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ENVIRONMENTAL TECHNOLOGIES TO SAFEGUARD COASTAL HERITAGE

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Abstract

In recent years, an increasing awareness of the importance of the coastal heritage has been raised. Coastal zones represent the interface between land and sea, and are characterized by ecosystems, natural resources, historical urban centres and traditions. During the last decades, both human activities conducted in coastal areas and the occurrence of natural hazards have increased their vulnerability. Thus, coastal management plans have been developed, focusing on the safeguard and enhancement of cultural and environmental heritage of these areas. For this purpose, several technologies have been proposed. The present paper discusses on the main critical issues affecting coastal heritage, paying attention to the coast of the Apulian region, in southern Italy. The most widely used technologies and the last frontiers to safeguard coastal areas are presented and some recent results in their application are shown.

Keywords

Coastal heritage, environmental technologies, vulnerability, Apulian coastline

1. *Introduction*

Coastal areas are a rich and valuable natural resource providing several important functions (Costanza, D'Arge, De Groot, Farber, Grasso, Hannon, Limburg, Naeem, O'Neill, Paruelo, Raskin, Sutton, & Van den Belt, 1997; Beaumont, Austen, Atkins, Burdon, Degraer, Dentinho, Derousd, Holmf, Hortong, Van Ierlandh, Marboef, Starkeyi, Townsenda, & Zarzyckij, 2007). Mud flats, salt marshes, sandy beaches and dunes have specific effects on the wildlife. As an example, dunes are an excellent natural flood barrier, while salt marshes absorb wave energy during storm surges, thereby counteracting erosion. Coastal waters have biological productivity and serve as spawning grounds and nurseries for many fish and invertebrates, including oceanic fish species (Elliott & Dewailly, 1995; Beck, Heck, Able, Childers, Eggleston, Gillanders, Halpern, Hays, Hoshino, Minello, & Orth, 2001; Able, 2005; Elliott, Cutts, & Trono, 2014).

The coastal environment is a dynamic ecosystem in which natural and anthropogenic processes interact, modifying its geomorphological, physical and biological characteristics. The most vulnerable territories, where such evolutions are greatly evident, are sandy coasts (D'Antoni, Battisti, Cenni, & Rossi, 2011; Boero, Foglini, Fraschetti, Goriup, Macpherson, Planes, Soukisann, & CoCoNet Consortium, 2016). The dynamic action of the sea (currents, tides, waves, storms) involves a continuous movement of sediments. As a result, coastal lands show continuous changes, with variations in the shoreline and in seasonal oscillations characterizing the cycle of emergent/submerged beaches.

In this fragile equilibrium, human interventions are crucial. The natural supply of sediments by rivers is often reduced, due to the installation of crossing barriers along their courses. As well, also maritime works, such as piers or breakwaters, generally intercept coastal currents and suspended sediments, thus creating preferred paths to sediments and modifying their deposition areas.

Even if highly vulnerable to natural hazards, including marine inundation, flooding and drainage problems, storm impacts, sea-level rise, and coastal erosion, coastal areas are the site of intense residential and commercial development which often makes them even more vulnerable. Consequently, the understanding of their continuous evolution represents a challenge for coastal communities. In fact, coastal regions provide goods and services with high monetary value and are used by many different stakeholders, e.g. for fishing and aquaculture, energy production, housing, military purposes, leisure and tourism, water supply, wastewater treatment, transportation of goods and people, construction, harbours and more. For all these reasons, coastal environments are often densely populated. They concentrate around 2/3 of the world population and, in many countries, support a flourishing tourist activity, especially along beaches and beautiful coastlines (Clark, 1995). Precisely, although the coastal zone (including land within 100 km from the coastline) only accounts for 20% of all land area in the world, it is inhabited by 41% of the world population and the population density will likely increase dramatically within the next decades (Martínez, Intralawan, Vázquez, Férez-Maqueo, Sutton, & Landgrave, 2007).

Because of the dense population and of the uses to which it is subjected, the coast is usually affected by pollution problems (Hinrichsen, 1999). The numerous activities involving coastal areas put the natural and cultural resources under heavy environmental pressure and place high demands on politicians and coastal managers, who need suitable tools to facilitate decision-making.

Accidental and illegal oil pollution constitutes a major threat to the marine environment. With information on oil slick location, extent, thickness, and expected drift direction, the response team can plan effective countermeasures to mitigate the effects of devastating pollution on the marine environment (De Carolis, Adamo, Pasquariello, De Padova, & Mossa, 2013; De Padova, De Serio, Mossa, & Armenio, 2017).

In recent years, considerable attention has been paid to the preservation and enhancement of coastal areas, also to ensure the coastline cultural and environmental heritage conservation. In all countries, land and sea represent an important part of cultural resources and require a proper safeguard and valorisation aimed to promote sustainable development, education and environmental protection (Campbell, 2000). For this purpose, many technologies have been developed and applied for the conservation of the coastal heritage (Ofiara & Seneca, 2006).

In the present paper an overview of the Italian coastal heritage is described in Section 2, especially focusing on the Apulia region. Section 3 deals with the principal critical issues in coastal management. Finally, section 4 describes the technologies adopted to support the coastal management and preserve the coastal heritage. Some specific applications and results are also described.

2. *Italian and Apulian coastal heritage*

Most of Italian and northern Mediterranean coastal areas are featured by urban centres built along the coastal strip (Jiménez, Gracia, Valdemoro, Mendoza, & Sánchez-Arcilla, 2011).

Italian coasts are characterized by a rich cultural heritage that includes both material elements (archaeological remains, architectural structures) and immaterial (typical crafts, traditions, events), as a tangible trace of the interaction between man and coastal environment during the centuries.

Coastal zones, in many parts of the Italian country, became over the centuries densely populated centres. During the 70s and 80s, an intense urbanization and an increasing population characterized the coastal areas. As well, the lack of attention to the environment and its transformations have caused, over the years, a strong deterioration, making the coastal areas extremely vulnerable.

On a total of 7,465 kilometres of coastline, the beaches (3,950 km) represent around the 50% of the total length. More than 55% of coastal areas have been built. Coastal pine forests, ponds and river mouths have been destroyed and replaced by palaces, villas, hotels and ports. This has irreversibly altered the coastal landscape and severely compromised the natural heritage.

As consequence, Italian coasts are slowly disappearing, threatened by overbuilding and erosion. In fact, in addition to the uncontrolled urbanization, the erosion phenomenon is a further strong risk threatening the coasts.

In the last decades, the Italian coasts have undergone a significant geomorphological evolution, including erosion, mostly of anthropic origin. The analysis of shoreline changes along the peninsula in the period between 2000 and 2007 has confirmed this trend: 37% of the coasts has suffered variations of over 10 meters and the stretches of coastline in erosion (897 km) still prevails on those in accumulation (851 km) (D'Antoni et al., 2011). In many cases, coastal erosion has put in crisis the safety of houses, roads and railways, especially during storm events.

The problem of erosion has greatly affected the Apulia region, located in southern Italy, a tourist destination during the summer season for the value of its beaches and the quality of its sea. The Apulian coast is characterized by heterogeneous and fascinating morphology, but also by a growing urbanization based on concrete constructions, that is progressively erasing its environmental and cultural heritage. It develops for a total length of 810 km, of which 454 kilometres (56%) are urbanized and therefore transformed by both legal and abusive anthropic interventions.

More precisely, infrastructural and industrial areas occupy 81 km, while 129 km are characterized by a very dense populated urban landscape. Settlements with lower population density are present along 244 km of coastline. Only 109 km are agricultural landscapes, while there are 247 km of natural landscapes, partly rocky and partly falling into protected areas (Manigrasso, Conte, Listorti, & Testa, 2015).

An example of a strong retreat of the shoreline along the Apulian coast is found in Figure 1, showing the historical shorelines at the Ofanto river's mouth, referring to the period from 1943 to 2013.

Fig. 1: Shoreline evolution of the Ofanto river (Apulia Region): 1943 (green line), 2005 (purple line), 2008 (blue line), 2013 (red line). (Source: Mossa, Nobile, & Petrillo, 2016).

The strong retreat occurred in recent decades is evident: from 1992 (purple line) to 2013 (red line) the mouth has retreated of about 930m, with the change from a delta to an estuary configuration, thus contributing to a progressive reduction of solid transport by the river and to an increasing sediment transport supplied by wave and sea currents. More details can be found in Mossa, Nobile and Petrillo (2016) and in Armenio, De Serio, Mossa, Nobile and Petrillo (2017).

3. *Critical issues in coastal management*

Despite using of cutting-edge technologies represents a fundamental tool for the knowledge of the processes occurring in coastal areas, a holistic management plan is necessary. This should be finalized to identify and timely program the appropriate corrective actions to solve potential critical issues and promote coastal cultural and environmental heritage conservation. The holistic approach is the key tool to manage the coastal resource, in which all the natural and anthropic resources cannot be considered separately, but rather related.

The most accepted holistic approach for the European coastal zones management is the Integrated Coastal Zone Management (ICZM). It integrates all aspects of the coastal zone to balance environmental, economic, social, cultural and recreational aims in an effort to achieve sustainability (Hopkins & Bailly, 2013) and avoid fragmentation and sectorial management (Khakzad, Pieters, & Van Balen, 2015).

Among the various aspects that an integrated coastal zone management program must face, beach management, coastal erosion control and natural hazards are the most frequent and critical. Specific input data is needed to enable such programs to be conducted in a scientifically consistent form. Typical coastal management problems include the control of beaches erosion, the design of artificial nourishment, the implementation and control of defence works, the evaluation of coastal morphodynamics evolution connected to winds, waves, tides, sediment supply, the changes in relative sea level and human activities, over different time scales.

For all these reasons, it is evident that the monitoring action is one of the major challenge to control and prevent the response of natural hazards on coastal zones (Ruggiero, Voigt, & Kaminsky, 2000; Rieb & Walker, 2001). Surveys and measurement campaigns along coastal areas provide a useful tool for the management of coastal defence, land use and planning (Hamm, Capobianco, Dette, Lechuga, Spanhoff, & Stive, 2002).

It can be clearly deduced that technologies play an essential role in acquiring data with high spatial and time resolution, in detecting potential critical processes and supporting environmental coastal management strategies.

To be fully successful and effective, the integrated coastal management programs must explicitly incorporate a realistic range of coastal processes and responses, based on a physical environment understanding, possible because of adequate technologies. The implementation of coastal management plans involves the use of technologies able to analyse the environment, to capture its typical features and to achieve the scheduled objectives. Specific and advanced instruments and technologies are required for examining the coastal environment, identifying and monitoring the main natural processes and planning reliable future scenarios of interventions (Armenio, Ben Meftah, Bruno, De Padova, De Pascalis, De Serio, Di Bernardino, Mossa, Leuzzi, & Monti, 2016; Armenio, De Padova, De Serio, & Mossa, 2017).

4. *Technologies to support coastal management*

This paragraph describes a not-exhaustive list of the most innovative technologies used in the field of environmental and cultural heritage investigation and monitoring in coastal zones.

4.1 Technologies on land and sea

Typical extremely vulnerable coastal sites, due to strong anthropization, urban discharges and pollution, are lagoons or shallow water basins, often suffering from scarce circulation and, therefore, strongly affected by potential contamination phenomena. To preserve the coastal heritage, it is fundamental to monitor the quality state of these areas and their hydrodynamic processes. For this purpose, several technologies have been developed and are in constant evolution still today. The use of Information and Communications Technology (ICT) for the detection of critical events and the appropriate analysis of sensor signals has proved to be a powerful tool for local authorities and stakeholders, leading to early warning and preventive measures against environmental degradation and related hazards.

A typical case in the Apulia region is represented by the case of Mar Grande and Mar Piccolo basins, that are two shallow waters basins located in the inner region of the Ionian Sea. They are highly vulnerable due to strong human pressure, urban and industrial discharges and intense naval traffic (De Padova, Mossa, Adamo, De Carolis, & Pasquariello, 2017). Consequently, a system composed by different technologies to enable the continuous monitoring has been set up, thus ensuring the continuous control of the principal hydrodynamic and biochemical parameters. During March 2006, a wave meter buoy was installed close to the Port of Taranto on the sea bed, at the depth of about 72 m (Figure 2).

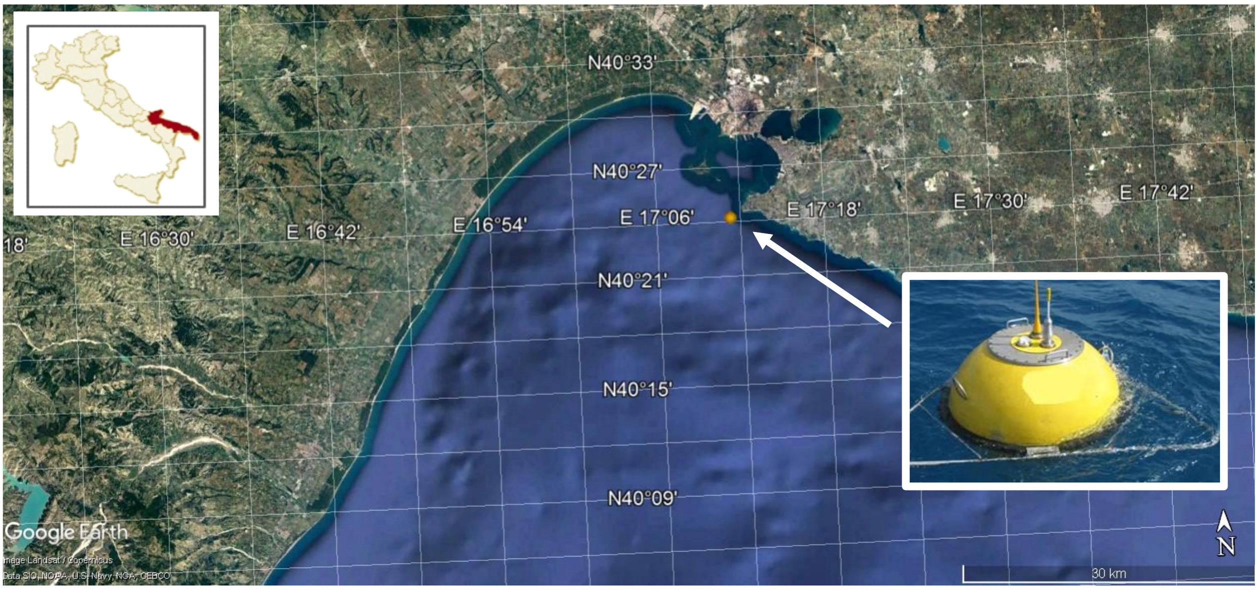

Fig. 2: Wavemeter located in Mar Grande (Taranto, Apulia region, South Italy).

The buoy is part of the Meteo-marine Monitoring Network of the Apulia Region (POR Puglia 2000 - 2006 funds). It is a Datawell Directional Waverider MKIII, able to measure wave height and direction, as well as the water temperature. The buoy operates continuously via GSM connected to a control and data acquisition centre, where measurements are regularly transmitted. In this way, real-time acquisition and constant monitoring are possible. All the collected data converge into a database at half-hour intervals and their quality is checked. Data recorded by this station have been extremely useful for the study of the wave climate in this site.

In addition to the wave-meter, in the following years, further instrumentations were installed in both Mar Piccolo and Mar Grande (Figure 3).

In particular, in the Mar Grande basin a system was settled in December 2013 composed by a bottom-mounted Acoustic Doppler Current Profiler (ADCP) to record current data, a multidirectional wave array to acquire wave data and a meteo station to detect meteo-oceanographic parameters. It was installed at a local depth of 23.25 m, on average.

In detail, the meteo station records the wind speed and direction at 1.5 m above the sea surface by means of an ultrasonic sensor, with an accuracy of 2%. These values are then hourly averaged. The ADCP measures the 3D velocity of currents along the vertical axis (De Serio & Mossa, 2016a). Mean current velocity profiles are collected continuously, at one-hour intervals, using an average of 60 measurements, acquired every 10s. In this way, hourly-averaged velocity components along the water column are available (De Serio & Mossa, 2016b). Figure 4 shows near bottom and near surface currents, as recorded by the Mar Grande Station during the year 2015.

The monitoring station in Mar Piccolo was installed in May 2014. It is equipped with a bottom mounted ADCP and a wave array. The local depth at this station is 13.7 m, on average. The current velocities are assessed along the vertical axis at constant intervals of 0.5 m. The acoustic frequency of both ADCPs is 600 KHz.

Fig. 3: Technologies for continuous monitoring installed in Mar Piccolo and Mar Grande basins (South Italy).

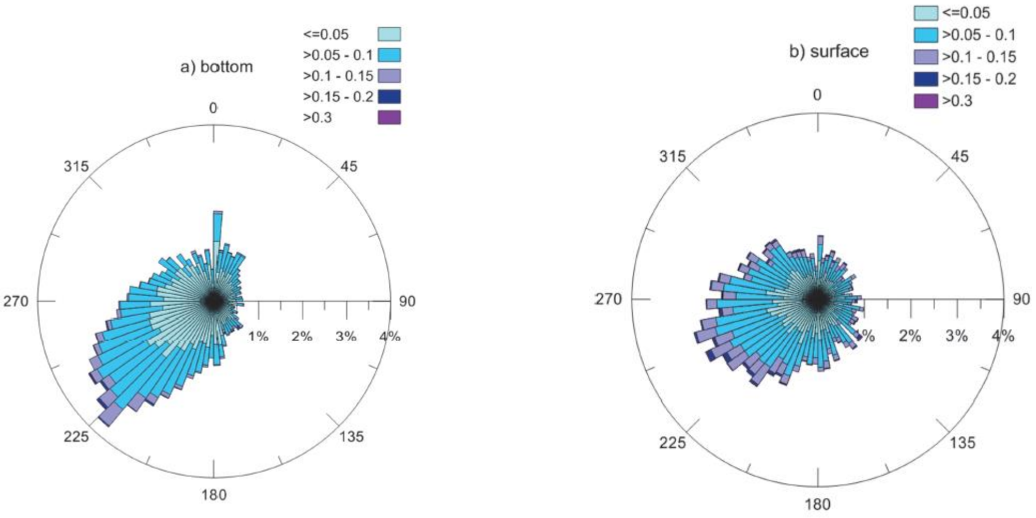

Fig. 4: Average annual values of the current velocity (m/s) and directions (degrees) at the bottom (a) and at surface (b) detected by the monitoring station in Mar Grande for the year 2015. (Source: De Serio & Mossa, 2016b).

An ultrasound tide gauge was also installed in Mar Piccolo near the ADCP station during August 2015 (Figure 5). It has an acquisition frequency of 5 Hz and a resolution of 1 mm (De Serio & Mossa, 2016b).

The described sensors are all connected to a datalogger (named LISC), which is an autonomous data acquisition unit, able to acquire data from 12 serial ports and 16 analogic channels. It allows the remote control and the data download.

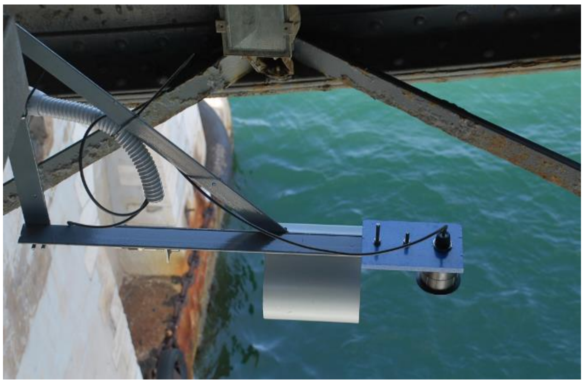

Fig. 5. Ultrasonic tide gauge installed in Mar Piccolo, South Italy (Source: De Serio & Mossa, 2016b).

This LISC datalogger processes ADCPs data and wave-meter data in real time. This operation is heavy in computing terms and requires high-energy consumption. Therefore, it is managed by a specific software (named MARLIN), installed in a proper device, which connects to the LISC at the end of the measurements for a short time window, just necessary to get the measured data and send back the processed data. The communication with remote systems is possible by means of a cellular modem 3G, connected to the datalogger through a serial port and provided with a stack TCP/IP to send data on the web cloud. In this way, remote systems can be reached, and communication from the web to the devices is possible, managed by a proper software (ROCS). In Figure 6, a sketch of data transmission is plotted as an example.

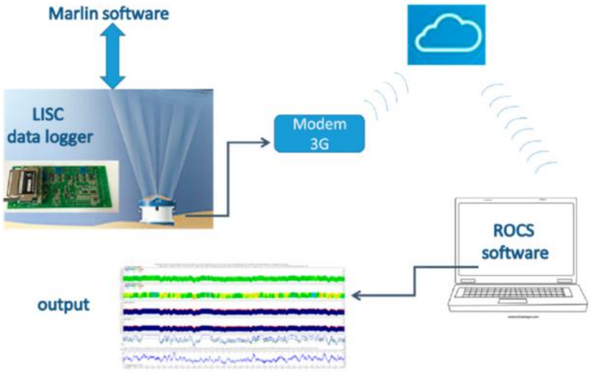

Fig. 6: Sketch of data transmission, from sensors to managing remote systems. (Source: De Serio & Mossa, 2018).

The advantages of the described monitoring technology can be summed up in the continuous acquisition of field data. Frequently, one of the critical issues of coastal datasets is the poor resolution in time of data, which are often intermittent. Also, spatial sampling represents another critical aspect. In fact, surveys are generally executed along fixed transects at regular intervals, but they last few days. Further, due to technical limitations and adopted instruments, it is also difficult to assess field data in confined basins or in very shallow coastal waters. Consequently, even if strongly necessary, field measurements are usually fragmentary or sparse, so that monitoring actions should be rationally programmed.

Specifically, the continuous monitoring of tides, waves and currents in a nearshore region is fundamental to understand the role that they play in coastal processes, morphodynamic changes and pollution spreading, even more in coastal restricted settings. The continuous recordings of meteorological and hydrodynamic data, collected in coastal areas, can be managed to rapidly provide fundamental insights on the hydrodynamic structure.

Data acquired by monitoring stations should include current velocity and direction, tides, meteorological parameters, water quality parameters (dissolved oxygen, percentage of oxygen saturation, chlorophyll, turbidity, oil, refined fuels). These parameters allow the monitoring of the coastal environment but, in addition, play a fundamental role in calibration and validation of numerical models. Further details about data acquisition and processing, referred to the aforementioned monitoring stations, can be found in Armenio et al. (2016), De Serio and Mossa (2015), De Serio and Mossa (2016a), De Serio and Mossa (2018).

It is worth noting that also software technologies are essential in the analysis of the environment and of its natural resources, contributing to monitoring and support cultural and environmental heritage. Software technologies are usually used in coastal areas for hydrodynamics modelling, as they allow to identify the main hydrodynamic processes (waves, currents and sediment transport) driving diffusion and dispersion of contaminants or even causing potential erosion processes. As an example, Figure 7 shows some numerical model results used to analyse the diffusion of contaminants released by a sewer in the marine area of Lesina (Apulia Region, Italy). Figure 7a displays the bathymetry map, while Figure 7b shows the trend of the average seasonal currents and Figure 7c the diffusion modelling of total suspended solids.

More recent technologies used for the coastal environment are based on the remote sensing analysis. Applications of acoustics to seafloor remote sensing include measurements such as: bathymetry, providing quantitative information; acoustic imaging, often used in a qualitative sense for geomorphology.

The ultimate frontiers for the acquisition of bathymetric data consist of multi-beam echo-sounder technology (MBES) (Figure 8a). This is a sonar used to map the sea bottom. Like other sonar systems, the multibeam system emits sound waves in a fan shape, beneath a ship's hull. The time interval occurring for the sound waves to reach the water bottom and return to a receiver is used to compute the water depth. It is an instrument able to operate at a frequency of 450 kHz using 256 beams, with a maximum swath coverage of about 150 °. Unlike other sonars, multibeam systems use beamforming to extract directional information from the returning soundwaves. This technology has resulted in substantial advance in the qualitative and quantitative use of bathymetric data for a wide variety of applications, leading to a vastly evolving exploration, mapping and monitoring of the seafloor over the last few decades (Lamarche & Lurton, 2018). A very high precision is obtained in the determination of depths and in the total coverage of the surveyed area, with a very high sampling density (usually higher than 50 points/m^2 for depths less than 10 meters).

A key issue persistently cited by users and developers is the absence of systematic calibration of equipment and data. Several recent studies address this topic, focusing on the use of field data from controlled seafloor areas to calibrate MBES under operational conditions (Figure 8a). Some authors (Eleftherakis, Berger, Le Bouffant, Pacault, Augustin, & Lurton 2018; Ladroit, Lamarche, & Pallentin, 2017) faced the cross calibration of MBES with a tilted calibrated fishery-type single-beam echosounder.

The latest research and study trends focus on procedures, advantages and problems relative to data calibration using natural reference areas or multiple detection on dedicated lines (Roche, Degrendele, Vrignaud, Loyer, Le Bas, Augustin, & Lurton, 2018). Another sonar system used to obtain image of large areas of the sea floor is the Side-Scan Sonar (SSS) (Figure 8b). It emits a pulse at high frequency that is diffracted-reflected from the bottom and received from the transducers (Figure 8c).

The SSS is a tool that allows the exploration of large areas of sea floor in a short time and is

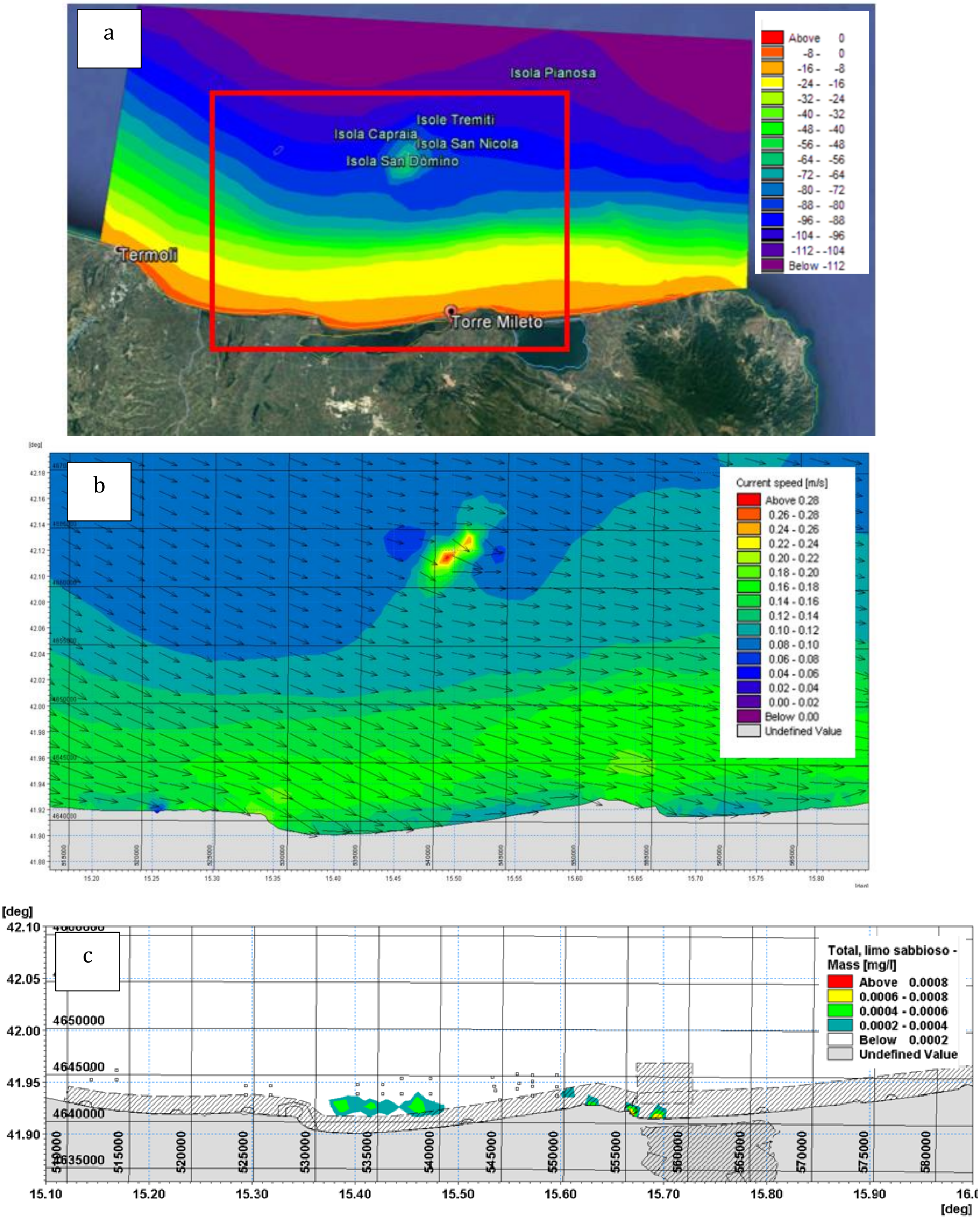

Fig.7: Example of software technology application for the modelling of bathymetry (a) sea current velocity and direction (b), diffusion modelling of total suspended solids (c).

commonly used on boats in motion with a cruising speed between 2 - 6 knots. It is generally applied for morphological surveys of the characteristics of the seabed. Especially, its use makes possible to recognize the different types and biocenosis that are present on the bottom. In addition, the SSS is widely used both in archaeological research (wrecks, man-made artefacts) and engineering

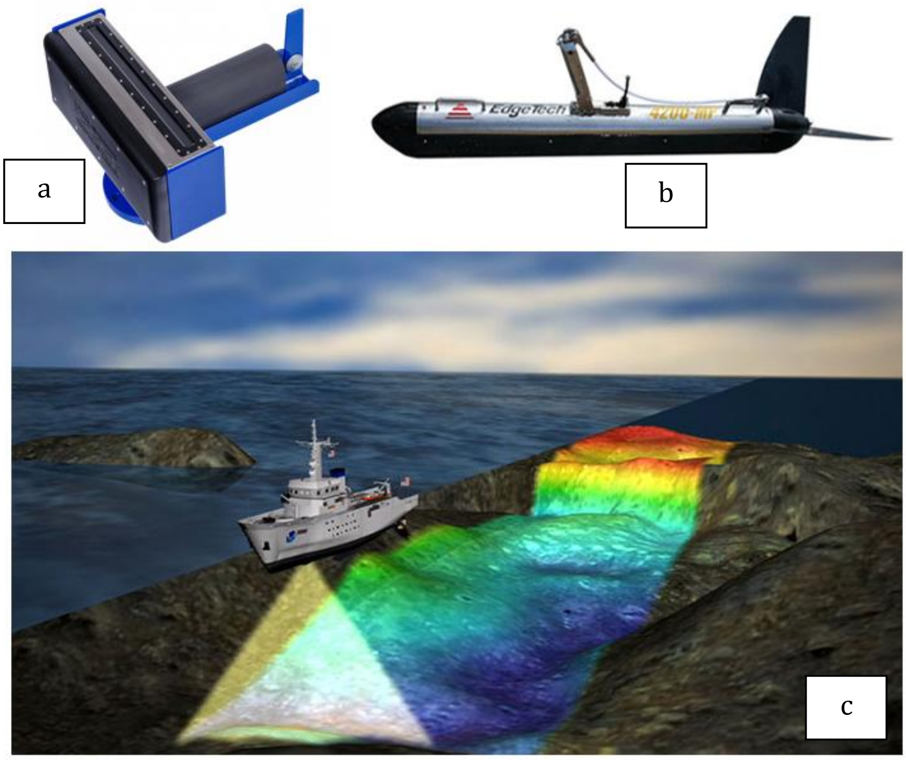

Fig. 8: a) Multi beam echo-sounder; b) Side-scan sonar; c) example of data acquisition from vessel. (Source: Google).

(monitoring marine constructions such as ballast, fills, location of pipelines, etc.).

The SSS transducer built in a tow fish is usually towed behind a surveying vessel by a cable. It emits a wide-angle beam and receives the seabed echoes at fixed time intervals to form the seabed image. The resolution of a SSS image is about 20–100 times larger relative to that of MBES bathymetric topography. Consequently, SSS images can vividly reflect the seabed targets, topography and sediment reflectivity (Blondel, 2010; Trucco, Petillot, Ruiz, Plakas, & Lane, 2010).

4.2 Aerial technologies

On a wide scale, measurement campaigns and continuous monitoring system, using traditional site-specific monitoring station, is often impractical because of logistics and high costs of in-situ operations.

Over the last few decades various methods have been developed, allowing to overcome or at least reduce these difficulties.

For several years, one of the most widespread monitoring technologies has been the collection of aerial photos of the study area, to detect shoreline modifications at annual or seasonal timescale or immediately after two swell events.

Aerial photos techniques have the advantage of providing wide coverage and accurate topography (point clouds and orthophotos), but their high cost and the necessity of an aircraft make virtually (and economically) impossible to perform regular surveys. The solution could be performing surveys on the ground (Morton, Leach, Paine, & Cardoza, 1993; Cariolet & Suanez, 2013), that are more repeatable in time, renouncing to the detail that a point cloud and an orthophoto can give.

Data from aerial photos are generally supplemented by a set of control points at ground, surveyed with high-accuracy GPS. The relief of the shoreline, both in its artificial and natural parts, is usually performed using a GPS technique in RTK (Real Time Kinematic) mode.

The procedure involves the use of a GPS receiver connected via internet to the GPS regional network site, that provides in real time the necessary differential correction to coordinates through the Networked Transport of Radio Technical Commission for Maritime Services (RTCM) via Internet Protocol NTRIP. The NTRIP is a generic, stateless protocol based on the Hypertext Transfer Protocol HTTP/1.1 and is enhanced for GNSS data streams (Lenz, 2004).

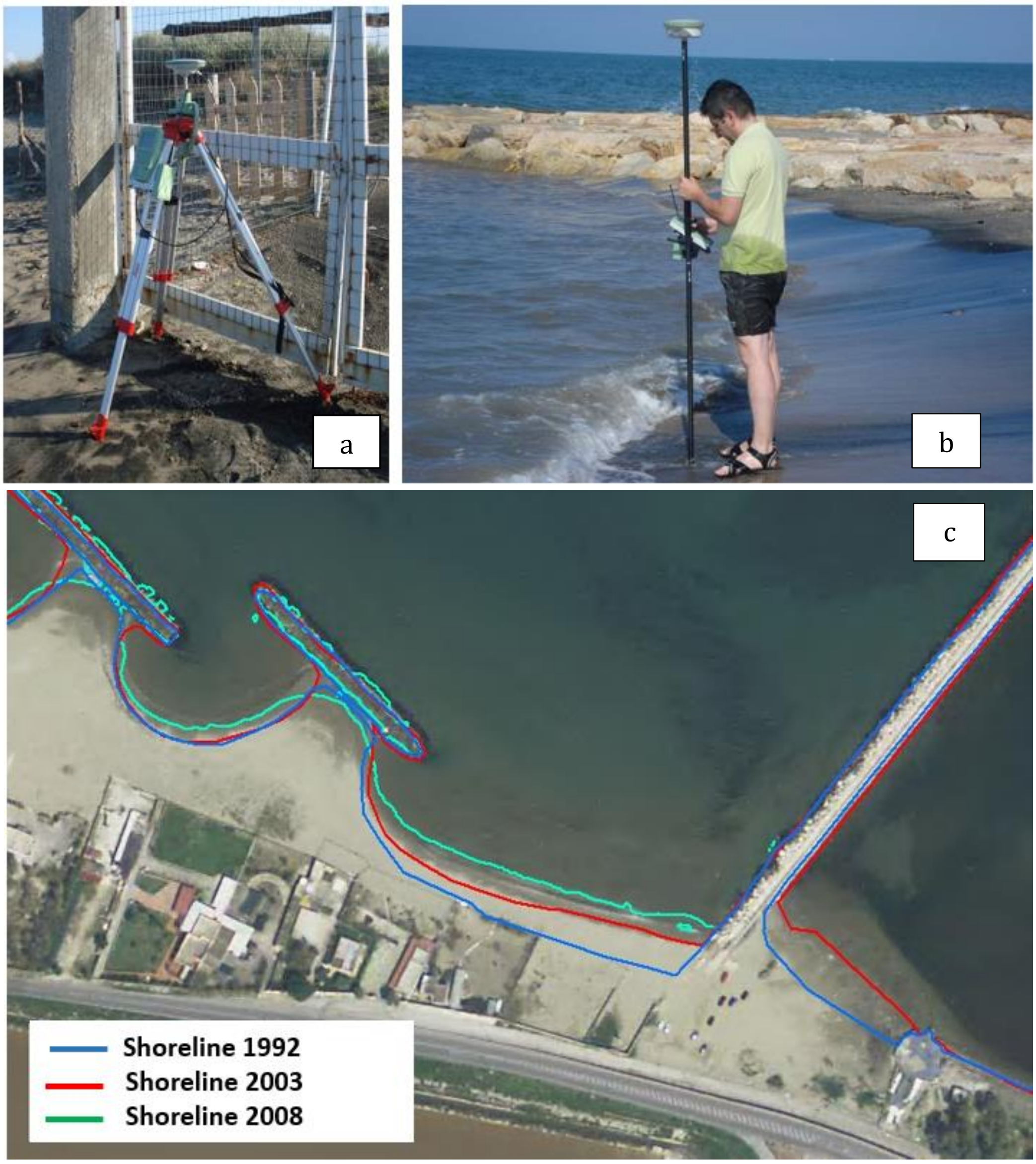

Fig. 9: a) Topographic survey by using total GPS station; b) survey of the shoreline; c) processed data of aerial-photos. (Source: Mossa, Nobile, & Petrillo, 2016).

The Networked Transport of RTCM via Internet Protocol NTRIP is a protocol for streaming differential GPS (DGPS) data over the Internet in accordance with specification published by RTCM.

Once the network has been hooked up and entered in RTK mode, and then reached the necessary accuracy, the topographer technician, equipped with a metered pole on which the GPS antenna is installed, will move along the planned theoretical transects recording the coordinates of the main points of the same. The beaten points are recorded in the instrument memory, the points not falling within the typical RTK tolerances (2-4 cm +- 1 ppm for horizontal plane XY and 4-6 cm +- 1 ppm for heights) are discarded and, usually, not used for the processing and return phase.

Aerial-photo in conjunction with topographic survey are widely used to monitor the evolution of the environment and the anthropic heritage of coastal areas, by performing change detection analysis. Generally, coastline topography data are merged with bathymetric datasets to have a detailed representation of coastal zones. This allows to extract topographic transects that can be used, for example, as an input for a model runup.

In this case, the position of the maximum wave runup can be identified from orthophotos. As an example, Figure 9a and 9b show some steps of a topographic survey conducted along the coast of Margherita di Savoia (Apulian Region, Italy). Figure 9c illustrates the extraction of shoreline profiles, derived for different years from aerial-photo and site survey.

Another innovative technology, that is finding considerable development, is the Synthetic Aperture Radar (SAR) interferometry. It is a remote sensing methodology, convenient in studying and monitoring the territory. It is a special radar technique permitting high resolution images to be obtained from a great distance. It is usually applied to create two- or three-dimensional images of objects, such as landscapes.

SAR technology is typically mounted on a moving platform, such as an aircraft or spacecraft, and has its origins in an advanced form of side looking airborne radar (SLAR). The motion of the radar antenna over a target region provides finer spatial resolution than conventional beam-scanning radars. The distance the SAR device travels over a target, in the time taken for the radar pulses to return to the antenna, creates the large synthetic antenna aperture (the size of the antenna). Generally, the larger the aperture, the higher the image resolution will be, regardless of whether the aperture is physical (a large antenna) or synthetic (a moving antenna). This allows SAR to create high-resolution images with comparatively small physical antennas.

Thanks to their all-weather, day-night imaging capability, the SAR techniques are becoming attractive for environment monitoring. Furthermore, the Italian Space Agency (ASI) has developed the national acquisition plan called Map Italy, to provide COSMO-SkyMed high resolution satellite images (CSK) covering the whole Italian territory with a revisit time of up to 16 days, thus allowing the implementation of operational services for an effective remote monitoring of the environment.

Recent studies have demonstrated the successful applications of SAR methodology, being a cost-effective choice to provide a preliminary assessment of coastal erosion hazard and allowing the identification of critical areas where more detailed investigations may be required. In this regard, Bruno, Molfetta, Mossa, Morea, Chiaradia, Nutricato, Nitti, Guerriero and Coletta (2016a) analysed the development of an integrated operational Earth Observation (EO) system to provide a complete monitoring of both natural and built coastal environments.

The estimation of the interferometric coherence can be also used to extract additional information for the remote classification of coastal morphology. Specifically, exploiting both the amplitude and phase information stored in Interferometric synthetic aperture radar (InSAR) data, it is possible to extract the coastline position through segmentation methods.

Figure 10 shows an example of the application of the SAR technique, as tested on a very popular beach in Apulia Region (Italy), affected by erosion problems induced by human activities. For further details see Bruno et al. (2016a).

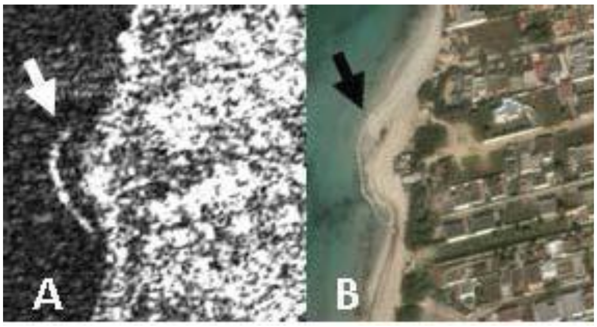

Fig. 10: Example of SAR image relative to sand bag barrier realized in February 2011 on Apulian beach: (A) SAR amplitude image (2012) and (B) aerial orthophoto (2012) (Source: Bruno, Molfetta, Mossa, Morea, Chiaradia, Nutricato, Nitti, Guerriero, & Coletta, 2016a).

The routinely acquisition of new high-resolution X-band SAR images from the Map Italy mapping program devised by the Italian Space Agency allows the large-scale shoreline variation analysis and the remote coastal structures monitoring. An integration of Multitemporal SAR and InSAR techniques can be an advanced system for the continuous remote monitoring of the coastal zones because it offers a valuable and sustainable approach for the development of an effective integrated coastal management (Bruno, Molfetta, Mossa, Nutricato, Morea & Chiaradia, 2016b).

Recently, a widely used tool to face adequate studies on coastal risks has been the acquisition and analysis of altimetric data of the coastal strip, particularly useful in the case of depressed and subsiding areas.

Reliable topographic and geomorphological data in coastal areas are obtained by using LIDAR (Light Detection and Ranging) (e.g. White & Wang, 2003). It is based on a laser-scanning technology that allows an altimetric acquisition from an aerial platform. The distance of an object or a surface is determined using a laser pulse and reconstructing the morphology and the dimensions of the overflowed territories.

LIDAR is a remote sensing technique for performing high-resolution topographic surveys. The survey is carried out by an aircraft on which a laser scanner, composed of a transmitter (essentially a laser), a receiver (consisting of a telescope) and a data acquisition system, is installed. A LIDAR survey allows obtaining a set of points, with associated data, relative to geographical coordinates (WGS system 84) and quota *Z*, computed on the time difference between the emitted and the reflected signal and the intensity value of reflected signal. From the cloud of total points, it is possible to implement a Digital Surface Model (DSM), while through successive elaborations, which include both automatic and manual filtering, ground points are extracted to build a Digital Elevation Model (DTM). Figure 11 shows an example of aerial-photo (a), Digital Surface Model (DSM) (b) and Digital Terrain Model (DTM) (c).

The advantage of this technology is the very high data acquisition speed combined with a high resolution.

Given its considerable usefulness in providing reliable topographic data for the Italian coastlines, the Italian ministry of Environment is performing coastal LIDAR surveys along the national coasts, and has recently made available coastal orthophotos from its web portal (www.pcn.minambiente.it). The LIDAR survey provide a new, unique and essential information layer for the enhancement of the basic knowledge aimed at the defence of the coastal territory. Figure 12 shows an example of data acquired by mean of LIDAR technology. Some of the purposes of using this technology are finalized to:

1. complete and improve the quality of cartographic products such as morphological

Fig. 11: Example of a 3D representation of the stretch of coast south of the Foce del Savio. A) Aerial photo, B) Digital Surface Model (DSM), C) Digital Terrain Model (DTM). (Source: Coluzzi, Lanorte, & Lasaponara, 2010).

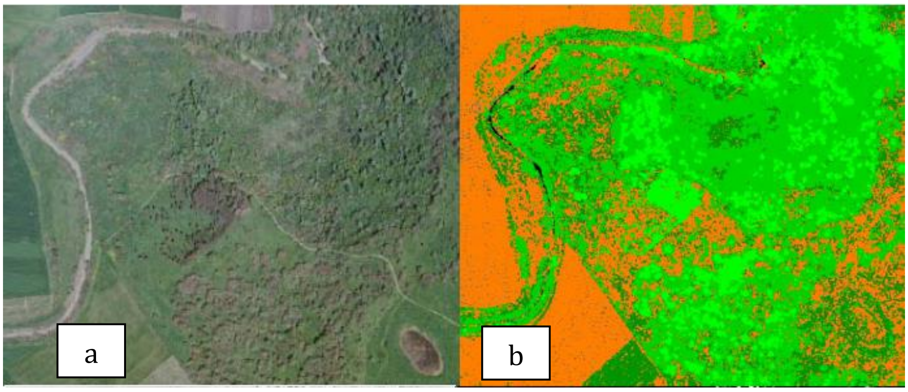

Fig. 12: Example of (a) orthophoto acquired at the same time as LIDAR data, (b) results from the classification of LIDAR raw data (Source: Coluzzi, Lanorte, & Lasaponara, 2010).

maps of coastal areas and morphodynamic classification of beaches. It is also used for cataloguing coastal defence works and for studies on coastal risk mapping;

2. carry out simulations on storm wave propagation along the beach;

3. define a basis of comparison for any future detection, also realized with different acquisition techniques.

As previously written, this list is not exhaustive, but it is worth noting that one of the last frontiers in environmental monitoring is the coastal and environmental remote sensing from unmanned aerial vehicles (Klemas, 2015). Remote sensing is widely used in coastal studies. Until now, most of the remote sensing studies on such areas are based on satellite images. However, coastal monitoring needs some requirements, which cannot be obtained from optical satellite data. In cloudy areas, ground and water surface cannot be observed (Klemas, 2015).

Technological development has led to a progressive reduction of sensors costs, overall dimensions, consumption and weight of the electronic components. This allowed realizing sensors that are smaller and lighter, such that they can be mounted in small aircraft, without pilot on board and checked by remote through a land station.

Despite recent improvements, in this case the resolution remains too low for some phenomena (for example hydrologic phenomena, that would require a spatial resolution finer than 50 cm). These limitations could be partly overcome using aerial platforms which could supply data with finer spatial resolutions (Casson, Delacourt & Allemand, 2005).

Platforms such as kites, microlights and drones, already used for surveying landslides and erosion slopes (Casson et al., 2005), rivers (Lejot, Delacourt, Piégay, Fournier, Trémélo, & Allemand, 2007), as well as agriculture (Sugiura, Noguchi, & Ishii, 2005), are very promising tools. Such remotely operated platforms are flexible in terms of use and allow to repeat surveys during short periods. They allow to observe coastal change and to quantify the motions of local features. In this framework, Klemas (2015) has developed an integrated system for the acquisition and processing of high-resolution images of coastal domains. This flexible system can acquire high-resolution images, which, after accurate processing, allow obtaining 3 cm resolution DEM, with an accuracy better than 3 cm.

Unmanned aerial vehicles (UAVs) offer a viable alternative to conventional platforms for acquiring high-resolution remote-sensing data at lower cost and increased operational flexibility (Figure 13). UAVs include various configurations of unmanned aircraft, multirotor helicopters (e.g., quadcopters), and balloons/blimps of different sizes and shapes.

Unmanned helicopters (e.g., quadcopters) have a major advantage over fixed-wing aircraft because they can hover over a target site, descend for a closer inspection, and change altitude to provide imagery for mapping at preferred spatial resolutions. The UAVs are finding use even for the exploration of underwater cultural heritage, which represents a significant historical resource and consists of different interesting sites, e.g. ancient shipwrecks, sunken cities, prehistoric submerged landscapes.

In this regard, the Italian legislation establishes, in accordance with the United Nations Educational, Scientific and Cultural Organization (UNESCO) conventions for underwater cultural heritage, a "*preventive verification of potential archaeological interests and surveillance during excavations*". Nevertheless, underwater cultural heritage is often not easily accessible by humans due to the many limitations of the marine environment. For these reasons, since a preliminary archaeological study is a regulatory obligation, the development of new techniques for archaeological investigations is reaching increasing interest. The last researches have focused their attention on the implementation of technologies for the underwater survey process automation, and systematic exploration of wrecks in known sites.

To this end, in recent years, AUVs have been widely studied and designed also for underwater expedition finalized to archaeology studies. These technologies have reached sufficient maturity allowing to automatically acquire different kind of data from the seafloor. They are capable of hundred meters depth and can be equipped with systems for autonomous navigation. In addition, they are endowed of optical, magnetic or acoustic sensors to perform an accurate scanning of the archaeological target sites, finalized to analyse in real time heterogeneous data with the aim of promptly detecting objects of interest.

In particular, the last frontiers of research in this field move toward the experimental use of swarms of AUVs to investigate and map the sea floors with archaeological interest and, also, to develop advanced methods for visualizing and rendering (Allotta, Caiti, Cocco, Colombo, Daviddi, Gualdesi, La Monica, Moroni, Pieri, Salvetti, & Tampucci, 2011; Bucci, 2018).

An example of AUV used for underwater exploration was developed in the frame of the research project named THESAURUS started on March 2011 (Figure 13), with the purpose to study the multidisciplinary methodologies and technologies to detect, census and document the underwater cultural heritage, by exploring several known and new underwater sites (i.e. artefacts and wreckage with archaeological and ethno-anthropological value) (Allotta et al., 2011; Bucci, 2018).

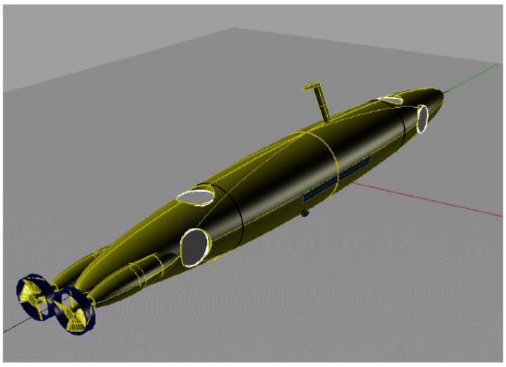

Fig. 13: Example of unmanned aerial vehicle used for underwater exploration of archaeological site (Source: Allotta, Caiti, Cocco, Colombo, Daviddi, Gualdesi, La Monica, Moroni, Pieri, Salvetti, & Tampucci, 2011)

It is worth mentioning that the innovative aspect characterizing the project THESAURUS is the concept of swarm autonomous vehicle: the AUVs can be deployed in a swarm since they are based on algorithms for cooperation, optimal search and coordination of vehicles, adaptive sampling for full coverage of large areas of sea floor. An interesting advantage is that AUVs of the swarm are not identical, but they are characterized of a certain degree of specialization.

For example, each AUV member is equipped with low-cost sensors such magnetometer and depth sensors. On the contrary, high accuracy velocity sensor such as the Doppler Velocity Log are installed only on some members of the swarm.

The specialization of the sensors installed on board clearly leads several advantages in a collaborative environment among the member of the swarm. Furthermore, each of the AUVs is equipped with optical, magnetic or acoustic sensors and is capable to execute an accurate scanning of sea-floor. If a signature of human artefacts is detected on a site by an AUV, then the mission may be planned on line at a swarm level, i.e. another AUV of the swarm may be required to explore around the same site making use of the most suitable sensing technology.

5. *Discussion and Conclusion*

Coastal zones are the place where a significant environmental and cultural heritage is present. The natural coastal landscape influences the human interaction with seas and, in recent decades, there has been an increasing awareness of our enormous coastal heritage. Thus, many technologies have been implemented to support coastal management plans and programs.

The sustainable preservation and management of coastal heritage is based onto an integrated approach, which refers to both natural and human aspects linked to coastal areas. Among the others, erosion control and natural hazards are the most critical issues in coastal management, because they can seriously damage the environmental and cultural heritage of coastal zones.

In the last few years, the need to develop methodologies and multidisciplinary technologies with the goal of monitoring marine ecosystems has been evident, in different contexts such as oil spilling, distribution of marine litter or mapping the prairies of marine Phanerogams.

Beside the traditional monitoring stations, the most widely technologies used to observe and control the coastal environment include MBES, SSS and remote sensing technique. The last frontiers of coastal technologies consider the use of UAVs, such as drones, to acquire high-resolution remote-sensing data at lower cost, with increased operational flexibility, and greater versatility. Data acquired by AUVs can be processed in different ways: 3D modelling, processing of point clouds acquired by Laser scanner systems, or LIDAR to generate DTM and DSM of the coastal areas, processing images by using Segmentation Image algorithms and Classification of Images.

The general trend is to develop technologies capable to integrate information collected by AUVs with data derived from fixed and mobile sensors at ground. Such technologies would allow to obtain an ICT system of command and control, to effectively manage both ordinary monitoring and any environmental emergencies.

REFERENCES

Able, K. W. (2005). A re-examination of fish estuarine dependence: evidence for connectivity between estuarine and ocean habitats. *Estuarine, Coastal and Shelf Science*, 64(1), 5-17.

Allotta, B., Caiti, A., Cocco, M., Colombo, C., Daviddi, W., Gualdesi, L., La Monica D., Moroni, D., Pieri, G., Salvetti, O., & Tampucci, M. (2011). THESAURUS: Techniques for Underwater Exploration and Archaeology through Swarms of Autonomous Vehicles. In *Proceedings of the 12th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST* (pp. 1–4). Prato, Italy: M. Dellepiane, F. Niccolucci, S. Pena Serna, H. Rushmeier, and L. Van Gool Editors.

Armenio, E., Ben Meftah, M., Bruno, M. F., De Padova, D., De Pascalis, F., De Serio, F., Di Bernardino, A., Mossa, M., Leuzzi, G., & Monti, P. (2016). Semi enclosed basin monitoring and analysis of meteo, wave, tide and current data: Sea monitoring. In *Proceedings of Environmental, Energy, and Structural Monitoring Systems (EESMS), IEEE Workshop* (pp. 1-6). Bari, Italy.

Armenio, E., De Padova, D., De Serio, F., & Mossa, M. (2017). Monitoring system for the sea: Analysis of meteo, wave and current data. In *Proceedings of IMEKO TC19 Workshop on Metrology for the Sea, MetroSea* (pp. 143-148). Naples, Italy.

Armenio, E., De Serio, F., Mossa, M., Nobile, B., & Petrillo, A. F. (2017). Investigation on coastline evolution using long-term observations and numerical modelling. In *Proceedings of the Twenty-seventh. International Ocean and Polar Engineering Conference.* San Francisco, USA.

Beck, M. W., Heck Jr, K. L., Able, K. W., Childers, D. L., Eggleston, D. B., Gillanders, B. M., Halpern, B., Hays, C.G., Hoshino, K., Minello, T.J., & Orth, R. J. (2001). The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates: a better understanding of the habitats that serve as nurseries for marine species and the factors that create site-specific variability in nursery quality will improve conservation and management of these areas. *Bioscience*, 51(8), 633-641.

Beaumont, N. J., Austen, M. C., Atkins, J. P., Burdon, D., Degraer, S., Dentinho, T. P., Derousd, S., Holmf, P., Hortong, T., Van Ierlandh, E., Marboef, A.H., Starkeyi, D.J., Townsenda, M., & Zarzyckij, T. (2007). Identification, definition and quantification of goods and services provided by marine biodiversity: implications for the ecosystem approach. *Marine pollution bulletin*, 54(3), 253-265.

Blondel, P. (2010). *The handbook of sidescan sonar*. Springer Science & Business Media.

Boero, F., Foglini, F., Fraschetti, S., Goriup, P., Macpherson, E., Planes, S., Soukisann, T., & CoCoNet Consortium. (2016). CoCoNet: towards coast to coast networks of marine protected areas (from the shore to the high and deep sea), coupled with sea-based wind energy potential. *SCIRES-IT-SCIentific RESearch and Information Technology*, 6(Supplement), 1-95.

Boero, F., Valzano, V., & Bartolomei, C. (2016). Editorial. A supplement of Scires-it on the COCONET european project. *SCIRES-IT - SCIentific RESearch and Information Technology*, 6(Supplement), I-II.

Bruno, M. F., Molfetta, M. G., Mossa, M., Morea, A., Chiaradia, M. T., Nutricato, R., Nitti, D. O., Guerriero, L., & Coletta, A. (2016a). Integration of multitemporal SAR/InSAR techniques and NWM for coastal structures monitoring: Outline of the software system and of an operational service with COSMO-SkyMed data. In *Proceedings of Environmental, Energy, and Structural Monitoring Systems (EESMS), IEEE Workshop* (pp. 186-192). Bari, Italy.

Bruno, M. F., Molfetta, M. G., Mossa, M., Nutricato, R., Morea, A., & Chiaradia, M. T. (2016b). Coastal observation through COSMO-SkyMed high-resolution SAR images. *Journal of Coastal Research*, 75, sp1, 795-799.

Bucci, G. (2018). Remote Sensing and Geo-Archaeological Data: Inland Water Studies for the Conservation of Underwater Cultural Heritage in the Ferrara District, Italy. *Remote Sensing*, 10(3), 380.

Campbell, H. (2000). Sustainable development: can the vision be realized? *Planning Theory & Practice*, 1(2), 259-284.

Cariolet, J.M. & Suanez, S., (2013). Runup estimations on a macrotidal sandy beach. *Coast. Eng*. 74, 11-18.

Casson, B., Delacourt, C., & Allemand, P. (2005). Contribution of multi-temporal remote sensing images to characterize landslide slip surface? Application to the La Clapière landslide (France). *Natural Hazards and Earth System Science*, 5(3), 425-437.

Clark, J. R. (1995). *Coastal zone management handbook*. CRC press.

Coluzzi, R., Lanorte, A., & Lasaponara, R. (2010). On the LiDAR contribution for landscape archaeology and palaeoenvironmental studies: The case study of Bosco dell'Incoronata (Southern Italy). *Advances in Geosciences*, 24, 125-132.

Costanza, R., D'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V, Paruelo, J., Raskin, R.G., Sutton P & Van den Belt., M. (1997). The value of the world's ecosystem services and natural capital. *Nature*, 387(6630), 253.

D’Antoni, S., Battisti, C., Cenni, M., & Rossi, G. L. (2011). Contributi per la tutela della biodiversità delle zone umide. *Rapporti ISPRA*, 153(11).

De Carolis, G., Adamo, M., Pasquariello, G., De Padova, D., & Mossa, M. (2013). Quantitative characterization of marine oil slick by satellite near-infrared imagery and oil drift modelling: The Fun Shai Hai case study. *International Journal of Remote Sensing,* 34 (5), 1838-1854.

De Padova, D., Mossa, M., Adamo, M., De Carolis, G., & Pasquariello, G. (2017) Synergistic use of an oil drift model and remote sensing observations for oil spill monitoring. *Environmental Science and Pollution Research,* 24 (6), 5530-5543.

De Padova, D., De Serio, F., Mossa, M., & Armenio, E. (2017) Investigation of the current circulation offshore Taranto by using field measurements and numerical model, In *Proceedings of the 2017 IEEE International Instrumentation and Measurement Technology Conference*. Torino, Italy.

De Serio, F., & Mossa, M. (2015). Analysis of mean velocity and turbulence measurements with ADCPs. *Advances in water resources*, 81, 172-185.

De Serio, F. & Mossa, M. (2016a). Environmental monitoring in the Mar Grande basin (Ionian Sea, Southern Italy). *Environmental Science and Pollution Research*, 23(13), 12662-12674.

De Serio, F., & Mossa, M. (2016b). Assessment of hydrodynamics, biochemical parameters and eddy diffusivity in a semi-enclosed Ionian basin. *Deep Sea Research Part II: Topical Studies in Oceanography*, 133, 176-185.

De Serio, F., & Mossa, M. (2018). Meteo and Hydrodynamic Measurements to Detect Physical Processes in Confined Shallow Seas. *Sensors*, *18*(1), 280.

Eleftherakis, D., Berger, L., Le Bouffant, N., Pacault, A., Augustin, J. M., & Lurton, X. (2018). Backscatter calibration of high-frequency multibeam echosounder using a reference single-beam system, on natural seafloor. *Marine Geophysical Research*, 39(1-2), 55-73.

Elliott M., & Dewailly, F. (1995). The structure and components of European estuarine fish assemblages. *Netherland Journal of Aquatic Ecology*, 29(3-4), 397-417.

Elliott, M., Cutts, N. D., & Trono, A. (2014). A typology of marine and estuarine hazards and risks as vectors of change: a review for vulnerable coasts and their management. *Ocean & coastal management*, 93, 88-99.

Hamm, L., Capobianco, M., Dette, H. H., Lechuga, A., Spanhoff, R., & Stive, M. J. F. (2002). A summary of European experience with shore nourishment. *Coastal engineering*, *47*(2), 237-264.

Hinrichsen, D. (1999). *Coastal waters of the world: trends, threats, and strategies*. Island Press.

Hopkins, T. S. & Bailly, D. (2013). The role of science in the transition to sustainability: the systems approach framework for integrated coastal zone management. *Global challenges in integrated coastal zone management* (pp. 1-18). Wiley.

Jiménez, J. A., Gracia, V., Valdemoro, H. I., Mendoza, E. T., & Sánchez-Arcilla, A. (2011). Managing erosion-induced problems in NW Mediterranean urban beaches. *Ocean & coastal management*, 54(12), 907-918.

Khakzad, S., Pieters, M., & Van Balen, K. (2015). Coastal cultural heritage: A resource to be included in integrated coastal zone management. *Ocean & Coastal Management*, 118, 110-128.

Klemas, V. V. (2015). Coastal and environmental remote sensing from unmanned aerial vehicles: An overview. *Journal of Coastal Research*, 31(5), 1260-1267.

Ladroit, Y., Lamarche, G., & Pallentin, A. (2017) Seafloor multibeam backscatter calibration experiment: comparing 45 -tilted 38-kHz split-beam echosounder and 30-kHz multibeam data. *Marine Geophysical Research,* 39, 41-53.

Lamarche, G., & Lurton, X. (2018). Introduction to the Special Issue "Seafloor backscatter data from swath mapping echosounders: from technological development to novel applications". *Marine Geophysical Researche*s, 39, 1-2.

Lejot, J., Delacourt, C., Piégay, H., Fournier, T., Trémélo, M. L., & Allemand, P. (2007). Very high spatial resolution imagery for channel bathymetry and topography from an unmanned mapping controlled platform. *Earth Surface Processes and Landforms*, 32(11), 1705-1725.

Lenz, E. (2004). Networked Transport of RTCM via Internet Protocol (NTRIP)–Application and Benefit in Modern Surveying Systems. *Allgemeine Vermessungs-Nachrichten*, 112(2).

Manigrasso, M., Conte, C., Listorti, M., & Testa, G. (2015). Il consumo delle aree costiere italiane. Legambiente. Retrived from: http://www.legambientesicilia.it/wp-content/uploads/Il-consumo-delle-aree-costiere-italiane.-La-costa-siciliana.pdf.

Martínez, M. L., Intralawan, A., Vázquez, G., Pérez-Maqueo, O., Sutton, P., & Landgrave, R. (2007). The coasts of our world: Ecological, economic and social importance. *Ecological Economics*, 63(2-3), 254-272.

Morton, R. A., Leach, M. P., Paine, J. G., & Cardoza, M. A. (1993). Monitoring beach changes using GPS surveying techniques. *Journal of Coastal Research*, 702-720.

Mossa, M., Nobile, B., & Petrillo, A. F. (2016). Studio di fattibilità sulla dinamica del trasporto solido lungo la costa di Margherita di Savoia e sulle possibili utilizzazioni di sedimenti per la difesa dei litorali a Nord e a Sud dell'abitato. Technical Report, DICATECh. Bari, Italy.

Ofiara, D. D. & Seneca, J. J. (2006). Biological effects and subsequent economic effects and losses from marine pollution and degradations in marine environments: Implications from the literature. *Marine pollution bulletin*, 52(8), 844-864.

Roche, M., Degrendele, K., Vrignaud, C., Loyer, S., Le Bas, T., Augustin, J. M., & Lurton, X. (2018). Control of the repeatability of high frequency multibeam echosounder backscatter by using natural reference areas. *Marine Geophysical Research*, 39(1-2), 89-104.

Rieb, G. & Walker, P. (2001). Le suivi morphologique du littoral. *GEOLOGUES-PARIS*, 75-78.

Ruggiero, P., Voigt, B., & Kaminsky, G. (2000). Beach monitoring for enhanced decision-making. In *Proceedings of Coastal Society 17th Conference Coast* (pp. 516-524). Portland, Oregon, USA.

Sugiura, R., Noguchi, N., & Ishii, K. (2005). Remote-sensing technology for vegetation monitoring using an unmanned helicopter. *Biosystems engineering*, 90(4), 369-379.

Trucco, E., Petillot, Y. R., Ruiz, I. T., Plakas, K., & Lane, D. M. (2000). Feature tracking in video and sonar subsea sequences with applications. *Computer Vision and Image Understanding*, 79(1), 92-122.

White, S. A., & Wang, Y. (2003). Utilizing DEMs derived from LIDAR data to analyse morphologic change in the North Carolina coastline. *Remote sensing of environment*, 85(1), 39-47.