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XXVIII CICLO

A GEOMORPHOMETRIC APPROACH TO ASSESS MULTI-SCALE SPATIAL DISTRIBUTION AND GEOMORPHOLOGICAL CHARACTERIZATION OF BENTHIC HABITATS

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Chapter 1 - Introduction

1.1 An overview on seafloor mapping and exploration

Exploration and environmental characterization of the ocean floor continuously presents new possibilities and challenges (Lecours et al., 2015). Thanks to recent and ongoing improvements in acoustic remote sensing technology and survey techniques (such as single-beam acoustic ground discrimination systems, side scan sonar systems (SSS), and more recently multibeam echosounders (MBES)), seabed morphology can now be measured rapidly, extensively and at fine spatial scales (Lurton, 2010) and marine mapping efforts have begun to match the quality and resolution of those in the terrestrial realm sets (Brown et al., 2011). Moreover, many analysis techniques developed for terrestrial (optical) remotely sensed data are transferable for use in analyzing marine (acoustic) remotely sensed data sets (Brown et al., 2011).

Multi-Beam Echo-Sounders have been used for almost 40 years for seafloor mapping in support of chart-making, naval activities and geoscience. As the resolution and capabilities of these systems have improved along the years, the applications have expanded to environmental monitoring and fisheries, surveys for hydrocarbon exploration, offshore engineering, coastal management and underwater archaeology (Lurton, 2016).

Most of the MBES data are collected during navigational charting efforts, with a particular focus on shallow coastal waters where the seabed relief can pose a hazard to navigation. Due to potential safety concerns, standards regarding data quality and uncertainty are high for these shallow datasets. Datasets from deeper waters, however, still lag behind in terms of quality and quantity (Lecours et al., 2015). Owing to the technological challenges and high costs associated with bathymetric mapping of large and deeper parts of the seabed, it is estimated that only 5-10% of the oceans are mapped with a resolution comparable to that on land, so marine geomorphology still represents a persistent gap in our knowledge (Wright et al., 2008).

Bathymetric data have proven their potential to help the scientific community and government agencies advance their understanding of seabed ecosystems and geomorphological processes (Anderson et al., 2008). The ability to produce a continuous acoustic image of the surface of the seabed using multibeam acoustics has revolutionized our ability to understand marine morphodynamics and the composition and distribution of sediments, which has in turn significantly improved our knowledge of seabed processes (Lecours et al., 2015). Technology and equipment to survey the seabed is improving in quality, accuracy and cost efficiency, which will allow an increase in data availability and quality. Algorithms that consider the specific characteristics of underwater surveying, such as the CUBE (Combined Uncertainty and Bathymetric Estimator)(Calder et al., 2003), are being developed to improve bathymetric data processing and are likely to become more accessible through processing software. Better practices to report data type, quality and scale within metadata will need to be implemented in order to allow the most informed analysis of these data (Greene et al., 2005).

1.2 Offshore Ecosystem-Based Management (EBM)

There is general acceptance that to effectively manage the oceans' resources, an ecosystem-based approach to management must be adopted (Castilla and Defeo, 2005; Douvere, 2008; Garcia et al., 2003). As on land, successful management and conservation of the environment requires knowledge of the extent, geographical range and ecological characteristics of the resource of interest, for that reason maps are the most excellent means of recording and communicating this information. These maps, in combination with spatial information on human activities, can then be used to assess conflicts or compatibilities between human uses and the environment (Cogan et al., 2009; Ehler and Douvere, 2009).

The environmental legislations and initiatives demonstrate an increasing effort at regional and global level to shift towards an ecosystem-based management of marine resources. Ecosystem-based management is a place-based, holistic and integrative approach, that aims to restore and protect the health, function and resilience of an entire ecosystem and the benefits it provides (Curtin & Prellezo 2011, Katsanevakis et al. 2011, UNEP 2011). Ecosystem-based management is an approach that goes beyond examining single issues, species, or ecosystem functions in isolation. Instead it recognizes our coasts and oceans for what they are: a rich mix of elements that interact with each other in important ways (UNEP 2011).

An essential tool for the practical implementation of EBM is the Marine Spatial Planning (MSP) (Douvere 2008). Ehler & Douvere (2009) describe MSP as “analysing and allocating parts of three-dimensional marine space to specific uses or non-use, to achieve ecological, economic, and social objectives that are usually specified through political process”. Within this context, marine protected area networks provide a means for emphasised protection of features and processes within the ecosystem to be managed (OSPAR 2010, Katsanevakis et al., 2011). Ocean Zoning can be applied to partition a larger region into zones designed to allow or prohibit certain activities (Halpern et al. 2008a, Katsanevakis et al. 2011). Geographic information systems (GIS) are commonly used to store, process, integrate, analyse and visualise relevant spatial data (Longley et al. 2005), even for the marine realm. The concept of ecosystem-based marine spatial planning has been adopted by multiple governments, ranging from European countries and the United States to China and Australia, which have developed and implemented first MSP initiatives of different spatial and integrative dimensions (Ehler & Douvere 2009, Foley et al. 2010).

1.3 Policy context

Worldwide, the oceans and seas are under increasing anthropogenic pressure (Halpern et al.,2008a) and there is an ever greater need for good international policy, both to protect more effectively the marine environment and to assess environmental and socio-economic impact of marine-related human activities.

Since the Barcelona Convention (the first-ever Regional Seas Programme, Table 1) international organisations have developed a number of legal instruments and regulations in order to protect marine biodiversity, to sustainably manage offshore marine resources and to control activities impacting the ocean (Table 1).

On a European level the characterisation of seabed habitats by European Member States has improved greatly over recent years mainly due to the last legislative requirements and for conservation purposes. In particular, the EU Habitats and Species Directive (92/43/EEC, Table 1) requires member states to implement Special Areas of Conservation (SACs), meanwhile, more recently, the Marine Strategy Framework Directive (MSFD, Table 1) enshrines in a legislative framework the ecosystem approach to the management of human activities having an impact on the marine environment, integrating the concepts of environmental protection and sustainable use.

Barcelona Convention (revised in 1995)	1976	Convention for the Protection Of The Mediterranean Sea Against Pollution
Helsinki Convention	1992	Convention on the Protection of the Marine Environment of the Baltic Sea Area
OSPAR Convention	1992	Convention on the protection of the marine environment of the North-East Atlantic
Bucharest Convention	1992	Convention on the Protection of the Black Sea Against Pollution
EU Habitats and Species Directive	1992	To promote the maintenance of biodiversity, EU Member States to maintain, restore and monitor natural habitats and wild species listed in Annexes I and II at a "favourable conservation status"
Arctic Council	1996	High level intergovernmental forum providing the means for promoting cooperation, coordination and interaction among the Arctic States, in particular issues of sustainable development and environmental protection in the Arctic
EU Water Framework Directive	2000	To establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater
EU Strategic Environmental Assessment Directive	2001	To enforce integration of environmental considerations into preparation and adoption of plans and programmes of industrial sectors in order to protect listed habitats from potential adverse impacts
EU Integrated Maritime Policy (IMP)	2002	To provide a more coherent approach to maritime issues, with increased coordination between different policy areas.
EU Marine Strategy Framework Directive (MSFD)	2008	To establish a framework within which EU member States shall take necessary measures to achieve or maintain "good environmental status" in the marine environment by the year 2020
EU Marine Spatial Planning Directive (MSP)	2014	To plan when and where human uses take place at sea to ensure these are as efficient, safe and sustainable as possible.

Table 1 - Examples of international frameworks relevant for the protection and conservation of marine biodiversity and vulnerable marine ecosystems.

In order to achieve the Good Environmental Status (GES) of the EU's marine waters by 2020, each Member State is required to develop a strategy for its marine waters (or Marine Strategy). In addition, because MSFD follows an adaptive management approach, the Marine Strategies must be kept up-to-date and reviewed every 6 years (MSFD, 2008).

As preliminary result of these European initiatives, Marine Protected Areas Report (2015) shows significant progress in establishing protected areas in Europe's seas, with benefits for the economy and the environment. The main outcome deriving from this report underlines that Marine Protected Areas (MPAs) constitute essential spatial management tools for nature conservation. They can function as sanctuaries for the threatened biodiversity of our seas and oceans. By supporting the resilience of ecosystems, effective networks of MPAs create valuable benefits to society. These socioeconomic benefits include job creation, food provision, or climate regulation (EU report on MPAs, 2015).

Follow these international main set of regulations several research projects was created. International research programmes, such INDEEP (www.indeep-project.org), the Census of Marine Life (www.coml.org) and EU-funded projects like HERMES (www.eu-hermes.net), HERMIONE (www.eu-hermione.net), MESH (www.emodnet-seabedhabitats.eu), CoralFISH (www.eu-fp7-coralfish.net), COCONET (www.coconet-fp7.eu) and some national and regional projects, Italian included such as RITMARE (www.ritmare.it) and BioMAP (www.biomapping.it), are rapidly expanding our knowledge of the seafloor morphology and benthic communities with the purpose of balancing environmental and economic concerns while not forgetting the important social issues, such as jobs and cultural heritage.

1.4 Benthic Habitat Mapping

Given the enormous extensions of the oceans and seas, their value in providing important goods and services and their vulnerability to the ever-increasing anthropogenic impacts, there is an urgent need to deepen our knowledge on vulnerable ecosystems, to map their spatial distribution and to ensure their sustainable management and conservation. One of the main goals of MSP is to promote a sustainable use of marine resources without putting biodiversity and habitats at risk. It's about *planning when and where human activities take place at sea* to ensure these are as efficient and sustainable as possible (EU MSP directive, 2014).

Knowledge about the spatial distribution, extent and health state of marine habitats is fundamental to our understanding of marine ecosystems and our ability to protect them from anthropogenic impacts (Jackson et al., 2001). Benthic habitat mapping (BHM) is the most important and useful tool that allow scientists implementing an EBM approach for marine resources. In marine context, mapping is a broad term encompassing strictly geological maps produced from acoustic survey of the seabed and habitat is defined by Kostylev et al. (2001) (with reference to marine benthic habitat), as a spatially defined area where physical, chemical and biologically environment is distinctly different from the surrounding environment.

For these reasons BHM it has been defined as “Plotting the distribution and extent of habitats to create a map with complete coverage of the seabed showing distinct boundaries separating adjacent habitats” (MESH, 2008). This definition makes the assumption that in order to spatially represent biological patterns, we must impose distinct boundaries between adjacent (and therefore discrete) habitat types.

In order to reach its goals, BHM needs the integration of state of the art technology and scientific expertise from a range of disciplines including geology, biology, chemistry and oceanography.

The objectives relating to marine biodiversity and habitats that are regulated by EU Habitat Directive, MSP and MSFD, affirm that no species or habitats should be lost, and that the integrity of the sea floor should not be compromised by human activities. This has led to an increased request for accurate mapping and monitoring activities that can assess the distribution, the extent and the status of marine benthic habitats.

A wide range of intergovernmental, conservation and fishery organization (e.g. IUCN, WWF, TNC, UNESCO, FAO, IOC, ICES, GEOSS…) require classification of marine benthic habitats and ecosystems to enable comparison between areas and to organize information in maps and reports.

An effective classification scheme is helpful to resource managers and scientists because it allows standardizing terminology, organizing data in a logical manner, coding habitat types for data management and improving communication among users. Nevertheless each classification scheme reflects how designers choose to organize, understand and rank the structures and functions of natural system (Valentine et al., 2005). Indeed, while several marine habitats classification schemes are available and used by various researchers and resource manager agencies, none are universally accepted because each scheme has unique benefits and challenges.

1.5 Benthic Habitat Mapping Techniques and Methods

According to literature, no universal techniques are available for BHM activities. The main reason depends on the wide variety of instrumentation and survey equipment that have evolved for characterizing the seafloor (Diaz et al., 2004; Kenny et al., 2003; Solan et al., 2003). Choosing the most appropriate single method or suite of techniques depends on the main objective(s) of each seafloor/habitat mapping activity, especially with respect to the scale and distribution of the targeted seafloor features and the required resolution of resulting maps. At a purely logistical level, therefore, the act of mapping benthic habitats encompasses a very diverse array of activities and technologies for both data collection and processing (Diaz et al., 2004).

However, following the review proposed by Brown et al. (2011), two type of approach for BHM resume the available methodologies: (i) Discrete Entities and (ii) Gradational Entities.

Discrete Entities: For several decades, marine geologists have produced seafloor maps based on acoustic survey data where the seafloor is divided into "spatial units" with distinct boundaries representing discrete sediment and/or geomorphological features. Many benthic habitat maps were extensions of this geological approach, based on segmenting acoustic data sets and incorporating biological information pertaining to habitat from in situ sampling (e.g. McRea Jr et al., 1999; Kostylev et al., 2001; Brown et al., 2002). Indeed, this approach has remained popular, and many studies continue to use this method for the production of benthic habitat maps (Brown et al., 2011).

Gradational Entities: Most recently BHM studies have started to consider ways to present habitat characteristics in a gradational manner, avoiding imposing discrete boundaries and therefore likely providing a more realistic representation of how seabed communities are structured, using species distribution models (SDM). This methods *predict* the spatial distribution of a given habitat (indicating where a particular focal species is likely to occur) on the basis of environmental conditions (e.g. Galparsoro et al., 2009). They basically provide gradational maps, predicting community distributions (i.e. biotopes) from modelled environmental parameters (e.g. Degraer et al., 2008), and maps representing purely abiotic environmental patterns in gradational form from which biological trends can be inferred (e.g. Lucieer et al., 2009).

However both the approaches (i.e.: Discrete entities and gradational entities) use very similar methodological strategies, even though the way that the habitat information is displayed on a map differs between studies (i.e. gradational versus discrete entities).

Generally the differences between the two approaches can be resumed in:

- Discrete Elements methods produce charts that represent the habitat distribution at a point in time making best use of the knowledge we have available at that time.
- Gradational Entities methods is generally used to product a prediction of the distribution of seabed habitats, with the complete coverage environmental data acting as a proxy for the habitat data.

The biological information about habitats was generally obtained from in situ sampling and observation of the seabed through: seafloor samplers (i.e.: cores, grabs, dredges, benthic lander, etc...) diving, surveying using Remotely Operated Vehicles (ROV) or Autonomous Underwater Vehicles (AUV), that provide the most direct mechanism to observe the characteristics of habitats in a process commonly called “ground-truthing”.

Nevertheless ground-truthing process only samples a very small proportion of the seafloor, and the complete coverage of habitats is therefore inferred from the association between the remotely sensed environmental data and the in situ sample data (Brown et al., 2011), consequently hydro acoustic surveys, the most efficient remote sensing tool for mapping and monitoring the subsurface oceans over large areas (Anderson et al., 2008), must be used in conjunction with well planned ground-truthing surveys for the most accurate BHM.

1.5.1 Geomorphometry in benthic habitat mapping

Geomorphometry is defined in literature as *“the science of quantitative land-surface analysis”* (Pike, 1995, 2000a; Rasemann et al., 2004). It is a modern, analytical-cartographic approach to representing bare-earth topography by the computer manipulation of terrain height (Tobler, 1976, 2000). Its operational focus is the extraction of land-surface parameters and objects from digital elevation models (DEMs) (Hengl et al., 2008) (Fig. 1).

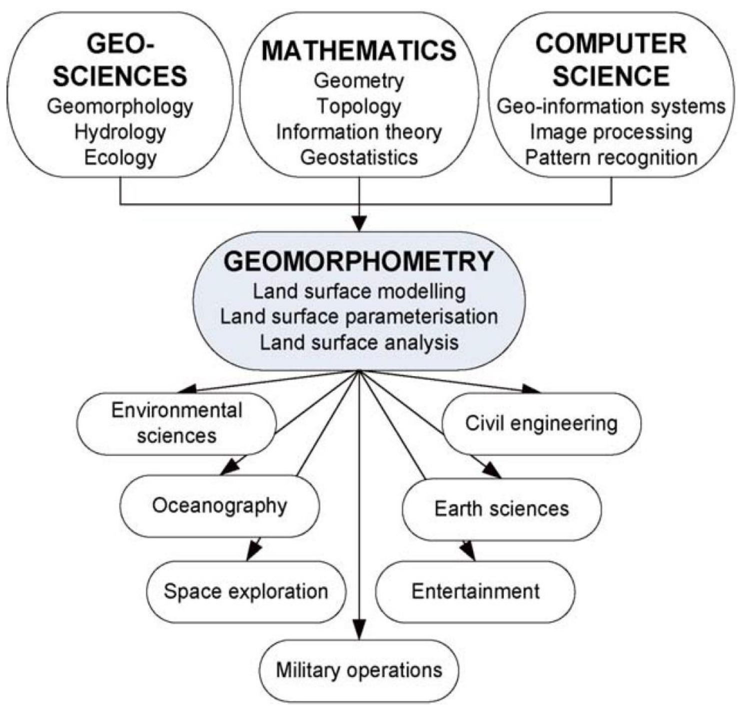

Figure 1- Geomorphometry and its relation to source and end-user disciplines. Modified after Pike (1995).

It is based on the assumption that there is a close quantitative relationship between surface processes and topographic characteristics (Moore et al., 1991), and that these characteristics contain geological information that can be extracted by numerical analysis (Micallef et al., 2007).

Geomorphometry commonly is implemented in five steps (Hengl et al., 2008):

1. Sampling the land surface (height measurements).
2. Generating a surface model from the sampled heights.
3. Correcting errors and artefacts in the surface model.
4. Deriving land-surface parameters and objects.
5. Applications of the resulting parameters and objects.

The process of calculating derivatives to obtain morphometric attributes has been at the basis of altitudinal data analyses since the 1970s (Evans, 1980). The importance of altitude and its primary and secondary derivatives (slope and curvature) to geomorphological studies was recognized by Curtis et al. (1965) and Anhert (1970) in pedological and slope morphology studies (Micallef et al., 2007). The technique was incorporated into geomorphometric systems by Evans (1972).

Since all physical, chemical and biological attributes that characterize a given habitat, are linked to terrain morphology (Brown et al., 2011), it is easy to understand the potential of geomorphometric approach to describe marine habitats and investigate their distribution.

Seabed habitat mapping is probably the field that has benefitted the most from techniques of geomorphometry to date (Lecours et al., 2015). The abundance and distribution of marine species can be strongly influenced by many biotic and abiotic factors, but topography and geomorphology are among the most important drivers of their distribution at many scales (Harris et al., 2012). Terrain parameters such as slope, aspect, curvatures and measures of seabed roughness have all been used in BHM studies (McArthur et al., 2010). MBES data have become essential in studying marine habitats due to their remoteness and the difficulties in sampling them. Seabed complexity and heterogeneity can allow us to numerically quantify the spatial arrangement and structure of habitats. Since the complexity of the seabed has been linked to the distribution of species at different scales, terrain attributes can be used as surrogates of species distribution (McArthur et al., 2010). Furthermore the availability of specific GIS tools to effectively combine multiple datasets and perform geomorphometric analyses is key in making marine geomorphometry accessible to marine scientists with a wide range of background and experience (Lundblad et al., 2006; Erdey-Heydorn et al., 2008). Since benthic species distribution is driven by depths and topographic conditions, bathymetric data was used to define areas which reflect distinctive biological characteristics, in a process defined segmentation (Brown et al., 2011). In this context segmentation is often referred to as "morphometric analysis", and has been used to map benthic habitats from a range of marine systems including: estuarine (Cutter Jr et al., 2003), coastal (Holmes et al., 2008; Iampietro et al., 2008; Diesing et al., 2009; Rattray et al., 2009; Verfaillie et al., 2009; Zieger et al., 2009), and deeper water environments (Wilson et al., 2007; Buhl-Mortensen et al., 2009; Guinan et al., 2009).

Geomorphometric parameters can be grouped into four types of information (Wilson et al., 2007):

(1) Slope,
(2) Orientation (aspect),
(3) Curvature and relative position of features,
(4) Terrain variability.

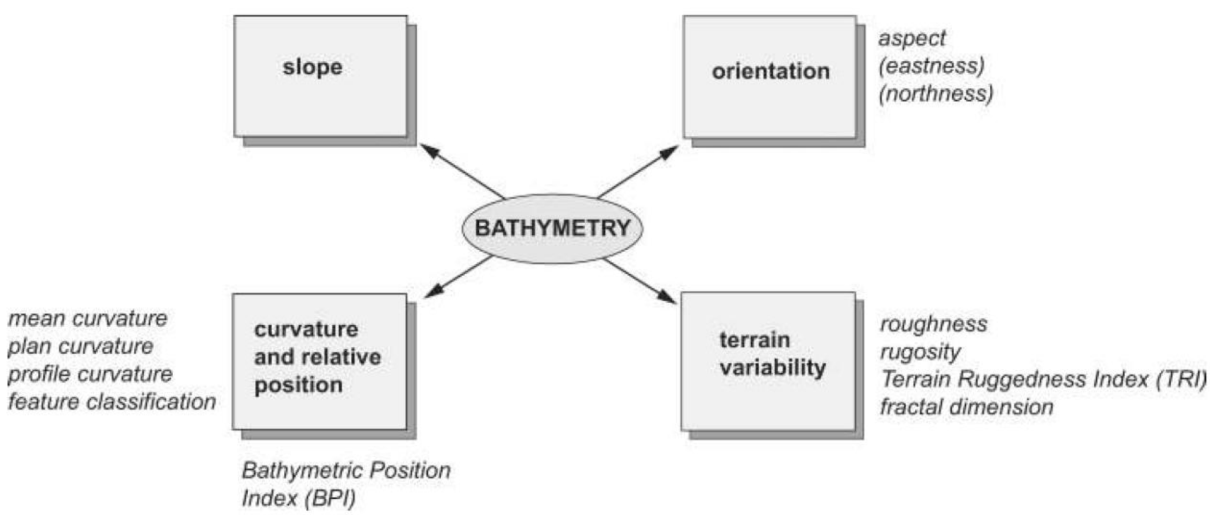

Figure 2 - Major classes of terrain parameters that may be derived from bathymetry data (Wilson et al., 2007).

Each of these parameters potentially gives important information for the delineation and characterization of habitats and may be valuable inputs to benthic habitat mapping.

These bathymetric parameters can be calculated in different ways and at different spatial scales, which have important implications for what the map layers show and how they relate to the distribution of the benthic organisms (Wright and Heyman, 2008; Dunn and Halpin, 2009).

1.5.2 Acoustic backscatter

Acoustic backscatter data are by far the most widely used form of remote-sensed data for habitat characterization and mapping (Brown et al., 2011). Segmentation process, the process of dividing acoustics datasets into “spatial units” prior to the incorporation and integration of habitat information, performed on acoustic backscatter signal from SSS has been used by geologists for many years in order to identify geological classes (i.e. surficial sediment types), and a close association is often reported between acoustic backscatter strength and geotechnical properties of the seafloor (Collier and Brown, 2005; Ferrini and Flood, 2006; Fonseca and Mayer, 2007; Brown and Collier, 2008). SSS were developed in the 1940s (Kenny et al., 2003), and operate at relatively high frequencies (between 100-500 kHz), recording acoustic backscatter data from seafloor in order to produce a textural image of the surficial seabed characteristics (Lurton, 2002; Kenny et al., 2003; ICES, 2007; Le Bas and Huvenne, 2009).

In a comparable way to SSS, MBES tend to be fairly complex systems requiring sophisticated motion reference units in order to rectify vessel pitch, roll and heave when positioning the data relative to the seafloor (Lurton, 2002; ICES, 2007; Le Bas and Huvenne, 2009; Van Overmeeren et al., 2009).

MBES backscatter imagery is roughly similar to SSS backscatter imagery. However, the backscatter data from an MBES was, until recently, of an inferior quality compared to the imagery from an equivalent side-scan system. This was mainly due to the lower along-track resolution of MBES systems (1°-3°) compared to side-scan systems (less than 1°), and the optimal range of incidence angles for backscatter measurement achieved by a towed SSS system (which have lower grazing angles) compared to a hull-mounted MBES (Brown and Blondel, 2009). However, recent on-going developments in data collection and processing of MBES, combined with the availability of co-registered bathymetry, have drastically improved the quality of the imagery, giving as much or more information than is available with SSS alone (Le Bas and Huvenne, 2009).

The present-day ability of MBES to simultaneously collect seafloor bathymetry and backscatter information over a swath of seafloor, may them the main survey tool of choice in the general field of seafloor habitat mapping (Pickrill and Todd, 2003; Mayer, 2006). Indeed, until recently, the use of MBES for habitat mapping was fairly restricted due to the relative high cost of data acquisition, and technical difficulties associated with data storage and processing (Kenny et al., 2003; Le Bas and Huvenne, 2009). However in the last years, with increased computing power, cheaper data storage media, and wider availability of systems, MBES has gained in popularity as a survey tool, with the derived seabed imagery (bathymetry and backscatter) providing the template for an increasing number of habitat mapping studies (Brown et al., 2011).

In the context of seafloor habitat mapping segmentation process, MBES backscatter data are broadly analogous to SSS, where backscattering data are divided into regions of similar backscatter characteristics (e.g. Kostylev et al., 2001; Kostylev et al., 2003; Pickrill and Todd, 2003; Roberts et al., 2005; Brown et al., 2011).

Generally there are two main segmentation methods (Brown et al., 2011):

Image-Based Segmentation

A MBES backscatter mosaic is a georeferenced grey-level image representing the acoustic intensity scattered by the seabed, with different seabed types usually showing different intensity levels (Le Bas and Huvenne, 2009). Since the acoustic intensity scattered by the seabed is varying with the angle of incidence of the acoustic signal at the seafloor at the time of data acquisition, a statistical normalization of this angular variation is required prior to forming the backscatter mosaic, so that the intensity variations in the image are due to geographical changes in seafloor-type only (Hellequin, 1997). This normalization process implies that the quantitative aspect of the intensity level is lost, so that any analysis of the resulting backscatter mosaic requires some form of qualitative interpretation or ground-truthing (Hughes et al., 1997). The backscatter mosaic grey-level has been extensively used as a feature in many classification techniques (Lockhart et al., 2005; Edwards et al., 2003; Dartnell et al., 2004; McGonigle et al., 2011) or as a source of derivative features describing, among other image characteristics, the grey-level statistics (Preston et al., 2004; Brown and Collier, 2008) or the texture (Blondel et al., 2009).

Whilst a variety of image-based segmentation methods have been tested, no widely accepted agreement on the best way to segment the data has yet been reached.

Signal-Based Segmentation

The MBES backscatter angular response is the acoustic intensity scattered by the seabed as a function of the angle of incidence of the acoustic signal at the seafloor. Often represented as the mean angular curve, the backscatter angular response is characteristic of the type of seafloor that reflected the acoustic signal (Hughes et al., 1997). Since the angular response is not normalized like the backscatter mosaic, it potentially allows the extraction of quantitative seafloor characteristics (Hughes et al., 1997; Fonseca and Mayer, 2007; Fonseca et al., 2009). The variation of the backscatter strength with the angle of incidence is an intrinsic property of the seafloor, which can be used as a robust method for acoustic seafloor characterization.

1.6 Structure of thesis

My thesis was developed starting from MBES data deriving from APLABES and MaGIC CORALFISH cruises on Santa Maria di Leuca Cold Water Coral province. In Chapter 2 we developed a methodology that allowed us to perform an to automatic extraction of the most significant morphometric features of the surveyed area that are related Cold Water Coral Mounds. Part of it was published within the scientific paper made by Savini et al. (2014).

Chapter 3 and 4 were developed in the framework of the BioMAP project. Starting in 2012 and ending in 2014 the author of the thesis took part of all the survey cruises and processed all the MBES data acquired. Methodology in Chapter 3 were presented at the at the Symposia on the Conservation of Mediterranean Marine Key Habitats, in 2014.

Chapter 2 and 3 include in their sections the abstract of the main publications in which the methodology was included. A publication for Chapter 4 is in preparation.

1.7 Summary of publications and activities

1.7.1 Publications

Other work that are not part of this thesis but where the thesis' author take a secondary role are listed in this section.

Coralligenous habitat in the Mediterranean Sea: a geomorphological description from remote data.

Bracchi, V.A., Savini, A., Marchese, F., Palamara, S., Basso, D., & Corselli, C. (2015).

ITALIAN JOURNAL OF GEOSCIENCES, 134(1), 32-40.

Abstract

Sea floor mapping along the Apulia continental shelf (Italy) verified the abundance of autochthonous red algae build-ups, mapped as coralligenous habitats (CHs), in a water depth range of 5-100 m. In general, CHs were found to develop three dimensional structures, with a rigid framework and to represent an important geomorphological and sedimentological element on the Mediterranean shelf.

Here, we provide the first geomorphological description of CHs (thus poorly categorized) using acoustic data obtained from Side Scan Sonar (SSS) and MultiBeam (MB) echosounder surveys, ground-truthed using a ROV and underwater camera. In SSS mosaics, CHs generally yielded intermediate to high backscatter in response to a rigid cavernous framework. According to the various shapes and the lateral continuity that coralligenous build-ups displayed in explored locations, two distinct textures were determined to be present. Various geomorphological expressions of CHs were noted within our dataset and in images obtained from MB bathymetry. We determined that coralligenous build-ups are typically represented by positive-relief structures that vary from isolated blocks (randomly scattered on a generally flat mobile soft bottom) to a field of blocks (adjacent or even coalescent), and/to ridge with several metres of lateral continuity. In most cases, CHs occurred on flat mobile soft bottom, thus representing an example of coralligenous *de plateau*. Our results characterize for the first time the CHs through seafloor mapping techniques, which demonstrated to represent an instrumental tool for their geomorphological characterization.

Submarine Slide Topography and the Distribution of Vulnerable Marine Ecosystems: A Case Study in the Ionian Sea (Eastern Mediterranean).

Alessandra Savini, Fabio Marchese, Giuseppe Verdicchio, and Agostina Vertino

Submarine Mass Movements and their Consequences - 2015 - Volume 41 of the series Advances in Natural and Technological Hazards Research pp 163-170

Abstract

In this work, we sought to document how submarine mass-movements influence the submarine landscape and associated habitat distributions on the upper portion of the northern Ionian Margin (eastern Mediterranean Sea) between 200 m to greater than 1,000 m in water depth (w.d.). In this area, mass-wasting processes have created unique morphological forms that, in turn, have generated high diversity for edaphic and hydrogeologic conditions; and these areas are marked by the patchy occurrence of varying natural benthic habitats. Surficial or sub-surficial Mass-Transport Deposits (MTDs) were documented by seismic and high-resolution morpho-bathymetric data and displayed dense aggregation for detached blocks spread over 1,200 km2 between 400 and 1,000 m in w.d.. Living Cold-Water Coral (CWC) communities populate the blocky region and form coral topped mounds. These habitats are important Vulnerable Marine Ecosystems (VMEs) that are exposed to human pressure in the deep sea. Through production of a detailed geomorphological map and an examination of published data on the extent and distribution of CWC communities in the area, we sought to document how comprehensive research into submarine slide topography should also take into account the peculiar characteristics of their biotopes.

The “Sardinian cold-water coral province” in the context of the Mediterranean coral ecosystems.
M. Taviani, L. Angeletti, S. Canese, R. Cannas, F. Cardone, A. Cau, A. B. Cau, M. C. Follesa,
F. Marchese, P. Montagna, C. Tessarolo
Deep-Sea Res.II (2016), http://dx.doi.org/10.1016/j.dsr2.2015.12.008i

Abstract

A new cold-water coral (CWC) province has been identified in the Mediterranean Sea in the Capo Spartivento canyon system offshore the southern coast of Sardinia. The ‘Sardinia cold-water coral province’ is characterized in the Nora canyon by a spectacular coral growth dominated by the branching scleractinian *Madrepora oculata* at a depth of 380–460 m. The general biohermal frame is strengthened by the common occurrence of the solitary scleractinian Desmophyllum dianthus and the occasional presence of *Lophelia pertusa*. As documented by Remotely Operated Vehicle survey, this area is a hotspot of megafaunal diversity hosting among other also live specimens of the deep oyster Neopycnodonte zibrowii. The new coral province is located between the central Mediterranean CWC provinces (Bari Canyon, Santa Maria di Leuca, South Malta) and the western and northern ones (Melilla, Catalan- Provençal-Ligurian canyons). As for all the best developed CWC situations in the present Mediterranean Sea, the new Sardinian province is clearly influenced by Levantine Intermediate Water which appears to be a main driver for CWC distribution and viability in this basin.

Geomorphological features of the archaeological marine area of Sinuessa in Campania, southern Italy.

Micla Pennetta, Corrado Stanislao, Veronica D'Ambrosio, Fabio Marchese, Carmine Minopoli , Alfredo Trocciola, Renata Valente, and Carlo Donadio.

Submitted to Geoarchaeology, 2016

Abstract

Submarine surveys carried out since the 90s along the coastland of Sinuessa allowed to draw up a geomorphological map with archaeological findings. Along the sea bottom, 650 m off and -7 m depth, a Campanian Ignimbrite bedrock was detected: dated 39 kyr BP, its position is incompatible with the current sea level. Towards the northern edge of the shoal, a depressed area with 24 cubic elements in concrete was surveyed. These artifacts (pilae) are typical of Roman maritime structures widespread along the southernmost Phlegrean coast. Beachrocks and accessory morphologies at the same depth of bedrock suggest that this was emerging and attended by man in Roman times, even for activities related to port facilities. Submerged palaeo-channels, in alignment of current watercourses on the mainland, dissect the shoal. These channels were modeled in subaerial environment during Würm glaciation, following the tuff deposition, and then were drowned by sea-level rise. The northernmost channel, next to the pilae, likely allowed transit and maneuvering of Roman ships. The recovery of a large stump of lead anchor, hundreds of Roman amphorae and fragments confirm this finding. Probably the sinuous physiography favored the choice of this site for the docking of Sinuessa, as sheltered from storms.

Geology of Mar Piccolo, Taranto (southern Italy): the physical basis for remediation of a polluted marine area

Stefania Lisco, Cesare Corselli, Francesco De Giosa, Giuseppe Mastronuzzi, Massimo Moretti, Agata Siniscalchi, Fabio Marchese, Valentina Bracchi, Chiara Tessarolo & Angelo Tursi

Journal of Maps, (2016) 12:1, 173-180, DOI:10.1080/17445647.2014.999136

Abstract

Four 1:15,000 maps for the coastal area of Mar Piccolo (Taranto, southern Italy) are presented. The study area is a small, sheltered shallow marine basin of about 20 km_2, located north of Taranto town. It contains some submarine, karstic freshwater springs (citri) that have determined the development of intensive aquaculture in the past. Now, the Mar Piccolo is a highly polluted area due to the presence of both military and industrial navy docks and various heavy industries located in proximal areas: (i) the ILVA steel plant in Taranto, the largest in Europe; (ii) the ENI oil refinery and (iii) the CEMENTIR, the largest cement and concrete plant in southern Italy. Many studies show that water and sediments are contaminated (heavy metals, isopropyl alcohol, polychlorinated biphenyl [PCB], etc.), and various remediation projects are now in preparation. In this study, we analyze the physical characteristics of the Mar Piccolo environment by producing several maps: a geological map; a geomorphological map; a bathy-morphological map and a map of the thickness of surficial sediment. All these maps are original products focused on the realization of a reliable geological picture for the Mar Piccolo area. They represent the first steps toward the detailed knowledge of the Mar Piccolo physical environment, which we consider to be a fundamental requirement for developing the most appropriate remediation techniques.

1.7.2 Activities

Here below a list of all the activities conducted by the candidate during the three years of PhD, that allowed gaining experience in acquiring, processing and manage seafloor acoustic data.

Attendance to didactic classes:

- Workshop sulle Tecnologie di rilevamento marino e PDS2000 (Rome, 2014)

Collaboration to research project

- Marine Strategy
- MaGIC (MArine Geohazard Along the Italian Coasts 2007-2012)
- EU Project CORALFISH
- RITMARE Project (Italian Research for the Sea, 2013-2015)
- Climate Change and Coral Reef (IUCN 2013)
- EU Project COCONET

Oceanographic cruises

- BIOMAP 1, R/V MINERVA UNO, march 2012 – Southern Adriatic Sea
- BIOMAP 2, R/V MINERVA UNO, may 2012 – Northern Ionian Sea
- COCOMAP14, R/V URANIA, march 2014 – Southern Adriatic Sea
- ALTRO, R/V URANIA, December 2012 – Southern Adriatic Sea
- RECORD, R/V URANIA, November 2013 – Central Mediterranean Sea

Other research activities

- BIOMAP CALAFURIA, BioMAP project shallow water survey aboard R/V Calafuria Issel for the acquisition of multibeam and SSS data, July 2012 – April 2013, Southern Adriatic Sea and Northern Ionian Sea
- shallow water survey aboard R/V Calafuria Issel for the acquisition of multibeam coupled with terrestrial laser scanner data, October 2013, Southern Adriatic Sea.
- shallow water survey board small boat for the acquisition of multibeam data, February 2014, Po River
- shallow water survey aboard R/V Calafuria Issel for the acquisition of multibeam, side scan sonar and sub-bottom profiler data, July 2013, Mar Piccolo Basin.

- shallow water survey board small boat for the acquisition of multibeam interferometric data, June 2014, Vernago lake, Italy.
- shallow water survey board small boat for the acquisition of multibeam interferometric data, May 2015, Gioveretto lake, Italy.
- shallow water survey board small boat for the acquisition of multibeam interferometric data, July 2015, Resia lake, Italy.
- Master's Course in "Marine Sciences for Sustainable Development, October 2014, MaRHE Center, tutor for Seafloor Mapping course
- Tropical Marine Ecology Internship, February 2015, MaRHE center, tutor for Seafloor Mapping course
- Tropical Marine Ecology Internship, October 2015, MaRHE center, tutor for Seafloor Mapping course

1.8 Scope of thesis

The objective and challenge of this Ph.D. were focused on the developing of proper geomorphometric analysis techniques that can be efficiently used to:

- Model the distribution of benthic habitats.
- Improve the multiscale geomorphological characterization of benthic habitats, providing also quantitative measurements.

Chapter 2 – Mapping cold water corals mounds offshore Santa Maria di Leuca (Northern Ionian Sea)

2.1 Introduction

The need to improve our knowledge on the deep seafloor in order to support the implementation of European and national legislation (such Habitat Directive and MSFD and the new marine management initiatives such as MSP and EBM) and to efficiently combine the human use of marine resources with the associated ecosystem functions, required the production of benthic habitat maps at a variety of spatial scales (Anderson et al, 2008, Guarinello et al., 2010), as an instrumental tool for implementing responsible management and conservation measures of offshore resources, with particular attention to Vulnerable Marine Ecosystems (VMEs).

The “VMEs concept” emerged from discussions at the United Nations General Assembly (UNGA) and gained momentum after UNGA Resolution 61/105. The FAO International Guidelines for the Management of Deep-sea Fisheries in the High Seas (FAO DSF Guidelines 2009) build on the resolution and provide details on the VME concept for fisheries management. A rapid implementation of effective and precautionary measures is required to hinder their unsustainable exploitation or destruction. Criteria for identifying VMEs include their rarity or uniqueness, their functional significance, fragility, structural complexity as well as life histories that limit the probability of recovery (Rogers et al. 2008).

VMEs are groups of species, communities or habitats that may be vulnerable to impacts from fishing activities. The vulnerability of an ecosystem is related to the vulnerability of its constituent population, communities or habitats. In UNGA Resolution, VMEs are obliquely defined, and can include seamounts, hydrothermal vents, cold water corals and sponge fields.

Within the present work I analyzed the bathymetric dataset obtained from different oceanographic cruises that operated in the *“Santa Maria di Leuca (SML) Cold Water Coral (CWC) Province”* (Tursi, 2004; Corselli, 2010). In this area CWCs display a mosaic-like distribution across a wide sector of the margin, occurring associated to the blocky pattern of mass-failed deposits and some of these morphological features have been interpreted as “coral mounds” (Savini and Corselli, 2010; Vertino et al., 2010; Malinverno et al. 2010; Rosso et al. 2010). Several national and international oceanographic expeditions from different research programs and activities (CNR COR2 Project, CoNISMa APLABES Project, EU-FP6 HERMES Project, EU-FP7 CORALFISH Project) were initiated after the province's discovery. Following a first attempt to locate and sample SML coral frameworks during the COR2 cruise, during CNR R/V Urania (Taviani et al., 2005), a large-scale multidisciplinary investigation of the SML CWC province, performed during several different cruises of the Italian R/V Universitatis within the Italian program APLABES and MaGIC, provided a comprehensive geophysical survey.

The aim of the work is: (1) to adapt established geomorphometric techniques, developing an ad-hoc methodology, in order to support a quantitative analysis of submarine elevation data and (2) to identify those terrain morphometric attributes (GEOMORPHOMETRIC PARAMETERS) that typify coral mounds in order to outline the distribution (based on geomorphometric attributes) of all positive seafloor morphologies related with the occurrence of CWC habitats.

Two methodologies has been used in order to reach the proposed objectives. Through the first one all the positive morphologies were extracted using a unsupervised classification algorithm and main results were presented at the 8th International Association of Geomorphologists (IAG/AIG) International Conference (Paris, 2013) and published within the scientific paper made by Savini et al. (2014). The second one was recently designed in order to better compare the proposed "geomorphometric" approach to traditional methods usually adopted to predict benthic habitat distribution in deep environment (performed by colleagues from IFREMER - Institut Français de Recherche pour l'Exploitation de la Mer), and will be part of a scientific paper that is in preparation.

2.2 Abstract

In this paper geomorphometric analytical techniques were applied to a high-resolution bathymetry data set acquired along 2000km2 survey area located on the upper part of the southern Apulian slope (Northern Ionian sea), between 80 and 1400m of water depth. The DEM provided by multibeam data processing and the computed terrain parameters, well show a broad area affected by mass-transport deposition, which results in a very complex hummocky seafloor, shaped by detached block-like features. We focus our analysis on the automatic extraction of the most significant morphometric features of the surveyed area. The objective identification of morphologic features represents indeed a significant step in defining spatial units that are related to geomorphological processes. Our

computation was in particular applied to observe the seafloor distribution of the complex pattern formed by the identified detached-blocks like-features. The quantitative analysis of these features showed that the blocky pattern is more pronounced where it regionally faces NE and SW on the more elevated sectors of the margin, where tectonic deformation has generated a suite of vertical offsets; whereas fewer blocky features are evident within the more depressed areas. Since these blocky features are colonised by carbonate framework building organisms (i.e.: cold water corals), our quantitative results strongly support the hypothesis that in this area cold water coral growth has tended to enhance the complex morphology of the seabed, originally generated by multiple mass-transport processes.

2.3 Study Area

The SML CWC province is located offshore south-eastern Italy, within the northern Ionian Margin (eastern Mediterranean Sea), at the southern prolongation of the Apulian Peninsula (south-eastern Italy) in the Ionian Sea, along the Apulian Ridge. The ridge is a NW–SE elongated structural high which is formed by thick cretaceous carbonatic sequences and discontinuous tertiary deposits, it extends from Apulia to offshore Greece and separates the southern Adriatic Basin, at the southern edge of the Otranto Channel, from the deeper Ionian Sea; and is a part of the present foreland system of both the Apennine Arc to the west and the Hellenic Arc to the east (Favali et al., 1993). Recent high-resolution bathymetric and shallow seismic surveys (Savini and Corselli, 2010) have revealed that the NNW-SSE normal fault network, which crosscuts the seabed, results in a number of prominent fault scarps and promontories that control the large-scale morphology of the margin (Etiope et al., 2010). On this part of Apulian margin the sedimentation is basically characterized by mass-wasting deposits, related to the local high seismicity of the margin, often regarded as a consequence of the supposed activity of the NNW-SSE normal fault network of the Apulian Ridge (Favali et al., 1993, Merlini et al., 2000, Argnani et al., 2001). The presence of large arcuate headscarps, indenting the shelf break and the superficial deformation (i.e. compressional and extensional ridges, low scarps, and lineations) of mass-failed deposits located within the upper slope are the major evidence of mass movements as main sedimentation process (Savini et al., 2010).

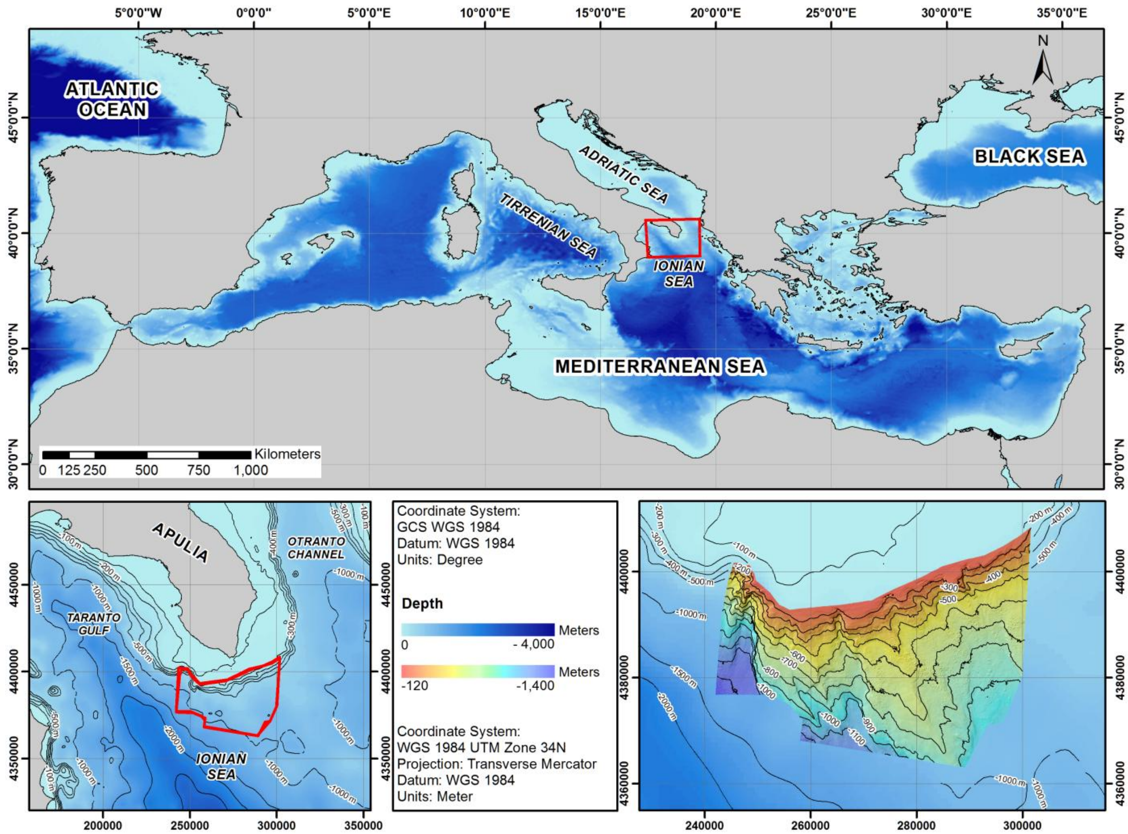

Figure 3 - Geografic framework of the Santa Maria di Leuca Cold Water Coral province.

The rough seafloor, associated with the mass-transport zone of deposition, is dominated by mound-like morphologies and resembled detached blocks. They had irregular shapes (from elongated to less-frequent sub-circular geometries), up to 10–25m high and 50–300m wide along their maximum extension. Such blocky patterns that extends over more than 600 km^2 (Savini and Corselli, 2010, Savini et al., 2014), were more pronounced to the east, at the top of the fault alignments oriented NNW–SSE (Savini et al., 2010).

Furthermore, as documented by the occurrence of sediment drifting (Taviani et al., 2005, Savini and Corselli, 2010], the margin is also impacted by bottom currents. The northern Ionian Sea receives water from the southern Adriatic Basin. In the study area, a core of cold (= 12.92uC), less saline (38.64%), and oxygenated water of Adriatic origin flows from the Otranto Channel and moves in geostrophic balance along isobaths of 600–1,000 m in depth (Budillon et al., 2010). During its flow toward the Ionian Sea interior, Adriatic Dense Water (ADW) mixes with bottom water, changes thermohaline properties, and becomes Eastern Mediterranean Deep Water (EMDW) (Budillon et al., 2010, Manca et al., 2006).

At the same depth range (i.e.: 500-1000 m) has been identified the SML CWC province (Tursi et al., 2004, Corselli, 2010). As documented, the SML CWC province hosts living coral colonies of *Madrepora oculata* and *Lophelia pertusa* (Tursi et al., 2004; Taviani et al., 2005; Rosso et al., 2010; Mastrototaro et al. 2010; Vertino et al., 2010), occurring on the seafloor both as isolated colonies and as small, patchy distributed reefs (Savini et al, 2004; Corselli et al., 2006; Taviani et al., 2005a). Coral colonies display a patched distribution across a wide sector of the margin and are associated with the blocky pattern of mass-failed deposits, capping clustered or isolated mounds (Savini and Corselli, 2010). Some of these morphological features have been interpreted as ''coral mounds'' (Vertino et al., 2010). The SML coral area, over 600 km^2 in extension, is located along the Apulian continental slope between 400 and 1000 m water depth, and represents the largest occurrence of a live CWC community so far known in the Mediterranean sea (Savini et al., 2010).

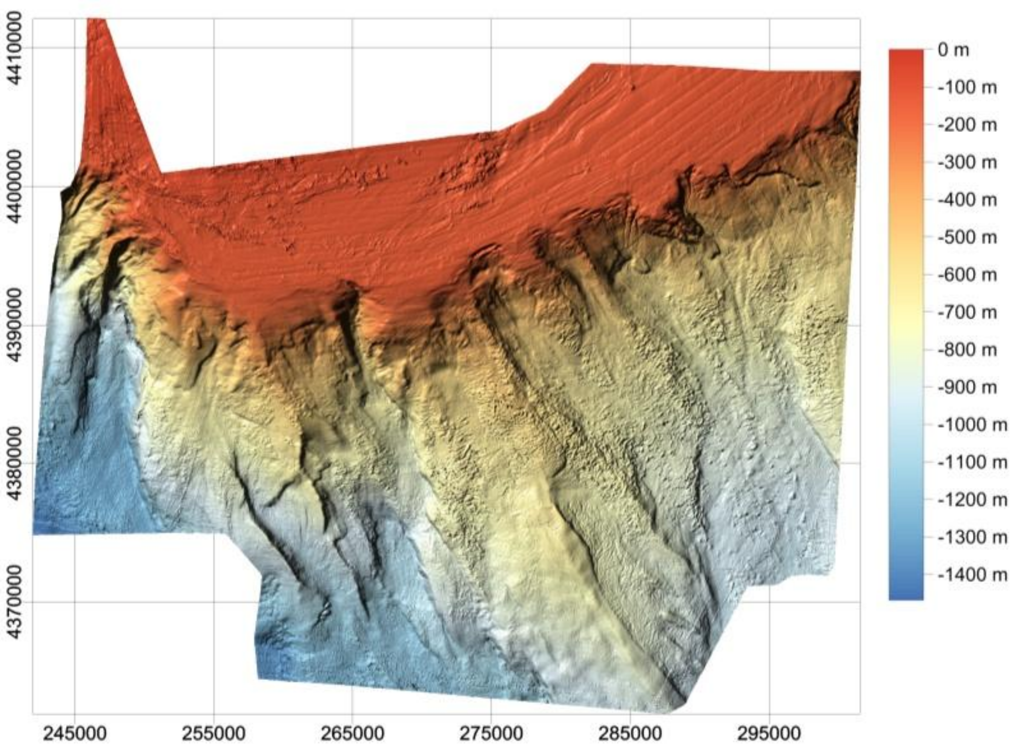

Figure 4 - Digital seafloor model of the study area (40 m resolution)

2.4 Bathymetry: Data Origin and Analysis

Bathymetric data set were obtained from two, ship-based research surveys (the 2004 APLABES cruise and the 2010 MAGIC CoralFISH cruise) carried out under the umbrella of the National Italian project APLABES and within the framework of the EU FP7 project CORALFISH and the National Italian project MaGIC (Mapping Geohazard along the Italian Coasts – http://www.magicproject.it).

A total of 2,000Km^2 of acoustic data were acquired using a Teledyne RESON SEABAT 8160 MBES. Data were processed and integrated to pre-existing multibeam data (Savini and Corselli, 2010) using dedicated software (CARIS Hips and Sips 6.1) to produce a Digital Terrain Model (DTM) of the entire survey area that extended from 50 m in water depth (w.d.) on the continental shelf down to 1,400 m w.d. on the slope. The resulting DTM was produced with a cell size of 40m (Fig. 4).

An "ad-hoc" geomorphometric analysis has been performed on the bathymetric dataset (performed applying two different approaches, as mentioned before - section 2.1). Geomorphometric parameters were computed in particular using specifics softwares (i.e. ESRI ArcGIS™, SAGA and Landserf). To perform the model on CWC mapping, the DTM, the geomorphometric analysis, the samples locations and all of the video tracks were integrated in ArcGIS™.

2.5 Groundtruthing

Groundtruthing used into the models were obtained using video data and samples collected during the several cruises operated in study area. In particular video data were obtained from two main cruises: APLABES on R/V UNIVERSITATIS (Etiope et al., 2010) and METEOR 70-1 on R/V METEOR. Video data were acquired using three different underwater videorecording systems - the tethered MODUS, GAS-SCIPACK (MGS) instrumentation (Vertino et al., 2010, Etiope et al., 2010, D'Onghia et al., 2011), the light workclass PLUTO 1000 ROV (Vertino et al., 2010) and the MARUM ROV 'QUEST 4000' (Freiwald et al., 2009).

Coordinates of corals samples data (collected after the province's discovery) were provided by the CNR CORSARO cruise (on R/V URANIA in 2006), the CoNISMa APLABES cruise (on R/V UNIVERSITATIS in 2006) and the CoNISMa MaGIC cruise (on R/V MINERVA UNO in 2010).

Video and samples data were analyzed during previous works (Taviani et al., 2005a, Rosso and Vertino, 2010; Mastrototaro et al. 2010; Vertino et al., 2010), and the obtained results were used during the present work as groundtruthing to calibrate the performed models (Fig. 5), in order to obtain the preliminary distribution of seafloor morphologies that could be related with the occurrence of CWC habitats.

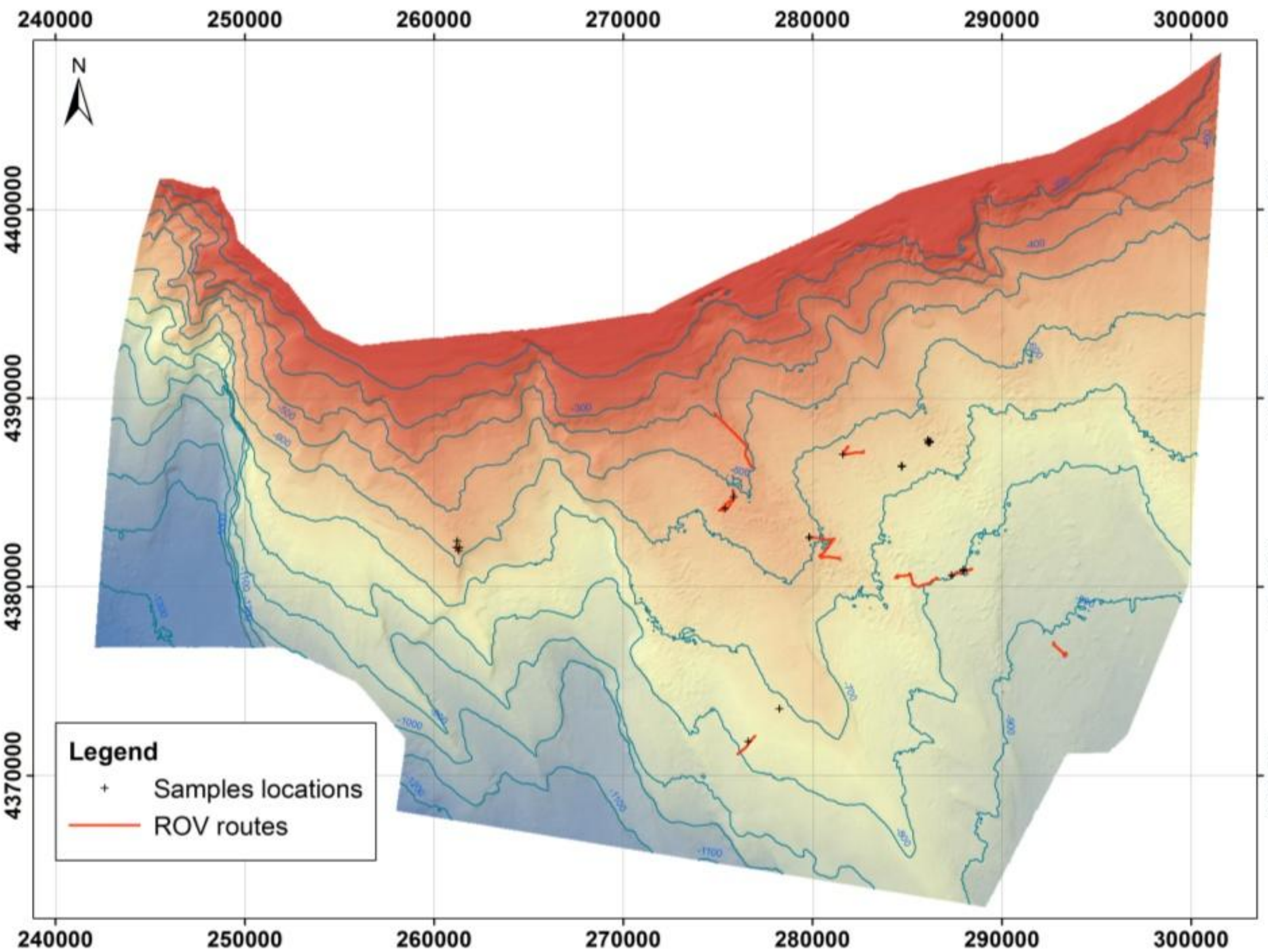

Figure 5 - Goundtruthing collected in the study area, ROV dives in red and black cross for saples location.

2.6 - 1st Methodology: Detached blocks from submarine slides investigated using quantitative geomorphological techniques

2.6.1 - Geomorphometric parameters

Considering the typical BHM techniques reviewed by Brown et al. in 2011, the approach used in this studies could be correlated with the Discrete Entities methodology, since the aim of the analysis has been the identification of a“spatial unit” (i.e.: geomorphological unit) associated to CWC habitat occurrences (and forming thus coral-topped mounds).

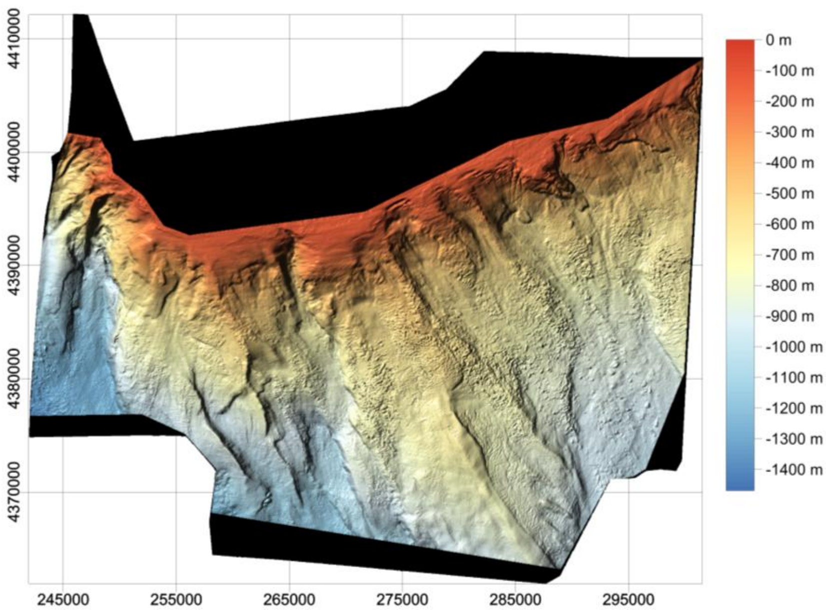

Figure 6 - Area selection for provide the geomorphometric analysis. The black polygon indicate some area that are excluded from the present study

First step of the analysis after the bathymetric data processing was the definition of the limits of the analysis. From previous studies (Savini et al, 2004; Corselli et al., 2006; Tursi et al., 2004; Taviani et al., 2005a; Rosso et al., 2010; Mastrototaro et al. 2010; Vertino et al., 2010) SML CWC province is located on the slope sector of the margin, the reason that the first step was been the selection of this portion of the DTM and the exclusion of the shelf part (Fig. 6).

The next steps of the analyses focused on the computation of geomorphometric parameters (Evans, 1998, Pike, 2000, Hengl et al., 2008). Within the present study, a number of secondary-derived bathymetric layers have been used to help segment the seafloor into biologically relevant units. Some of these parameters are common to terrestrial applications; others have been modified for the marine environment.

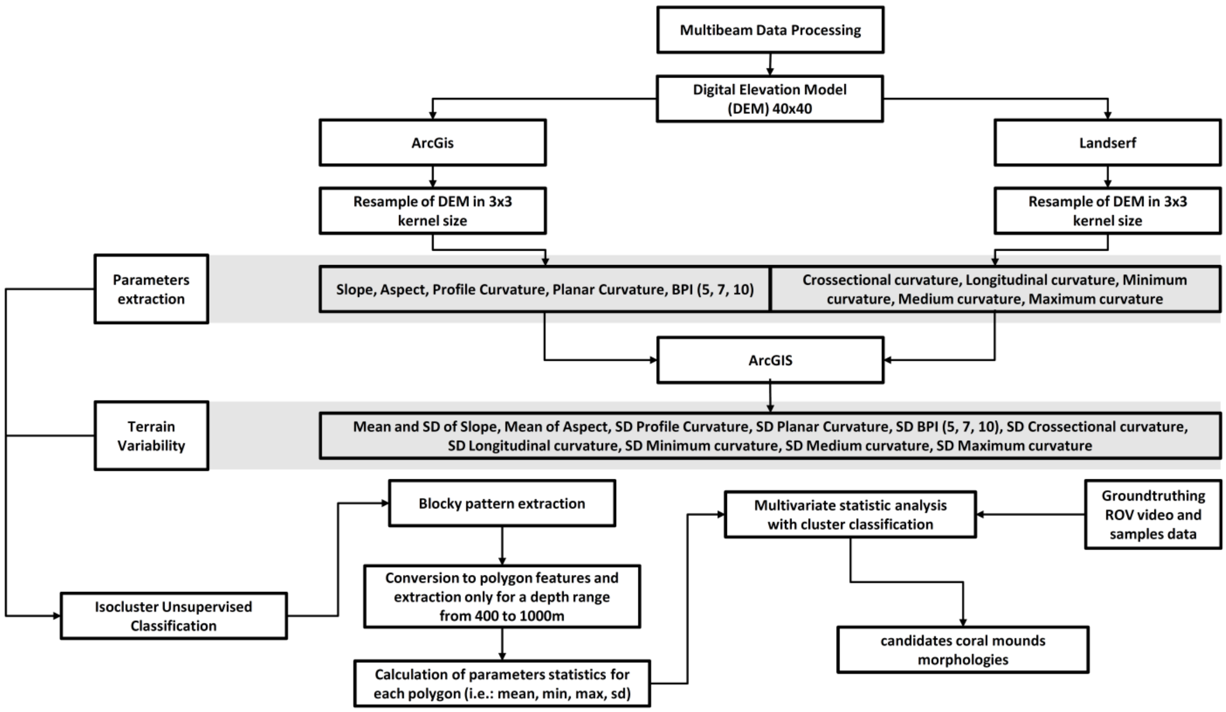

Figure 7- Key-steps in the workflow for the 1th methodology here presented

Through the analysis performed on SML CWC province bathymetric data set, some geomorphometric parameters were calculated. Six of the main parameters were computed by applying topographic modelling using the ArcGIS™ spatial analyst extension's surface analysis and the Landserf 2.2 software (used to compute the parameters proposed by Wood, 1996) (Table 2). As additional algorithm, the Bathymetric Position Index (BPI), which is derived from Topographic Position Index (Gallant and Wilson, 2000), is frequently used in seafloor mapping (Iampietro et al., 2005; Lundblad et al., 2006; Verfaillie et al., 2006; Wilson et al., 2007; Wright and Heyman, 2008; Zieger et al., 2009; Young et al., 2011) and was also run in ArcGIS™ using the ArcGIS™ Benthic-Terrain Modeller extension (Wright et al., 2012). The slope, the orientation and the curvatures were computed using a window analysis of 3x3; whereas the BPI was calculated over a range of scales (Table 2). Based on Evans (1990) and Micallef (2007), maps generated by all of the provided parameters were used to produce descriptive maps that helped identify areas with a set of different morphometric properties that may be linked to typical seafloor geomorphologies.

Type of Terrain Analysis	Parameter	Analysis window	Algorithm
Slope	Slope	Rectangular 3x3	Burrough et al., 1998
Orientation	Aspect	Rectangular 3x3	Burrough et al., 1998
Curvature and relative position	Profile curvature	Rectangular 3x3	Moore et al., 1991
	Plan curvature	Rectangular 3x3	Moore et al., 1991
	Cross-sectional curvature	Rectangular 3x3	Wood, 1996
	Longitudinal curvature	Rectangular 3x3	Wood, 1996
	Minimum curvature	Rectangular 3x3	Wood, 1996
	Maximum curvature	Rectangular 3x3	Wood, 1996
	Mean curvature	Rectangular 3x3	Mitasova, 1994
	Bathymetric Position Index (BPI)	Annulus 1-5,7,10	Lundblad, 2006

Table 2 - Geomorphometric parameters used in the 1th methodology

Following Evans (1990) and Micallef (2007), surface terrain variability was analyzed by calculating the moment statistics of all of the computed parameters. Surface roughness has been defined in different ways (Evans, 1990) and it lacks a definite measurement scale. In this approach the surface roughness parameter was defined as the deviation of the terrain surface from a perfectly smooth terrain due to the presence of irregular features. The greater the height between the apex of the feature and the surrounding terrain, and the more frequent the features are, the higher the surface roughness. Therefore the presence of features such mound-like morphologies in the mass-failed deposits increases the surface roughness of the terrain. Evans (1990) suggested that moment statistics of

Type of Terrain Analysis	Parameter	Analysis window	Algorithm
Terrain Variability	SD of Slope	Rectangular 3x3	ArcGIS™ Focal Statistics Tool
	Mean of Slope	Rectangular 3x3	ArcGIS™ Focal Statistics Tool
	SD of Profile curvature	Rectangular 3x3	ArcGIS™ Focal Statistics Tool
	SD of Plan curvature	Rectangular 3x3	ArcGIS™ Focal Statistics Tool
	SD of Cross-sectional curvature	Rectangular 3x3	ArcGIS™ Focal Statistics Tool
	SD of Longitudinal curvature	Rectangular 3x3	ArcGIS™ Focal Statistics Tool
	SD of Minimum curvature	Rectangular 3x3	ArcGIS™ Focal Statistics Tool
	SD of Maximum curvature	Rectangular 3x3	ArcGIS™ Focal Statistics Tool
	SD of Mean curvature	Rectangular 3x3	ArcGIS™ Focal Statistics Tool
	SD of Bathymetric Position Index 5,7,10	Circle 3	ArcGIS™ Focal Statistics Tool

Table 3 - Terrain variability parameters used in the 1th methodology.

morphometric attributes can be used in measuring components of surface roughness (Table 3), as follow: mean and standard deviation of slope gradient, and standard deviation of profile and plan curvature. The standard deviations (SD) from all of the curvature maps and the mean slope were calculated.

2.6.2 Mounds Morphologies Extraction

The subsequent step of the analysis is represented by the extraction of the positive morphologies that can be related to mound-like features (Fig. 7)In particular in this first approach has been used a unsupervised classification that allowed the description of multivariate data in terms of clusters of data points that possess strong internal similarities (Duda et al., 1973). We further used a suite of GIS-based tools (i.e. the Isocluster Unsupervised Classification that combines the Iso-Cluster and Maximum Likelihood Classification - MLC) to extract and classify all of the mound-like morphologies as distinct polygons from the DTM and to perform an additional analysis in order to localize suitable morphologies for CWC colonization (Fig. 8).

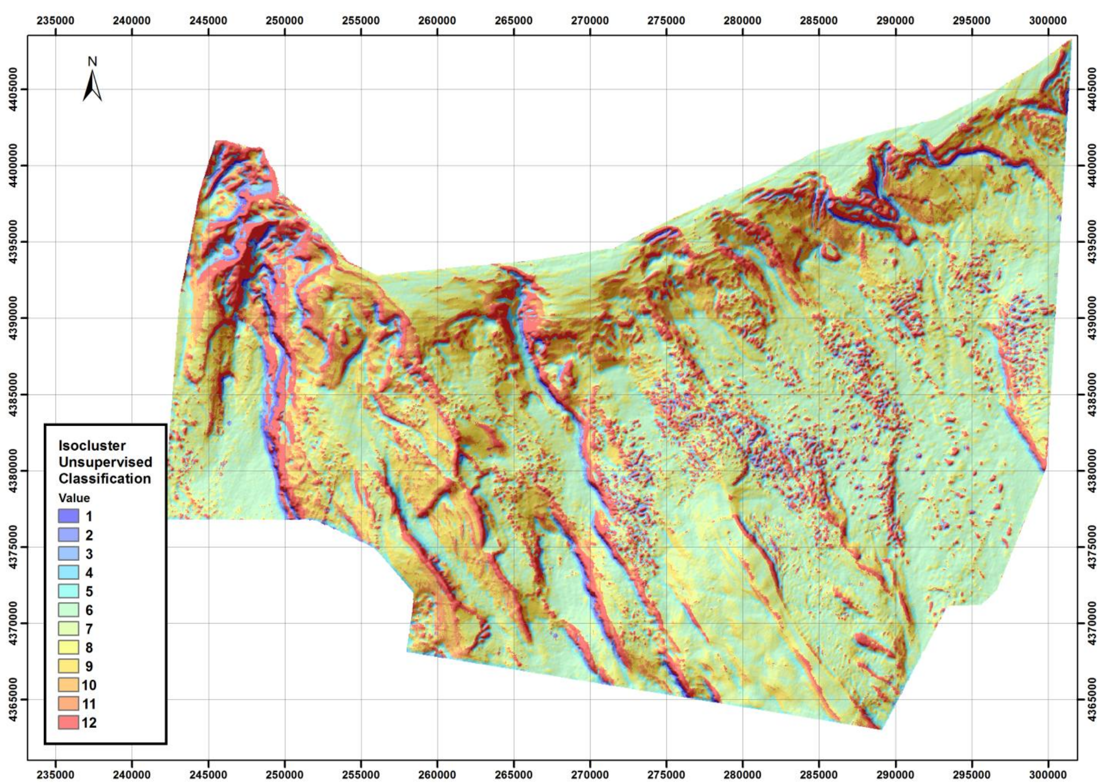

Figure 8 - Isocluster map of the study area

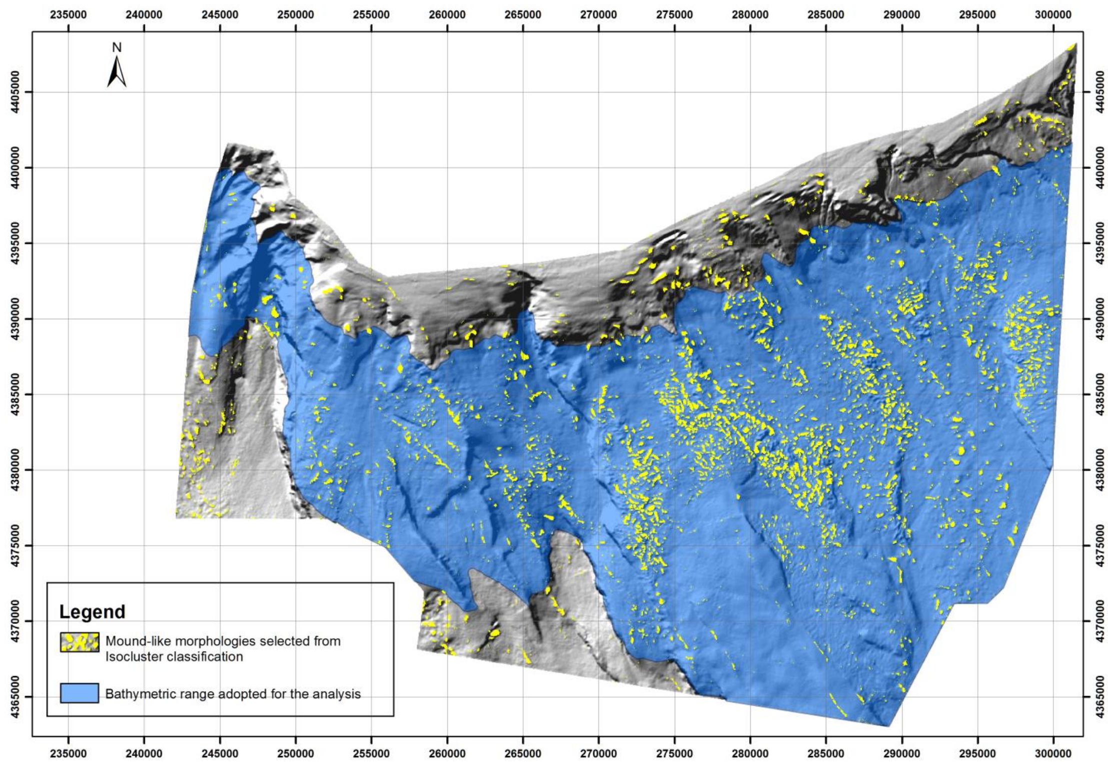

Figure 9 - Mound like morphologies extracted from the Isocluster Classification, the blue area represent the bathymetric range of the Adriatic Deep Water current.

This approach comes from one of the most widely used unsupervised clustering algorithms, the Iterative Self-Organizing Data Analysis Technique (ISODATA). This technique defines natural groupings of multivariate data in attribute space (Adediran et al., 2004) and is a commonly used algorithm in satellite image classification and civil engineering (Hall and Khanna, 1977). The technique is based upon estimating some reasonable assignment of cells to candidate clusters, and then moving them from one cluster to another so that the sum of the squared errors of the preceding session is reduced. The output of the classification is a digital thematic map where each cluster is represented by a different class.

The Maximum Likelihood Classification tool considers both the variances and covariances of the class signatures when assigning each cell to one of the classes represented in an optional signature file. With the assumption that the distribution of a class sample is normal, a class can be characterized by the mean vector and the covariance matrix. Given these two characteristics for each cell value, the statistical probability is computed for each class to determine the membership of the cells to the class.

Through the Isocluster Unsupervised Classification we extracted all the mound-like morphologies as distinct polygons (Fig. 9). From all of the isolated polygons, those occurring in a depth range located between 400 and 1,000 m in w.d. (the same depth range of coral occurrences in our study area – Budillon et al., 2010) were selected. Each polygon represents a distinct feature of the whole DEM, with its own geomorphometric properties.

2.6.3 Coral Mounds Morphologies Selection

Since not all the identified polygons isolated by Isocluster Unsupervised Classification might be associated to CWC occurrences, we performed additional statistical computation. Ground-truthing obtained from coral samples or video data collected during oceanographic surveys allowed to identify few coral mounds from the resulting features of the unsupervised classification, then it was possible to calculate geomorphometric parameters statistics for each polygon (i.e.: mean, min, max and sd) associated to a coral-mound (i.e. mounds where were collected).

Multivariate statistic analysis through cluster analysis was run using a non-hierarchical algorithm (K-means cluster analysis) through R software, performing repetitive classifications using from 5 to 10 number of classes. Within each performed classification, all the documented coral mounds resulted to be included within the first 3 classes. Thus we consider these first three classes as the ones that better represent morphometric proprieties of coral-mounds. Classifications that were run using from 5 to 9 classes, grouped in the first 3 classes exactly the same mounds. Setting 10 classes, the 50% of the total mounds classified using from 5 to 9 classes was excluded from the first 3 classes. The classification maps obtained from our calculation represent how we model coral-mound mapping (Fig. 10 and Fig. 11).

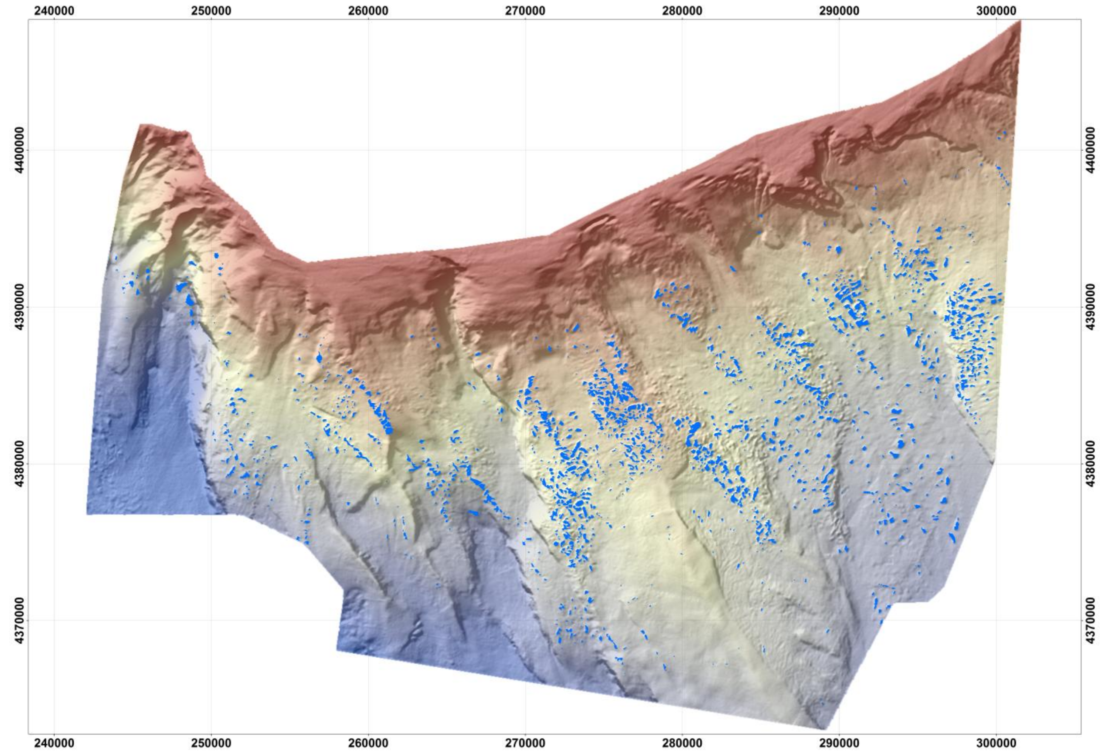

Figure 10 - Coral mounds extracted using 9 class k-means algorithm.

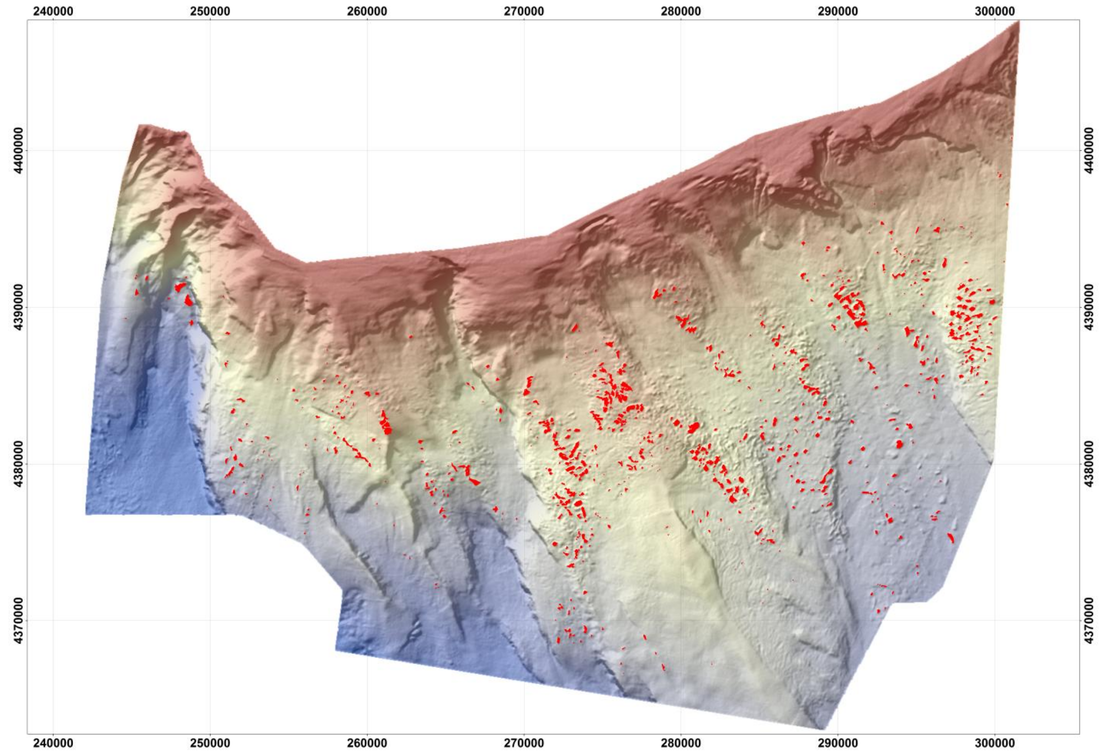

Figure 11 - Coral mounds extracted using 5 class k-means algorithm.

2.7 - 2^dn Methodology: Predictive Habitat Mapping using geomorphological proxies

2.7.1 Geomorphometric Parameters

The second methodology adopted to obtain the coral mound distribution of the SML CWC province was developed in order to improve the first one, and in particular we focused on:

- reducing the number of geomorphometric parameters,
- use a more supervised method during the landform extraction.

To effectively discriminate among landforms or terrain types, the constituents of a geomorphometric feature must describe important attributes of topographic form and take different parameter values over the range of observed surface features. According to Iwahashi et al. (2007), the optimal number of variables to be used to extract morphologic features, depends on spatial scale and the requirements of the proposed target (Iwahashi et al., 2007). In addition, while no one parameter suffices for a general classification of topography (Evans, 1972), a large number of variables would create an unmanageable number of derived categories and introduce needless duplication, especially because a lot of measures (e.g. relative relief and the standard deviation of elevation, the hypsometric integral and skewness of elevation) describe the same attribute of surface form and thus are redundant (Iwahashi et al., 2007).

The improved methodology (here after presented) is thus characterized by the use of a single specific parameter for the extraction of positive (conical?) morphologies and the process entails the identification of coral mounds, based on morphometric attributes, computational slicing of the domain of each attribute into intervals, along with identification and mapping of these intervals (Fig. 12).

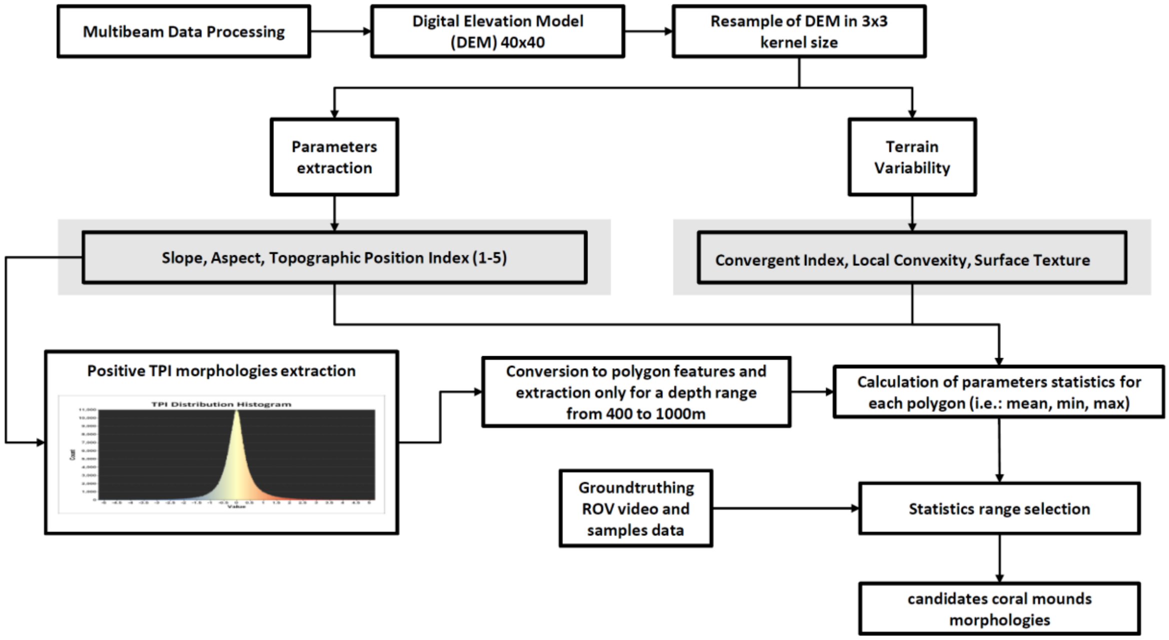

Figure 12 - Key-steps in the workflow for the 2dn methodology here presented

Following the type of terrain analysis proposed by Wilson (2007), for seafloor mapping, and considering the possible redundancies of some geomorphometric parameter proposed in the first method here presented (section 2.6), we here used a different set of algorithms, as shown by Fig. 14 and Table 13. Each parameter is briefly presented here after.

Type of Terrain Analysis	Parameter	Analysis window	Algorithm
Slope	Slope	Rectangular 3x3	Burrough et al., 1998
Orientation	Aspect	Rectangular 3x3	Burrough et al., 1998
Curvature and relative position	Topographic Position Index	Annulus 1-5	Weiss, 2001
	Convergent Index	Rectangular 3x3	Koethe et al., 1996
Terrain Variability	Local Convexity	Rectangular 3x3	Iwahashi and Pike, 2007
	Surface Texture	Rectangular 3x3	Iwahashi and Pike, 2007

Table 4 - Geomorphometric and terrain variability parameters used in the 2dn methodology.

Convergent Index

The Convergent Index is based on the aspect which is defined as the slope direction (Zevenbergen and Thorne, 1987) and computed from the local surface function CI ranges from −90◦ to 90◦ (Kothe and Lehmeier, 1996; Kiss, 2004). In the resulting grid, positive values represent divergent areas and negative values represent convergence areas. Null values relate to areas without curvature as planar slopes.

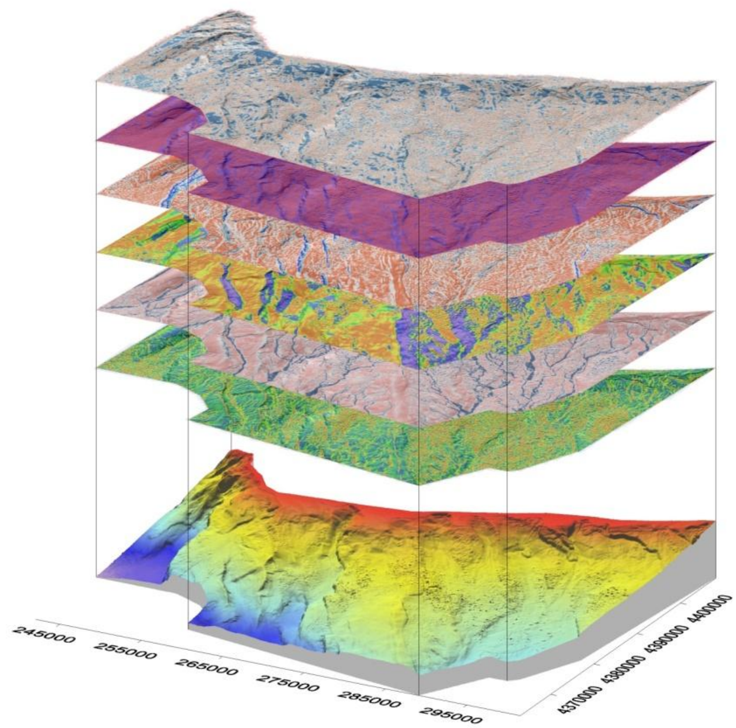

Figure 13 - 3D reconstruction of parameters extraction from the bathymetric dataset

Local Convexity

Surface curvature is measured by the Laplacian filter, an image processing operation that is used in edge enhancement and approximates the second derivative of elevation with aim of discriminating low-relief features (Iwahashi et al., 2007).

Surface Texture

Terrain texture can be represented by such measures of spatial intricacy as drainage density and changes in sign of slope aspect or curvature per unit area. Previously termed “frequency of ridges and valleys” or “roughness” (Iwahashi, 1994; Iwahashi and Kamiya, 1995; Iwahashi et al., 2001), the measure is renamed “texture” to emphasize its fine-versus-coarse expression of topographic spacing (Iwahashi et al., 2007).

2.7.2 Mounds Morphologies Extraction

In order to extract all positive seafloor features using a single parameter, we computed the Topographic Position Index – TPI (Weiss, 2001). TPI measures the relative topographic position of the central point as the difference between the elevation at this point and the mean elevation within a predetermined neighbourhood. TPI is only one of a vast array of morphometric properties based on neighbouring areas that can be useful in topographic and DEM analysis (Gallant and Wilson, 2000).

In particular TPI results can be related to: Positive TPI values represent locations that are higher than the average of their surroundings, as defined by the neighborhood (ridges). Negative TPI values represent locations that are lower than their surroundings (valleys). TPI values near zero are either flat areas (where the slope is near zero) or areas of constant slope (where the slope of the point is significantly greater than zero).

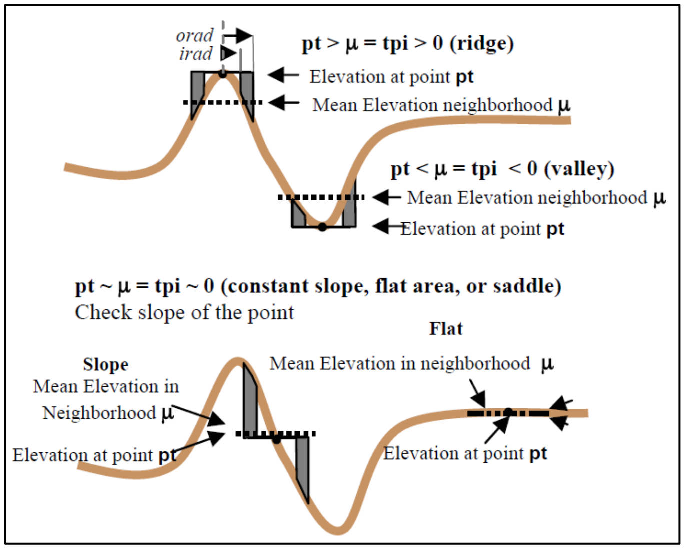

Figure 14 - TPI algorithm (Weiss, 2001)

In order to better define the mound-like features the TPI was performed at the finest possible scale, according to the SML CWC province DTM resolution (i.e. 40 x 40 m grid cell size) of the. The algorithm was tested at different scales but, as expected, the increase of the radius causes a decrease in the algorithm efficiency in detecting typical mound features of the surveyed area (that range in diameter from ... to ... m). We considered as minimum TPI value 0.5, and therefore all cells under this value were excluded from the analysis as negative or flat morphologies.

2.7.3 Coral Mounds Morphologies Selection

Considering the distribution of the TPI value on the entire analyzed DTM and what TPI mean from morphologic point of view (Fig. 14), in this study were considered positive morphologies all features that had TPI value higher than 0.5 (Fig. 15).

Each positive feature (delimited by a single polygon) obtained by computation of TPI, represents a distinct feature of the whole DEM, with its own geomorphometric properties and parameters statistics (i.e.: mean, min, max and sd). Furthermore from all of the isolated polygons, those occurring in a depth range located between 400 and 1,000 m in w.d. (the same depth range of coral occurrences in our study area – Budillon et al., 2010) were selected. Ground-truthing obtained from coral samples or video data were here used to select documented coral mounds from all the detected polygons. For each of them, range values of each computed geomorphometric parameter were extracted. Successively, all polygons with the same values were identified, among all the positive features identified from TPI computation (Fig 16).

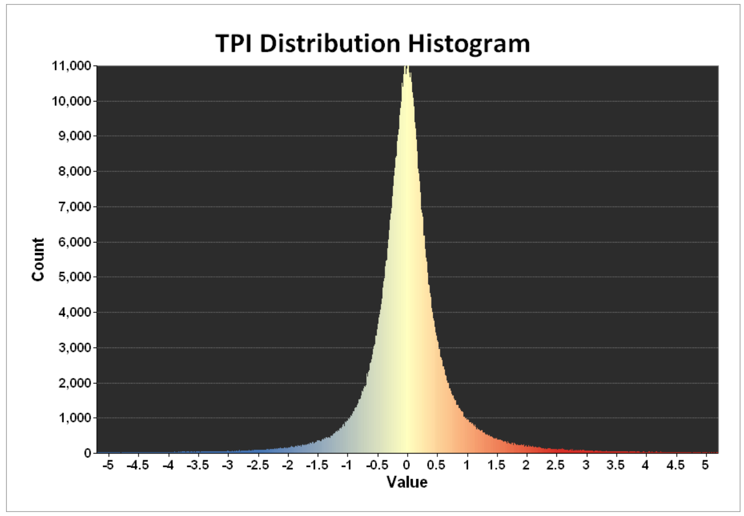

Figure 15 - Distribution histogram of TPI value calculated in the study area

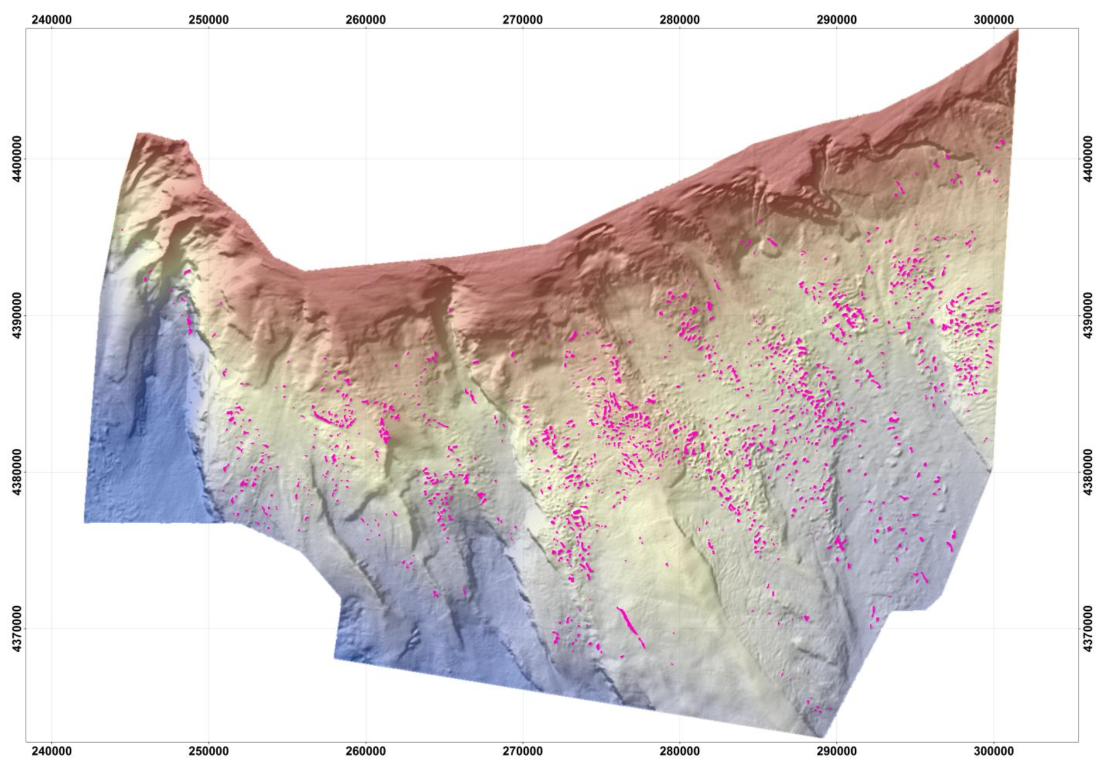

Figure 16 - Coral mounds distribution extracted from the 2nd methodology

2.8 Results

Terrain analyses on the obtained DTM were focused on quantitatively outlining the blocky pattern within which coral mounds are densely distributed. Both the adopted methods aimed at:

(1) Outline the blocky pattern that is 600 km^2 in area and that extends over the entire investigated sector of the northern Ionian Margin.

(2) Isolate all of the mound-like features occurring within the study DTM. Each polygon represents a distinct feature of the entire DTM with its own morphometric properties.

2.8.1 Results from Isocluster methodology

Cluster analysis on the isolated seafloor features (Section 2.6.3 - Fig. 10 and Fig.11), we obtained a descriptive morphometric characterization for each extracted feature, as summarised here below (Table 5):

(1) Considering the end members obtained from cluster analysis (5 and 9 classes) coral mounds were determined to be from 720 to 1441 in total number with an average area of 35,000 m^2 per mound.

(2) 4493 positive features were identified by the Isocluster Unsupervised Classification. After statistical analysis (k-mean cluster analysis, Section2.6.3) from 16% to 32% of them result to be “candidate sites” for CWC.

(3) CWC candidates morphologies have heights that range from 0.4 to 40 meters

(4) CWC candidates morphologies have an average slope of 3.2°

(5) 90% of CWC candidates morphologies have an aspect between SE and SW

(6) Total areal coverage obtained summing all candidates features: 26 to 50Km^2

2.8.2 Results from TPI methodology

Once obtained all candidate coral-mounds (Fig. 16), also for this second method a morphometric characterization of each extracted feature was provided, as summarised here below (Table 5):

(1) 1186 positive features were considered “coral-mounds”, on the 3319 total features (35%) extracted from TPI computation

(2) CWC candidates morphologies have heights that range from 0.4 to 40 meters
(3) CWC candidates morphologies have an average slope: 3.5°
(4) Approximately the 90% of CWC candidates morphologies have an aspect between SE and SW
(5) CWC candidates morphologies cover a total area of 40Km^2 (obtained summing areas of all the selected morphologies)

2.9 Discussion

The outlined fine-scale geo-morphological pattern of the coral-mound well reflected how the pre-existing morphology of the settlement sites was fundamental in dictating the mound morphology. The complex irregular topography created by failure events, likely exposed indeed older strata at the seafloor, creating suitable substrates for coral colonization (i.e. blocks of lithified or partially lithified sediments and/or extensional ridges of the upper, not fully evacuated areas of slides) and sediment trapping occurred through coral growth (during the time of accretion) enhanced then the mound elevation with respect to the surrounding seafloor.

Since this work did not focus on a single species, and actually modeled (i.e.: predicted) the distribution of coral-mounds (i.e. the positive seafloor morphologies associated with the occurrence of CWC habitats) and not of a defined taxon, it can't be defined as a typical Habitat Suitability Model (HMS). Specific geomorphometric techniques and geomorphological analysis were, instead, used to analyze DTM proprieties and to extrapolate the terrain features associated with coral-mounds.

HSM is an approach aimed at estimating single species or community distributions in geographic space, and it is a key research tool in theoretical and applied ecology (Guisan & Zimmermann 2000, Elith & Leathwick 2009). HMS, also referred to as species distribution models (Elith & Leathwick 2009) statistically relate species occurrence data with environmental predictor variables to estimate full-coverage potential species distribution in geographic space (Guisan & Zimmermann 2000, Elith & Leathwick 2009, Franklin 2009). HSM produce gradational maps (i.e. using Gradational Entities methods defined by Brown et al., 2011) predicting community distributions from modeled environmental parameters (e.g. Degraer et al., 2008).

Our methodology consists in a semi-automated method that combines a suite of geomorphometric techniques to map specifics seafloor morphologies within the study area, from which previous geomorphological and ecological studies allowed the identification of a "*geomorphological proxy*" associated with the coral mound distribution.

		Isocluster methodology	TPI methodology
Curvature Parameters		8	1
Terrain Variability Parameters		10	3
Total polygons detected		4493	3319
Coral mounds polygons		720-1441	1186
Coral mounds	**Total Area**	26 – 50 Km^2	40 Km^2
	Height	0.4 – 40 m	0.4 – 40 m
	Average slope	3.2°	3.5°
Aspect		SE - SW	SE - SW

Table 5 - Results summary table of the two methodology proposed

Both the approach allowed to delineate the boundaries of finite geomorphometric objects from the continuous grid of morphometric parameters by generating a geomorphometric map, which is a parametric representation of the general morphology of a landscape.

The results of two analysis are not exactly the same, because of some difference in the two approaches, although they are similar and comparable (Fig. 17). The main differences between the two approach are reliable to the polygons detection algorithms and coral mounds selection methods. Nevertheless the distribution of coral mounds polygons results quite similar in both the two applied methods, and they localised a high density of coral mounds in the same sector of the margin (Fig. 17).

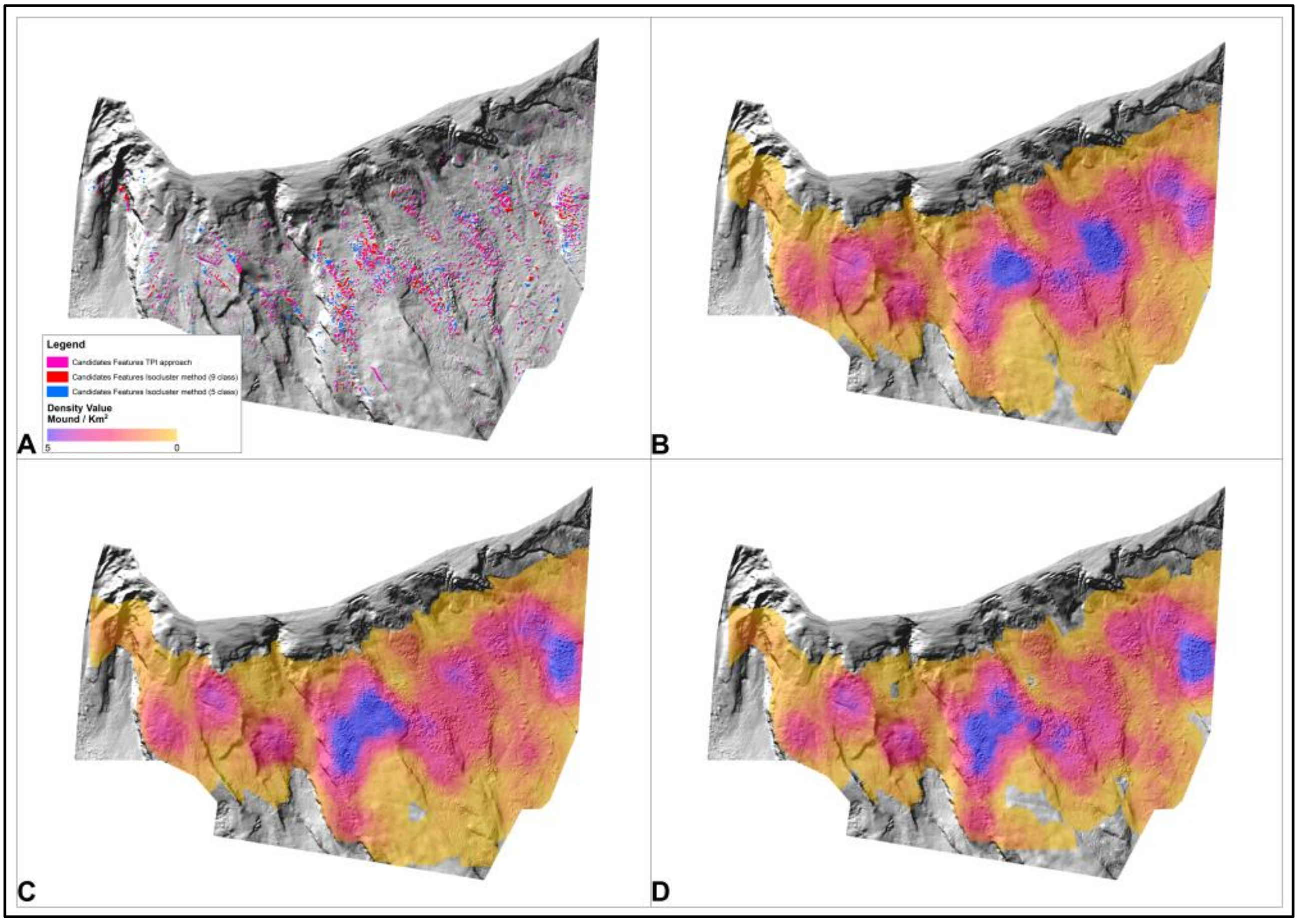

Figure 17 – (A) coral mounds distribution resulting from both the approaches, (B) Coral mounds density resulting from TPI method, (C) Coral mounds density resulting from Isocluster method (5 class), (D) Coral mounds density resulting from Isocluster method (9 class).

The work presented here provides a quantitative distribution of CWC-coverage within the study area and information at scales relevant for Marine Spatial Planning and Ecosystem-Based Management. Unluckily the absences of others environmental and acoustics data limited the analysis. Continuous information layers as currents direction and intensity, multibeam backscatter, bottom water temperature and salinity, and more groundtruthing data well distributed in the study area could improve both the models and probably get closer the results. Nevertheless this approach should offer an efficient and cost-effective technique for supporting the growing global need for better spatial management within the Mediterranean marine environment.

Chapter 3 - Geomorphometric analysis of coralligenous habitat along the Apulian continental shelf: an assessment of seafloor coverage and volume

3.1 Introduction

Italian initiatives promoted within the framework of MSFD take into account 4 main habitats: Coralligenous, Maerl, Cold water Corals and Posidonia oceanica. This present study is based on a new experimental methodology performed to analyze multibeam data in order to quantify the spatial distribution and the total volume of Coralligenous Habitat (CHs). Coralligenous (C) communities constitute the second most important 'hot spot' of species diversity in the Mediterranean, after the Posidonia oceanica meadows (Boudouresque 2004) and they are an outstanding example of the role of carbonate bioconstruction (Bosence 1983; Ballesteros 2006; Nalin et al. 2006; Basso et al. 2007). For this reason a precise knowledge of Coralligenous distribution is nowadays strongly important because this habitat produces large deposits of biogenic calcium carbonate (Basso, 2012) and is very sensitive to the ongoing global change (Kuffner et al., 2007; Basso, 2012).

In the framework of Mediterranean marine benthic zonation CHs is indicative of a circalittoral biocoenosis consisting of a three dimensional biogenic build up, formed by the overlapping growth (in dim light conditions) of organism with calcareous skeletons, that forms a new solid substrate primarily dominated by coralline algae (Laborel, 1961; Pérès & Picard, 1964; Bellan-Santini et al., 1994; Bressan et al., 2001).

C build-ups vary in shape and dimension and their morphological expression have not been exhaustively categorized. From this point of view, two main classification of C morphologies have been indicated: the first one (Pérès & Picard, 1964; Laborel, 1987; Ballesteros, 2006) that divide C in banks and rims, the second proposed by Bracchi et al., (2015) that define three morpho-acoustics C facies. Furthermore various definitions, reflecting different building morphologies, are found in the scientific literature: columnar crustose coralline algal build-ups described as heads, blocks patches, or banks (Sarà, 1968), vertical pillar (Di Geronimo et al., 2002), horizontal pillar (Sartoretto, 1994), algal reefs (Bosence, 1983), and minute reef aggregation (Georgiadis et al., 2009). Marine bionomists consider the substrate to be a key factor in distinguishing C typologies, although it represents a difficult aspect to investigate. Only recent acoustic-sismic techniques have been applied to determine the type of substrate were the coralligenous develops (Georgiadis et al., 2009; Bracchi et al., 2014).

This study aims at highlighting the importance of combining acoustic survey techniques and geomorphometric analysis to successfully support a preliminary quantitative assessment of CHs distribution and extent. Our results offer a relevant contribute to obtain a quantitative description on Coralligenous habitat distribution and give an overview of the importance of Coralligenous habitat as carbonate deposits on the Mediterranean shelf.

This work was presented at the Symposia on the Conservation of Mediterranean Marine Key Habitats, International Conference took place in Portroz, Slovenia on 2014.

3.1.2 BioMAP Project

Coralligenous habitat along the Apulian continental shelf is known in literature since decades (Sarà 1966; 1968; Parenzan, 1983) but in the last four years large areas along the Apulian coast have been investigated from the coastline down to 100 m w.d. in the framework of BIOMAP project.

BIOMAP Project (BIOcostruzioni Marine in Puglia), promoted by CoNISMa and funded by Apulia Region, Italy, is a part of the program "PO FESR 2007/2013 – AXIS IV – line 4.4: intervention for the ecological network". It promoted actions in order to map and monitor coralligenous habitats along the Apulian coast (southern Adriatic margin and northern Ionian margin – Mediterranean sea). Acoustic (multibeam and side-scan sonar), video data and samples were collected through several oceanographic cruises, to identify and locate coralligenous habitats in 21 Site of Community Interest (SCI), 3 Marine Protected Areas (MPA) (BIOMAP project Final Report, 2014).

BioMAP Project produced 59 maps (44 maps at 1:25.000 and 15 maps at 1:10.000) covering the entire Apulian coast, including all SCI and MPAs. Main result discover that Coralligenous habitat covers about 450 Km^2 and representing the most relevant habitat within SCI and MPA originally instituted considering only Seagrass occurrences (BIOMAP project Final Report, 2014). The total volume provided by all the Coralligenous build-up mapped by the BIOMAP project was then estimated comparing our results with the total distribution of Coralligenous habitats.

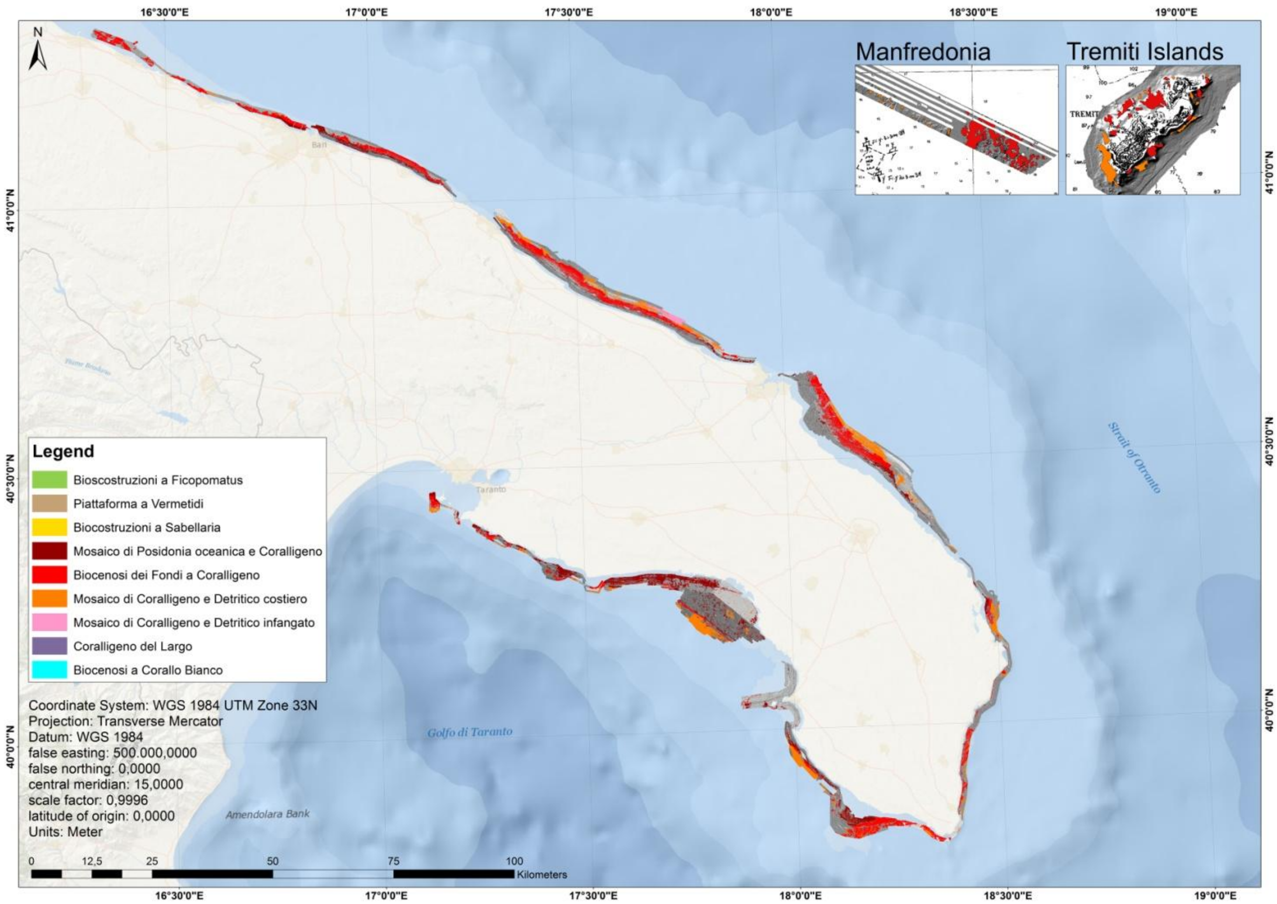

Figure 18 - Map of the distribution of BioMAP projects habitats

This knowledge is critical for quantify and map such CHs and to promote further conservation measures in order to plan an appropriate protection strategy for Apulian coastal and deep sea areas. This results are relevant for all sites of community interest in the western Mediterranean, highlighting the importance of habitat mapping in improving EBM and MSP for conservation and protection purposes.

3.2 Abstract

Within the framework of the BIOMaP Project (BIOcostruzioni Marine in Puglia, - P.O. FESR 2007/2013), promoted by Puglia region, Italy, new acoustic data were acquired in order to identify and locate Coralligenous Habitats along the Apulian continental shelf (South Adriatic Sea – Northern Ionian Sea), from 10 down to 100 meters of water depth, in 21 Site of Community Interest (SCI) and 3 Marine Protected Areas (MPA). The dataset covered an area of 1000 km^2 and was obtained through

the use of MultiBeam Echosounder Systems (MBES) and Side Scan Sonars. Ground-truthing were collected by 3 ROV dives (Prometeo) and more than 30 underwater camera transects. We discovered that Coralligenous habitat covers a total area of roughly 450 km^2, representing the most relevant habitat within all the SCIs and MPAs of the Apulian continental shelf. The analysis of MBES dataset allowed us to identify several morphological expression of Coralligenous Habitat. Geomorphometric techniques (developed through proper GIS-based tools) have been thus applied on the MBES data in order to (1) figure out relationships between the observed morphologies and the associated habitat distribution and (2) quantify the total volume of selected Coralligenous build-ups. Our work underlines the importance of combining acoustic survey techniques and geomorphometric analysis in order to have a preliminary quantitative characterization of Coralligenous habitat distribution and its 3-dimensional extent. Our results offer relevant quantitative information which contribute in understanding the importance of Coralligenous habitat as carbonate deposits on the Mediterranean shelf (that has been probably underestimated, due to poor knowledge of their distribution).

3.3 Study Area

BioMAP Project had allowed to distinguish some meso-habitat groups (Fig. 18) dominated by Coralligenous build-ups and some other bioconstructor organisms, such as: *Trottoir of Rhodophycea, Bioconstructions of Sabellaria (Annelida, Polychaeta), Bioconstructions of Ficopomatus (Annelida, Polychaeta), Mosaic of Coralligenous and Posidonia oceanica, Coralligenous Mosaic of Coralligenous and coastal Detritic, Mosaic of Coralligenous and muddy Detritic, Deep Coralligenous* and *Cold Water Corals.*

In this work the experimental approach consisted of comparing three different groups of Digital Terrain Models (DTMs) collected in three selected CHs mapped in the project (Fig. 19):

- Mosaic of Coralligenous and Posidonia meadows (MCP).
- Coralligenous Biocenosis (BC).
- Mosaic of Coralligenous and coastal Detritic (MCD).

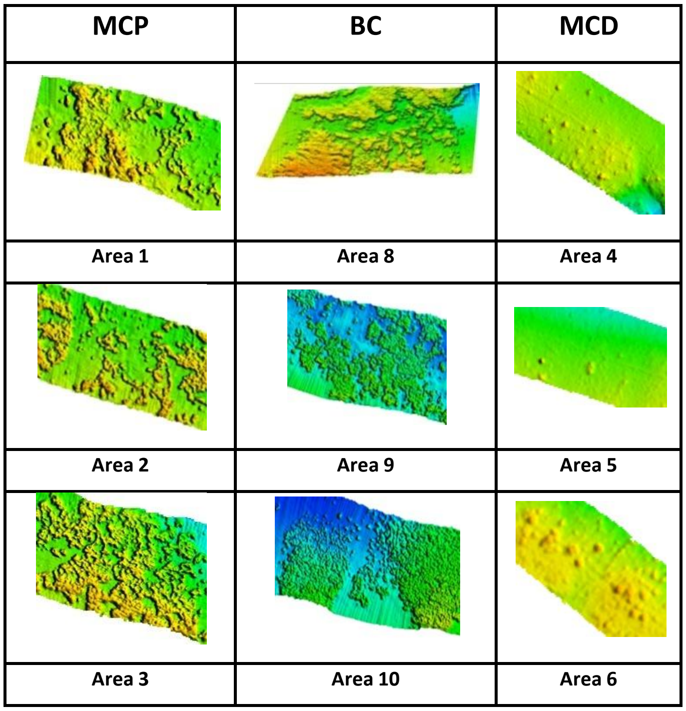

Figure 19 - Sample areas from the 6 DTMs used for the analysis.

The first and the second habitats are composed of six very high resolution DTMs (grid cell size of 30cm), provided by processing bathymetric data acquired through a Teledyne Reson 8125 MBES, from 10 to 15 m of w.d. The third one includes three DTMs (1m grid cell size) provided by processing bathymetric data acquired through a MBES Teledyne Reson 8160 from 30 to 45 m of water depth.

The selected habitats extensions mapped by the BioMAP Project, that will be used as reference to the final step are indicated below.

Habitat	MCP	BC	MCD
Coverage resulting from BioMAP Project	103,8 Km^2	185,6 Km^2	101,9 Km^2

3.4 Materials and Methods

Acoustic dataset was obtained from several oceanographic research cruises, performed between March 2012 and may 2013 under the framework of the BIOMAP project. Two main research ship-based survey on board of R/V MINERVA UNO (BIOMAP I and BIOMAP II respectively on March and May 2012) explored the deepest areas, between 30m to 100m w.d., using the 50kHz Teledyne RESON 8160 MBES, water sound velocity was derived using the Seabird SBE 21 device, meanwhile side scan sonar (SSS) data deriving from two models of dual frequency SSS, the 100/500 kHz Klein3000 system and the 100-400 kHz EdgeTech 4- 2000.

To explore the shallowest part of the study area (between 2m and 30m w.d.) several small cruises were provided on board of the CoNISMA research boat Calafuria ISSEL (from July 2012 until June 2013) using the Teledyne RESON SeaBat 8125 MBES. The Reson 8125 is a 455-kHz high-resolution MBES that insonifies a swath on the seafloor that is 120º across track by 1º along track. The receive array forms 240 individual beams with 0.5° spacing of the beam centres across track. The along-track width of the receive beams is 20°. Because the receive array is flat, the across-track beamwidth varies with the steering angle from 0.5° for the innermost beams to 1.0° for the outermost beams. As a result, the sonar beams formed by the intersection of the transmitted and received beams are 0.5 x 1° wide in the centre and 1 x 1° wide at the outer edges (RESON, 2002; Parnum, 2007; DeFalco et al., 2010). During the system installation, the static positional offsets were measured and a calibration (i.e., patch test) was carried out in order to measure and then correct for the dynamic sensor offsets. The correct position of the acquired data has been assured by the interfacing of the MBES with the Hemisphere Crescent R-Series dGPS, directly connected to the IXSEA OCTANS motion sensor and gyro. SSS data were provided by pole-mounted Klein3000 system.

MBES data where acquired and processed using Teledyne RESON PDS2000 software, the entire dataset did not cover all the investigated areas with 100% of coverage, but provided high-resolution bathymetry of the surveyed seafloor (i.e. from 0.3m cell size at 5m w.d. to 1 m cell size at 100 m w.d.). The digital terrain model (DTM), provided by the MBES survey, was used for the final georectification of the processed SSS mosaic obtained from the R/V MINERVA UNO surveys.

SSS operated at 200 m range setting and we reached 50% of overlap between adjacent lines. SSS data processing, performed using Triton ISIS (Triton Elics Information-TEI) suite software packages, produced geo-referenced gray-tone acoustic images of the seafloor at 0.5 m resolution. Only for SSS data acquired during the survey on the R/V Minerva 1, the track of the fish was computed using the position of the ship, the length of the tow cable, and the elevation of the fish above the sea floor. On the R/V ISSEL the SSS fish was anchored on a vertical pole, consequently a simple fixed offset (from the dGPS antenna position) was used to obtain georeferenced SSS images.

Groundtruthing were made by video inspections collected during all the oceanographic cruises, in particular 3 ROV dives using a Prometeo ROV (R/V MINERVA UNO) and more than 30 subaqueous transects by Quasi-Stellar©(Elettronica Enne) trawled camera (R/V Calafuria ISSEL).

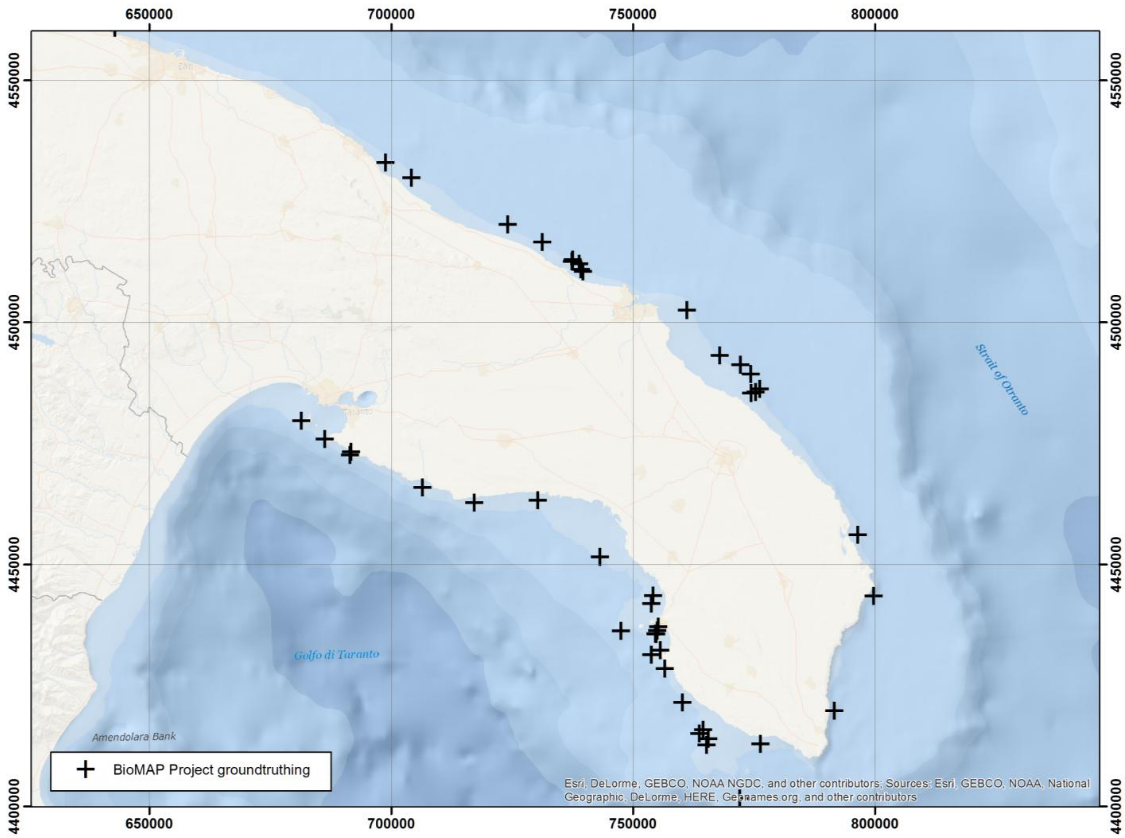

Figure 20 - Distribution of the all groundtruthing collected in the BioMAP project

The BIOMAP project's datum was WGS84 and the projection chosen for navigation and display was UTM fuse 33. All data were integrated and analyzed using GIS-based procedures (ArcGISTM software). CHs were mapped using SSS mosaics that had complete coverage of the MPAs and SCI. The geomorphometric analysis were computed using SAGA (System for Automatic Geoscientifics Analysis, Conrad et al., 2015). DTMs interpolation was made with Golden Software Surfer®.

3.5 Geomorphometric Analysis

The first step in the analytical process required the geomorphometric analysis of the above-mentioned DTMs, in order to identify all the Coralligenous build-up structures present on the mapped seafloor.

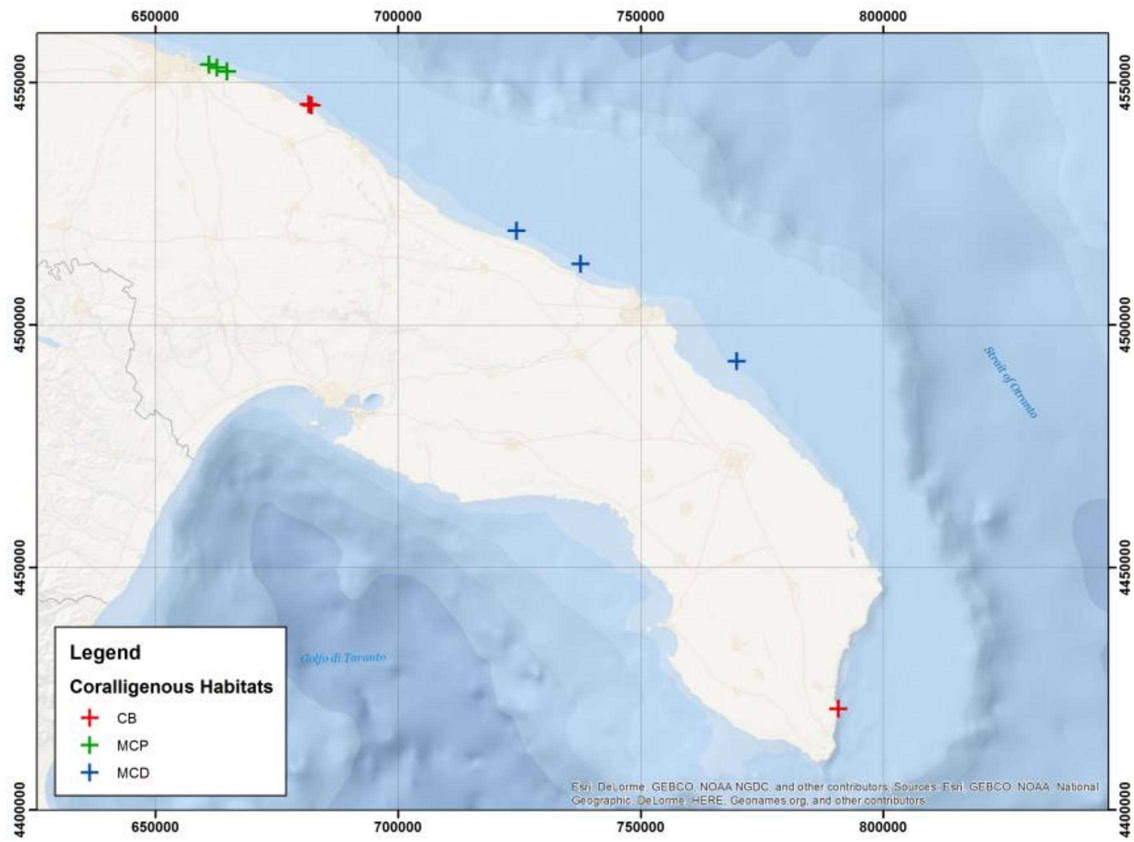

Figure 21 - Distribution of the 9 samples areas used for the analysis

This step started from a selection of testing areas within the huge BioMAP dataset that were representative of each selected CHs (MCP, BC and MCD), matching two main criteria: (1) data resolution (0.30m for MCP and BC, 1m for MCD) and (2) the absence or very low presence of artefacts. In order to respects these conditions 3 testing areas for each CHs were selected from the entire dataset (Fig. 19 and Fig. 21).

The primary goal of the performed methodology was the identification of the Coralligenous morphologies at the best possible resolution. Considering the three dimensional nature of C morphologies, that rise from the seafloor with steep and often sub-vertical flanks and sharp boundaries (Bracchi et al., 2014), the nature of the algorithm chosen to provide the C morphologies extraction, should necessary be powerful enough to discriminate between the typical aspect of CHs and the surrounding seafloor. As previously observed in Chapter 2, the Topographic Position Index (TPI) (Guisan et al., 1999, Weiss, 2000, Wilson & Gallant, 2000) is the best algorithm able to identify positive morphologies on the seafloor. After several analysis using different inner and outer radius, the best solution that improve the CHs identification was the selection of 1 cell for the inner radius and 10 cells for the outer radius. Then, using ArcGIS all the Coralligenous structures were isolated and removed from the DTMs (Fig.22).

A "reference surface" without bioconstructions was created for each DTM through Golden Software Surfer®. The interpolation function, used for the creation of the reference surface, was the natural neighbour (Sibson, 1981). Natural neighbour interpolation algorithm is a weighted average interpolation technique not affected by anisotropy or variation in the data density issues because the selection of the neighbours is based on the configuration of the data (Watson, 1992). It does not infer trends and will not produce peaks, pits, ridges or valleys that are not already represented by the input samples. The surface passes through the input samples and is smooth everywhere except at locations of the input samples. It adapts locally to the structure of the input data, requiring no input from the user pertaining to search radius, sample count, or shape. It works equally well with regularly and irregularly distributed data (Watson, 1992).

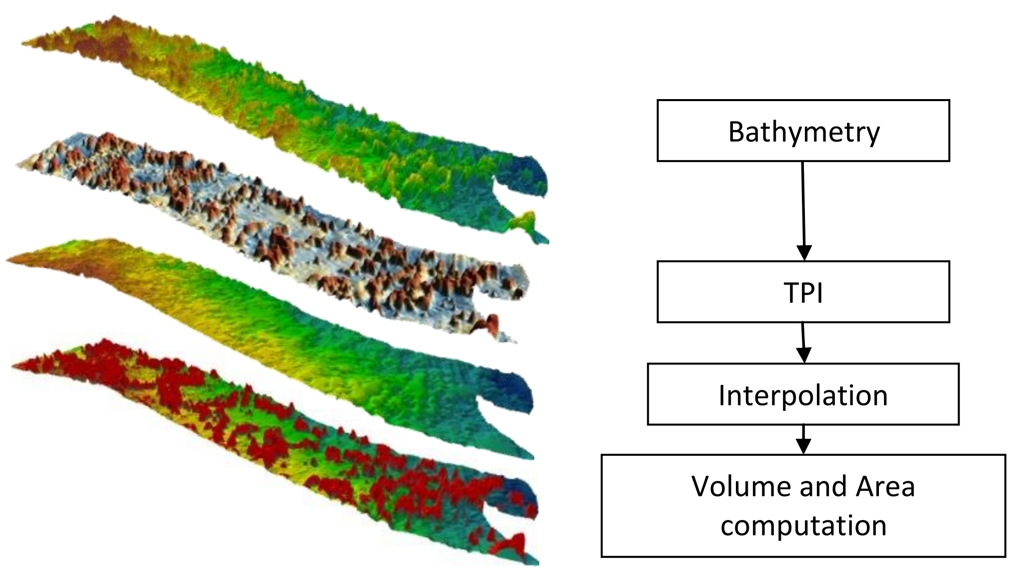

Figure 22 - Key concepts for the volume analysis

3.6 Volume analysis

The last analytical step included the comparison of the analyzed DTMs with the corresponding reference surface in order to calculate the volume of the isolated Coralligenous build-up structures. ArcGIS^{TM} provide a Cut/Fill tool that summarizes the areas and volumes of change from a cut-and-fill operation, i.e. by taking surfaces of a given location at two different time periods, the function will identify regions of surface material removal, surface material addition, and areas where the surface has not changed. To reach that results some conditions for the analyzed DTMs must be respected (ESRI ArcGIS user's guide):

- The Cut/Fill tool enables you to create a map based on two input surfaces (original DTMs and reference surface DTMs).
- Both the input raster surfaces must be coincident. That is, they must have a common origin, the same number of rows and columns of cells, and the same cell size.
- The z units should be the same as the x,y ground units.
- The attribute table of the output raster presents the changes in the surface volumes following the Cut/Fill operation. Positive values for the volume difference indicate regions of the before raster surface that have been cut (material removed). Negative values indicate areas that have been filled (material added).

Since the reference surface were obtained from the analyzed DTMs, all the conditions were respected and the volume calculus was easily performed (Fig. 22 and Table 6).

3.7 Results

Volume calculus performed through the above mentioned analisys (section 3.6) provided quantitative results (tabella risultati) for each CHs selected by TPI algorithms. In order to relate this volume to the entire dataset of the BioMAP project, a ratio value between the total area of CHs mapped by BioMAP project and by the one obtained from the method here presented, was calculated (Table 6).

Mosaic of Coralligenous and Posidonia meadows							
Areas	Polygons Area	BioMAP Area		Average	Biomap MCP total Area	MCP Area	
A1	1439.10	5052.78	28.48%			m^2	Km^2
A2	2957.85	9611.45	30.77%	29.69%	103,871,121.29	30,839,846.44	30.84
A3	1205.37	4042.71	29.82%				
Mosaic of Coralligenous and coastal Detritic							
Areas	Polygons Area	BioMAP Area		Average	Biomap MCD total Area	MCD Area	
A4	8144.00	57616.56	14.13%			m^2	Km^2
A5	24680.00	333964.68	7.39%	12.56%	101,944,115.54	12,809,100.60	12.81
A6	5836.00	36092.31	16.17%				
Coralligenous Biocenosis							
Areas	Polygons Area	BioMAP Area		Average	Biomap BC total Area	BC Area	
A8	4827.06	9871.48	48.90%			m^2	Km^2
A9	3762.45	9438.75	39.86%	43.79%	185,663,885.67	81,295,471.32	81.30
A10	4836.78	11354.40	42.60%				

Table 6 - Area computation results

Each analysed area (A1, A2,...A10), is totally included within the corresponding habitat detected by the BioMAP project. Nevertheless, the applied method selected for each analysed area (ref) the actual C coverage and the associated percentage was calculated. The average percentage obtained from all the areas (corresponding to one of the three CHs) was considered as representative of the real C coverage for the CHs mapped by Biomap project. With the same approach, after this first step, the volume was also estimated for the entire BioMAP dataset, as indicated in table (Table 7).

Mosaic of Coralligenous and Posidonia meadows						
areas	Polygons Area	Volume	Area/Volume	Average	MCP total Area	MCP Volume
A1	1439.10	497.41	2.89			
A2	2957.85	1311.26	2.26	2.62	30,839,846.44 m^2	80,947,833.12 m^3
A3	1205.37	442.27	2.73			
Mosaic of Coralligenous and coastal Detritic						
areas	Polygons Area	Volume	Area/Volume	Average	MCD total Area	MCD Volume
A4	8144.00	2392.70	3.40			
A5	24680.00	4335.00	5.69	4.33	12,809,100.60 m^2	55,405,655.25 m^3
A6	5836.00	1504.28	3.88			
Coralligenous Biocenosis						
areas	Polygons Area	Volume	Area/Volume	Average	BC total Area	BC Volume
A8	4827.06	1875.35	2.57			
A9	3762.45	1425.55	2.64	2.47	81,295,471.32 m^2	200,393,625.56 m^3
A10	4836.78	2216.91	2.18			

Table 7 - Volume computation results

3.8 Discussion

The area/volume computation obtained by the perfomed analysis, allowed also to compare the difference between the maximum (Hmax) and the medium (Hmed) highness of the CHs mapped in each detected polygons. Plotting a normalized frequency distribution of the Hmax-Hmed difference from 0 to 1 m (Fig. 23), allowed the following observation:

- The most part of CHs polygons have a Hmax-Hmed difference less than 10cm, in particular MCD.
- The rest of polygons show a Hmax-Hmed difference ranging from 10 to 50 cm.
- Polygons belonging to MCP are distinctively more abundant than CB, considering the range between 0.2 an 0.5 m (highness difference).

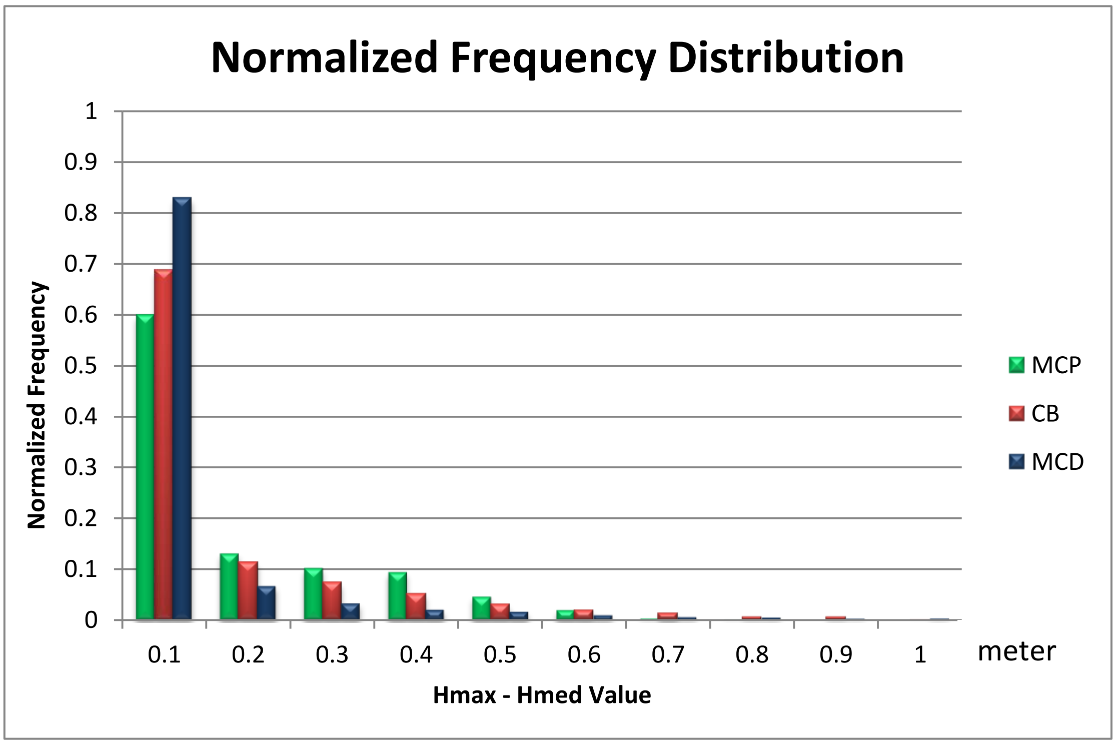

Figure 23 - Normalized frequency distribution plot for the highness value

Such difference has been confirmed also by the cumulative frequency distribution (Fig. 24), where it is evident, for instance, that considering the 80% of the C polygons, MCP reach more than 30cm of highness variation, whereas CB is 15cm and MCD less than 10cm.

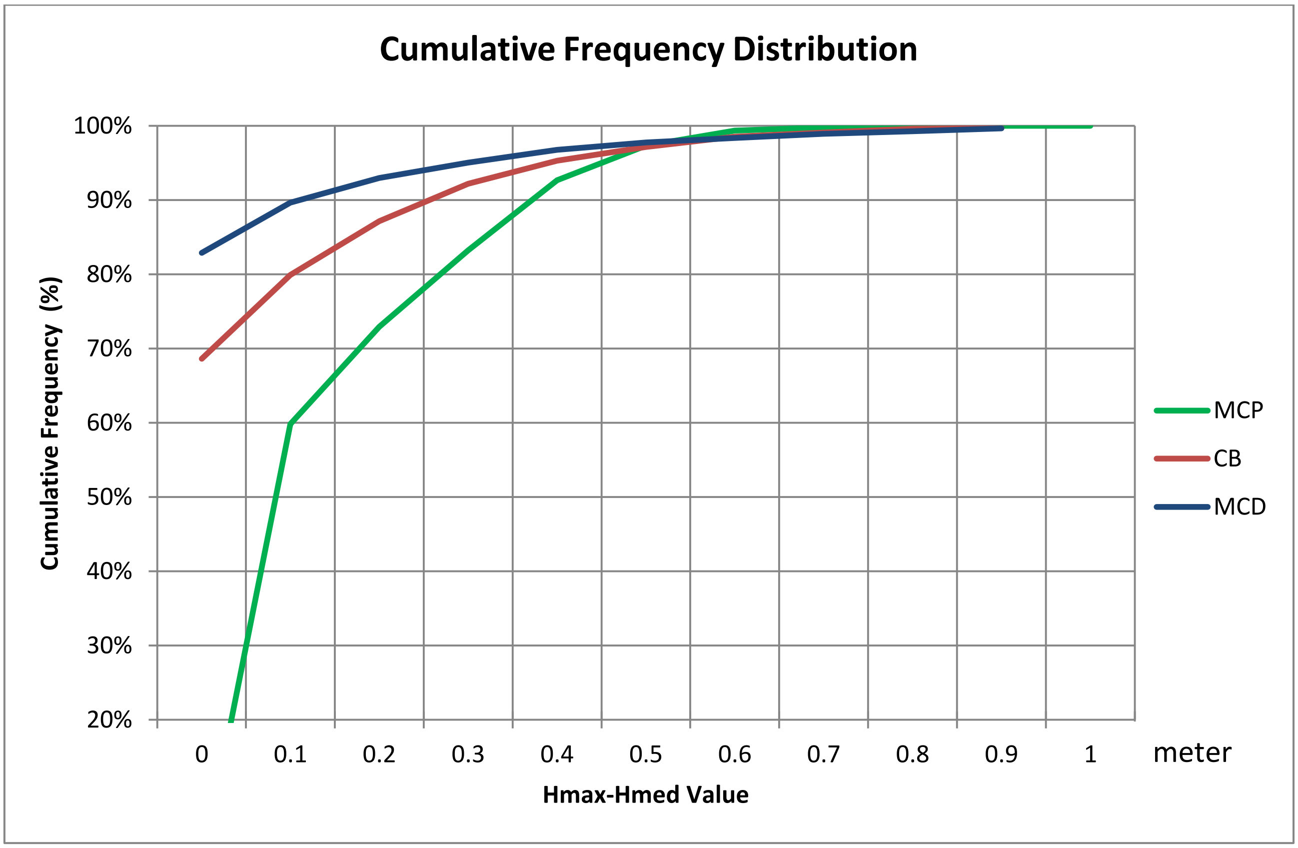

Figure 24 - Cumulative frequency distribution plot for the highness value

MCP polygons show the highest difference between highness value. This may be related to C morphology. Indeed, as well depicted from the studied DTMs, C morphologies within MCP habitat show a minor lateral continuity than the other CHs (CB and MCD) and are more isolated within the entire habitat. These consideration suggest that they are developed more in vertical direction than the horizontal one, forming isolated columns and field of columns (as described by Bracchi et al., 2014).

MCP developed in infralittoral setting, close to Posidonia meadow. Therefore the reason why build-ups are not so big as in the CB, could lay in the competition with *P. oceanica*. Posidonia plants likely obstacle the dominant growth of C.

The Hmax-Hmed frequency distribution graph (Fig. 23) shows a pronounced difference also for the CB, even if not higher as for the MCP. Indeed CB as typified by characteristics bank frameworks (Ballesteros, 2006), where C morphologies are flat, laterally continuous and well developed in highness.

Finally, MCD represents the end-member of the series, showing very low difference in C polygons highness that could be indicative of more rounded morphologies, in particular regarding MCP where there are more polygons whit higher value.

The present results highlight how the different CHs are characterized by distinctive C morphologies, showing that CHs may have a different morphological expression. The observed differences may be related to the different environmental condition in which C build-ups growth. For instance, from MCP through CB to the MCD there is a progressive increase of the depth, and consequently a decrease of light penetration. MCP usually located in the shallowest zone, and develop where also good conditions for seagrass growth are reported. CB develops in deeper bathymetric interval than MCP, where dim light conditions are reported. Moreover such conditions favoured the developed of coralline algae, that are considered the major framework builders (Ballesteros, 2006). MCD represents CH that grow in the deepest bathymetrical area of our dataset (maximum 100m w.d.). Very dim light condition characterize this zone, growth form are more rounded than MCP but not well developed as BC. Other data are actually needed to support the relationships between environmental condition and growth forms in CHs (i.e substrate, ecc...), nevertheless the present work documented for the first time a quantitative relationships between C growth forms and the associated habitats in which they are distributed (that in turn is controlled by environmental conditions).

Chapter 4 - Geomorphological expression of coralligenous habitats: an assessment of seafloor ruggedness and backscatter

4.1 Introduction

The BioMAP project (see Chapter 3, Section 3.1.2), based the production of the maps showing the distribution of coralligenous habitats, on the interpretation of the seafloor backscattering, acquired by means of high frequency SSS. Backscatter deriving from MBES and SSS is indeed largely used in benthic habitat mapping because it allow segmenting the seafloor images in different "texture" that in turn may be associated to different benthic habitats.. Coralligenous habitats along the Apulian coast have been mapped using SSS mosaics, which covered all the surveyed areas. MBES data did not reached the 100% coverage on the surveyed areas, therefore MBES backscatter data were available only for small BioMap project areas .

The present study focused the analysis on MBES backscattering of some selected areas, in order to improve the geomorphological characterization of CHs.

MBES are calibrated to very high standards, and they provide high-resolution bathymetry along with measurements of the variations in returning signal strength (backscatter), which gives indications of geologic materials on the seabed and their acoustic ''hardness''. This backscatter measurements can generally be recorded as: complete backscatter waveforms from each beam (''snapshots"), sidescan-like time series of amplitudes derived from snapshots by combining the backscatter signals from all beams (''sidescan-like"), fragments of the full backscatter envelope around the bottom return signal from each beam (''snippets") and maximum amplitudes from each snippet (i.e. one value per beam).

Another characteristics that was been considered in the C complexity is the ruggedness. This terms is usually associated to the terrain variability group of bathymetric information (Wilson et al., 2007) that had been linked to the distribution of fauna by several researchers (Beck 2000; Kostylev et al. 2005), and, at the appropriate scales, may be a key parameter in distinguishing suitable habitat for particular fauna. At a local level, certain species require a complex habitat with a strong structural component (e.g., rocky outcrops) whilst others tend to occupy flat terrain typical of soft sediment areas. At a broader scale, terrain variability indices reflect variations related to seabed morphology.

This study aims at highlighting the importance of combining acoustic survey techniques and geomorphometric analysis to successfully support a preliminary quantitative assessment of CHs morphological expression and spatial extent in order to offer a relevant contribute to obtain a quantitative description on Coralligenous habitat on the Mediterranean shelf.

4.2 Data origin and location

The marine area analyzed in this work is located on the Apulian continental shelf (Adriatic Sea), between 15 m and 30 m of w.d. and includes two Apulian Sites of Community Interest – SCI ("*Bosco Tramazzone*" and "*Stagni e Saline di Punta della contessa*"), placed approximately at 1.5 nm from the shoreline. Seafloor acoustic data are part of the BioMAP project and were collected in 2008. 3 DTMs at very high resolution (0.5 x 0.5 m grid cell) were selected from the entire BioMAP dataset, called respectively Area 1, 2 and 3 (Fig. 25). MBES backscatter models were produced at the same resolution of the DTMs for each area. Groundtruthing were made by video inspections collected during BioMAP Project (Fig. 20).

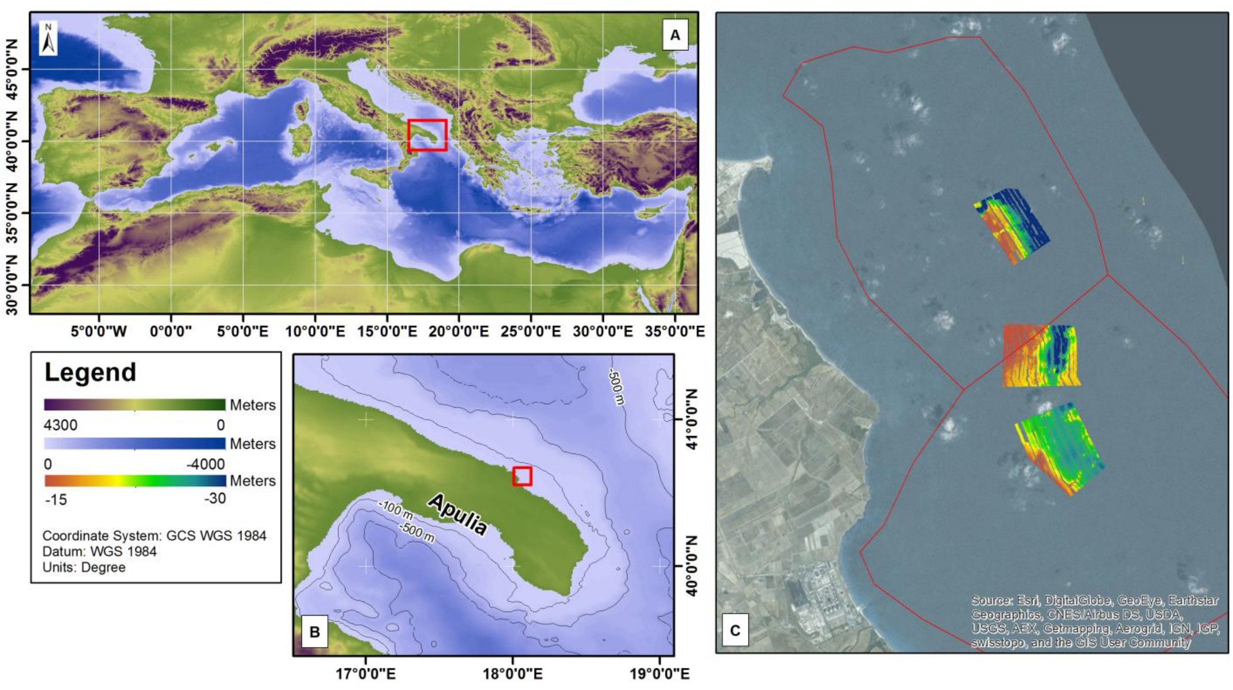

Figure 25 - Geographical settings and location of the 3 DTMs used for the analysis

The survey was carried out on board of the CoNISMa research boat R/V Calafuria ISSEL, with the same configuration adopted for the BioMAP project (see Chapter 2), using a pole-mounted Teledyne Reson

SeaBat 8125 (a 455 kHz MBES) that provides sub-metric depth resolution data. The survey lines were run parallel to the coast without overlap between swaths. Teledyne PDS2000^{TM} software was used to acquire and process bathymetric data producing very high-resolution DTMs (0.5 m x 0.5 m). Backscatter data collected by MBES systems are usually derived from backscatter intensity, the measurement of sound scattered back toward the transmitter by acoustic reflection and scattering (Parnum, 2007). The Reson 8125 was able to log backscatter intensity according two methods: Snippet and Sidescan-like options (RESON, 2002). Snippets are fragments of the complete signal envelope that aim to contain the seafloor backscatter from each beam (Parnum, 2007; De Falco et al., 2010). Bathymetry beams on the port and starboard sides (respectively 0–119 and 120–239 for the sonar used here) are combined to produce the Sidescan-like images. The process combines adjacent pair of beams by averaging and then combining the averages by selecting the brightest points from the averaged beams. The array of intensity values is a series of amplitudes, one for each sample interface for each Sidescan beam (RESON, 2002). Snippet data range corresponds to the bathymetric data.

During this survey only Snippet data were acquired in order to identify different habitat types on the basis of their acoustic response (Fig. 26). Even though various methods to process MBES bathymetry data are well established and implemented in the software provided by the sonar manufacturers, there is no universal, standard approach to process and interpret MBES backscatter data (Parnum et al., 2011).

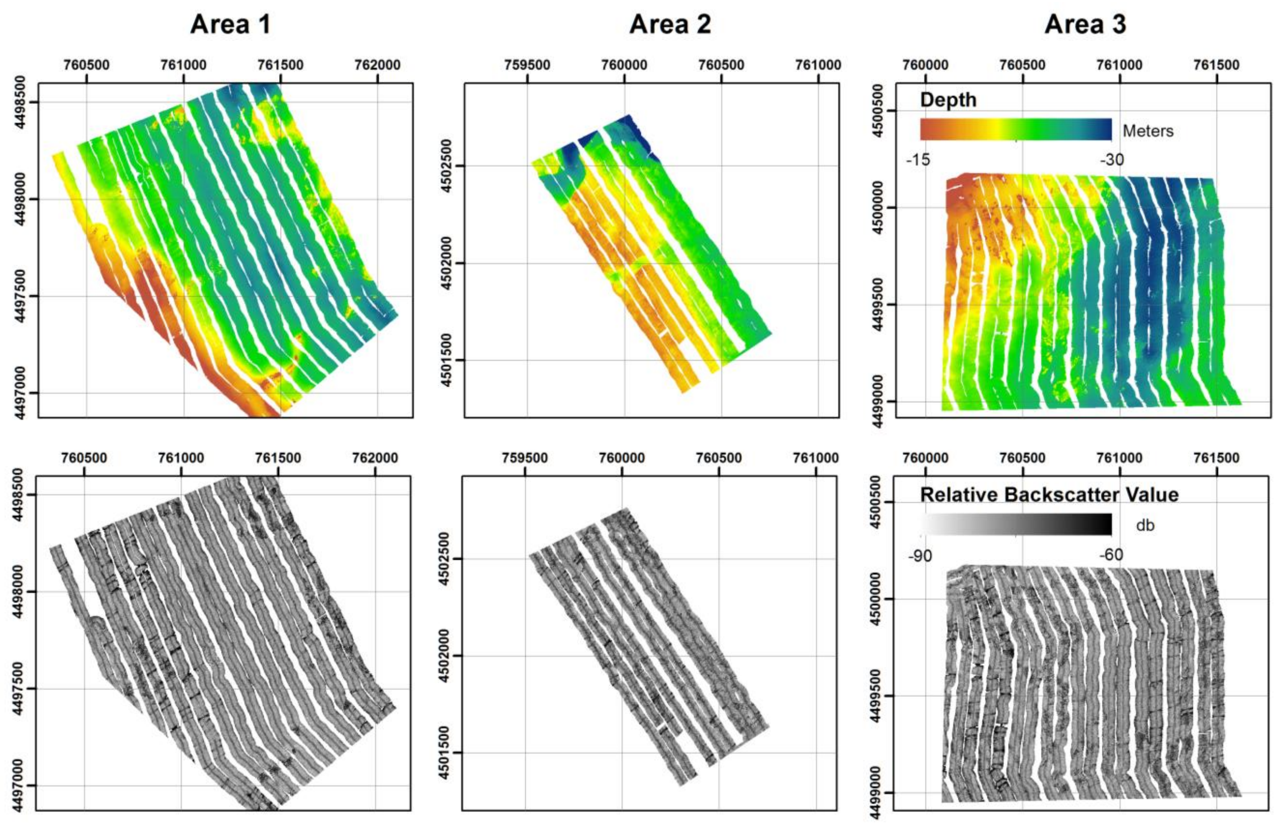

Figure 26 - DTMs and bakcscattering models of the three areas selected

4.2.1 Snippets

Snippets are fragments of the complete series of amplitude values reflected from a beam's footprint signal that aim to contain the seafloor backscatter from each beam. One Snippet is produced for each beam for each sonar pin, with the length of each Snippet varying as a function of the individual beam angle, seafloor depth, and the Snippets operating mode. If the Snippets data for each swath is concatenated, with each individual beam centered at its corresponding bottom detect point (footprint) location, the combined series will provide a result similar to slant range corrected sidescan imagery (Parnum, 2007). The start position of each snippet, known as the fragment offset, and the length (or number of samples) of each snippet is predetermined by the sonar processor based on the estimate of slant range to the edge of the beam footprint on the seafloor. In the Reson 8125, the snippet fragment's start position and length are determined using stepwise functions (RESON, 2002).

4.3 Processing snippets

There are two main approaches to processing MBES snippets data (Parnum, 2007):

1. Determine one backscatter intensity value for each snippet;

2. Use a series of intensity values from each beam.

In the first approach usually either the maximum or average intensity values are calculated for each snippet and the seafloor backscatter strength can be found from the average backscatter intensity based on the energy conservation law and estimates of the transmission loss. Such an approach reduces noise due to stochastic variations of backscatter. However, using one backscatter value for each snippet does not allow resolution of useful backscatter features that may be present within the footprint of individual beams. The use of a series of amplitude values within the beam will offer finer spatial resolution. If all the values in the beam are used, then an image similar to sidescan sonographs can be created, but with a reduction in noise from side-lobes and the water column compared to the actual side-scan recorded.

In this work the MBES snippets was processed using a series of intensity values and Time Varied Gain, Speed correction and Lambert's Law Correction were applied using Teledyne RESON PDS2000™ software.

TVG

The Time Varied Gain applies a variable gain to the sonar data in order to correct the backscatter amplitude for the transmission loss which includes spreading and absorption losses. TVG is a robust approximation to the transmission loss that aids in bottom detection in the real-time processing by equalizing, to some extent, the amplitude of signals received by the system at different angles and distances to the bottom.

Speed Correction

The speed correction applies a variable necessary to compensate changes in the vessel speed. This correction results in a backscatter data with a constant scale of the bottom.

Lambert's Law Correction

The intensity of the reflection will decrease further away from the centre because of the smaller angle with the surface, the reflection will be diffused. With the Lambert's Law correction the intensity of the reflection will be corrected. The correction is a multiplication factor which is related to the angle with the surface.

The MBS used for this study was not calibrated to obtain absolute backscatter levels. Consequently, backscatter data presented are in relative (dB) units and cannot be compared with absolute values reported in other studies. Backscatter absolute values can be obtained from relative values by adding a fixed gain, which is usually unknown for end-users unless the sonar is fully calibrated (Parnum, 2007). However, for the purpose of evaluating the correlation between backscatter and ruggedness data, this study was not affected by the use of relative instead of absolute values. After the processing the backscatter mosaic was been created and exported as an ASCII file extension where the "z" value was represented by the relative backscatter intensity.

4.4 Extraction of Coralligenous features

With the aim of assess the ruggedness and the backscatter proprieties of CHs, the analysis was initially focused on the extraction of the C builds-up structures from the DTMs. This step was performed using geomorphometric analysis techniques in order to extract C polygons containing geomorphometric parameters (Table 8) and backscatter data.

Type of Terrain Analysis	Parameter	Analysis window	Algorithm
Slope	Slope	Rectangular 3x3	Burrough et al., 1998
Orientation	Aspect	Rectangular 3x3	Burrough et al., 1998
Terrain Variability	Terrain Ruggedness Index (TRI)	Rectangular 1x5	Riley et al., 1999

Table 8 - List of geomorphometric parameters used for the analysis

Terrain Ruggedness Index

TRI is a measurement developed by Riley, et al. (1999) for terrestrial ruggedness and subsequently adapted by Valentine et al. (2004) for bathymetry data to express the amount of elevation difference between adjacent cells of a digital elevation grid. The process essentially calculates the difference in elevation values from a centred cell and the eight cells immediately surrounding it.

After the parameters computation the Isocluster Unsupervised Classification (for reference see Chapter 1) performed using slope, TRI and backscatter, was used to extract and classify all of the C build-up morphologies as distinct polygons from the DTM. Successively, an additional analysis was performed in order to find relationships between morphology, ruggedness and backscatter (Fig. 27).

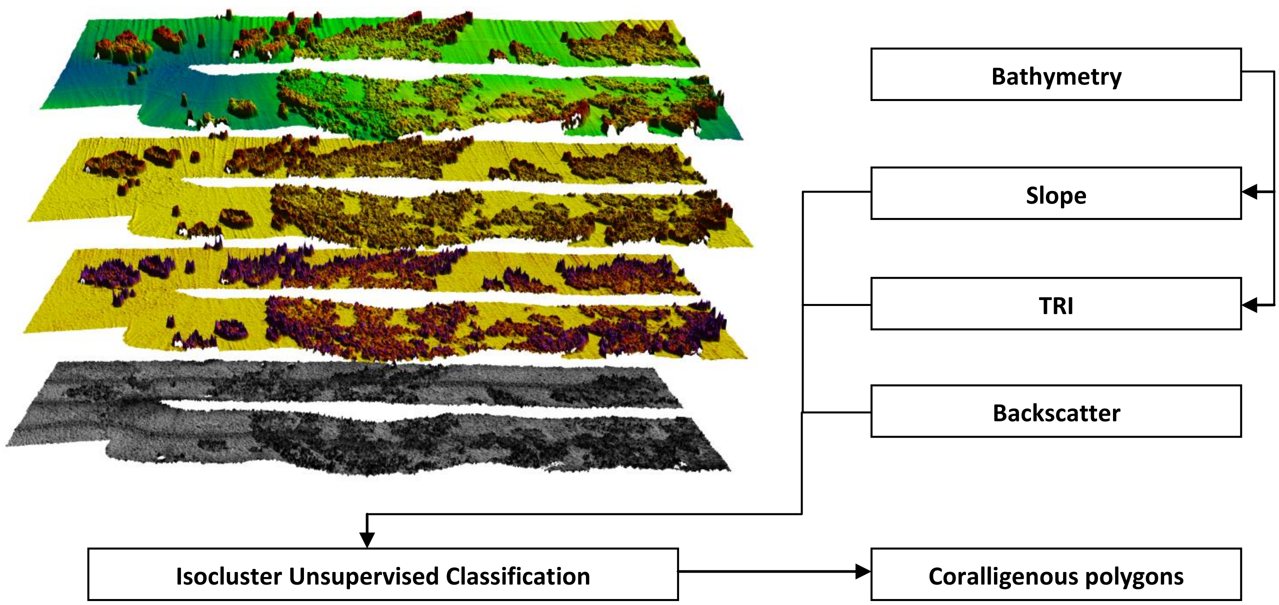

Figure 27- schematic workflow of the analisys performed

4.5 Results

The first results obtained from the above mentioned analysis, provided a number of polygons that were manually filtered in order to delete the ones that were not associated to C morphologies, but due to artefacts created by noisy seafloor models or related to other seafloor structures. The filtered polygons were then analysed in order to extract their main morphometric attributes (Table 9 and Fig. 28).

Results	Area 1	Area 2	Area 3
C polygons identified	907	854	576
C polygons area	105000m^2	187500m^2	250000m^2
Depth range (w.d.)	18-26 m	16-24 m	16-26 m
Highness range	0.8-4 m	0.1-5.6 m	0.3-6 m
Relative Backscatter Intensity range	-67 to -95 db	-84 to -95 db	-77 to -92 db

Table 9 - Summary of the results for each area analyzed

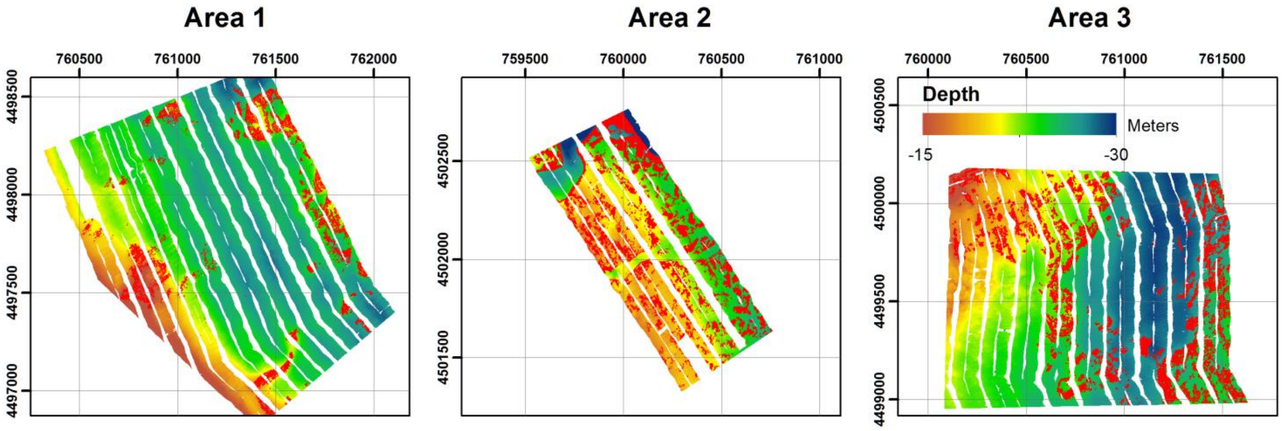

Figure 28 - Coralligenous polygons identifyed by the methodology

The measurements listed in table 8 were used to perform statistical correlation between the morphometric and backscatter characteristics of each C polygon for each area, as presented here after (Section 4.5.1).

4.5.1 Slope, Highness and Area

The three scatterplot obtained by correlation between slope, highness and area showed an almost direct correlation between slope and highness (this latter indicated as meters of depth range in Fig. 29-30-31). The observed correlation actually tends to decline with the increasing of the polygons area. This is consistent with the fact that an higher C structure is also obviously steeper. This does not necessary mean that bigger C structures are flat, but obviously the slope algorithm is more attenuated by the polygons dimension.

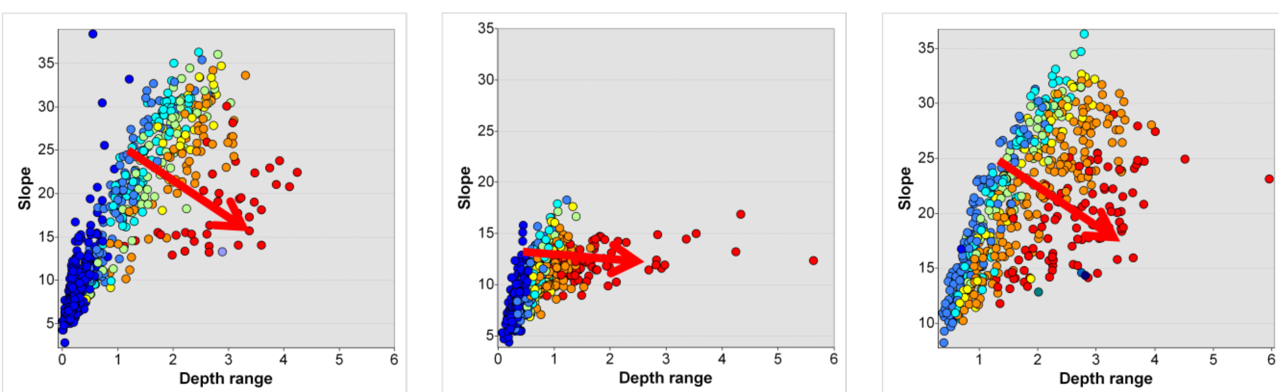

Figure 29 - Correlation scatterplots between slope and highness (depth range) for the three studied areas, colorscale from blue (smaller) to red (bigger) indicate the area dimension

4.5.2 Backscatter, Highness and Area.

The relationship between Backscatter, highness and area is shown in Fig. 30. The scatterplots do not show any relevant correlation between backscatter and highness value; although with the increasing of polygons areas the BS mean values pattern remains concentrated within a quite fixed range (from -87 db to -93 db) throughout all the three areas.

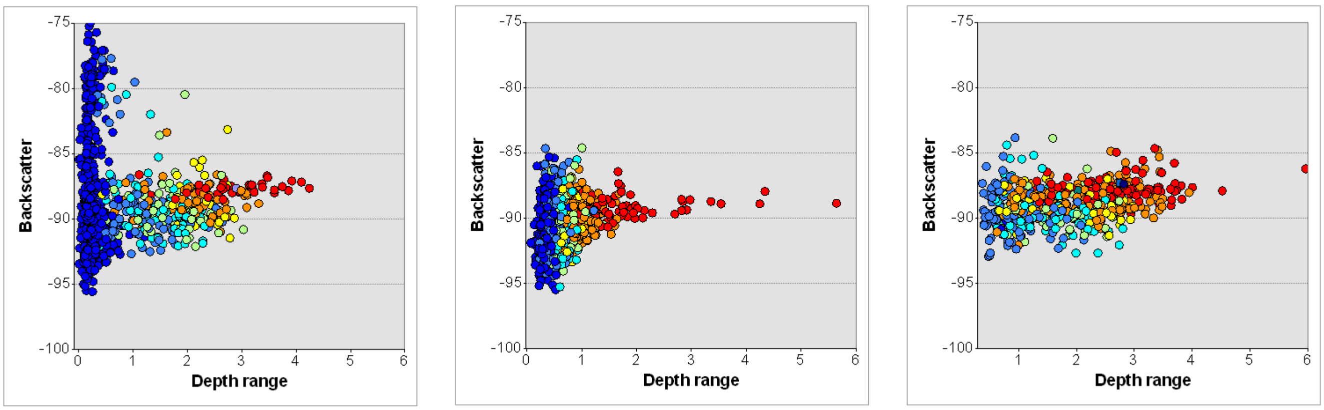

Figure 30 - Correlation scatterplots between backscatter value in relative backscatter intensity (db) and highness (depth range) for the three studied areas, colorscale from blue (smaller) to red (bigger) indicate the area dimension

4.5.3 Terrain Ruggedness Index, Highness and Area.

Similarly to slope (Section 4.5.1), the direct correlation observed between TRI and polygons area tends to decline as the polygons areas increase (Fig. 31). As in the case of the slope (section) the behavior of the observed correlation is related to the variation of C morphologies. Indeed with the increasing of the polygons area the TRI value is less influenced by the steep borders of the C structures.

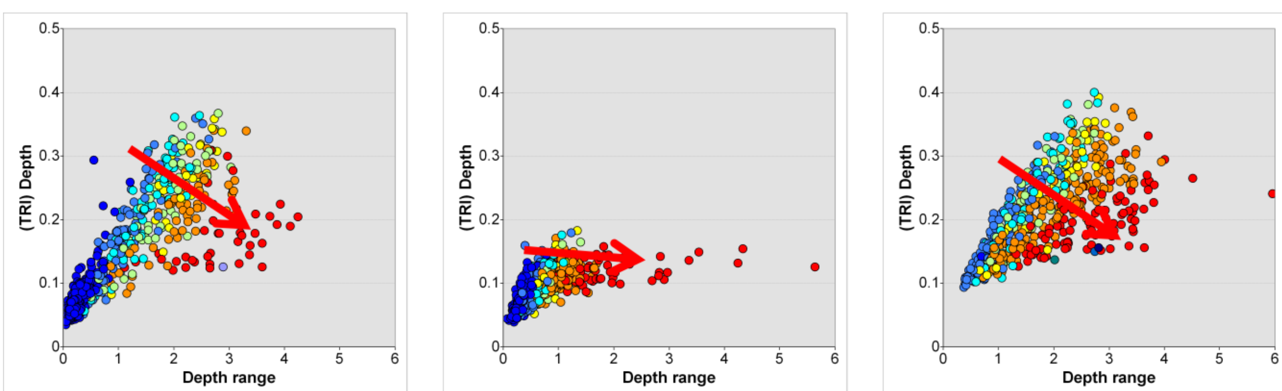

Figure 31 - Correlation scatterplots between TRI value and highness (depth range) for the three studied areas, colorscale from blue (smaller) to red (bigger) indicate the area dimension

4.6 Discussions

The applied methodology documented that the resulted variation in C geomorphometric parameters is strictly correlated to the dimension of the polygons representing C build-ups (i.e. area of C structures), in particular:

1. Based on the Slope and TRI scatterplots (Fig. 29 and Fig. 31), it has been noted that the detected geomorphological complexity of coralligenous features is inferred by the proximity of polygon boundaries to the analysis window.

2. As the polygons area increases, the BS mean values pattern remains concentrated within a quite fixed range throughout all the three areas. This would suggest that a continuous digital model of the seafloor could better define the BS values range of the coralligenous habitat.

The terrain analysis performed within the present study, gives relevant information on the geomorphological characterization of C structures, complexity and distribution. In particular the MBES backscatter data deeply contributed to the analysis, both for feature extraction obtained by isocluster classification and results on geomorphometric characterization. Actually, the main outcomes highlighted that coralligenous features extraction is a complex process, and better and more exploitable results can be obtained from the acquisition of a large dataset able to cover all the extension of C build-ups (in the present study most polygons were sharply interrupted by the lack of adjacent MBES data, this caused also the impossibility to apply further geomorphometric analysis such as the investigation of preferential direction and orientation of C structures).

Conclusion

The scope of this thesis is to assess the application of geomorphometric analysis techniques in improving benthic habitat mapping activities. Such analysis can be very useful in developing predictive habitat models that can be settled "ad hoc" for a given target area or a type of habitat. Geomorphometry is able identify a "geomorphological proxy" used to model habitat distribution, allowing a better understanding of the spatial relationships between habitats an local geomorphology, the one created by habitat itself included.

In addition this type of analysis is able to provide quantitative measurements that can be used for further applications, i.e. Chapter 3, where geomorphometric analysis provided a 3d volume computation and a preliminary assessment on the different morphological expressions of coralligenous habitats.

Generally the methods performed within the present thesis did not focus on the modelling of the distribution of a single species or a defined taxon, therefore they are not perfectly comparable to a typical HSM; in addition other environmental data were not available in order to perform a HSM.

Using only bathymetry, groundtruthing and backscatter, specific geomorphometric techniques and geomorphological analysis were, instead, used to analyze DTMs proprieties and to extrapolate the terrain features associated with habitats.

Usually analysis performed on DTMs are fundamental for HSM, where a multiscale model typically includes all the small-scale terrain variability relevant to the species distribution (Wilson et al., 2007) along with other environmental data (i.e.: currents, seafloor temperature, water density etc...). Within this work, the absence of available environmental data, led to study new "ad hoc" methods, focusing on how seabed topography can influence habitat distribution. Indeed seafloor geomorphology often has a major role in controlling habitat distribution by governing currents regime and therefore the delivery of food particles, sediments distribution and biogeochemical processes at the benthic boundary layer. For this reason the analysis performed within the present work aimed at identify habitat morphologies at the best possible resolution, working on small kernel size for the geomorphometric analysis.

In conclusion the methods developed within the present thesis documented that:

- Geomorphometric analysis techniques can be efficiently used to develop predictive models for habitat distribution, using seafloor geomorphological features associated to benthic habitat occurrences as “proxy”.
- Geomorphometric analysis techniques can offer relevant addition information providing quantitative measurements on seafloor coverage and 3D topographic reconstruction (i.e. volume provided by bioconstructions) of the examined habitats.

The main results provided by the geomorphometric analysis presented within the present thesis produced important advancement of knowledge in the geomorphological characterization of benthic habitats. This improved knowledge can be used to support further geological and/or ecological studies, such as sediment transport processes, quantification of carbonate budget, density of some characteristic species, cover rate of engineer species, habitat structural complexity etc...

Finally the proposed methodologies can support the development of proper monitoring and management programs (i.e. MSFD and MSP), providing instrumental tools and information that can be used to selecting proper sites to be monitored, identify key-parameters to be measured and proposing monitoring guidelines and protocols. Therefore our approach offer an efficient and cost-effective technique for supporting the growing global need for better spatial management of marine environment.

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