DRONE REMOTE SENSING FOR COASTAL HABITATS PROTECTION

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Abstract – The growing beach touristic vocation of the Lecce Province has led to increasing human pressures along its coasts over the years, often on habitats of conservation interest. Furthermore, the ever-increasing erosion phenomena of the sandy shoreline constantly requires fast and effective monitoring activities assessing the conservation status of the dunes and shoreline. Remote sensing through the use of RPAS (Remotely Piloted Aircraft Systems or Drones) is proving to be very useful for identifying phenomena that act on a small scale and supporting and implementing protective measures according to an adaptive management approach and to favour the creation of a long term investigation model, through multi-year surveys on conservation interest habitats. The photographic data and their photogrammetric elaboration allow to find a specific point, thanks to georeferencing, on which evaluate the evolution of certain phenomena following the analysis by different types of experts able to extract a large amount of data from the same photogrammetric product, this thanks to the possibility of choosing analysis scales from the meter to the centimetre. In recent years this technique has proved to be extremely effective and interesting in the environmental analysis of a multitude of matrices. The present work consists of a protocol for monitoring the dune cordons and the nearby shorelines through the use of RPAS. This kind of survey allows to create a geodatabase with spatially-explicit detailed maps able to provide a useful tool for monitoring overtime the erosive phenomena and/or the anthropic abuses on nature to the detriment of the beach system.

Introduction

Along the Mediterranean sandy shores there are many habitats of conservation interest, such as the dune cordons present in the Porto Cesareo MPA area. The increase in anthropogenic pressure added to natural erosive phenomena requires a rapid and effective monitoring capability to determine the conservation status of these habitats. In recent years, numerous regulatory interventions have been implemented to plan the appropriate actions to protect these habitats. The Puglia Region in particular in the last decade has made operational various legislative instruments that put environmental protection first among the objectives. The Puglia Regional Coastal Plan (PRC) is the instrument that governs the use of the areas of the State Property, with the aim of ensuring the correct balance between protection of the environmental and landscapes aspects of the Apulian coast, the free use and development of recreational tourist activities. The PRC is also an instrument of knowledge of the coastal territory and in particular of the geomorphological and meteorological dynamics connected to the priority problem of coastal erosion, the evolution of which requires careful and constant

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monitoring and interventions of recovery and rebalancing. The Puglia Region, therefore, entrusts new and laborious monitoring tasks of the phenomena that contribute to the dynamic morpho imbalance of the coastal strip to the coastal Municipalities. Coastal erosion can be defined by way of example, without renouncing in any way an effective expressive clarity, such as the invasion of the land by the sea. Coastal erosion is assessed by referring to a sufficiently long period of time, such as to allow to eliminate, by means of mediation, extreme events such as storms and sediment dynamics of a local character. Coastal erosion involves different types of impact or risks such as the loss of areas with economic value and the destruction of precious natural habitats, even following a single stormy event. Along the sandy coasts of Salento there are several habitats of community and priority importance subject to strong stress due to human action and extreme marine weather events. The Apulia Region issued in 2016 the "Regulation containing Conservation Measures pursuant to Community Directives 2009/147 and 92/43 and Presidential Decree 357/97 for Sites of Community Importance (SIC)". Conservation Measures provide for a series of actions and behaviors in order to improve the conservation status of different habitats of conservation interest. Conservation measures also include monitoring of species and habitats in order to evaluate the effectiveness of the measures. Local Authorities (coastal Municipalities, Park Authorities, etc.) therefore find themselves having to carry out routinely monitoring on coastal habitats, often covering large areas such as the beaches. Hence the need to develop effective and economic monitoring techniques that can be rapidly performed by local authorities. Remote sensing through the use of RPAS has proved extremely useful in identifying phenomena that act on a small scale, as support for protection measures with a view to an adaptive management approach and to encourage the creation long-term investigative models with multi-annual monitoring of habitats of conservation interest.

Materials and Methods

For this work the Phantom 4Pro drone produced by DJI was chosen. The site investigated in the tests falls in the area named "Riva degli angeli"(40°17'36.08" N - 17°47'14.07" E) in the Municipality of Porto Cesareo (LE), has an extension of about 54 hectares, and is affected by the presence of various environmental and territorial constraints due to the presence of the Porto Cesareo Marine Protected Area (Ministerial Decree 12/12/1997), the Palude del Conte and Duna Costiera Regional Natural Reserve (LR 5/2006) and Natura 2000 Network Site "Torre Colimena" (IT9130001). The area under study consists of a sandy coast with coastal dunes in *Juniperus* spp. habitat code 2250*. It is a priority habitat, characterized by forest communities dominated by junipers, in particular *Juniperus oxycedrus* subsp. macrocarpa and, less frequently, *Juniperus phoenicea* subsp. turbinata. It develops in the summit areas of the dune systems, in a more internal position than that occupied by habitat 2120 - Mobile dunes of the coastal cordon with the presence of *Ammophila arenaria* (white dunes). This type of habitat offers fundamental ecosystem services in terms of dune stabilization, soil formation and biodiversity. Non-native species are frequent mainly due to inadequate reforestation interventions conducted in the last century. The total length of the coast being monitored amounts to a total of 450 meters and the coordinates of the vertices, expressed in EPSG 32633 - WGS 1984 - UTM Zone 33N format, are respectively 17°47'10.18" E, 40°17'39.54" N for the NW vertex, 17°47'26.11" E,

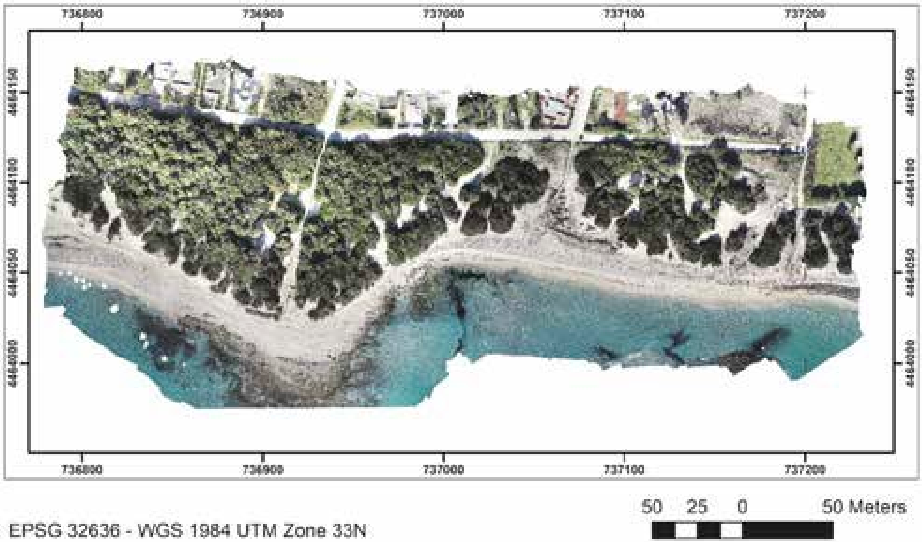

Figure 1 - January 2019 orthomosaic reconstruction.

40°17'38.20" N for the NE vertex, 17°47'25.63" E, 40°17'34.73" N for the SE vertex, 17°47'9.65" E, 40°17'36.17" N for the SW vertex. The total remote sensed area was 4.3 hectares with flights at an altitude of 50 meters (Figure 1).

During the 2019, a total of four RPAS flights sessions were performed, respectively in January, April, September and November. The survey area has been designed and the flight plans loaded for each flight session through the dedicated Pix4D Capture application. This made it possible to keep the study area vertexes unchanged during the different flight sessions, a fundamental parameter for a correct evaluation of the dynamics. The identification of ground control points (GCP) also facilitated the validation and quality control phase of the output models through the dedicated software (Pix4D Mapper).

Although the survey area has remained unchanged, the automatic acquisition parameters led to a negligible discrepancy in the resolution of orthomosaic and Digital Elevation Models (Figure 2) output from photogrammetric processing resulting from different measurements with a $\sigma = 0.003475$ for orthomosaic and $\sigma = 0.012$ for DEMs. Respectively for the month of January 349 images were acquired and the photogrammetric processing produced an orthomosaic with a resolution of 1.19 cm/pix and a DEM of 2.39 cm/pix. In April, 340 images were acquired and the photogrammetric processing produced an orthomosaic with a resolution of 1.26 cm/pix and a DEM with a resolution of 2.51 cm/pix. In September 326 images were acquired, the generated orthomosaic has a resolution of 1.26 cm/pix and the DEM of 2.53 cm/pix, finally, in November, 226 images were acquired, the resolution of the orthomosaic resulted of 1.22 cm/pix and of 2.45 cm/pix for the DEM. It was decided to set the automatic acquisition to an 80 % overlap between pictures (Table 1).

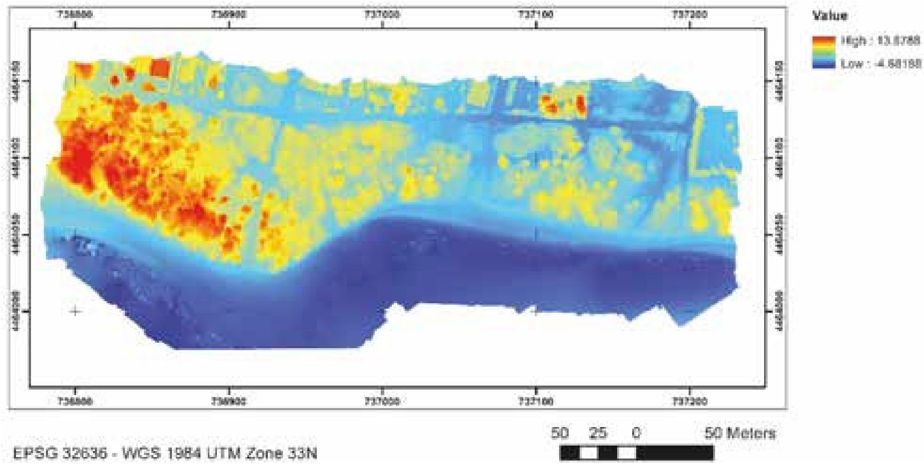

Figure 2 - Digital Elevation Model (DEM) output form drone images elaboration, January 2019.

Table 1 - Data acquisition resuming and quality detail of orthomosaic and DEM.

Month	Pictures	Orthomosaic resolution (cm/pix)	DEM resolution (cm/pix)
January 2019	349	1.19	2.39
April 2019	340	1.26	2.51
September 2019	326	1.26	2.53
November 2019	226	1.22	2.45

The orthomosaics and the georeferenced DEMs, thanks to the RPAS native GPS system, were firstly validated by importing them into Google Earth, resulting in a corrected geolocation for all of them, and then imported in GIS environment for subsequent processing phases. Once the DEMs were loaded in GIS, the height (Z) were corrected and validated using the ground quotas of the Thematic Cartography of the Puglia Region (CTR) (www.sit.puglia.it update of 2011). Using the Slope tool (3D Analyst ArcGIS) with DEM as input, it was possible to identify both the dune foot line and the shorelines in the new layers, the latter was then traced and saved as a new layer necessary for the running of the analysis (Figure 3). The same operation was carried out for each investigated month with a definitive product of 4 coastlines with the same starting and ending points. At the same time, thanks to the DEMs, it was possible to study the change in volume of the area under investigation using the month of January as a baseline to calculate the gain or net loss of sediment on an annual basis. This procedure was carried out by using the Cut Fill tool (3D Analyst ArcGIS) (Figure 5). To evaluate the dynamics linked to the shorelines, we used the Digital Shoreline Analysis System (DSAS) Version 5.0, distributed for GIS platform by the United States Geological Survey (USGS) Whoods Hole Coastal and Marine Science Center. A "Baseline" feature was created on urban road infrastructure (via Lago di Cecita) for the application of the shoreline dynamic's calculation algorithm. Subsequently, the shorelines extrapolated from the DEMs

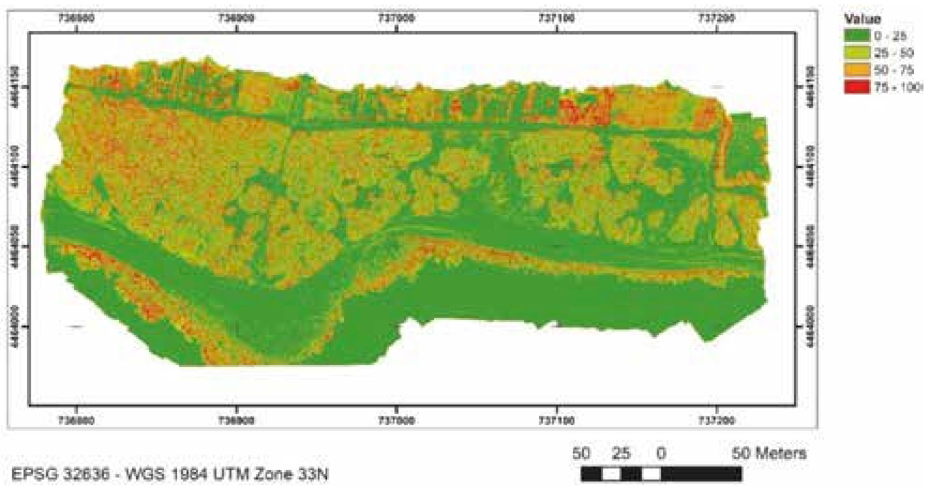

Figure 3 - Output of “Slope” tool for January 2019. Values expressed as percentage.

processed with the Slope tool were combined in a single feature. Once these two layers were created, the DSAS tool allowed, through the use of the "Attribute automator" key, the automatic population of the attribute tables with the fields necessary for the algorithm operation. The second step were the insertion, through the "Set Default Parameters" key, of the "Baseline" and "Shorelines" layers properties and the metadata population.

The "Cast Transect" key generated transects, perpendicular to the “Baseline”, which intercept the “Shorelines”. Finally, the key "Calculate Rates" and "Shoreline Forecasting" generated the output statistics, in the second case linked to long-term forecasts at 10 or 20 years. Clearly, the "Shoreline Forecasting" algorithm was not used for this analysis, focused exclusively on the assessment of seasonal variation over a single year. Each method used in calculating the variation of the coast line is based on different measurements between the positions of the coastlines over time (Table 2) [6].

Table 2 - List of DSAS outputs.

Distance Measurement	Shoreline Change Envelope	SCE
Distance Measurement	Net Shoreline Movement	NSM
Point Change	End Point Rate	EPR
Regression Statistics	Linear Regression Rate	LRR
Regression Statistics	Weighted Linear Regression	WLR

Shoreline Change Envelope

The shoreline change envelope reports a distance (in meters), not a rate. The SCE value represents the greatest distance among all the shorelines that intersect a given transect. As total distance between two shorelines has no sign, the value for SCE is always positive.

Net Shoreline Movement

The net shoreline movement is the distance between the oldest and the youngest shorelines for each transect; therefore, units are in meters. If this distance is divided by the time elapsed between the two shoreline position measurements, the result is the end point rate.

End Point Rate

The end point rate is calculated by dividing the distance of shoreline movement by the time elapsed between the oldest and the most recent shoreline. The major advantages of the EPR are the ease of computation and minimal requirement of only two shoreline dates. The disadvantage is that in cases where more data are available, the additional information is ignored. Changes in sign (in other words, accretion to erosion), magnitude, or cyclical trends may be missed [5, 15].

Linear Regression Rate

A linear regression rate-of-change statistic can be determined by fitting a least-squares regression line to all shoreline points for a transect. The regression line is placed so that the sum of the squared residuals (determined by squaring the offset distance of each data point from the regression line and adding the squared residuals together) is minimized. The linear regression rate is the slope of the line. The method of linear regression includes these features: 1- All the data are used, regardless of changes in trend or accuracy; 2- The method is purely computational; 3- The calculation is based on accepted statistical concepts; 4- The method is easy to employ [5, 15]. However, the linear regression method is susceptible to outlier effects and tends to underestimate the rate of change relative to other statistics, such as EPR [7, 15].

Weighted Linear Regression

In a weighted linear regression, the more reliable data are given greater emphasis or weight towards determining a best-fit line. In the computation of rate-of-change statistics for shorelines, greater emphasis is placed on data points for which the position uncertainty is smaller. The weight (w) is defined as a function of the variance in the uncertainty of the measurement (e) and e is shoreline uncertainty value [7]:

$$w = 1/e^2 \qquad 1$$

Results

For the sake of brevity, only the Net Shoreline Movement are reported here (Figure 4). From the report (Table 3) could be assumed that the transect with ID 13 is the most dynamic, but in reality, by intercepting a stretch of low rocky coast, the variation could be the result of the wave motion dynamics on this substrate. Consequently, the areas intercepted by the transects 1 to 5, corresponding instead to sandy bottoms, are those most subjected to seasonal dynamic phenomena. The observations made so far have shown a strong dynamism in the study area, so we wondered where this sediment goes to settle in the regression periods of the coast line. Aware of the limits of the means available, RPAS surveys data were used to give a qualitative value on the emerged dynamics. Using the Cut Fill tool (3D Analyst ArcGIS), the DEMs were used to evaluate the sediment net gain and net loss by area, between a baseline identified in January 2019 and the subsequent surveys (Figure 5). This method is particularly affected by the quality of the input data and influenced by the time of day, the presence of long shadows and the cloud cover, but still provides an idea of the areas subjected to accumulation and erosion.

Table 3 - Report **s**ummary for seasonal variability and annual changes relative to 2019 (rates are in meters/year, distances are in meters).

DISTANCE: NSM (Net Shoreline Movement, m) NSM OVERALL AVERAGES	
total number of transects	39
average distance	-5.16
number of transects with negative distance	22
percent of all transects that have a negative distance	56.41 %
maximum negative distance	-26.27
maximum negative distance transect ID	13
average of all negative distances	-13.71
number of transects with positive distance	17
percent of all transects that have a positive distance	43.59 %
maximum positive distance	11.92
maximum positive distance transect ID	22
average of all positive distances	5.9

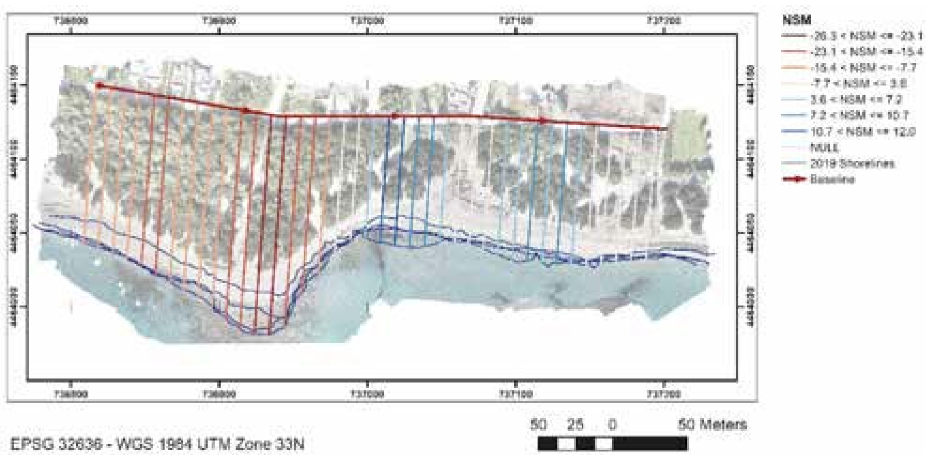

Figure 4 - Seasonal variability and annual changes relative to 2019 (NSM).

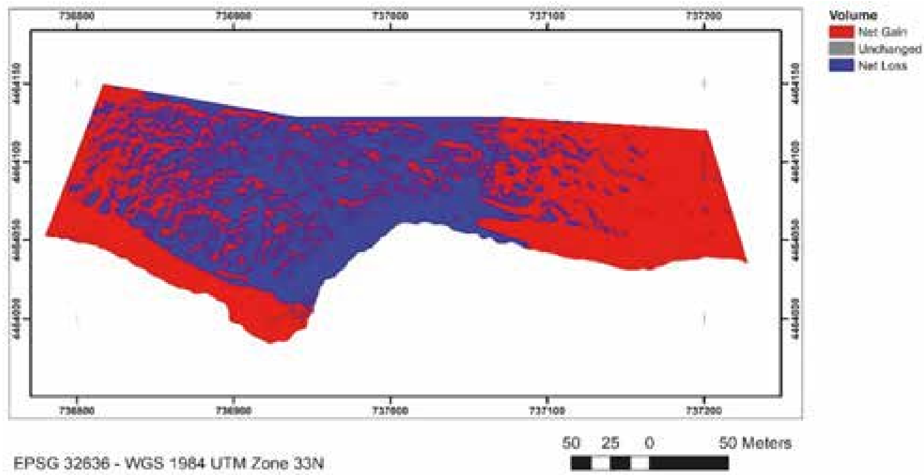

Figure 5 - Volume gain and loss for January-September confrontation.

Table 4 - Report summary relative to 1954-2019 (rates are in meters/year, distances are in meters).

DISTANCE: NSM (Net Shoreline Movement, m) NSM OVERALL AVERAGES	
total number of transects	39
average distance	-10.35
number of transects with negative distance	39
percent of all transects that have a negative distance	100 %
maximum negative distance	-29.95
maximum negative distance transect ID	10
average of all negative distances	-10.35
number of transects with positive distance	0
percent of all transects that have a positive distance	0 %
maximum positive distance	
maximum positive distance transect ID	
average of all positive distances	

The seasonal results were intended as a pilot analysis for the construction of a multi-year model of coastline dynamics with a view to long-term monitoring to evaluate the erosive effects in the Porto Cesareo MPA, especially in light of the evidence relating to the changes and the conservation and protection mission of the organization. To this end, it was decided to use the historical coastlines present in the project "Geortification and mosaicing of historical aerial photos of the coastal area of the AMP of Porto Cesareo and creation of maps of use in the GIS environment", relating to the years 1954, 1977, 1992, 2000, 2005, 2006 integrating to these January 2019 (Table 4, Figure 5). The same algorithm used for seasonal dynamics was launched but in addition, thanks to the large time scale, a forecast was also implemented with a projection for the year 2030 (Figure 7).

Results reported in Table 4 clearly states that we are facing a perspective of almost total coastline regression over the whole study area, the percentage according to the Net Shoreline Movement method is equal to 100 %, with a maximum negative distance near to -30 meters, associated with the ID 10 transect. Furthermore, the mean negative distance was found to be -10.35 meters.

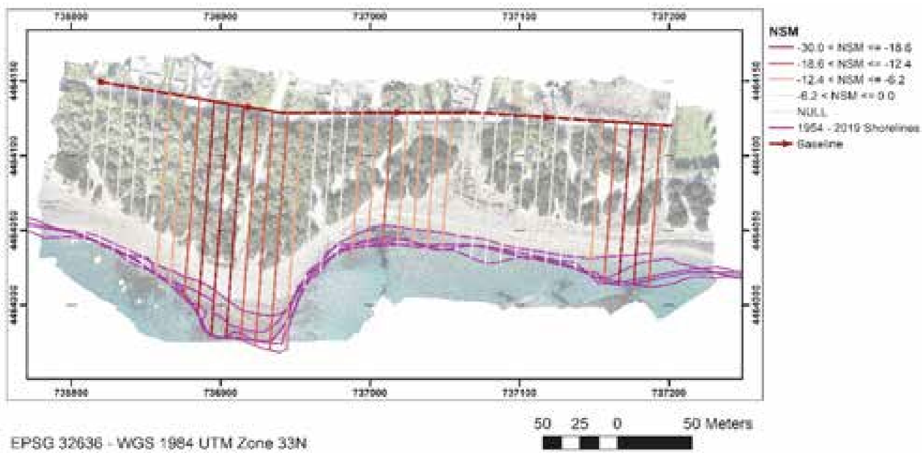

Figure 6 - Multiannual variability and shoreline changes relative to 1954-2019 elaboration (Net Shoreline Movement).

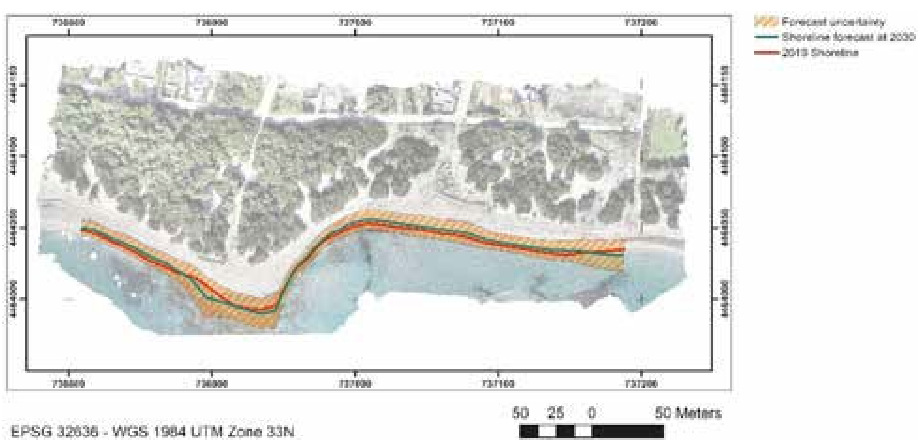

Figura 7 - 2030 shoreline forecast.

Conclusions

The objective of this work was to highlight the effectiveness of widely used, cost-effective and reliable tools, together with the necessary expert staff involved in monitoring activities of protected areas, not only in order to have a mere acquisition of data, but also to facilitate their rapid processing and integration in an adaptive management of protected areas. In the specific case of a marine protected area, where land-sea interactions are the very essence of threats to the environment, together with the stressors of global climate change, an increase in direct knowledge of the environment and the threats it faces is mandatory.

The methodology presented here, thanks to a simple approach based on tools validated and used globally, is in our opinion a small step in this direction, to face those challenges, once future but now current and no longer postponable.

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