Dataset of Submerged Sand Deposits organised in an interoperable Spatial Data Infrastructure (Western Sardinia, Mediterranean Sea)

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Abstract. The expected sea level rise by the year 2100 will determine an adaptation of the whole coastal system and the land retreat of the shoreline. Future scenarios coupled with the improving of mining technologies will favour an increased exploitation of sand deposits for nourishments, especially for urban beaches and sandy coasts with lowlands behind. Objective of the work is to provide useful tools to support planning actions in the management of sand deposits located in the continental shelf of western Sardinia (western Mediterranean Sea). The work has been realized through the integration of data and information collected during several projects. Available data consist of morpho-bathymetric data (multibeam) associated with morphoacoustic (backscatter) data, collected in the depth range -25 to -700 m. Extensive coverage of high-resolution seismic profiles (Chirp 3.5 kHz) have been acquired along the continental shelf. Also surface sediment samples (Van Veen grab and box corer) and vibrocores have been collected. These data allow mapping of the submerged sand deposits with the determination of their thickness and volumes, and their sedimentological characteristics. Furthermore, it is possible to map the seabed geomorphological features of the continental shelf of western Sardinia. All the available data (doi: https://doi.pangaea.de/10.1594/PANGAEA.895430) have been integrated and organized in a geodatabase implemented through a GIS and the software suite Geoinformation Enabling Toolkit StarterKit ® (GET-IT), developed by researchers of the Italian National Research Council for RITMARE project. GET-IT facilitates the creation of distributed nodes of an interoperable Spatial Data Infrastructure (SDI) and enables unskilled researchers from various scientific domains to create their own Open Geospatial Consortium (OGC) standard services for distributing geospatial data, observations and metadata of sensors and datasets.

Data distribution through standard services follows the guidelines of the European Directive INSPIRE (DIRECTIVE 2007/2/EC); in particular, standard metadata describe each map level, containing identifiers such as data type, origin, property, quality, processing processes to foster data searching and quality assessment.

1 Introduction

The sediments used for coastal defence from erosion and flooding have assumed a strategic value in the last decades and they will be even more important in the future considering the expected scenarios of sea level rise.

Several studies have predicted that the global sea-level will rise at 2100 in a range between 530 and 1400 mm (Church 2013; Horton et al., 2014; Kopp et al., 2016; Mengel et al., 2016; Rahmstorf et al., 2007). The predicted sea level rise can determine an adaptation of the whole coastal systems in terms of shoreline retreat and growing risk of coastal flooding (Antonioli et al., 2017). In order to counteract the coastal flooding due to sea level rise, an increasing in the exploitation of Submerged Sand Deposit (SSD) could be necessary, as a strategic resource to carry out coastal protection programmes.

The management of coastal erosion has received greater attention during the past decade (Jimenez et al., 2011).

Several projects funded by the European Commission (Eurosion, Conscience, Micore) were launched to achieve the strategic objective of developing guidelines on sustainable management of coastal erosion in Europe (Marchand et al., 2011). A basic concept of coastal erosion management is the 'favorable sediment status', defined by Eurosion project as the situation where the availability of coastal sediments supports the objective of promoting coastal resilience in general and of preserving dynamic coastlines in particular (Merchand et al., 2011, Gault et al, 2011, Sànchez-Arcilla et al., 2011). Within this framework, the strategic sediment reservoirs are an essential component and they can be used as sediment supply for nourishment as an intervention measure.

The exploitation of SSD can be addressed to: (i) beach nourishments, especially along urban beaches and sandy coasts facing lowlands, and (ii) the reconstruction and recovery of the foredune.

Extensive interventions of beach nourishment based on the massive use of sediments have been carried out in northern and southern Europe and along the United States to tackle problems of erosion (Finkl and Walker 2005; Radermacher et al., 2017; Pranzini 2017; van Egmond et al., 2018). In some cases, these interventions were realized using tens of millions of m³ of sand (Richards et al., 2009). Due to the large volumes of sand required for beach nourishment projects, dredging from the offshore sediment reservoirs is the preferred method of sediment supply. As easily accessible and previously known deposits have been exploited, apparent sand reserves are seen as a dwindling resource that becomes more precious over time (Finkl and Khalil, 2005). In fact, the marine sand deposits on the continental shelves are non-renewable resource. For these reasons, some countries have implemented mapping and characterisation of SSD in order to plan their future exploitation: the characterization of SSD, in terms areal distribution, thickness, grain size and chemical and mineralogical composition, represents the first step of knowledge to plan the exploitation of reservoirs over the next decades, considering the predicted sea level rise scenarios.

Along the Mediterranean Sea, and in particular along the Italian coastline, the characterization of SSD is one of the main objective of the Italian Ministry of Environment that in 2017 issued national guidelines to prevent and protect coasts from erosion and from the effects of Climate Changes (Eurosion, 2004).

Nevertheless, only one examples of planning and management of the SSD can be found along the Adriatic Sea (Correggiari et al., 2011; Correggiari et al., 2013; Paganelli et al., 2014), where a tool named InSAND (Correggiari et al., 2016)) was realized to manage the exploitation of SSD.

In this work, we present a large dataset collected and organised to support the management of the SSD located along the
5   continental shelf of western Sardinia island (Mediterranean Sea).

The dataset results from the integration of geomorphological, seismic and sedimentological data collected in several projects, along the western Sardinian (Italy) margin. A set of maps showing information about thickness, volumes and sedimentological features of SSDs have been produced. They represent a fundamental knowledge to support planning and management actions of marine space and resources. The dataset has been organised following the indication of InSand guide
10   line (Grande et al., 2015) issued by the Italian Ministry of the Environment. Furthermore, all data have been organized and are managed by means of the software suite Geoinformation Enabling Toolkit StarterKit ® (GET-IT), developed by the Italian National Research Council, which facilitates the creation of distributed nodes of an interoperable Spatial Data Infrastructure.

2 Regional setting

15   The sand reservoirs are located along the shelf of the central sector of the western Sardinian margin (western Mediterranean Sea, Fig.1), a passive type margin, tectonically stable since late Quaternary (Lambeck et al., 2011). The morphology of the margin is mainly controlled by tectonic features, and is characterized by a wide amphitheatre facing the Gulf of Oristano, which shows a smooth transition between the 25 km wide continental shelf and the deep basin. The Oristano amphitheatre is bordered to the north and south by a continental shelf which is twice as wide (Sage et al., 2005; De Falco et al. 2015). Along
20   the study area, the Paleozoic–Early Miocene acoustic basement rises and outcrops (Fig.1). Eastwards, a small basin was filled by the Pliocene sequence and westwards the basement is depressed and is overlaid by the Pliocene and Quaternary sequence (Lecca, 2000; De Falco et al. 2015). South of the study area the acoustic basement is tectonically down-thrown and the resulting structural depression is filled by the Miocene sequence, truncated at the top by the Messinian erosional surface and covered by the Pliocene sequence (Lecca et al., 1986).

25   The continental shelf is sediment-starved, with limited land to sea sedimentary run-off. The transgressive deposits associated with the last sea level rise are characterized by siliciclastic sands and calcareous bioclastic sands (Carboni et al., 1989; De Falco et al., 2008; De Falco et al., 2010, De Falco et al., 2015, De Falco et al., 2017) along the inner shelf as well as clays and calcareous mud along the outer shelf (Carboni et al., 1989).

Along wave-dominated and starved shelves, transgressive deposits mainly derive from the re-working of sediments
30   deposited during either low stand conditions of the sea level or the production and re-working of intrabasinal biogenic carbonate sediments.

3 Methods

The thicknesses and volumes of the submerged sand deposits and their sedimentological characterisation were obtained through integration and analysis of available data collected during several projects (MAGIC, RITMARE, SIGLA). Geophysical data were collected during several oceanographic cruises using the CNR research vessels R/V URANIA, R/V

5 MINERVA UNO, R/V THETIS. The sector where the SSD is located is showed in Fig.1. The organisation of the GIS of SSD was based on the GIS architecture developed by Correggiari et al. (2013) for the SSD of Emilia Romagna Region (InSAND project).

To ease processing and data sharing among researchers, all available data were integrated and organized in a geodatabase implemented through a GIS and the software suite Geoinformation Enabling Toolkit StarterKit ® (GET-IT), (Fugazza et al.,

10 2014; Pavesi et al.,2016; Lanucara et al., 2017) developed by researchers of the Italian National Research Council for RITMARE project. GET-IT facilitates the creation of distributed nodes of an interoperable SDI and enables unskilled researchers from various scientific domains, such as geologists, oceanographers, and biologists, to create their own Open Geospatial Consortium (OGC) standard services for distributing geospatial data, observations and metadata of sensors and datasets in an interoperable way. Interoperable SDI approach prevents useless and error-prone duplication of data sources,

15 which are made available (for visualization, access and, if allowed, download) through standard web services, reachable from whichever OGC standard web authorised client.

The following subsections illustrate methods adopted for different data collected in the work. The following subsections illustrate methods adopted for different data collected in the work.

3.1 Multibeam echosounder data

20 Multibeam echosounder (MBES) data were collected along 2400 km^2 of the western continental shelf of Sardinia (Fig. 2) in order to create a detailed bathymetric map, thus providing a Digital Terrain Model (DTM) of the seabed along the mid-outer continental shelf/upper slope sectors. Different MBES devices were used. They include a ResonSeaBat7125 operating at a sonar frequency of 200 – 400 kHz, ResonSeaBat 8111 (100 kHz), Kongsberg EM710 (100 kHz) (see De Falco et al., 2010, 2015, 2017 for a detailed description of MBES and backscatter data acquisition and processing). MBES data allowed the

25 production of the seabed DTM at a resolution of 2.5 m (Fig.3A). Furthermore, a backscatter map (Fig.3B) of relative backscatter intensity values was realized to recognize the morphological features of the seabed. Rocky outcrops and superficial limits of sedimentary bodies were mapped through the interpretation of the DTM with 2.5 m cell size and backscatter map.

MBES data were processed using the software Reson PDS-2000 and DTMs were produced and analysed by using the

30 Golden Software Surfer program and. Global Mapper software.

3.2 Seismic data

More than 100 km of very high resolution seismic data were collected along the study area (Fig. 2) using a Data Sonic Chirp II operating at 3.5 kHz (2.5-7 kHz). The base of SSD was determined from reflection characteristics visible from profiles that were interpreted by means of the GeoSuite® software and calibrated with the vibrocore data.

5 More than 100 km of high-resolution, single-channel seismic profiles were collected in the investigated shelf sector. The technical specifications and the methods of seismic data processing are described in De Falco et al. (2015).

The interpretation of seismic profiles is based on the seismic stratigraphic criteria of Mitchum et al. (1977) and is mostly in accordance with former interpretations reported in the literature on the regional geology (Fais et al. 1996; Lecca 2000; Casula et al. 2001; Conforti et al., 2016). The seismic data analysis and the stratigraphic features of the study site have been

10 described in De Falco et al., 2015 and Conforti et al., 2016.

The maps of seismic facies boundaries has been used as key-beds to define the lower limit of sand reservoirs, called Sand Base (Fig. 4). The Sand Base is the unconformity which separates the transgressive sands deposited during the Holocene from the underlying Pleistocene sediments or Miocene to Pliocene bedrock.

The shape of the Sand Base surface was obtained by interpolating the depth values (referred to the present sea level) of the

15 surface, from each seismic lines, in order to obtain the digital terrain model 10 m cell size of the bottom of sand deposits.

The conversion of two-way travel time to real depth was obtained assuming an average velocity of about 1,550 ms^{-1} within the first 300 ms of seismic record below the sea floor (Carlson et al. 1986; Budillon et al. 2011). The vertical resolution of seismic data is 0.1 m.

20 ### 3.3 Sedimentological data

Sediment samples collected during the oceanographic cruises (Fig. 2) cited above were used to characterize the sandy sedimentary deposits. 149 superficial sediment samples were collected with a Van Veen grab and a Box Corer, whereas 5 sediment cores up to 3 m long where collected by using a vibrocorer (Fig. 2). In all samples, grain-size distribution was measured using dry sieving for the gravel/sand fraction between 4000 and 90 μm at half-phi intervals. Multivariate statistical

25 techniques were used to classify sediment samples into sedimentary facies (De Falco et al., 2015; De Falco et al., 2011; Brambilla et al., 2016; De Muro et al., 2017). The statistical analysis of sediments data was performed by the software Gradistat (Blott and Pye, 2011). Sedimentological data provided the ground-truth observations used to classify the acoustic facies obtained by multibeam bathymetry and backscatter data.

3.4 Thickness and volumes computation

30 The model of the thickness of SSD was created with the GIS spatial analysis tools. The thickness was estimated by subtracting the elevation value of each cell of the DTM of the Sand Base surface from the corresponding cell of the DTM

of the seabed obtained through MBES surveys. The latter DTM was reduced from 2.5 m to 10 m cell size. The volumes were estimated from the digital map of the thickness of each deposit (Fig.5) (Correggiari et al.,2013; Trobec et al., 2018).

The submerged sand deposits recognised were classified in seven hierarchic categories, based on the volume of each deposit as shown in table 1. The sediment volume estimation margin of error was based on the vertical resolution of the seismic data

5   used for surface interpolation (i.e. 0,1 m).

4 Results

4.1 Seabed morphology

The seabed features of the continental shelf of central-western Sardinia, including the distribution of rocky outcrops,

10   sedimentary facies and seagrass meadows is showed in Fig. 6. The map was obtained integrating the geophysical and sedimentological data with the map of seagrass meadow of Sardinia island (Ministero dell'Ambiente e della Tutela del Territorio, 2002), realized in 2002 by the Italian Ministry for the Environment.

The outcropping and rocky basement was recognized mainly in the shelf sector facing the Sinis Peninsula and the Gulf of Oristano down to 150 m of depth. About 40 volcanic cones mounds, sub-circular in plain view (Fig.6), were recognized on

15   the high-resolution DTM in a sector of approx. 40×20 km^2 (Conforti et al., 2016).

Sedimentary basins fill the depressions of the bedrock along the inner shelf. The backscatter data indicates a sharp acoustic contrast of the sedimentary deposits along the basins. The sector reported in Fig. 1 (150 km^2, 25 m to 140 m of depth) was considered the more interesting for the analysis of SSD. Backscatter data, calibrated with sedimentary data, revealed an alternation of low and high backscatter values that reveal the presence of finer sediments alternating with coarse sediments:

20   this sedimentary pattern is associated with the presence of sorted bedforms (De Falco et al., 2015). Lower backscatter values allowed to identify the spatial limits of the finer sediments which corresponds to the transgressive sand layer deposit during the last sea level rise.

4.2 Submerged sand deposit

The features of sand deposits are shown in table1. The sedimentological analysis allowed to characterize the study area and

25   sand reservoirs. Four textural and compositional groups were recognized: (i) muddy sands (CaCO3 66±8%), (ii) fine sands (CaCO3 63±17%); (iii) medium sands (CaCO3 43±29%) and (iv) sandy gravels (CaCO3 14±11%) (see De Falco et al., 2015 for the sedimentary facies classification). This subdivision is also of a spatial nature with the most muddy sediments located in the southernmost sector of the investigated area, the fine sands corresponding to the areas occupied by sorted bedforms and the medium sands located at the mouth of the Gulf of Oristano.

The muddy sands were not considered as potential SSD due to the high average mud content (24±11%). Fine and medium sands were fully characterized because those deposits were sampled by vibrocores. Consequently, the SSD reported in this work are referred to mixed fine and medium sand form whose geophysical and sedimentological data are available.

The stratigraphy of mixed fine and medium sand shows the presence of a few meters of acoustically transparent sedimentary cover, superimposed on a thicker layer formed by sandy gravel.

Twenty-five mixed fine and medium sand deposits have been detected for a total surface of 148 km^2 (Fig. 5). The thickness reaches 4 meters, but is mostly in the range of 1 to 2 meters. The total volume of the superficial sedimentary bodies has been estimated at 130,000 Mm^3.

An identification number (id_n) has been associated with each deposit (Table 1).

The deposits were classified in several categories to facilitate data management and description. Eight deposits category (named Type-n) are recognized based on the volumes value of the single deposit:

- The Type-1 (Volume <0.001Mm^3) consist of 4 deposits (id_01, id_02, id_03 and id_09) that have irrelevant volumes of less than 1000 m^3 each and thicknesses between 0.5m and 1m. These small deposits composed mainly by fine sand, have been mapped to complete the characterization SSD of the studied area.

- The Type-2 (Volume 0.01< 0.06Mm^3)is composed by 6 deposits (id_04, id_08, id_12, id_14, id_16 and id_21), has a total volume of 0.166 Mm^3 corresponding to 0.1% of the total volume detected and has thickness c and ranges from 0.50m to 2m. The deposits of this group cover an area of about 9.8 km^2 and consist mainly of fine and medium-fine sand.

- The Type-3 (Volume 0.10< 0.35 Mm^3) consists of 8 deposits (id_6, id_10, id_11, id_13, id_15, id_17, id_22 and id 23) that contain from 0.11 to 0.32 Mm^3 each, for a total of 1.41 Mm^3. They cover an area of about 3.6 km^2 and range from very fine to medium sand textural groups.

- The Type-4 (1.000 < 1.300 Mm^3) consists of three deposits (id_05, id_18 and id_20) made up of over 1 Mm^3 each, for a total of 3,424 Mm^3. They have a total surface of 6.6 km^2 and are characterized by thicknesses ranging from 0.50m to 3m. These deposits are characterized by fine sands.

- The Type-5 (3.00 < 4.00Mm^3) consists of 2 deposits. The first (id_07) from 3.6 Mm^3 and the second from 3 Mm^3 (Id_19). The two deposits are developed for about 14.6 km^2 and are characterized by thicknesses ranging from 0.5m to 3m, consisting of fine and medium-fine sands.

- Type-6 is represented by a single deposit (id_25) of 8.5 Mm^3, spread over an area of 16.8 km^2. The thickness of this deposit varies from 0.5 m to 2 m. The weaving class of sands from fine to very fine.

- Type-7 (>100 Mm^3) is represented by the biggest single deposit (id_24) which, with its 110 Mm^3, represents 85% of the total volumes measured. It covers an area of 104 km^2 and the thickness varies from 0.5 m to 4 m. The sands of this deposit belong to the fine and very fine dimensional classes.

5 Data availability

The dataset described in this study are publicly available, free of charge, from the PANGAEA data repository with doi: https://doi.pangaea.de/10.1594/PANGAEA.895430.

The dataset presented is referred to the UTM 32N system WGS84 datum and is composed by all data needed to characterize the SSD, as well as the SSD themselves features.

6 Discussion and conclusion

Decision makers who face managing SSD need knowledge that can be derived from complex dataset of geophysical and sedimentological data: in this work we provided an example of organization of such knowledge, collected and delivered in a useful online fashion. A wide portion of continental shelf of western Sardinian margin has been investigated. Along this area several SSD were detected and characterised in terms of grain size, stratigraphy, composition and available volumes.

This deposition area of SSD is located in a small structural basin limited by rocky outcrop, mainly formed by volcanic mounds of Early Pliocene (Conforti et al., 2016 and reference therein).

The mixed fine and medium sands derive from the mixing and winnowing of siliciclastic riverine sediments (De Falco et al., 2015b) with bioclastic sediments derived from marine benthic ecosystems (Posidonia oceanica and coralligenous assemblages) (De Falco et 2017).

The fine and medium sand deposits are associated to submerged depositional terraces characterized by a distinct clinoform pattern and were considered as transgressive deposits related to the last sea level rise (Carboni et al., 1989, De Falco et al., 2015).

The future policy of coastal area and the marine spatial plans will be driven by the expected sea level rise (Finkl and Khalil 2005; Armstrong et al., 2015; Barbanti et al., 2015; Brown et al., 2016) which will strongly influence the measures of protection against coastal flooding (Marchand et al., 2011; Mcglade et al., 2017). The knowledge of SSD location and characterization will be fundamental to plan the sand reservoir exploitation, in order to plan coastal nourishment as protection against flooding.

Furthermore, as recommended by several project funded by European Union Commission (Eurosion; Coscience, Micore) the recognition and classification of strategic sediment reservoirs that can be used as sediment supply for mitigation measures to contrast climate change are the basic concepts of coastal erosion management (Merchand et al., 2011).

Well-curated, federated sources of dataset, organized in SDI, is strategic to provide a means to support of exploitation strategies and the projects that provide use and monitoring of dredging, both during and after mining.

The dataset and the resulting maps of this work have been organized in an interoperable system based on the software suite Geoinformation Enabling Toolkit StarterKit ® (GET-IT) developed by in the frame of Ritmare project, (Fugazza et al.,

2014; Pavesi et al.,2016; Lanucara et al., 2017) which allows data sharing and connection with other spatial data infrastructure. This will facilitate searching, accessing and downloading information for policy makers.

Concluding, this work summarises a large dataset of geophysical and sedimentological data in order to map the spatial features of Submerged Sand Deposits as a tool useful in future climate change scenarios.

5   Author Contributions

BW interpreted geophysical data, modelled the surfaces and thickness, mapped the seabed features, prepared the figures, wrote the manuscript and managed data and metadata handling on the online repository. CA acquired and processed the multibeam dataset and the seismic profiles and managed data and metadata handling on the online repository. SS, acquired and processed the multibeam, seismic and sedimentological data in various campaigns and contributed in writing the manuscript. CP and LS developed the interoperable system based on the software suite Geoinformation Enabling Toolkit StarterKit ® (GET-IT). DFG conceived and managed the study, processed data and contributed in writing the manuscript.

Competing interests

No potential conflict of interest was reported by the authors.

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References

Armstrong, J., Wilby, R., and Nicholls, R. J.: Climate change adaptation frameworks: an evaluation of plans for coastal Suffolk, UK, Nat. Hazards Earth Syst. Sci., 15, 2511–2524, 2015, doi:10.5194/nhess-15-2511-2015.

Barbanti, A., Campostrini, P., Musco, F., Sarretta, A., and Gissi, E.: Developing a Maritime Spatial Plan for the Adriatic-Ionian Region, CNR-ISMAR, 2015, ISBN 978-88-941335-4-7, doi: 10.5281/zenodo.48231.

Blott, S.J., and Pye, K.: GRADISTAT: A grain size distribution and statistics package for the analysis of unconsolidated sediments, Earth Surface Processes and Landforms, 26(11), 1237–1248, 2011, doi:10.1002/esp.261.

Brambilla, W., van Rooijen, A., Simeone, S., Ibba, A., and De Muro, S.: Field observations, coastal video monitoring and numerical modeling at Poetto Beach, Italy, Journal of Coastal Research, 75, 825–829, 2016, doi:10.2112/SI75-166.1.

Brown, J., Ciavola, P., Masselink, G., McCall, R., and Plater, A.: Monitoring and modelling to guide coastal adaptation to extreme storm events in a changing climate, Natural Hazards and Earth System Sciences, 16, 463-467, 2016, doi: 10.5194/nhess-16-463-2016.

Budillon, F., Conforti, A., Tonielli, R., De Falco, G., Di Martino, G., Innangi, S., and Marsella, E.: The Bulgheria canyon-fan A small-scale proximal system in the eastern Tyrrhenian Sea (Italy), Marine Geophysical Researches, 32(1):83-97, 2011.

Carboni, S., Lecca, L., and Ferrara, C.: La discordanza versiliana sulla piattaforma occidentale della Sardegna, Bollettino Società Geologica Italiana 108, 503–519, 1989.

Carlson, R.L., Gangi, A.F., and Snow, K.L.R.:Empirical reflection travel time versus depth and velocity versus depth functions for the deep sea sediments column, J Geophys Res 91:8249–8266, 1986.

Casula. G,Cherchi, A., Montadert, L., Murru, M., and Sarria, E.: The Cenozoic graben system of Sardinia (Italy): geodynamic evolution from new seismic and field data, Mar Pet Geol 18(7):863–888, 2001,doi: 10.1016/S0264-8172(01)00023-X.

Church, J.A., Clark, P.U., Cazenave, A., Gregory, J.M., Jevrejeva, S., Levermann, A.,Merrifield, M.A., Milne, G.A., Nerem, R.S., Nunn, P.D., Payne, A.J., Pfeffer, W.T.,Stammer, D., and Unnikrishnan, A.S.: Sea level change. In: Climate Change 2013: the Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, CambridgeUniversity Press, Cambridge, United Kingdom and New York, NY, USA, 2013.

Conforti, A., Budillon, F., Tonielli, R., and De Falco, G.:A newly discovered Pliocene volcanic field on the western Sardinia continental margin (western Mediterranean), Geo-Mar Lett, 36:1–14, 2016,doi: 10.1007/s00367-015-0428-0.

Correggiari, A., M. Aguzzi, A. Remia, and M. Preti, Caratteristiche sedimentologiche e stratigrafiche dei giacimenti sabbiosi in Mare Adriatico Settentrionale utilizzabili per il ripascimento costiero, Studi costieri 19: 11-31, 2011.

Correggiari, A., Remia, A., Foglini, F., Grande, V., Nicoletti, L., Perini, L., Piazza, R., and Bertaggia, R.: Research and exploitation of shelf marine sand deposit for coastal nourishment: geodatabase guidelines from northern Adriatic Shelf experience, SHAPE - Shaping an Holistic Approach to Protect the Adriatic Environment between coast and sea, IPA Project, Final meeting,Lignano 16-17th Oct., 2013.

Correggiari, A., Perini, L., Remia, A., Luciani, P., Foglini, F., Grande, V., Moscon, G., Calabrese, L., and Lorito, S.: Sistema Informativo per l'utilizzo della risorsa Sabbia offshore nei progetti di protezione costiera: geodatabase in_Sand, Regione Emilia Romagna, technical report, 2016.

De Falco, G., Baroli, M., Cucco, A., and Simeone, S.: Intrabasinal conditions promoting the development of a biogenic carbonate sedimentary facies associated with the seagrass Posidoniaoceanica, Continental Shelf Research 28 (6), 797–812, 2008.

De Falco, G., Tonielli, R., Di Martino, G., Innangi, S., Simeone, S., and Parnum, I.M.: Relationships between multibeam backscatter, sediment grain size, and Posidoniaoceanica seagrass distribution, Continental Shelf Research 30, 1941–1950, 2010.

De Falco, G., Budillon, F., Conforti, A., Di Bitetto, A., Di Martino, G., Innangi, S., Simeone, S., and Tonielli R.: Sorted bedforms over transgressive deposits along the continental shelf of western Sardinia (Mediterranean Sea), Marine Geology, 359 (2015) 75–88, 2015.

De Falco, G., Molinaroli, E., Conforti, A., Simeone. S., and Tonielli. R.: Biogenic sediments from coastal ecosystems to beach–dune systems: implications for the adaptation of mixed and carbonate beaches to future sea level rise,Biogeosciences, 14, 3191–3205, 2017,doi:10.5194/bg-14-3191-2017.

De Muro, S., Ibba, A., Simeone, S., Buosi, C. and Brambilla, W.: An integrated sea-land approach for mapping geomorphological and sedimentological features in an urban microtidal wave-dominated beach: a case study from S Sardinia, western Mediterranean, Journal of Maps, 13:2, 822-835, 2017, doi: 10.1080/17445647.2017.1389309.

Emery, K.O.: Relict sediments on continental shelves of the world, American Association of Petroleum Geologists Bulletin 52, 445–464, 1968.

Eurosion: A guide to coastal erosion management practices in Europe, Eurosion project, 30 June 2004, URL: http://www.eurosion.org.

Fais, S., Klingele, E.E., and Lecca, L.: Oligo-Miocene half graben structure in western Sardinian Shelf (western Mediterranean): reflection seismic and aeromagnetic data comparison, Mar Geol 133:203–222, 1996, doi:10.1016/0025-3227(96)00030-8.

Finkl, C.W. and Khalil, S.: Offshore exploration for sand sources: General guidelines and procedural strategies along deltaic coasts. Journal of Coastal Research, SI(44), 203–233. West Palm Beach (Florida), ISSN 0749-0208, 2005.

Finkl, C.W., Walker, H.J.: Beach Nourishment, Encyclopedia of Coastal Science, Encyclopedia of Earth Science Series, Springer, Dordrecht, 2005, ISBN978-1-4020-1903-6, ISSN1388-4360.

Folk, R. L., and Ward, W.: Brazos river bar: A study in the significance of grain size parameters, Journal of Sedimentary Petrology, 27(1), 3–26l, 1957.

Fugazza, C., Oggioni,A., and Carrara, P.: RITMARE: Linked Open Data for Italian Marine Research", ERCIM-News, No. 96 (January 2014), pp. 17-18, 2014, ISSN0926-4981.

Gault, J., O'Hagan, A.M., Cummins, V., Murphy, J., and Vial, T.: Erosion management in Inch beach, South West Ireland, Ocean and Coastal Management, 54 (12), 930-942, 2011.

Grande, V., Proietti, R., Foglini, F., Remia, A., Correggiari, A., Paganelli, D., Targusi, M., Franceschini, G., La Valle, P., Berducci, M.T., La Porta, B., Lattanzi, L., Lisi, I., Maggi, C., Loia, M., Pazzini, A., Gabellini, M., and Nicoletti L.: Sistema Informativo per il monitoraggio ambientale della risorsa sabbia offshore nei progetti di protezione costiera: geodatabaseEnv_Sand. ISPRA, Manuali e Lineeguida, 127/2015: 63 pp., 2015, ISBN 978-88-448-0742-9.

Horton, B.P., Rahmstorf, S., Engelhart, S.E., and Kemp, A.C.: Expert assessment of sea-level rise by AD 2100 and AD 2300, QuatSci Rev. 84, 1 e 6, 2014.

Khalil, S.M., and Finkl, C.W.: Spoil or Resource? Managing sediment for coastal restoration, Journal of Coastal Research, SI 64 (Proceedings of the 11th International Coastal Symposium), Szczecin, Poland, 2011, ISSN 0749-0208.

Jiménez, J.A, Gracia,V., Valdemoro,H.I., Mendoza T., and Sánchez-Arcilla A.: Managing erosion-induced problems in NW Mediterranean urban beaches, Ocean & Coastal Management, 54, 907-918, 2011.

Kopp, R.E., Kemp, A.C., Bittermann, K., Horton, B.P., Donnelly, J.P., Gehrels, W.R.,Hay, C.C., Mitrovica, J.X., Morrow, E.D., and Rahmstorf, S.: Temperature-drivenglobal sea-level variability in the Common Era, PNAS E1434eE1441, 2016,doi: 10.1073/pnas.1517056113.

Lambeck, K., Antonioli, F., Anzidei, M., Ferranti, L., Leoni, G., Scicchitano, G., and Silenzi, S.: Sea level change along Italian coast during Holocene and a projection for the future, Quat. Int. 232(1e2), 250e257, 2011,doi: 10.1016/j.quaint.2010.04.026

Lanucara, S., Oggioni, A., Modica, G., Carrara, P.: Interoperable Sharing and Visualization of Geological Data and Instruments: A Proof of Concept, Computational Science and Its Applications – ICCSA 2017, Lecture Notes in Computer Science, vol 10407, 2017,doi:10.1007/978-3-319-62401-3_42.

Lecca, L.: La piattaforma continentale miocenico-quaternaria del margine occidentale sardo: blocco diagramma sezionato, Rendiconti Seminario Facoltà di Scienze Università di Cagliari 70 (1), pp. 49–70, 2000.

Lecca, L., Carboni, S., Scarteddu, R., Sechi, F., Tilocca, G., and Pisano, S.: Schema stratigrafico della piattaforma continentale occidentale e meridionale della Sardegna, Memorie Società Geologica Italiana 36, 31–40, 1986.

Marchand, M., Sanchez-Arcilla, A., Ferreira M., Gault, J., Jiménez, J.A., Markovic, M., Mulder, J., van Rijn, L., Stanic, A., Sulisz, W., and Sutherland, J.: Concepts and science for coastal erosion management e An introduction to the CONSCIENCE framework, Ocean & Coastal Management 54 (2011) 859e866, 2011,doi: 10.1016/j.ocecoaman.2011.06.005.

Mcglade, K., Barquet, K., Bogaard, T., Ciavola, P., van Dongeren, A., Ferreira, Ã., Higgins, R., Martinez, G., McCall, R., Stelljes, N., and Viavatenne, C.: Resilience-Increasing Strategies for Coasts - toolKIT (RISC-KIT), Synthesis Report, 2017.

Mengel, M., Levermann, A., Frieler, K., Robinson, L., Marzeion, B., and Winkelmann, R.: Future sea level rise constrained by observations and long-term commitment, PNAS 113, 10, 2016.

MINISTERO DELL'AMBIENTE E DELLA TUTELA DEL TERRITORIO.: Mappatura delle praterie di Posidonia oceanica lungo le coste della Sardegna e delle piccole isole circostanti, Ministero dell'ambiente e tutela del territorio e del mare, 2002.

Mitchum, R.M.Jr., Vail, P.R., and Sangree, J.B.: Seismic stratigraphy and global changes of sea level. Part 6. Stratigraphic interpretation of seismic reflection patterns in depositional sequences, AAPG Mem 26:117–133, 1977, doi:10.1306/M26490C8.

Paganelli, D., La Valle, P., Ercole S., Lisi, I., Teofili, C., and Nicoletti, L., 2014 - Guidelines for environmental studies related to the construction of coastal defence works, ISPRA, Handbooks and Guidelines 105 bis: 69 pp , 2014.

Pavesi, F., Basoni, A., Fugazza, C., Menegon, S., Oggioni, A., Pepe, M., Tagliolato, P., and Carrara, P.: EDI - A template-driven metadata editor for research data, Journal of Open Research Software, 4: e40, 2016, doi: 10.5334/jors.106.

Pranzini, E.: Coastal erosion and shore protection: A brief historical analysis, Journal of Coastal Conservation, 2017, doi: 10.1007/s11852-017-0521-9.

Radermacher, M., Geerlof, W., de Schipper, M., Huisman, B., Aarninkhof, S., andReniers, A.: Evolution of alongshore bathymetric variability around a mega-scale beach nourishment, In T. Aagaard, R. Deigaard, & D. Fuhrman (Eds.),

5   Proceedings of Coastal Dynamics 2017: Helsingør, Denmark, pp. 1370-1375, 2017.

Rahmstorf, S.:A semi-empirical approach to projecting future sea-level rise, Science 315, 368e370, 2007.

Richards, J.A., and Nicholls, R.J.: Impacts of climate change in coastal systems in Europe. PESETA-Coastal Systems study, European Commission, Institute for Prospective Technological Studies, Joint Research Centre EUR 24130 EN, 2009, doi: 10.2791/3558, ISBN 978-92-79-14627-5, ISSN 1018-5593.

10   Sage, F., Von Gronefeld, G., Déverchère, J., Gaullier, V.,Maillard, A., and Gorini, C.: Seismic evidence for Messinian detrital deposits at the western Sardinia margin, northwestern Mediterranean, Marine and Petroleum Geology 22, 757–773, 2015.

Sánchez-Arcilla, A., Jiménez, J.A., and Marchand, M.: Managing coastal evolution in a more sustainable manner. The Conscienceapproach, Ocean & Coastal Management, 54, 951-955, 2011.

15   Trobec, A., Busetti, M., Zgur, F., Baradello, L., Babich, A., Cova, A., Gordini, E., Romeo, R., Tomini, I., Poglajen, S., Diviacco, P., and Vrabec, M.: Thickness of marine Holocene sediment in the Gulf of Trieste (northern Adriatic Sea), Earth Syst. Sci. Data, 10, 1077–1092, 2018, doi: https://doi.org/10.5194/essd-10-1077-2018.

van Egmond, E.M., van Bodegom, P.M., Berg, M.P., Wijsman, J.W.M., Leewis, L., Janssen, G.M., and Aerts, R.: A mega-nourishment creates novel habitat for intertidal macroinvertebrates by enhancing habitat relief of the sandy beach, Estuarine,

20   Coastal and Shelf Science 207 (2018) 232e241, 2018, doi: 10.1016/j.ecss.2018.03.003.

Figure 1: (A) Location of the study area and schematic geomorphological map; (B) Geographic surroundings of the study area;(C) Regional map.
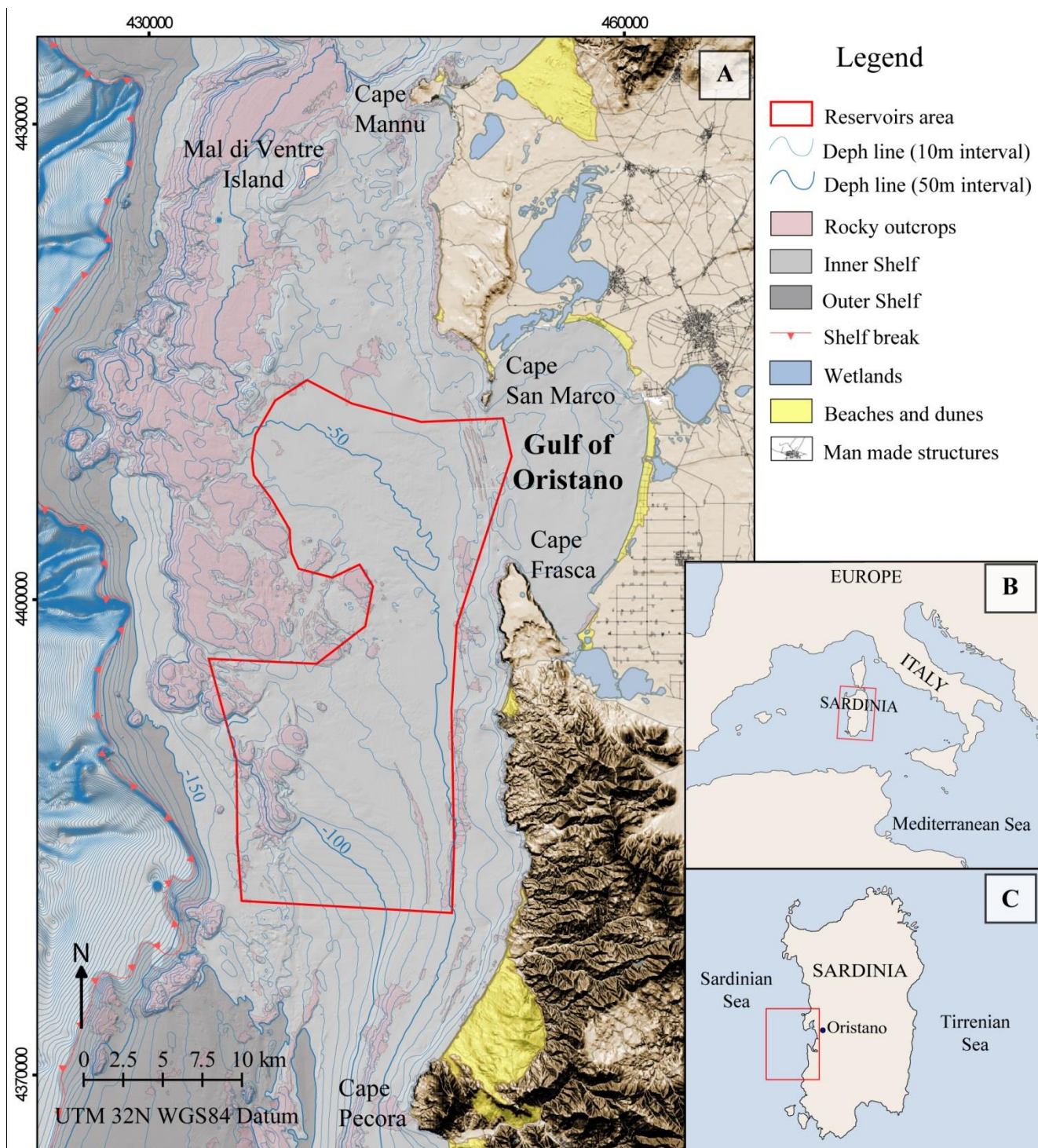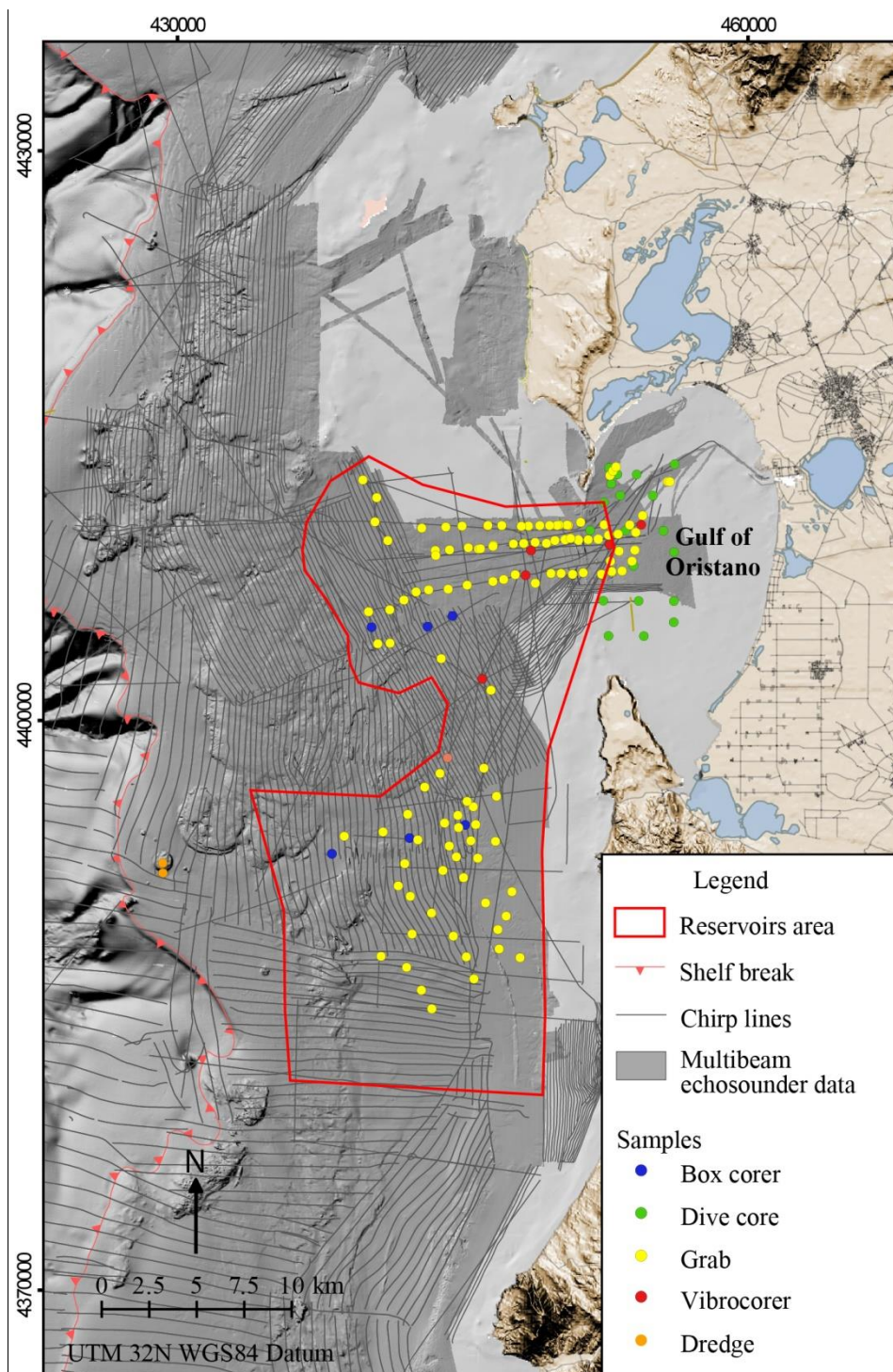
Figure 2: Locations of acquired datasets.
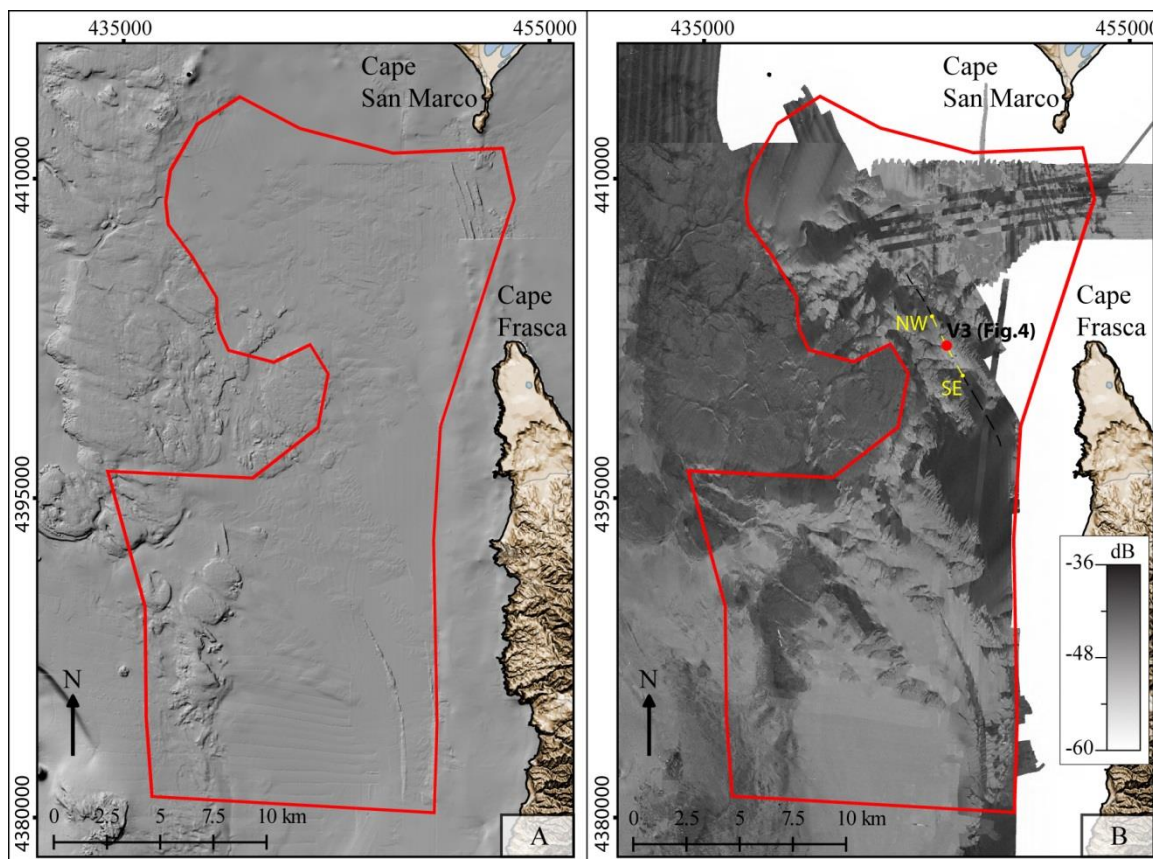
Figure 3: A) Shaded relief map of digital terrain model of the study sector; (B) distribution of relative backscatter intensity values of the same sector.
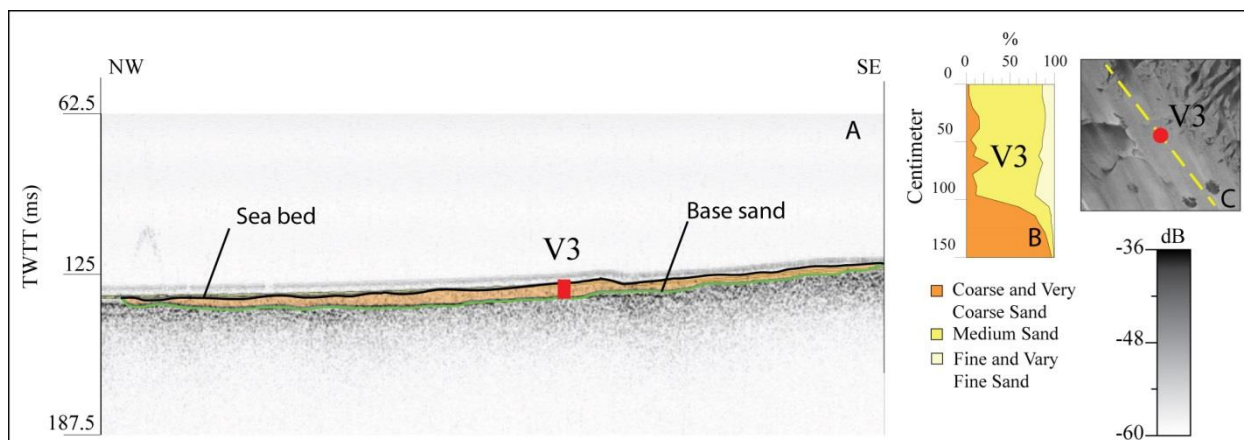
Figure 4: (A) Example of digitization of the sand base in a chirp profile which is correlated with the core V3; (B) stratigraphic profile of the cores located on the chirp profile; (C) relative backscatter intensity value.
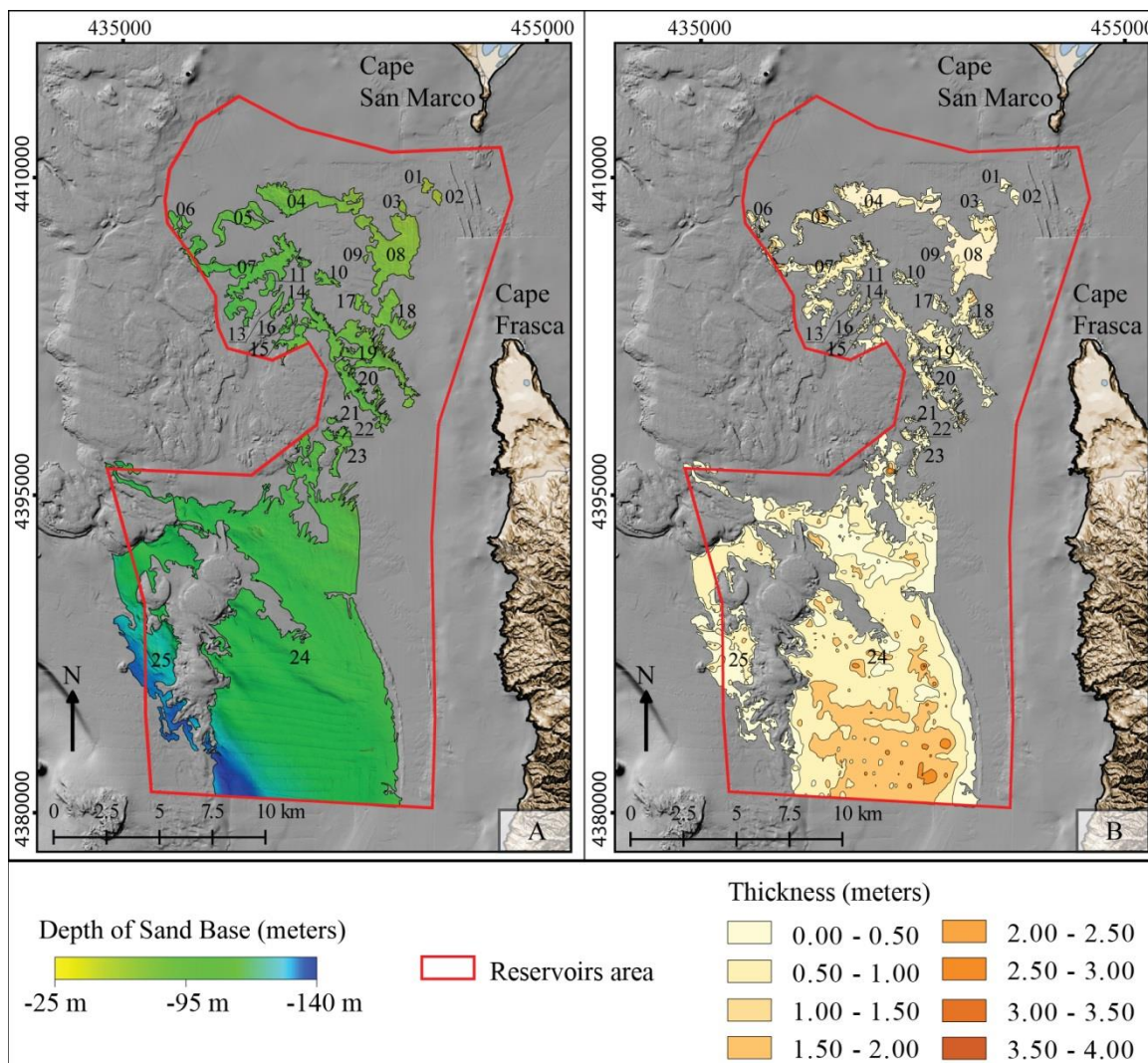
Figure 5: (A) Digital terrain model of the sand base; (B) thickness map of Submerged Sand Deposits (SSD).
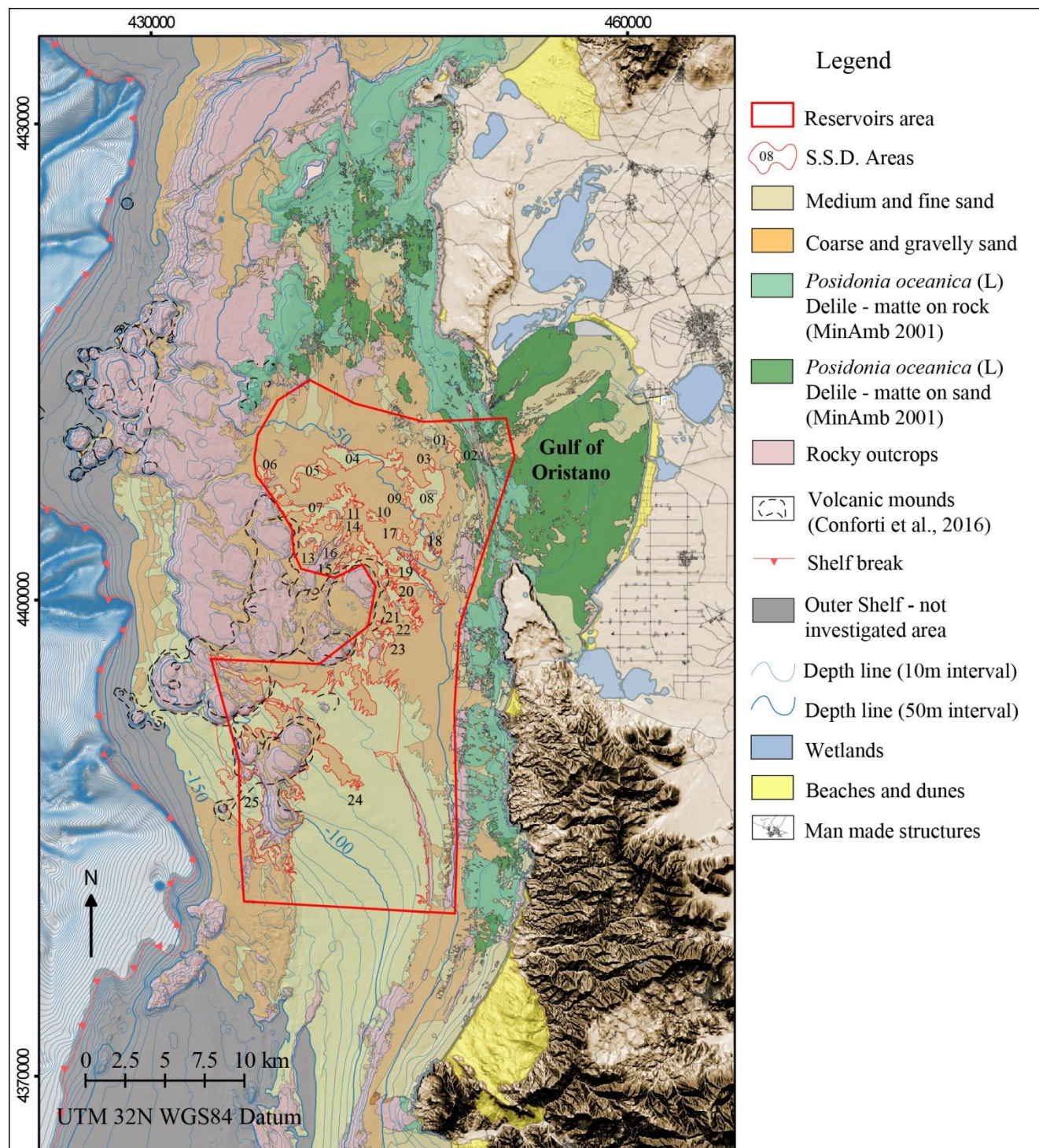
Figure 6: Map of seabed features of the continental shelf of central-western Sardinia.

Name_id	Perimeter (km)	Volume (m³)	Sand class (Falk and Ward 1957)	Type
01	2.7 km	$< 1 \times 10^3 \pm 100$	Fine sand	1
02	2.0 km	$< 1 \times 10^3 \pm 100$	Fine sand	1
03	2.0 km	$< 1 \times 10^3 \pm 100$	Fine sand	1
04	2.2 Km	$3.7 \times 10^3 \pm 370$	Medium fine sand	2
05	13.0 km	$1285 \times 10^3 \pm 120000$	Medium fine sand	4
06	6.5 km	$312 \times 10^3 \pm 30000$	Medium fine sand	3
07	45.8 km	$3600 \times 10^3 \pm 360000$	Medium fine sand	5
08	20.0 km	$16 \times 10^3 \pm 1600$	Fine sand	2
09	1.0 km	$< 1 \times 10^3 \pm 100$	Fine sand	1
10	5.7 km	$146 \times 10^3 \pm 14000$	Fine sand	3
11	3.5 km	$161 \times 10^3 \pm 16000$	Fine sand	3
12	1.8 km	$13 \times 10^3 \pm 1300$	Fine sand	2
13	3.5 km	$115 \times 10^3 \pm 11500$	Fine sand	3
14	2.7 km	$56 \times 10^3 \pm 5500$	Fine sand	2
15	3.6 km	$110 \times 10^3 \pm 11000$	Fine sand	3
16	1.2 km	$7.6 \times 10^3 \pm 760$	Fine sand	2
17	4.1 km	$115 \times 10^3 \pm 11500$	Fine sand	3
18	12.1 km	$1118 \times 10^3 \pm 111000$	Fine sand	4
19	65.5 km	$3003 \times 10^3 \pm 300000$	Fine sand	5
20	29.1 km	$1021 \times 10^3 \pm 10000$	Fine sand	4
21	2.6 km	$36 \times 10^3 \pm 3600$	Fine sand	2
22	2.5 km	$127 \times 10^3 \pm 12000$	Fine sand	3
23	11.0 km	$322 \times 10^3 \pm 30000$	Fine sand	3
24	165.3 km	$11038 \times 10^3 \pm 1104000$	Fine / very fine sand	7
25	72.5 km	$8471 \times 10^3 \pm 800000$	Fine / very fine sand	6

Table 1:Submerged Sand Deposit features.