Coastal morphology and dynamics of two beaches of Favignana

Results of an investigation on the coastal morphology and dynamics of two pocket beaches of Favignana, Cala Azzurra and Lido Burrone, are presented. Four detailed hydrographic surveys were performed using multibeam echo sounder with sidescan sonar and differential marine GPS. Surveys were repeated in different periods following the same navigation project. Moreover, incident wave climate and coastal hydrodynamics were investigated using state-of-the-art numerical models. Results of in-situ activities indicate little bathymetric variations among different surveys and suggest a substantial stability of submerged beach profiles limited to surveyed area.
Slightly greater bathymetric changes and a generally more intense coastal dynamics were observed at Cala Azzurra compared to Lido Burrone. Simulations of wave propagation and nearshore circulation currents provided results consistent with field observations

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Introduction

Favignana is the major of the Aegadian Islands (Figure 1), where tourism pressure is concentrated the most. The marine area surrounding the islands presents an extraordinary biodiversity and the largest *Posidonia oceanica* meadow in Europe; in 1991, the area was declared Marine Reserve to preserve its fragile and valuable natural resources.
The coastline of Favignana island is about 32 km long and is composed of an extremely large extent of rocky shores. A very limited number of small sandy beaches is present, mainly along the south-eastern coast of the island; the present study focuses on Cala Azzurra and Lido Burrone beaches, much appreciated by tourists and having a high landscape and economic value.
As regards coastal morphology, both sites show the typical features of a pocket beach, i.e. a pebbly or sandy beach confined in plan by two bedrock headlands [1, 2]. The exchange of sediment between a pocket beach and the adjacent shores due to long-shore transport is generally little, depending on the incident wave climate and seaward extension of the headlands. When

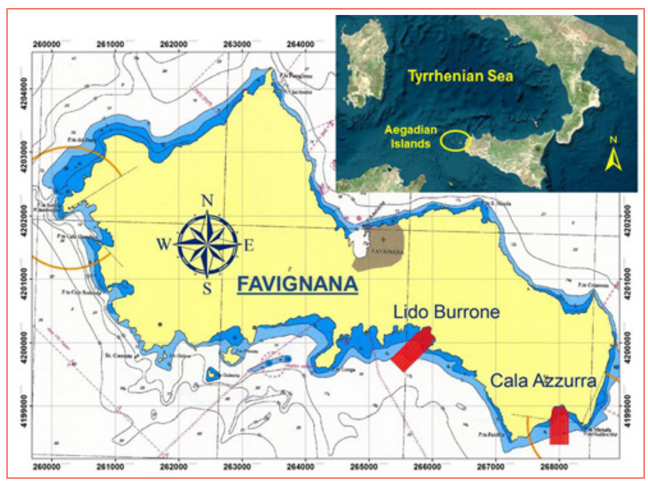

FIGURE 1 Geographic setting of study areas (coordinate system UTM33N-WGS84)

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the closure depth of the site (i.e., the maximum water depth of significant sediment transport, depending on wave climate) is located within the headlands, long-shore sediment exchange is negligible. In this case, the pocket beach can be regarded as a closed sediment cell, where sediment supply to the beach is essentially due to shoreward cliff erosion (if comprised of soft rock), or stream discharge (if present).

A large body of literature exists on the dynamics of pocket beaches [3, 4, 5, 6, 7, 8]. As regards plan-view geometry, a number of planform parameters and ratios are used in literature to describe and classify the coastal morphology and estimate the equilibrium status of the beach [9]. Due to the limited sediment transport at ends, the coastline generally tends to align itself with prevailing incident wave fronts, assuming a typical seaward concave plan shape that can be approximated by a logarithmic spiral or different mathematical functions. The resulting coastline configuration, corresponding to ideal conditions of stability, is a classical and appreciated conceptual scheme for coastal stabilization projects. The coastline orientation – i.e. the orientation of the line connecting the edges of the beach – is a typical parameter used to empirically describe coastline adaptation to incident waves. In general, if coastline orientation is aligned with the line connecting the headlands of the bay, a relative stability of the beach is to be expected, while coastline rotation can be regarded as a morphological response to changes in approach angles of prevailing incident waves. Assuming a substantial stability in terms of long-shore sediment processes, the dynamics of a pocket beach is frequently dominated by cross-shore modelling of beach profile. As well established in literature [10, 11, 12], for a given profile geometry and sediment grain size, cross-shore modelling can result in beach accretion or erosion depending on incident wave conditions. In case of high energy incident waves, offshore sediment transport (destructive forces) prevails, resulting in coastline retreat; on the contrary, with milder wave activity, the onshore transport (constructive forces) prevails and the result is a coastline advance (Figure 2). Cross-shore modelling processes are generally reversible, and the effects are alternations between two typical beach profile shapes, referred to as "storm", "winter" or "bar-type" profile, and "ordinary", "summer" or "berm-type" profile, respectively [13, 14].

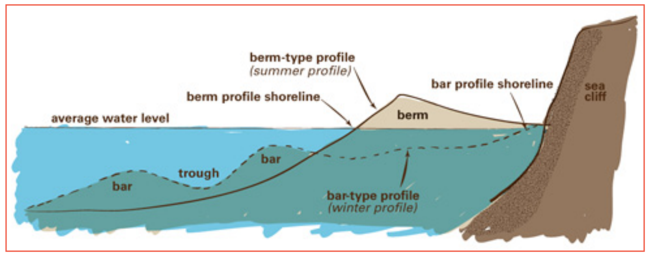

FIGURE 2 Typical features of cross-shore beach profile modelling
Source: Exploring Florida. A Social Studies Resource for Students and Teachers, University of South Florida

Sometimes, however, beach changes can be permanent and non-reversible. This occurs when sediment supply from the backshore is reduced or interrupted, typically for man-induced causes as land-use change, modification of hydrographic network, sediment extraction from riverbed, destruction of dunes, construction of seawalls and other hard structures [15, 16, 17]. Other possible cases of barely reversible beach changes can be due to sediment delivered by streams during extreme flood events, as reported for the Elba Island, [18, 19]. These are not the cases in Favignana, given the absence of an organized river network.

In the framework of a wider research program, an extensive investigation of coastal morphology and dynamics was performed at Cala Azzurra and Lido Burrone sites during the period 2012-2014. First results of the work, including an outline of materials and methods and partial data analysis, have been synthetically presented in a previous paper [20]. Besides any scientific interest, the results of the projects will contribute to create a knowledge base aimed to implement measures for sustainable tourism and management of marine resources.

Materials and methods

Hydrographic surveys

Four hydrographic surveys were performed at Cala Azzurra and Lido Burrone, in the following periods: November 2012 (Survey 1), July 2013 (Survey 2), September 2013 (Survey 3), and May 2014 (Survey 4).
The temporal planning of surveys was defined in order to

describe the seasonal variability of the beach morphology as completely as possible, compatibly with the timetable of the project and suitable sea and weather conditions.

Survey equipment and instrumentation are listed below:

- Multibeam echo sounder with sidescan sonar Odom Echoscan (30 beams, acoustic frequency 200 kHz, swath angle 90°);
- Marine Differential GPS Trimble SPS461, dual antenna, for position and heading measure;
- Trimble HydroPro software for survey planning and navigation;
- Communication Technology GeoPro/SwanPro software for multibeam and sidescan sonar data acquisition;
- Triton BathyPro, Triton ISIS Sonar and Golden Software Surfer software for data processing and presentation.

Figure 3 shows some of the above listed resources.

As regards compensation of measurement errors, the echo sounder is provided with a Teledyne TSS dynamic motion sensor (DMS) for random errors due to heave, pitch and roll. The heading information for yaw compensation is obtained by simultaneous GPS acquisition at two antennas aligned along the main axis of the vessel. Patch tests [21] were performed per each operation day, to compensate the systematic errors due to mounting offsets of the transducer.

Survey vessel and personnel for marine operations were provided by the Marine Reserve Management Authority (*Area Marina Protetta Isole Egadi*). The transducer was mounted at the port side of the vessel, using a flange pole and an *ad-hoc*-designed steel framework.

As regards the navigation project, survey lines normal to the shoreline were adopted, oriented to North for Cala Azzurra and 45°N for Lido Burrone, respectively. Line spacing was defined, considering the multibeam swath angle, in order to obtain, at nominal depth of 10 m, a 100% bottom coverage with 50% overlap between parallel consecutive swath lines. Overall, 30 transects were adopted for both sites, with 10 m line spacing. The orientation and spacing of survey lines is the result of an optimal compromise between swath angle and resolution of the instrument, maneuverability of vessel and safety of navigation, and allowed to maximize the surveyed area, also considering the bottom morphology and the presence of rocks and other obstacles in the nearshore zone.

The offshore limit of navigation lines was planned in order to extend the survey beyond the depth of closure d_c of the active beach that, according to Hallermeier [22], can be estimated as follows:

$$d_c = 2.28 H_s - 68.5 \frac{H_s^2}{g T_s^2}$$

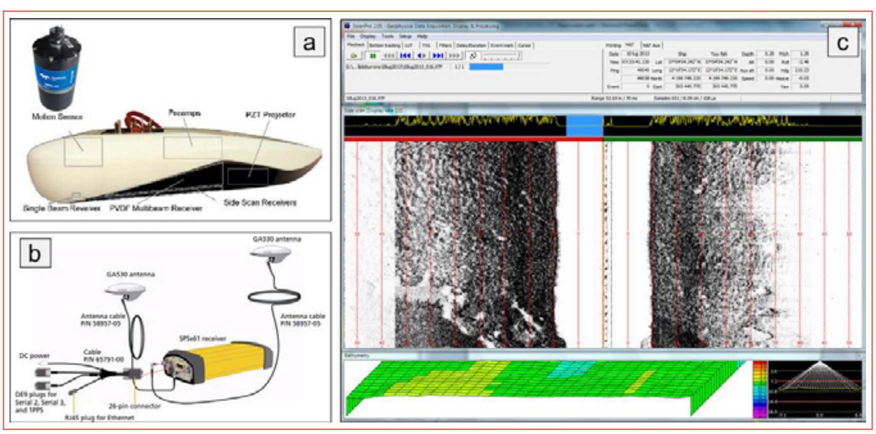

FIGURE 3 Main resources used for hydrographic surveys. a) Multibeam and sidescan sonar transducer with dynamic motion sensor. b) Marine DGPS dual antenna for position and heading. c) Example of multibeam echo sounder and sidescan sonar data acquisition during survey operations

In the above formula, g is the gravitational acceleration, while H_s and T_s are, respectively, the significant wave height and period representative of incident wave conditions exceeded only 12 hours per year (exceedance probability 0.137%).

Based on the statistical analysis of incident wave climate discussed in the next section, the values $H_{s(12hr)}$=4.55 m and $T_{s(12hr)}$=9.28 s were derived, resulting in a depth of closure d_c=8.70 m.

A well-established extension of the Hallermeier formulation is to relate the depth of closure

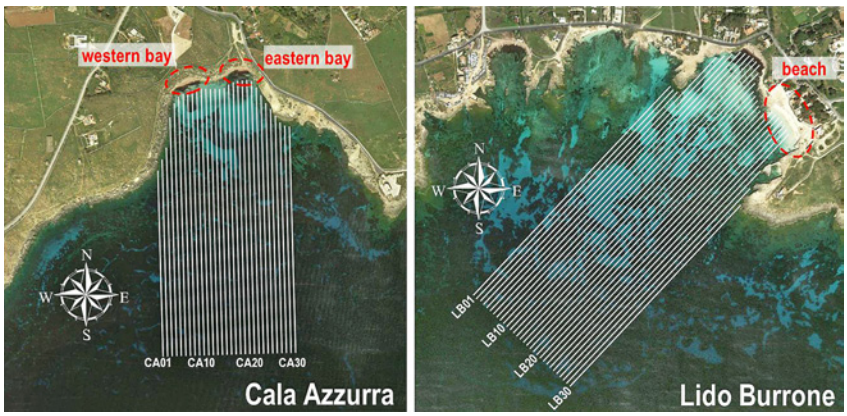

FIGURE 4 Satellite view of Cala Azzurra and Lido Burrone sites and cross-shore survey lines

to storm wave conditions associated to a given recurrence frequency or return period, based on the analysis of extreme events [23, 24]. In the present study, a 25 years return period was adopted and, following Gumbel's distribution, values of H_s=6.21 m, T_s=10.39 s were estimated, resulting in a depth of closure d_c=11.66 m.

Based on the above considerations, survey lines were extended in the offshore direction beyond a depth of about 12 m, according to the available nautical charts provided by the Hydrographic Institute of Italian Navy. In Figure 4, the navigation projects are shown for each site; survey lines are numbered from CA01 to CA030 toward East for Cala Azzurra and from LB01 to LB30 toward South-East for Lido Burrone. The average length of the transects is 500 m at Cala Azzurra and 700 m at Lido Burrone.

Bathymetric data were processed using BathyPro and Surfer software. Post-processing tools and data filters were applied for error compensation and spike detection. Then, using algorithms for spatial interpolation, digital models of the sea bottom were built, with grid spacing consistent with spatial density of data. Finally, beach profiles, contour maps and 3D surface were derived for presentation of data and further elaborations.

All data were projected and presented in the UTM33N-WGS84 coordinate system.

Wave climate and coastal hydrodynamics investigation

Incident offshore wave climate, nearshore wave conditions and wave-induced coastal circulation at study areas were investigated using available wave data and mathematical models.

The offshore wave climate was derived from historical data measured from July 1989 to March 2008 at Mazara del Vallo recording station of the Italian Sea Wave Measurement Network [25]. Wave data were transferred to a virtual buoy located off Cala Azzurra and Lido Burrone sites, at 100 m depth. At this aim, a geographic transposition method [26] was used, based on comparison among effective fetches measured, respectively, at real and virtual station. Offshore wave data were processed to estimate mean annual wave climate, in terms of joint occurrence frequency of wave height and direction. A statistical analysis of extreme waves was also performed to derive sea state parameters associated to different values of the return periods, based on suitable probability distribution functions.

Offshore wave conditions were transferred shoreward using state-of-the-art numerical models. Namely, different modules of MIKE 21 suite (DHI Water & Environment) were applied to simulate wave refraction, diffraction, breaking and to evaluate radiation stress components [27, 28]; finally, using the two-dimensional, depth-averaged hydrodynamic module [29], the surface elevation and nearshore currents due to incident waves were simulated.

Numerical simulations were performed using interpolated bathymetric grids with different resolutions, considering the model formulation, spatial data density, required accuracy and computational effort. Offshore bathymetry was derived by the official nautical charts provided by the Hydrographic Institute of Italian Navy, whereas survey data were used for detailed simulations in the nearshore shallow water zone.

Results and discussion

Macro features of coastal morphology and dynamics

From general observation of beach morphodynamics at Cala Azzurra and Lido Burrone site, some qualitative differences can be noticed.

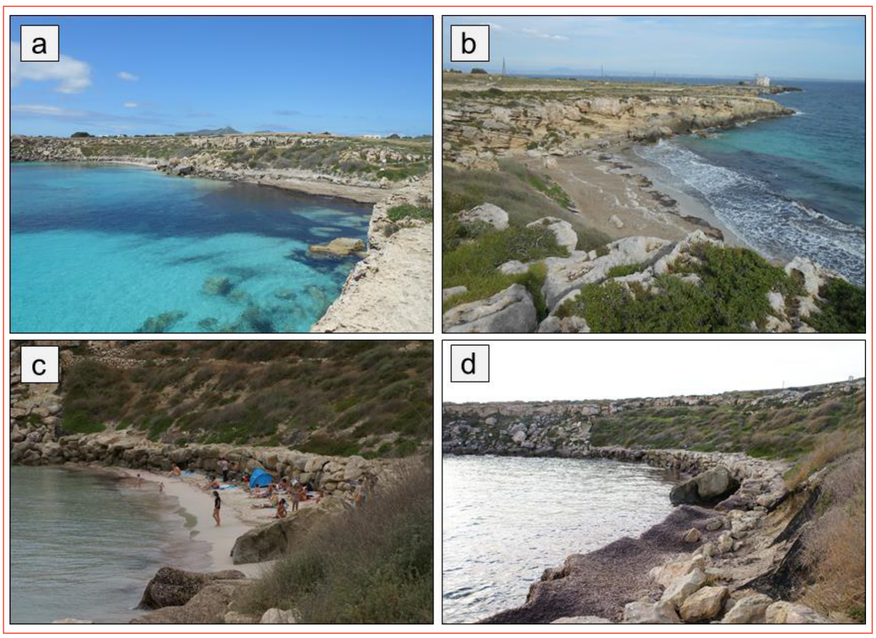

FIGURE 5 Cala Azzurra. a) Overview of the site; the western beach on the left and the eastern bay on the right are visible in the picture. b) View of the eastern bay. c) View of the western bay, with emerged beach (May 2012). d) View of the western bay, with beach completely eroded (November 2012)

FIGURE 6 Lido Burrone beach. Picture a was taken in late autumn (November 2012), picture b in spring (May 2014). A huge amount of Posidonia oceanica banquettes is visible at the shoreline in picture a, owing to high energy incident waves; however, the emerged beach maintains a noticeable width

As regards Cala Azzurra, two small sandy bays can be observed in Figure 4 (hereafter referred to as "western bay" and "eastern bay"), separated by a central rocky headland. Emerged beach is flat and narrow, with a maximum width of about 8 m at western bay and 12 m at the eastern bay. In order to reduce the risk of landslides, the entire backshore slope is protected by a geotextile net revetment, with a significant reduction in sediment supply to the beach. Moreover, at the western bay, a quarry stone seawall is present at the toe of the slope, increasing wave reflection onshore.

As historically reported and observed during the monitoring project, the impact of wave storms on Cala Azzurra beach can induce severe modifications (Figure 5), with huge coastline retreat and, sometimes, with complete disappearance of the emerged beach at western bay, where changes can take place in very short times (days or even hours).

As regards Lido Burrone, two coves can be distinguished just as for Cala Azzurra (Figure 4), but here emerged beach is present only at the south-eastern side; the emerged beach is relatively flat, with a width comprised between about 10 m at ends and 30 m in the middle. Based on historical reports and direct observations, the effects of coastal modelling due to waves impact are generally milder compared to Cala Azzurra, with rather limited coastline retreat and noticeable beach width even under severe wave conditions (Figure 6).

At both sites, sediment samples were collected in the emerged and submerged beach. Results of grain size analysis indicate little

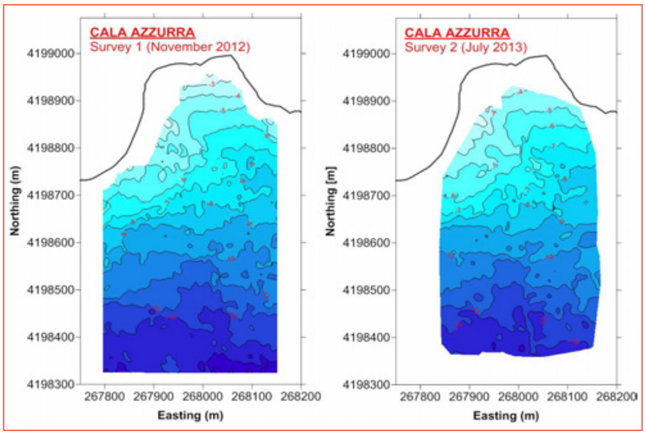

FIGURE 7 Bathymetric maps of Cala Azzurra derived from Survey 1 and Survey 2 data

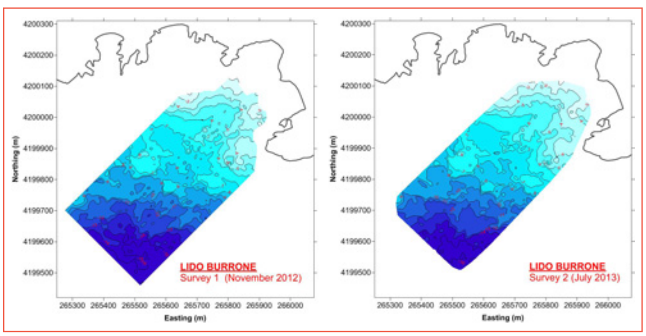

FIGURE 8 Bathymetric maps of Lido Burrone derived from Survey 1 and Survey 2 data

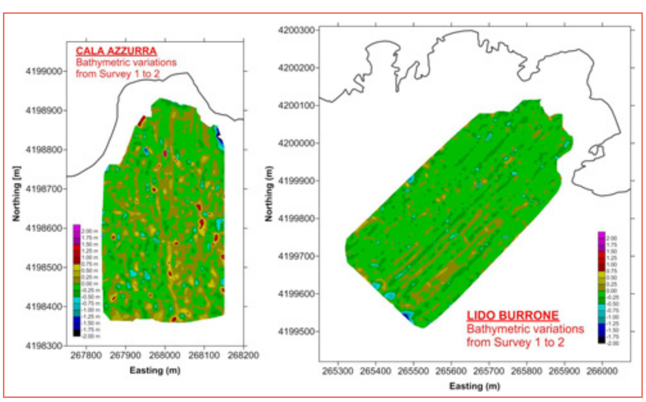

FIGURE 9 Bathymetric variations estimated from Survey 1 to Survey 2

variations in median grain diameter d_{50} along beach profile and little difference between the two sites. So, as an approximation, consistently with the purpose of the present work, a constant value of d_{50}=0.20 mm was assumed for both Cala Azzurra and Lido Burrone beaches.

Bathymetry of submerged beaches

Based on survey data, a quite complex morphology of submerged beach was observed at both sites. Mean slope of submerged beach can be estimated as 2.5% at Cala Azzurra and 1.8% at Lido Burrone.
For example purpose, bathymetric contour maps derived from surveys 1 and 2 are plotted in Figures 7 and 8. Depending on instruments operation and safety of navigation, the minimum investigated depth is about 1.5-2.0 m.
Examples of bathymetric changes estimated by two consecutive surveys are plotted in Figure 9. Positive bathymetric variations indicate sediment deposition, being the opposite for bottom erosion. To a large extent, slight bathymetric variations can be noticed between the surveys at both sites, whereas only in a few limited areas bathymetric changes of 1 m in absolute value can be observed. Overall, Cala Azzurra showed greater bathymetric variations than Lido Burrone. Similar results were obtained comparing data from the other surveys.
However, for a correct interpretation of results, considering the various sources of uncertainty in data acquisition and processing, bathymetric differences lower than 0.30 m in absolute value should be regarded as negligible.
In Figures 10-13, beach profiles extracted from measured data at selected cross-shore transects are plotted. As regards Cala Azzurra, profile CA09 is representative of the western bay, whilst CA21 corresponds to the eastern bay. As regards Lido Burrone, profile LB10 is taken near the North-West end of the site, where emerged beach is absent, whilst LB23 corresponds to the part of the bay where emerged beach is present.
As already observed from contour maps, submerged beach has a quite complex geometry and bathymetric changes among different surveys are relatively small. In particular, survey data do not seem to indicate a clear seasonal regime of submerged beach profiles.

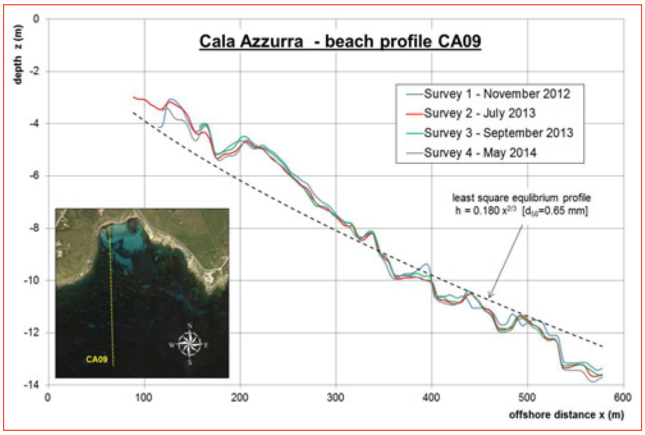

FIGURE 10 Cala Azzurra, transect CA09. Surveyed beach profiles and theoretical equilibrium profile

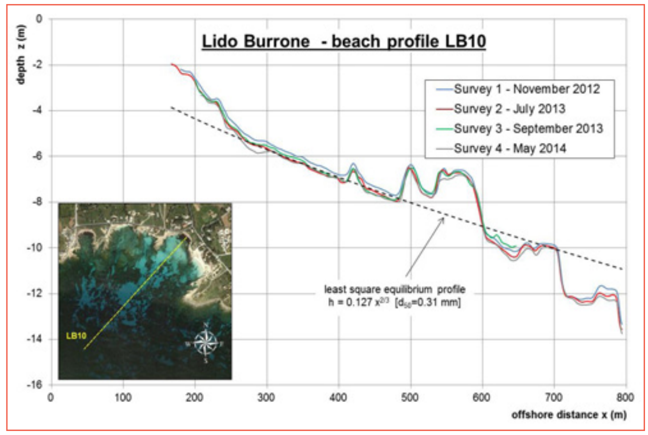

FIGURE 12 Lido Burrone, transect LB10. Surveyed beach profiles and theoretical equilibrium profile

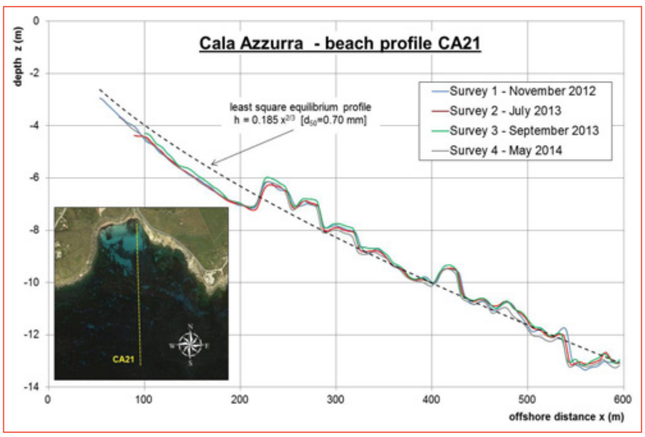

FIGURE 11 Cala Azzurra, transect CA21. Surveyed beach profiles and theoretical equilibrium profile

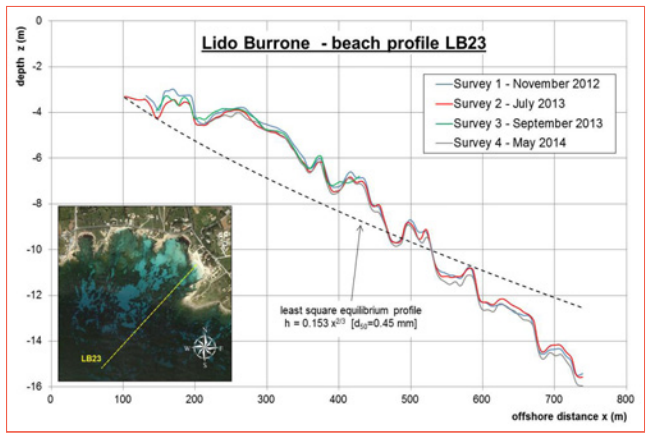

FIGURE 13 Lido Burrone, transect LB23. Surveyed beach profiles and theoretical equilibrium profile

For each of surveyed transects, theoretical equilibrium profiles which best fit measured data were derived using the least squares method. In the ideal case in which there is no net cross-shore sediment transport, i.e. same magnitude of constructive and destructive forces, beach profile tends to assume a concave configuration, classically described by Dean [30] with a power function:

$$h = A \cdot x^{2/3}$$

where h *is* the water depth, x is the offshore distance from shoreline and A is a scale parameter that increases with sediment size. The use of equilibrium profile to compare measured data is to be considered as a first approximation, consistent with a qualitative description of the coastal morphology and dynamics. Main criticisms to this approach can be: (a) the equilibrium profile concept is applicable to uniform sandy beach profile, disregarding the possible presence of rock and differences in seafloor coverage, and (b) the Dean formulation can be considered to progressively become less realistic as the depth of submerged profile increases (i.e., starting from 6 m depth).

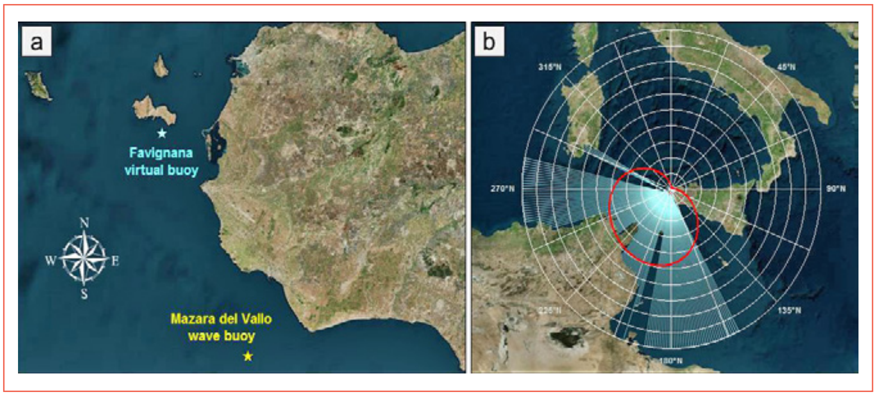

FIGURE 14 a) Positions of the real and virtual stations used for geographical transposition of wave climate. b) Polar plots of geographic and effective fetches at virtual buoy off study areas

Considering all the above considerations, for all surveyed profiles, the best-fit values of scale parameters *A* were estimated; all values correspond to ideal values of d_{50} greater than that of the actual sediment (0.20 mm). Limited to the only sections of coast where emerged beaches are present, theoretical mean values of d_{50} can be estimated as 0.68 mm at Cala Azzurra western bay, 0.72 mm at Cala Azzurra eastern bay and 0.47 mm at Lido Burrone beach.

Considering the minor bathymetric variations observed during the project period, results seem to suggest an overall stability of the submerged beach profile greater than that expected from the actual sediment size distribution. It can be reasonably hypothesized that this is due to presence of rock or to the stabilizing effect of *Posidonia oceanica* on the sea bottom, though more investigations are needed to confirm this hypothesis.

In particular, it should be necessary to investigate in detail the nature of sea bottom materials and its coverage and further extend measures in the emerged beach and in the nearshore zone, where intense sediment dynamics is to be expected.

Wave climate and coastal hydrodynamics

In Figure 14, the positions of Mazara del Vallo wave buoy and Favignana virtual buoy used for geographic transposition of wave data are plotted. In the same Figure, polar graphs of geographic and effective fetches estimated at virtual buoy are shown; the highest values of geographic fetch are comprised in the directional sectors 150-190°N and 260-290°N. A rose plot of the offshore annual wave climate derived from geographic transposition is depicted in Figure 15. Two directional sectors for prevailing incident waves can be distinguished: the first comprises the south-eastern quadrant, whilst the second is centered on south-western direction.

Considering the coastline geometry and orientation, it can be assumed that only the waves comprised in the sector 120-300°N are likely to propagate shoreward and reach the study areas. Based on the above considerations, the directional sector can be divided in two prevailing

Directional sector	Relative frequency	Direction of mean annual wave energy flux
120-300°N (complete sector)	100%	250°N
120-180°N (SE sector)	30%	158°N
190-300°N (SW sector)	70%	257°N

TABLE 1 Main offshore wave climate parameters

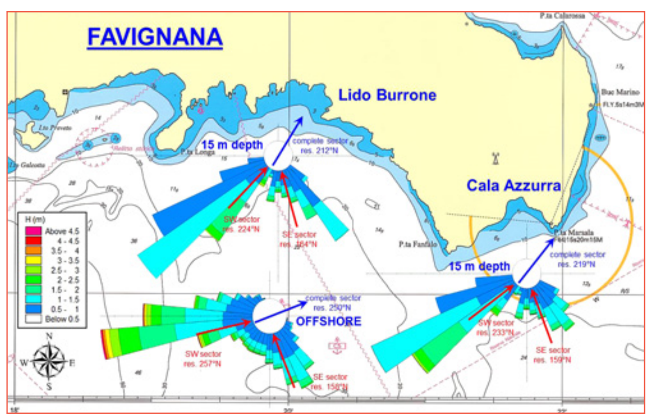

FIGURE 15 Rose plots of estimated offshore annual wave climate and wave climate obtained by simulation of wave propagation at Cala Azzurra and Lido Burrone sites (reference depth 15 m)

waves sub-sectors, namely the sector 120-180°N, with 30% relative occurrence frequency, and the sector 190-300°N, with 70% relative occurrence frequency. For both the complete sector and each sub-sector, the resultant vector of offshore annual wave energy flux was evaluated; results are summarized in Table 1. Based on the direction of annual wave energy flux, the above directional sub-sectors were referred to as SE sector and SW sector, respectively.

Offshore waves were transferred shoreward using different numerical models. First, MIKE 21 NSW (Nearshore Spectral Waves) module was applied to simulate wave propagation from deep water to intermediate depth off the Cala Azzurra and Lido Burrone site. Bathymetry was derived by available nautical charts. Considering the spatial resolution of data and the formulation of the model, rectangular grids with Δx=30 m and Δy=100 m were adopted for simulations, with x-axis directed shoreward.

For example purpose, Figure 16 illustrates one of the simulations performed for offshore wave direction 260°N. It can be observed that the wave fronts rotate due to refraction. Results of all simulations are condensed in the rose plots of wave climate at 15 m reference depth, shown in Figure 15. Consistently with wave refraction and with coastline and bathymetry configuration, a general wave height reduction and rotation of wave direction southward are noticed; the sheltering effects of headlands for waves propagating from the western quadrant is also evident, especially at Lido Burrone.

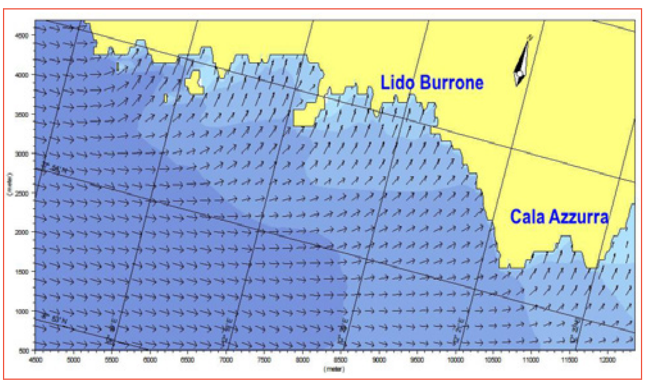

FIGURE 16 Example of wave propagation from deep water toward study areas. Vectors indicate the wave direction. Offshore wave direction is 260°N

Offshore directional sector	Relative frequency	H_m (m)	T_m (s)	Direction of mean annual wave energy flux
120-300°N (complete sector)	100%	1.01	5.47	219°N
120-180°N (SE sector)	30%	0.93	5.26	159°N
190-300°N (SW sector)	70%	1.04	5.53	233°N

TABLE 2 Main results of wave propagation at Cala Azzurra site (15 m depth)

Offshore directional sector	Relative frequency	H_m (m)	T_m (s)	Direction of mean annual wave energy flux
120-300°N (complete sector)	100%	0.96	5.37	212°N
120-180°N (SE sector)	30%	0.86	5.11	164°N
190-300°N (SW sector)	70%	1.00	5.46	224°N

TABLE 3 Main results of wave propagation at Lido Burrone site (15 m depth)

As a general observation, compared to Lido Burrone more intense wave conditions can be estimated at Cala Azzurra.

For each sector of offshore wave direction, resultant vectors of mean annual wave energy flux at 15 m depth were calculated. Significant heights (H_m) and periods (T_m) of the ideal waves representative of the annual wave climate in terms of wave energy flux and steepness, i.e. the so-called "morphological waves", were also estimated. Results are summarized in Table 2 and Table 3.

At both sites, MIKE 21 PMS (Parabolic Mild Slope Waves) was used to simulate wave propagation and breaking from 15 m depth to the shore and to calculate the radiation stress components. Finally, MIKE 21 HD (Hydrodynamic) module was used to simulate the wave-induced currents in the nearshore, based on results from previous simulations. Bathymetric survey data were used for simulations with PMS and HD modules, and finer bathymetric grids (Δx=Δy=5 m) were adopted. Wave conditions used for simulations corresponds to morphological waves representative of SE and SW sectors, as reported in Table 2 and 3.

Figure 17 and Figure 18 illustrate results of nearshore wave propagation provided by PMS module, described by directional wave vectors.

The radiation stress components derived by PMS module results were used as input in the HD module to simulate nearshore hydrodynamics induced by incident morphological waves. Results of HD simulations are

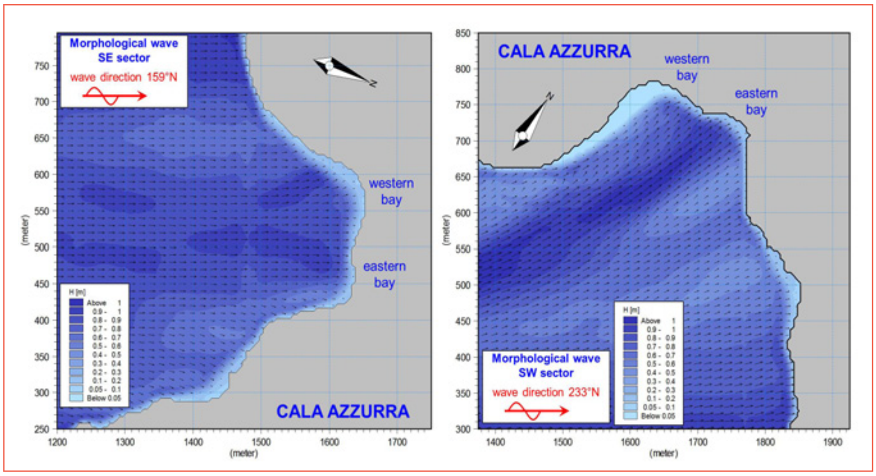

FIGURE 17 Simulation of nearshore wave propagation at Cala Azzurra. Incident wave conditions correspond to morphological waves for SE and SW sectors at 15 m depth

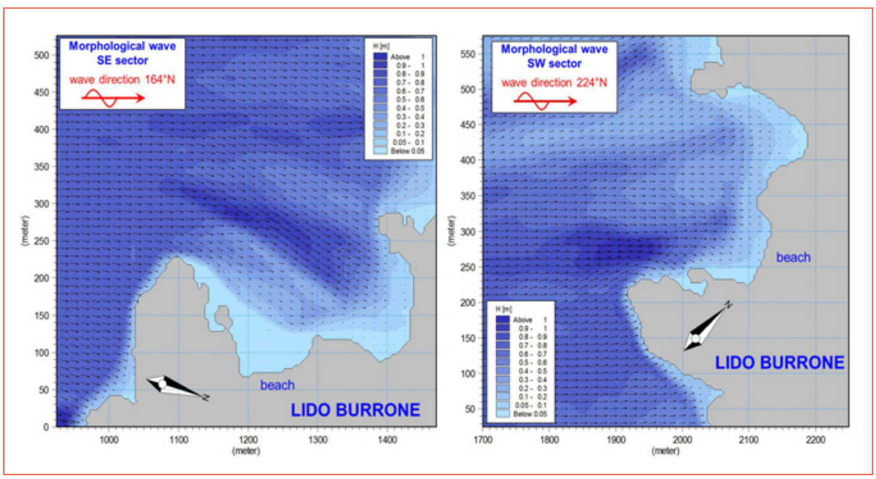

FIGURE 18 Simulation of nearshore wave propagation at Lido Burrone. Incident wave conditions correspond to morphological waves for SE and SW sectors at 15 m depth

depicted in Figure 19 and Figure 20 in terms of time-averaged surface elevation, whilst Figure 21 and Figure 22 illustrate the wave-driven nearshore circulation currents.

At both sites, offshore-directed return currents can be noticed in the middle of the nearshore area. Nearshore currents are strongly affected by the coastline geometry and seabed morphology and, as expected from what discussed above, more intense hydrodynamic conditions are observed at Cala Azzurra compared to Lido Burrone.

From nearshore circulation patterns, a general transport toward the eastern ends of both sites can be noticed. This seems to suggest a certain potential sediment supply to the Cala Azzurra eastern bay and to the Lido Burrone beach, where, in fact, permanent emerged beach can be observed. The above observation, however, takes into account only average incident wave conditions and is not to be considered exhaustive of the complex sediment dynamics of study area.

Conclusions

In-situ activities and model studies performed during the project provided a detailed knowledge of coastal morphology and dynamics of Cala Azzurra and Lido Burrone coastal sites.

The main results can be summarized as follows:

1. Both sites present a quite complex bathymetry.
2. Limitedly to surveyed areas, an overall stability of submerged beach was observed, with little bathymetric variations among different surveys. A clear seasonal regime of beach profiles was not noticeable from survey data, even if this aspect should be better clarified by further investigation on sea bottom geology and coverage.
3. Results of the hydrodynamic study are consistent with field observations.

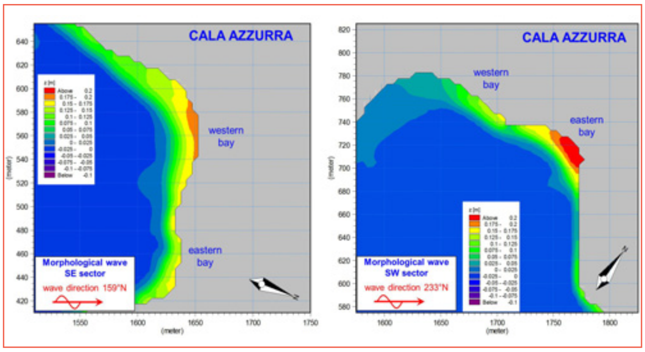

FIGURE 19 Simulation of mean surface elevation induced by morphological waves at Cala Azzurra

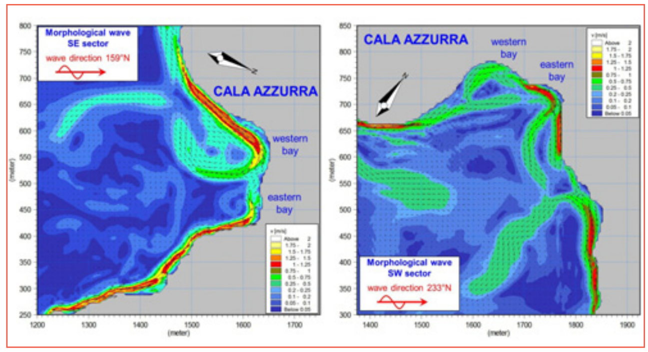

FIGURE 21 Simulation of nearshore circulation currents induced by morphological waves at Cala Azzurra

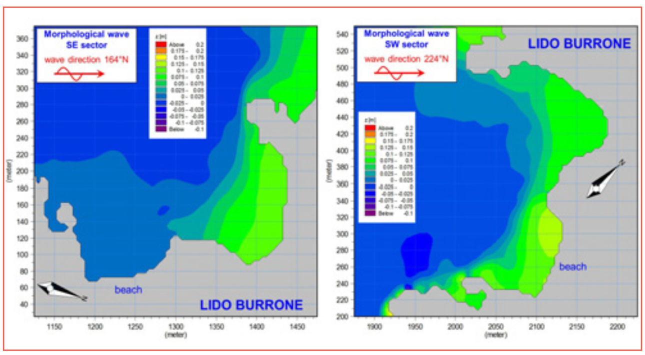

FIGURE 20 Simulation of mean surface elevation induced by morphological waves at Lido Burrone

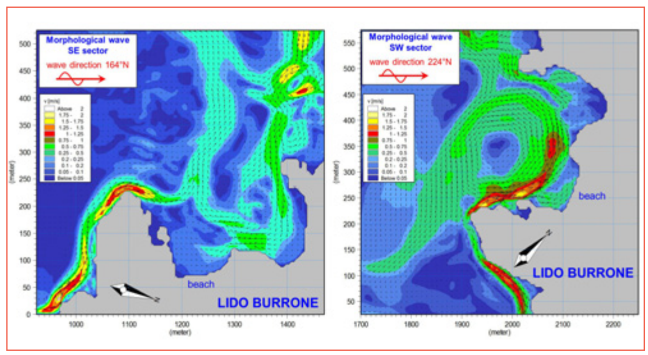

FIGURE 22 Simulation of nearshore circulation currents induced by morphological waves at Lido Burrone

4. In general, more intense coastal dynamics and hydrodynamic conditions were observed at Cala Azzurra compared to Lido Burrone.

The results are interesting not only for the purpose of the project, but also because they can be considered as representative of the typical morphology and dynamics of the pocket beaches, that is a key issue in coastal sciences.

Further studies could be suggested in order to better investigate the possible causes for the evidences observed in field activities. In particular, assuming that the *Posidonia oceanica* coverage has undoubtedly positive effects on sea bottom stability, its role could be investigated by means of measures, experimental and mathematical model studies, including the description of coastal hydraulics and sediment dynamics.

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references

[1] Istituto Geografico Militare (2004), *Atlante dei Tipi Geografici*, *Morfologia Costiera,* IGM, Firenze

[2] U. Simeoni, C. Corbau, E. Pranzini, S. Ginesu (2012), *Le Pocket Beach. Dinamica e Gestione delle Piccole Spiagge*, Franco Angeli, Milano

[3] R. Silvester (1960), "Stabilization of Sedimentary Coastlines", *Nature*, 188, pp. 467-469, Nature Publishing Group

[4] R. Silvester, Y. Tsuchiya, Y. Shibano (1980), "Zeta Bays, Pocket Beaches and Headland Control", *Proc. 17th International Conference on Coastal Engineering*, Sidney, pp. 1306-1319

[5] T. Yamashita, Y. Tsuchiya (1992), "Numerical Simulation of Pocket Beach Formation", *Proc. 23rd International Conference on Coastal Engineering*, Venice, pp. 2556-2566

[6] H.G. Wind (1994), "An Analytical Model for Crenulate Shaped Beaches", *Coastal Engineering*, 23, pp. 243-253, Elsevier

[7] L. Moreno, N.C. Kraus (1999), "Equilibrium Shape of Headland-bay Beaches for Engineering Design", *Proc. Coastal Sediments '99,* Hauppage (Long Island, NY), pp. 860-875

[8] J. R.-C. Hsu, L. Benedet, A.H.F. Klein, A. Raabe, C.-P. Tsai, T.-W. Hsu (2008), "Appreciation of Static Bay Beach Concept for Coastal Management and Protection", *Journal of Coastal Research*, 24 (1), pp. 198-215, Coastal Education and Research Foundation

[9] D. Bowman, V. Rosas, E. Pranzini (2014), "Pocket Beaches of Elba Island (Italy) – Planview Geometry, Depth of Closure and Sediment Dispersal", *Estuarine, Coastal and Shelf Science*, 138, pp. 37-46, Elsevier

[10] R.G. Dean, R.A. Dalrymple (1991), *Water Wave Mechanics for Engineers and Scientists*, World Scientific Publishing, Singapore

[11] U.S. Army Corps of Engineers (2002), *Coastal Engineering Manual*, Eng. Man. 1110-2-1100, Washington D.C.

[12] APAT (2007), *Atlante delle Opere di Sistemazione Costiera*, Manuali e Linee Guida, 44, Istituto Superiore per la Protezione e la Ricerca Ambientale, Roma

[13] P.H. Kemp (1960), "The Relationship between Wave Action and Beach Profile Characteristics", *Proc. 7th International Conference on Coastal Engineering,* The Hague, pp. 262-277

[14] C.E. Nordstrom, D.L. Inman (1975), *Sand Level Changes on Torrey Pines Beach, California*, Miscellaneous Paper no. 11-75, Coastal Engineering Research Center, U.S. Army Corps of Engineers

[15] A. Micallef (2003), "Monitoring Beach Stability on the Mediterranean Island of Malta", *Proc. MEDCOAST 03*, Ravenna, pp. 1357-1368

[16] N.J. Cooper, J. Pethick (2005), "Sediment Budget Approach to Addressing Coastal Erosion Problems in St. Ouen's Bay, Jersey, Channel Islands", *Journal of Coastal Research*, 21 (1), pp. 112-122, Coastal Education and Research Foundation

[17] L. Cipriani, E. Pranzini, V. Rosas, L. Wetzel (2011), "Landuse Changes and Erosion of Pocket Beaches in Elba Island (Tuscany, Italy)", *Journal of Coastal Research*, SI 64, pp. 1774-1778, Coastal Education and Research Foundation

[18] E. Pranzini, V. Rosas (2007), "Pocket Beach Response to High Magnitude-Low Frequency Floods (Elba Island, Italy)", *Journal of Coastal Research*, SI 50, pp. 969-977, Coastal Education and Research Foundation

[19] E. Pranzini, V. Rosas, N.L. Jackson, K. Nordstrom (2013), "Beach Changes from Sediment Delivered by Streams to Pocket Beaches during a Major Flood", *Geomorphology*, 199, pp. 36-47, Elsevier

[20] F. Pasanisi, C. Tebano, S. Grauso (2014), "Rilievi Batimetrici e Studio della Dinamica Costiera delle Spiagge di Favignana", *Proc. 5th International Symposium: Monitoring of Mediterranean Coastal Areas: Problems and Measurement Techniques*, Livorno, pp. 687-696

[21] U.S. Army Corps of Engineers (2002), *Engineering and Design. Hydrographic Surveying*, Eng. Man. 1110-2-1003, Washington D.C.

[22] R.J. Hallermeyer (1981), "A profile Zonation for Seasonal Sand Beaches from Wave Climate", *Coastal Engineering*, 4, pp. 253-277, Elsevier

[23] N. Kraus, S. Harikai (1983), "Numerical Model of the Shoreline Change at Oarai beach", *Coastal Engineering*, 7, pp. 1-28, Elsevier

[24] N. Kraus, M. Larson, R.A. Wise (1998), "Depth of Closure in Beach-Fill Design", *Coastal Engineering Technical Note*, CETN II-40 (3/98), U.S. Army Corps of Engineers

[25] APAT, Università di Roma 3 (2006), *Atlante delle Onde nei Mari Italiani*, Istituto Superiore per la Protezione e la Ricerca Ambientale, Roma

[26] P. Contini, P. De Girolamo (1998), "Impatto Morfologico di Opere a Mare: Casi di Studio", *Atti VIII Convegno AIOM*, Lerici, pp. 85-95

[27] J.C.W. Berkhoff (1972), "Computation of Combined Refraction-Diffraction", *Proc. 13th International Conference on Coastal Engineering*, Vancouver, pp. 471-490

[28] L.H. Holthuijsen, N. Booij, T.H.C. Herbers (1989), "A Prediction Model for Stationary, Short-Crested Waves in Shallow Waters with Ambient Currents", *Coastal Engineering*, 13, pp. 23-54, Elsevier

[29] DHI Water & Environment (2000), *MIKE 21. Hydrodynamic Module. Scientific Documentation*

[30] R.G. Dean (1991), "Equilibrium Beach Profiles: Characteristics and Applications", *Journal of Coastal Research*, 7 (1), pp. 53-84, Coastal Education and Research Foundation