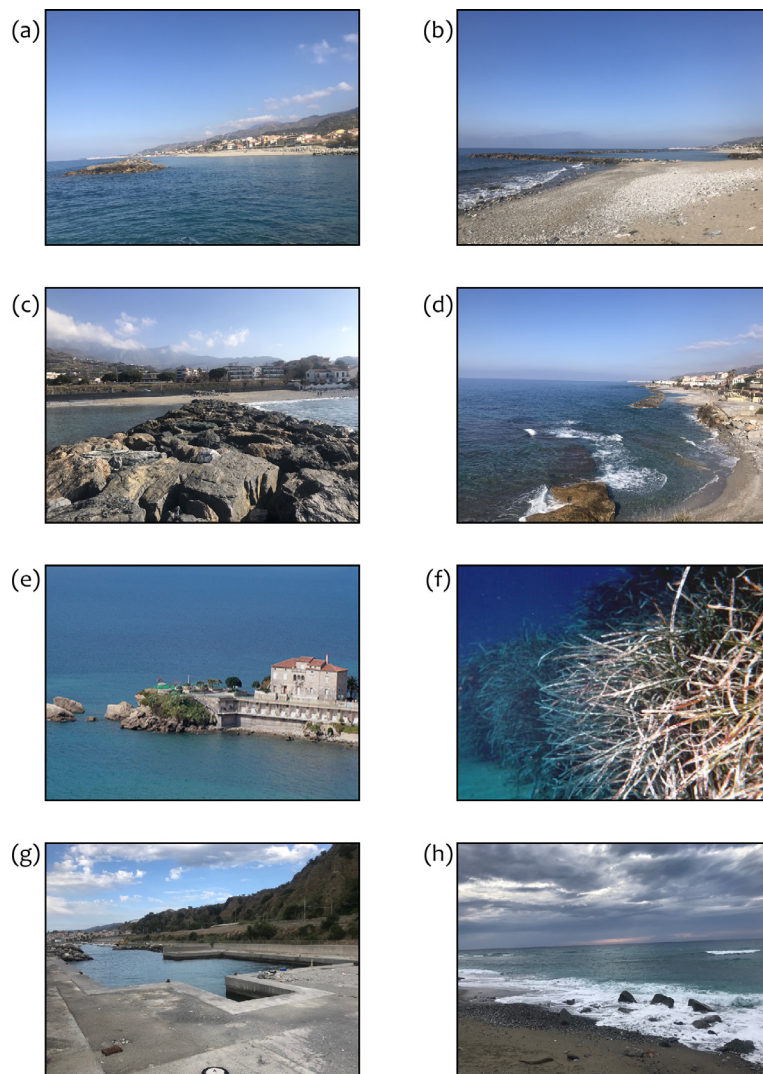


Fig. 10 - Study area of the Marine Experimental Station of Capo Tirone (MESCT). Panels (a) and (b) show longitudinal breakwaters located perpendicularly to the shoreline, protecting the railway located Belvedere Marittimo and Diamante. Panels (c) and (d) illustrate the north and south view of the sea-defence located in the locality “Scogli Oremus” (Belvedere Marittimo). Panel (e) shows the “De Novellis Palace” located in Capo Tirone, which will be used as sea museum, supporting the dissemination activities of the MESCT. Panel (f) shows the *Posidonia oceanica* in the SIC area of Capo Tirone. Panel (g) represents the port of Belvedere Marittimo and panel (h) the shoreline located south of the port

focused on the sustainable management of the land, such as:

- MARine Experimental site and Integrated Solutions for the BOating Sector, with the partnership of the University of Calabria, which aims to achieve a safe, attractive and sustainable environment for the skippers. The main target is to improve the competitiveness of the land by optimizing the hosting capacity and by enhancing the services of the port. The partnership involves research institutions, universities, nautical consortia and private companies;
- H2020 Nautilus project, started in October 2020, aimed at addressing the lack of high resolution chemical and biological data concerning the marine ecosystems. Nautilus will promote the marine monitoring by means of the development of sensors, technologies and approaches by the optimization of the cost of the monitoring campaigns. The ultimate goal of the project is to develop an accessible monitoring system to disseminate the data, allowing the stakeholders to know the present status of the ecosystem and to estimate the future evolution of the marine environment by means of mathematical models, in order to support the management process;
- TIRONE project, linked to the health of the marine ecosystem, which aims to support the monitoring and the spread of the *Posidonia oceanica* the MESCT.

In addition, the MESCT can provide supplementary information concerning the climate and the environment of Belvedere Marittimo, test innovative approaches and technologies to study the marine environment; promote the dissemination of a new scientific culture in the school and amongst the population, and support the development of start-ups concerning the Blue Growth. In particular, the research areas involved are: the development of sensors to monitor the environmental parameters (e.g. temperature, coastal erosion, eutrophication, ecotoxicology); the monitoring of sea pollution by means of satellite data; the development of mathematical models, the monitoring of marine protected areas; the forecasting of the flood

events that affect the coastal urban settlements; the development of underwater robotics; the remote monitoring of maritime traffic; the sustainable development of coastal areas; marine biology and underwater archaeology.

CONCLUSIONS

This work describes the characteristics and the needs of southern coast of the Tyrrhenian Sea, with particular reference to the historical, architectural and environmental processes that drive the development of the land, with the aim to support a sustainable Blue Growth. The environmental characterization of the land includes the geological, geomorphological and hydrographic characteristics, together with the classification of the protected sites. Coastal hydrodynamics, erosion process and the operation of the former sea-defence structures have been analysed on the basis of the historical data, with the aim to provide insights into the hazards that threaten the shoreline and to identify the strategies, choices and interventions that drove the history, the development and the fate of the land. In particular, this manuscript focuses on the municipality of Belvedere Marittimo, where it is located the Experimental Marine Station of Capo Tirone (MESCT), an advanced research structure that promotes research activities and technology transfer concerning flood hazards and the major environmental issues threatening the worldwide coastal regions, by developing and testing new technologies, facilities and interoperable systems. The MESCT aims to be a hub, where several authorities should be involved to cooperate effectively and efficiently. Research needs should focus on the new challenges concerning the environmental protection in coastal and maritime areas, through the cooperation between physicists, biologists, mathematicians and engineers. The MESCT can rapidly become an examples of a sustainable Blue Growth in the Mediterranean region, promoting citizen science and cooperation between stakeholders and authorities.

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