Third beach nourishment project with submarine sands along Emilia-Romagna coast: geomatic methods and first monitoring results

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Third beach nourishment project with submarine sands along Emilia-Romagna's coast: geomatic methods and first monitoring's results

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1. Introduction

Coastal areas are always growing from an economic point of view, involving several interests, such as tourism, navigation, fishing and maritime transports. On the other hand, from an environmental point of view, these systems strongly suffer from erosion's phenomenon, which depends on many factors, both natural and anthropic. Therefore, the problem of coastal erosion appears like one of the most important issues within the environmental protection, even more considering the strong increasing of mass tourism which transformed coastal areas since the last century (Van Rijn 2011; Cipriani et al. 2004). Approximately one-fourth of the EU Mediterranean coastline suffers from erosion, with variation among countries (UNEP/MAP 2012). Italy has about 7.500 km of coast, which are in part affected by erosion (Ministero dell'Ambiente 2017). GNRAC (the Italian research group on coastal environment) estimated that about 42% of the national beaches suffers from this phenomenon (GNRAC 2006). In a more detailed context, Emilia-Romagna's coast consists of 110 km of low and sandy beaches, which are particularly exposed to coastal erosion. In 2012, Arpae (the regional agency for the environmental protection of Emilia-Romagna) estimated in Emilia-Romagna a rate of erosion equal to the 37%, without considering defence interventions (Aguzzi et al. 2016). These considerations clearly point out the importance of studying and reduce this phenomenon, by performing different defence interventions.
The coastal environment is a complex landform characterized by a very dynamic balance. Beach erosion occurs when the amount of sand leaving a specific site is greater than the amount arriving (or remaining) (Cipriani et al. 2004; Komar 1983). On the other hand, erosion process is the result of the interaction between several processes (Eurosion 2004; Fabbri et al. 2001):

- waves;
- sediment's transport;
- subsidence of the coastal area;
- climate changes;
- human activities.

Wind-generated waves are important as energy-transfer agents; it's essential to evaluate their effects in the coastal zone, where they can generate a variety of nearshore currents and sand transport patterns (Komar 1983). Littoral sediments play an important role in the maintaining of beaches' balance, because they can be transported by currents, obtaining a natural rearrangement of the shoreline (Komar 1983). However, rivers' sediments, which represent one of the major natural sources of material, have suffered for anthropic activities, such as the extraction of inert materials from river beds and rivers' regulation through damming (Crossland et al. 2005). For what concerns subsidence along Emilia-Romagna's coast, in the period between 2011 and 2016, the average value was about 3-4 mm/y (Arpae, Regione Emilia-Romagna 2018). As for human activities, the construction of hard defence structures and the urbanization close to beach areas continue causing the stiffening of the coast (Perini et al. 2008). Finally, the climate change background should be considered: in this context, erosion's effects may be worsened by the sea level rise (E. Degano 2017; Zhang et al. 2004; IPCC 2019; Leatherman et al. 2000; Rodella et al. 2017). According to these considerations, the design and management of a coastal defence project appear to be very complicated because of the several factors to be considered (Phillips and Jones 2006).
The problem of coastal erosion can be reduced through structural interventions or management projects, like prevention and maintaining strategies in a short and long-time point of view. Structural interventions include hard structures whose layouts imply different interactions with the morphology of the beach. However, in general, the construction of hard structures could modify the profile of the beach and the longshore sediment transport, maybe with increased erosion in adjacent areas (Van Rijn 2011; Semeoshenkova and Newton 2015; Gillie 1997; Eurosion 2004). On the other hand, they induce visual and environmental effects and they require continuous maintenance works (Van Rijn, 2011; Semeoshenkova and Newton 2015; Phillips and Jones 2006; UNEP/MAP 2012). For these reasons, the current trend of coastal policies is going towards a decreasing of effects on the environment and the population. About this, soft techniques as beach nourishments could be a good alternative (Phillips and Jones 2006; Semeoshenkova and Newton 2015). Beach nourishment is a non-structural - "soft" - defence intervention, which consists of the replacing of sand on eroded beaches, where the material could be later rearranged by natural processes. These interventions imply a balancing of the natural sediment contribution's lacks, obtaining a stronger beach system, thanks to the height's increase and the sandy shore's enlargement (Semeoshenkova and Newton 2015). The sandy material can be taken from different areas, such as land quarries, river beds, coastal areas and underwater borrow areas. Material from submarine borrow areas can be transported

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by sea, using dredges and floating duct, minimizing effects on the anthropic use of the beach. Beach nourishments need to be related to Monitoring Plans, to analyse the state and the evolution of each involved beach and the effectiveness of the intervention itself. Monitoring activities are realized by performing surveys at different times on the emerged and submerged beach. In fact, the amount of material, the shoreline's changes and the height's variations can be evaluated by comparing surveys related to different times in the same area.

2. Study area

Emilia-Romagna's coast is a great naturalistic and economical asset, with considerable tourist attractions; it is among the top summer locations in all of Italy. The regional coast consists of 110 km of low and sandy beaches which go from the beach of Cattolica to the mouth of the Po River in Volano (Comacchio), and the barrier-lagoon system in Sacca di Goro. Since the last century, the Emilia-Romagna Region performed several coastal defence interventions to reduce erosion problem. Emilia-Romagna's coast is actually protected by 75 km of hard structures, made starting in the first half of the '900 (Aguzzi et al. 2016). However, the regional shoreline has stiffened by the presence of these structures (Perini et al. 2008). The *Project for the protection of the Adriatic emiliano-romagnola shoreline* – "Piano Costa 1981", adopted by Emilia-Romagna Region at the beginning of the '80s, suggested nourishment interventions as an alternative of the hard defence structures. One of the first nourishment's techniques consisted of taking sand from inland borrow areas and transporting it with trucks to the beach. In 2002, Emilia-Romagna Region carried out the first beach nourishment intervention on a regional scale, using material from a submarine borrow area located offshore the regional coast. Thanks to specific monitoring surveys which constantly monitored the environmental effects and the decreasing of erosion, in 2007, the Region Authority decided to carry out a second intervention on a regional scale (Preti 2011). Since good results obtained from previous interventions (Aguzzi et al. 2016), lastly, in 2016, the third intervention of "*Security projects through submarine sand nourishment for critical areas of the regional coastline*" was completed (Regione Emilia-Romagna 2015). It is the most important intervention along Emilia-Romagna's coast, in terms of technical and economic resources and sand volumes involved. The activity involved 8 beach areas in a critical state, with a total extension of more than 12 km (Fig. 1) (Table 1).

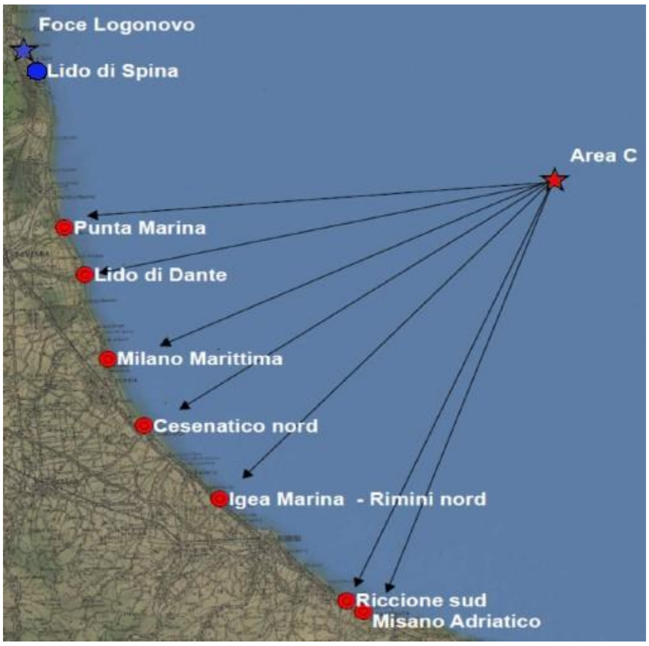

Fig. 1 Nourishment intervention of 2016: sand extracting area and involved beaches (Guida and Montanari 2016, *modified*)

Table 1 - Intervention sites and volumes. Column 1: involved sites; Column 2: length of each stretch; Column 3: sand's volume, according to the project; Column 4: fill volume according to Arpae's calculation, the related uncertainty is obtained by the equation (5) at page 5.

Site	Stretch's length (m)	Designed volume (m^3)	Fill volume (m^3)
Misano Adriatico	1.550	195.000	221.500
Riccione	1.400	165.000	212.200
Igea Marina	1.500	134.207	220.200
Cesenatico	1.100	115.000	141.040
Milano Marittima	1.600	180.000	228.530
Lido di Dante	1.250	110.000	122.050
Punta Marina	2.500	222.000	249.780
Lido di Spina Jamaica Beach	1.150	148.000	175.640
South Lido di Spina	450		24.000
Total	12.500	1.269.207	1.594.940

3. Materials and Methods

The monitoring of beach nourishment projects requires to perform precise topo-bathymetric surveys (Gibeaut et al. 1998). The analysis is obtained by comparing surveys related to different times and, therefore, it depends on surveys' accuracy. In order to obtain reliable and comparable measures, it's necessary to define a common reference system, which needs to be suitable for the required purposes. The realization of surveys related to the Nourishment Intervention of 2016 could take advantages from the presence of a new geodetic infrastructure along Emilia-Romagna's coast, the Coastal Geodetic Network (RGC). RGC was realized in 2016, thanks to a collaboration between the Coastal Monitoring Unit of Arpae and the Department of Civil, Chemical and Environmental Engineering (DICAM) of the University of Bologna. The monographs of each point are available on Arpae's cartographic portal (https://arpae.it/cartografia/), with coordinates related to the official national reference system ETRS89-ETRF2000 (2008.0 period) (Gandolfi et al. 2017). Orthometric heights have been estimated for each point of the RGC Network, starting from the regional leveling Network for Subsidence's Monitoring (Benedetti et al. 2000), last time measured in 2005. Using subsidence's models provided by Emilia-Romagna Region for the period between 2005 and 2011, the orthometric heights have been updated at the 2011 time. The use of this geodetic network in the specific context of Emilia-Romagna's coastal monitoring ensures to achieve proper comparisons between surveys performed at different times, using modern techniques, thus providing an effective support for the study of the dynamics affecting the coast.
The nourishment intervention of 2016 required a Monitoring Plan for the years 2017 and 2018: the surveys concerned a wider area than the one involved in the sand nourishment, allowing to evaluate the dynamics of the sediment transport, as well. Moreover, surveys on areas where changes aren't expected could guarantee a further possibility to verify obtained results. The monitoring, designed by Arpae - Coastal Monitoring Unit, involved the survey of over 200 km of topo-bathymetric profiles on about 20 km of emerged and submerged beach and the bathymetry of the withdrawal area (Aguzzi et al. 2017). The survey-site area concerned a height ranged from 2 m to -10 m. Transects were about 500-1000 m long, each with 100-200 m inter-transect spacing. Some of these transects were orthogonal to the coast, while others were parallel to the shoreline, especially for what concerns the emerged beach area or other areas near hard defence structures (Fig. 2).

Fig. 2 - Example of monitoring's survey in a beach involved in the nourishment of 2016.

In the emerged beach, surveys were performed using GNSS (Global Navigation Satellite System) double-frequency receivers, through RTK-OTF (Real-Time Kinematic – On The Fly) technique, which is based on phase observables. *Master* receivers were located on RGC's points, while *rover* receivers were working on the field. GSM or radio were used as data transmission systems, depending on the signal. Using ambiguity fixed solutions from the RTK approach, it was possible to reach accuracy in the order of 2 cm for the height component (Gumus et al. 2016; Aykut et al. 2015). Furthermore, during these surveys, *master-rover* distances were always within 5 km. The submerged beach required the use of a precise *echo-sounder* for the depth's data, coupled with the navigation unit, which were composed by a GNSS and an IMU system (Inertial Measurement Unit) for the definition of the transducer attitude, all installed on a suitable boat. *Echo-sounders* measure depth's data through the return time of the signal at the seabed (Carli et al. 2004). A *single-beam* echo-sounder was used for low depths, while a *multi-beam* was used for higher depths (Beachmed 2004; Maso 2002; Carli et al. 2004). The navigation software allowed to follow the sections of the Monitoring Plan (Gibeaut et al. 1998; Stone Marine Engineering 2017), while the obtained data were transferred to a PC for the real-time processing (Matsumoto et al. 2001). GNSS are particularly suitable for coastal surveys, thanks to the general absence of obstacles on the beach which could reduce the sky's visibility. Moreover, the use of real-time approaches implies the elimination of the post-processing and, above all, it allows to know immediately the survey's state, pointing out any critical issues. The processing phase refers to:

- first plant survey: before the nourishment intervention, between April and May 2016;
- second plant survey: immediately after the nourishment intervention, between May and June 2016;
- first monitoring survey: about 18 months after the intervention, in November 2017.

The elaboration of topo-bathymetric data required the use of specific software packages (Surfer, Grapher - http://www.goldensoftware.com, QGIS - http://qgis.org), providing the bathymetries, the comparison maps (height's variation), the accumulated/eroded volumes and the profiles along defined sections for each involved beach.
Digital Terrain Models (Digital Terrain Model – DTM), created starting from scattered data, represent the starting point for each following analysis. Therefore, the first operation consists of the analysis of detected points, improving the representativeness of topo-bathymetric maps. This phase allows identifying any outliers or other points which could produce wrong interpretations of the maps (for example, points on high crested structures).

- **Bathymetry**

Topo-bathymetric maps are obtained with a process of spatial interpolation. In the specific case of this study, East, North and orthometric height's variables were interpolated through *Triangulation with linear interpolation* (TIN).
The availability of ellipsoid and orthometric heights for each point of the RGC Network allowed the evaluation of the local geoid undulation for each of these points. The conversion between the ellipsoid heights of GNSS system and the orthometric heights was calculated using a *bias*, based on this local geoid undulation.
The grids' spatial limits and the distance between each point of the grid must be the same for all the grids to be compared (those related to the same beach). The map of comparison is performed starting from two DTMs related to the same beach at different times. These maps show height's variations between different surveys, displayed according to colour's classes. Variations within 10 cm for height are represented in white colour, to indicate equilibrium situations, also considering the precision of survey's methods (Fig. 3).

- **Shoreline**

The shoreline represents the ultimate boundary between land and sea, it coincides to the bathymetry of 0 m (Fig. 3).
Usually, coastal projects are based on maintaining a well-defined shoreline, but, on the other hand, shoreline's variation should consider the effect of nourishment interventions. It's important to determine the average and the maximum value of shoreline's variation for each coastal stretch, in order to understand beaches' state of health and the effectiveness of defence interventions.

- **Volumes of accumulated and eroded sand**

Volume changes allow evaluating losses and accumulations of sand in the period between two different surveys.
Volume function (*Surfer* - http://www.goldensoftware.com) operates from a comparison map, imposing z = 0 plane as the bottom surface. It's also possible to choose the calculation area, thus allowing to evaluate variations due to sand migrations to near areas. Operation's results are given in terms of:

- positive volume: above the surface $z = 0$, accumulated volume;
- negative volume: below the surface $z = 0$, eroded volume;
- net volume: result, given by the combination of previous ones.

Assuming to split the whole area into square cells (grid), each having side p, the total volume (V) is obtained by (1), where n is the number of cells of the grid, and h_i is the associated height.

$$V = \sum_{i=1}^{n} h_i \cdot p^2 \tag{1}$$

Being $\sigma_{h_i}^2$ the variance of the height estimation for each cell, the variance associated to the Volume (σ_V^2) can be estimated through the equation (2):

$$\sigma_V^2 = \sum_{i=1}^{n} \sigma_{h_i}^2 \cdot p^4 \tag{2}$$

Since all the height measurement were performed with the same technique, the cell variances can be considered as equal, thus the total volume variance can be written as (3)

$$\sigma_V^2 = n \cdot p^4 \cdot \sigma_h^2 \tag{3}$$

Therefore, the uncertainty related to the total volume (at 68% confidence level) is obtained by (4). Finally, the uncertainty associated to the volume's variation should be calculated using (5), where the second term considers the potential *bias* that might occur during field's operations (master station's set up, antenna's height measurement, etc.) and which could induce a systematic shift in the coordinates:

$$\sigma_V = \sqrt{n} \cdot p^2 \cdot \sigma_h \quad (4)$$

$$\sigma_{\Delta V} = \sqrt{2n} \cdot p^2 \cdot \sigma_h + bias_{RTK} * Area \quad (5)$$

In this study, we used a value of σ_h equal to 5 cm, combining uncertainty related both to the GNSS and to the *echo-sounder*; while the $bias_{RTK}$ was set to 1 cm, having considered the tests performed on other RGC's points during the field operations. Moreover, the uncertainty σ_V has been multiplied by 2 to consider a 95% confidence level. The results obtained applying (5) show values between 1.1 % and 1.5% in terms of volume's uncertainty per square meters (m^3/m^2).

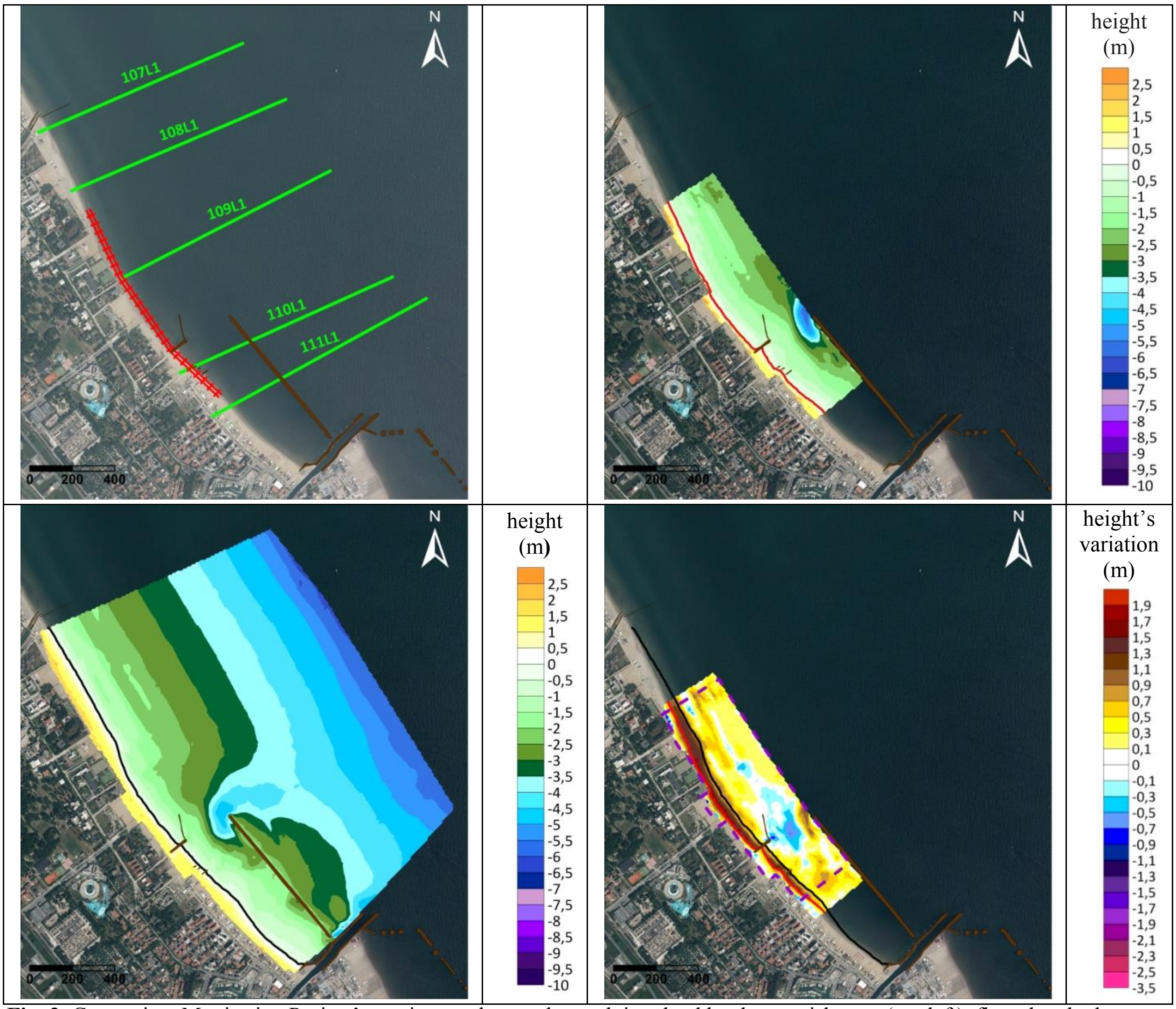

Fig. 3 Cesenatico: Monitoring Project's sections and coastal stretch involved by the nourishment (top left), first plant bathymetry and shoreline (top right), first monitoring bathymetry and shoreline (bottom left), map of height's variations between first plant and first monitoring (bottom right)

▪ **Beach profiles**

The processing of profiles along defined sections (set by the Survey Project) is performed using a *Buffer* function (*QGIS* - http://qgis.org), which selects points close to a specific section. Since boats don't follow perfectly sections' lines during their surveys, it's necessary to make corrections on automatic profiles. Profiles are based on table files, which contain East, North and H (orthometric height) coordinates. This data must be properly processed to obtain the progressive distance from the reference point. For almost all the available profiles, the reference coincided with the first point of the profile related to the year 2000. 2D graphs representing seabed's profile along selected sections have been generated, considering the trend of the orthometric height with the progressive distance (Fig. 4). Beach's profiles along monitoring sections have been compared at three different times: before the intervention, immediately after the nourishment and after about 18 months from it.

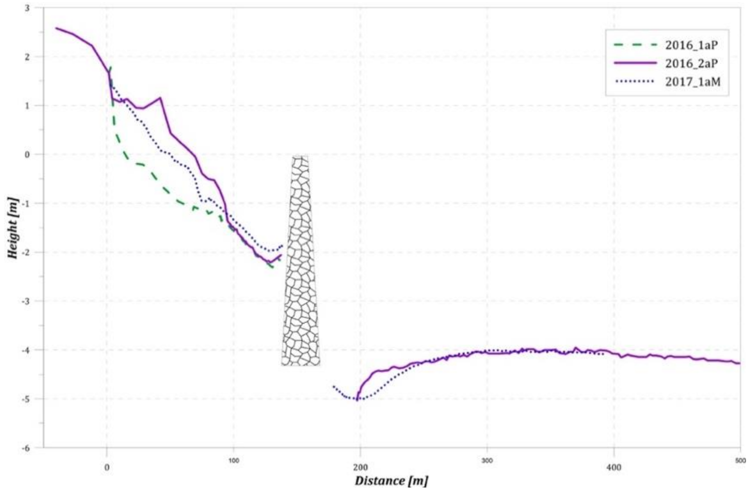

Fig. 4 Beach profile of section 141L1 in Igea Marina: first plant, second plant and first monitoring profiles

Arpae describes erosion conditions on the coast using two coastal state indicators, ASPE (Accumulation, Stability, Precarious balance, Erosion) and ASE (Accumulation, Stability, Erosion) (Aguzzi et al. 2012). These indicators can represent the complexity of coastal areas, considering the hypothetical state of the coast without defence interventions (ASPE) and the actual situation after performed interventions (ASE). The analysis concerning the state of Emilia-Romagna's coast in the period between 2006 and 2012 showed a decreasing in erosion of about the 12%, thanks to defence interventions, especially beach nourishments, thus confirming the efficiency of Emilia-Romagna's defence policies (Aguzzi et al. 2016).

4. Results

Comparing surveys performed before and after the nourishment with those related to the first monitoring, it was possible to evaluate the morphological evolution of involved beaches and the efficacy of the intervention itself. Using DTMs obtained from the first plant and second plant surveys, nourishment's volumes were estimated: they amounted to about 1.6 million m^3. The average unit fill volume, related to the length of each coastal stretch involved by the nourishment, was about 130-150 m^3/m, except for Lido di Dante and Punta Marina, with values of about 100 m^3/m and South Lido di Spina, with a contribution a little over 50 m^3/m. Beach nourishment led to significant advancements in the emerged beach, between 35-65 m (except for Lido di Spina - Jamaica Beach where it was between 15-50 m) and height's increases in emerged and submerged beach, between 0,7 m and 2,0 m (Table 2).

Table 2 – Second plant survey: nourishment's results in terms of average unit volume, average shoreline's advancement and average height's increase for each beach.

Site	Average unit volume (m³/m)	Average shoreline's advancement (m)	Average height's increase (m)
Misano	143	40-50	1,5-2,0
Riccione	152	50-60	1,5-2,0
Igea Marina	147	50-60	1,0-1,5
Cesenatico	128	55-65	1,0-1,5
Milano Marittima	143	40-50	1,3-1,6
Lido di Dante	98	35-45	0,8-1,5
Punta Marina	100	40-50	0,5-1,0
Lido di Spina – Jamaica Beach	153	15-50	0,8-1,3
South Lido di Spina	53	25-35	0,7-0,9

After about 18 months (first monitoring survey), a variation of the beach profile is observed in any beach, with a distribution of sand from the emerged to the submerged beach within the intervention's area and migration towards deeper depths along the coast. The analysis of Misano, Riccione and Milano Marittima shows a migration beyond the sandbags barriers. In Cesenatico, part of the material has settled in the deep hole at the head of the low crested barrier, while in Lido di Spina – Jamaica Beach a migration to the hole located about 100-150 m from the shoreline occurred.
Obtained results show variable trends, starting from Cesenatico where the material loss was a little over the 10% of the filling material, to Lido di Dante, which lost over the 90% of the fill volume. The beaches of Riccione, Igea Marina and Lido di Spina – South of Jamaica Beach have lost about a third of the total fill material. Misano and Punta Marina have lost about a half of the sandy material and Milano Marittima and South Lido di Spina about two thirds. About the 54% of the total material is remained in the intervention areas and an additional 15% of the material is located on adjacent beaches (only where the calculation was possible thanks to available data) (Table 3). About this, it must be stressed that eroded material is not lost at all, because it nourishes both the shoreface, which has an active function in defending beaches from wave's attack, and the adjacent beaches. Comparing the first monitoring situation with that of pre-intervention, Riccione,

Igea Marina, Cesenatico and Punta Marina still show a shoreline's progress of about 25-45 m; while Misano and South Lido di Spina show values of about 10-25 m. Remaining beaches show stretches where the shoreline is increased of about 10-25 m, while others where the shoreline settled back to the pre-intervention position.

Table 3 - First monitoring survey in 2017 – nourishment's results after 18 months. Column 1: involved sites; Column 2: volume of sand (m^3) remained on the intervention's area after about 18 months from the nourishment; Column 3: volume of sand (%) remained on the intervention's area compared to the volume filled during the nourishment; Column 4: average volume of sand remained on the intervention's area, in terms of linear stretch interested by the intervention; Column 5: average advancement of the shoreline after about 18 months from the nourishment intervention; Column 6: average increase of height after about 18 months; Column 7: sand's volume calculated considering beaches near the site

Site	Sand's volume remained (m^3)	% remained on the total fill material	Average unit volume (m^3/m)	Average shoreline's advancement (m)	Average height's increase (m)	Volume in adjacent beaches (m^3)
Misano	108.930	45%	70	10-20	0,3-0,5	32.390
Riccione	146.490	66%	105	25-35	0,5-0,8	93.590
Igea Marina	143.060	68%	95	30-40	0,7-1,0	7.810
Cesenatico	124.290	88%	113	35-45	0,6-1,0	43.480
Milano Marittima	85.310	36%	53	0-15	0,5-0,7	9.920
Lido di Dante	9.820	8%	8	0-25	0,2-0,5	-
Punta Marina	143.710	54%	57	25-35	0,4-0,7	22.470
Lido di Spina - Jamaica Beach	133.540	62%	116	0-15	variable trend	37.700
South Lido di Spina	7.190	30%	16	15-25	0,3-0,5	-
Total	**902.390**	**54%**				**247.360**

The final analysis researched for a possible correlation between the nourishment's trend and the typology of hard defence structure located on the beach (Table 4).

Table 4 - Nourishment's trend according to the typology of the hard defence structure. Column 1: involved sites; Column 2: configuration of the hard defence structures on the beach (some beaches are protected using different structures); Column 3: remained sand volume related to each configuration on each beach; Column 4: remained sand volume considering the whole involved area in each beach.

Site	Hard defence structure's typology	Remained sand volume (%)	Sand volume Remained in the whole area (%)
Misano Adriatico	rock groynes and submerged sandbag barriers	45%	45%
Riccione	submerged sandbag barriers	66%	66%
Igea Marina	low crested structures and rock groynes	57%	68%
	detached breakwaters	82%	
Cesenatico	low crested structures and rock groynes	96%	88%
	no hard defence structures	86%	
Milano Marittima	submerged sandbag barriers	36%	36%
Lido di Dante	low crested structures and rock groynes	32%	8%
	no hard defence structures	0%	
Punta Marina	low crested structures and rock groynes	54%	54%
Lido di Spina - South of Jamaica Beach	wood groynes	10%	62%
	no hard defence structures	104%	
South Lido di Spina	no hard defence structures	30%	30%

The eight sites are protected using very different configurations, while some of them are completely free from hard structures (Table 4). Riccione and Milano Marittima are both completely protected by submerged sandbag barriers: the first has still the 66% of the material, while the second one has only the 36%. Relating to beaches protected by low crested structures, it is observed that: Punta Marina and Igea Marina maintained about the 55% of sand, Cesenatico over the 95% and Lido di Dante only the 32% of the material. Beach stretches which are free from hard defence structures show different trends, too: in Lido di Dante the fill volume has been quite completely eroded, South Lido di Spina preserved less than one third of the material, Cesenatico maintained more than the 85% of the nourished sand and South of Jamaica Beach has more material than the filled quantity (104%).

5. Discussion

Coastal systems are exposed to continuous evolutions, due to several natural and human factors. Therefore, the reduction of coastal erosion through defence interventions is an essential issue among coastal management projects (Cipriani et al. 2004). There are no simple universal technical or engineering criteria which can be applied to the resolution of an erosion problem (Gillie 1997; Eurosion 2004; Cipriani et al. 2004), but the latest trend is going toward the realization of *soft* interventions, such as beach nourishments (Eurosion 2004). For what concerns the coast of Emilia-Romagna, good results obtained from previous interventions (Aguzzi et al. 2016) led to the realization of the third beach nourishment project using submarine sands. This paper concerned the analysis of the eight coastal stretches involved by this nourishment project, performed in 2016. Morphological variations in terms of shoreline, height, beach profiles and accumulated or eroded volumes, have been evaluated by comparing surveys performed on each beach at different times. Most of the elaborations are based on Digital Terrain Models: the comparison between DTMs related to following surveys allows to identify the eroded beaches, while other evaluations can result from the comparison of different profiles. All the observed results show good evolutions from a general point of view, even if it's difficult to deduce a single trend for the eight beaches. The remained material has guaranteed the sedimentary balance of most of the involved beaches. On the other hand, even if part of the material has moved from the involved area, it has restored the natural longshore sediment transport. Therefore, eroded material can nourish both the shoreface and the adjacent beaches. About this, total evaluations from the first monitoring survey show that almost the 55% of the material is still located in the intervention area, while the 15% has moved to adjacent beaches.

Available geomatic methods allow obtaining measures with centimetre level precision, but they require the definition of a shared reference system, to guarantee proper comparisons. From this point of view, some problems could occur if surveys are not aligned to the same reference system. The consequence due to a geodetic datum error could be the presence of a *bias* which leads to overestimate or underestimate sand volumes. Considering that the cost of these interventions depends on sand's volume evaluated by comparing different DTMs, these biases could produce significant effects also in economic terms, even more if related to large-scale projects. In the case of Emilia-Romagna's coast, since 2016, this need is guaranteed by the presence of the RGC geodetic infrastructure.

Another analysis looked for a possible correlation between nourishment's trends and the typology (even the absence) of hard structures, showing in many cases different trends even for beaches protected in the same way. Looking at the results, it's quite difficult to identify the nourishment's trends according to the typology of hard structures or, in other words, which between unprotected or protected nourishment leads to better results. Other considerations concerned the research for possible correlations between the morphological changes and beaches' slopes, maximum beach's heights or meteo-marine conditions before and after the nourishment. However, this analysis didn't lead to significant results and it can't be considered fully reliable, due to the short and inhomogeneous available dataset. These results are not reported in this paper for the sake of simplicity. Anyway, from this perspective, monitoring surveys ensure the availability of topo-bathymetric data on the coast, which can be used for several examinations. The increasing availability and spatial coverage of this data could provide powerful instruments for coastal studies.

In the light of these considerations, the present work confirms monitoring activities as an efficient way to evaluate beaches' morphological changes and coastal defence intervention's effectiveness. In particular, beach nourishments need to be related to periodic surveys on the coast, firstly, to acquire data about erosion's trends and, secondly, to evaluate their effects on involved beaches.

6. References

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