THE ISPRA GEODATABASE FOR MONITORING AND ANALYSIS OF THE STATE OF THE ITALIAN COASTS: AN EXAMPLE OF ITS APPLICATION TO THE ROCCHETTE - CASTIGLIONE DELLA PESCAIA COAST LINE

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Abstract – The Italian peninsula has a wide variety of coastal areas: whether natural or human-made, they should in any case be understood as interactive sea-land systems, dynamic and fragile, to be protected through the development of - often very complex - planning and management techniques. Knowledge of long-term coastal dynamics, connected to the action of the sea, to anthropic activities and to climate change, is a fundamental element in coastal areas planning and management. In the past few years, the Italian National Centre for Coastal Defence (CN COS) of the Institute for Environmental Protection and Research (ISPRA) has been carrying out environmental monitoring and characterization of the coast and coastal dynamics at national level. As of today, the CN COS has gathered a range of information on the coastal strip (from the backshore to the shoreline) by digitization and characterization from ortophotos over a period of approximately 20 years, from 2000 to 2020 (nominal survey years: 2000, 2006, 2020). In addition, a further information layer was created for year 1950 derived from historical maps of the Italian Military Geographical Institute (IGM). This activity allowed to develop a Geodatabase containing the linear information on the characterization of the natural and artificial elements shaping the Coast Line ("Linea di Costa", LC) and the Backshore Line ("Linea di Retrospiaggia", LR) as well as the areal elements representing the beaches, derived from photointerpretation of aerial and satellite images. The structure of the Geodatabase allows to perform many kinds of spatial analysis on the recorded geometrical elements, thus allowing to provide a periodic update, at national level on the evolution of the coast line.

The main objective of this work is to highlight the potential of a continuously updated geodatabase over time in monitoring and analyzing the state of the coasts at a local level, presenting one of several case studies carried out by ISPRA, following specific requests received from stakeholders.

More specifically, the temporal variations of the coastline have been analyzed, in terms of advancement, stability and erosion, of the whole Physiographic Units to which the study areas belong, in order to obtain evolutionary trends.

The methodological approach developed and tested over the case studies resulted in a "tool" that the stakeholders may use to query the LC data, thus obtaining information about the coastal dynamics in the area of interest. In this context, guidelines to the access and use of the information contained in the Geodatabase, will be compiled, in order to facilitate the user of the "Linea di Costa" ISPRA.

Introduction

Directive 2007/2/EC of the European Parliament and Council established the INfrastructure for SPatial InfoRmation in Europe (INSPIRE[1]), with the aim of making georeferenced environmental information homogeneous and shareable within the European Union. In Italy, this directive was implemented with D. Lgs. 32/10, which addressed the Ministry for the Ecological Transition - MiTE as the competent authority for its implementation. In this context, the ministry must send to the European Commission georeferenced environmental data, and ISPRA is the technical coordination structure of the ministry for this function. This includes the role of the CN COS as the official supplier of national coastal monitoring data. The CN COS has been monitoring and characterising the coastline and coastal dynamics at a national level for over 20 years and now those data has been organized in a Geodatabase (GeoDB) containing a wide range of information on the coastal strip, from the backshore to the shoreline. Additional, very important, data which are included are polygon features describing the beaches. The main features composing the GeoDB are the digitized coastlines, relatively to four reference dates: 2020, 2006, 2000 and 1950, as described in the following section.

To date, various stakeholders at the local level (Authorities, Associations, etc.) have addressed ISPRA with explicit requests for technical-scientific advice on the morphological analysis and evolutionary trend of the coast, often related to areas of particular naturalistic-environmental value and/or tourist accommodation activities, where either maritime works or coastal defence works were planned. In the past, ISPRA satisfied such requests with the drafting of dedicated studies and technical reports.

Today, with this work, we present a procedure that may allow any interested stakeholder to perform a first monitoring of the coastal areas of interest in terms of analysis and dynamics, based on the "Linea di Costa" ISPRA. The data are distributed free of charge, updated and downloadable by accessing the Institute's "Portal of the Coast" and the procedure will soon be accessible by the same portal, together with the Guidelines for the use of the "Coastline" Geodatabase. This procedure has already been applied by ISPRA experts to four pilot cases, concerning coastal stretches located in the following locations, three in Calabria region: Zambrone (Vibo Valentia); San Lorenzo (Reggio Calabria); the coastline between Crotone and Le Castella (Crotone), and one in Tuscany: the coastline between Rocchette and Castiglione della Pescaia (Grosseto). In order to provide an example of the application of the procedure, the latter case has been chosen because that study was undertaken in response of a request from a citizens' committee, namely 'Save the Coast', based in Castiglione della Pescaia and engaged to defending the integrity of a landscape of high cultural and environmental value in the aforementioned coast stretch. The committee's request arose after the adoption by the Tuscany regional administration of the "Project for beach nourishment and rebalancing of the Castiglione della Pescaia sandy shoreline"[2]. The committee argued that the solutions announced by the project to counteract the phenomenon of coastal erosion - which envisaged to put in place rigid structures (groins, islands and barriers) made with quarry boulders - may eventually create more damage than benefits, thus negatively affecting the area both from the ecological-environmental-

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[1] https://inspire.ec.europa.eu/
[2] Commissioner Ordinances no. 558/2018 -. 29/2018 -. 82/2019.

landscape and from the economic point of view. In particular, the committee addresses the landscape problems potentially introduced by the project, since it would affect the coastal territories and those immediately behind, located in the municipality of Castiglione della Pescaia, which are recognised as Tuscany's landscape assets with constraints set by law[3].

Materials and Methods

The procedure applied by ISPRA to respond to the question was based on the use of the GeoDB "Linea di Costa", which includes the digitisation and characterisation of the "historical" 1950 Coastline and the 2000, 2006, 2020 Coastlines.

The attributes of the geometrical features have been designed so as to allow an easy analysis of the shore characteristics, also in a time frame. The study activity behind the implementation of GeoDB led to the development of criteria on which to base the characterisation of the natural and artificial elements that make up the coastline, the backshore line and beach polygons, through specific attributes supporting the query-based analysis. The GeoDB is structured in such a way as to easily receive future periodic update, allowing spatial-temporal analysis of the data, at national and local level, thus providing the possibility to extract a wide range of information on coastal dynamics and shoreline evolution.

These information layers have different levels of accuracy:
- the 'historical' coastline was derived from the digitisation of 1:25 000 IGM tiles, mostly dating back to the 1950s. Due to this origin, the data obtained has a limited accuracy, due to the lower resolution of the historical data compared to more recent data obtained with more modern techniques.
- the coastlines 2000 and 2006 are the result of the digitisation and characterisation of the orthophotos IT2000 and IT2006 by the Ministry of the Environment (now Ministry for the Ecological Transition - MiTE), with ground resolution values of 1 and 0.5m, respectively. The orthophotos were almost always taken in ideal weather conditions: the few cases of rough sea were indicated and excluded from the spatial calculation. Considering that the tidal variations of the shoreline are observable only in some low-lying stretches of coastline (such as the northern Adriatic), the expected error is generally limited to a few metres, a quantity that was assessed as an acceptable trade-off between the possibility of having homogeneous and complete data with national coverage, and the need to investigate other local and temporal forcing factors.
- the 2020 coastline, which is now represented by the LC2020v1.0 version, is an update based on Google Maps images, with resolution values in the decimetre range and therefore more definite than the previously used flights.

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[3] According to the Strategic Territorial Plan (containing the Landscape Plan), issued by Tuscany Regional administration and ratified by the Ministry of Cultural Heritage and Tourism in 2015, this area is of considerable public interest "because it constitutes, with its tree vegetation, a natural framework of uncommon landscape beauty that can be enjoyed from the ancient coastal road and the rocks of the Fortress of the Rocchette". As a strategic goal, the plan recommends "the maintenance of the geomorphological characteristics of the coastal dune system and the relations that it maintains with the shoreline" as well as "the preservation of the level of naturalness and the constituent characteristics of the site", which is included in the list of Sites of Community Importance.

The Historic "Linea di Costa" of 1950 and the "Linea di Costa" 2000, 2006, 2020 are divided into three different features: the Coastline (LC) both natural and artificial, complete with the digitisation and characterisation of the defence and port works; the Backshore Line (LR) both natural and artificial with the relative characterisation of the neighbouring land use; the Emerged Beaches polygons. In particular, both the LC and the LR are made up of three main groups of attributes concerning the digitisation-characterisation of the coastal objects: Natural, Artificial and Fictitious; the latter corresponds to the segments traced conventionally to isolate the artificial objects, in order to give geometrical continuity to the LC and LR. Additional attributes are included to perform the analysis of the evolution of the coastline over time. For further specifications on the elements of the GeoDB, please refer to the link of the Portal of the Coast[4], from which it is possible to download the full elements in geopackage (Gpkg) format and view the related documentation. The portal, which is a section of the ISPRA Cartographic Portal, also contains a web-GIS viewer, where one can view the Coastline information layers directly.

The coastal dynamics calculations for the case study were carried out both at the level of the Physiographic Unit (UF)[5] where the stretch of coastline in question is located and - at a more detailed level - on specific tracts, for the periods 1950-2000, 2000-2006 and 2006-2020. Recent studies conducted in the marine-coastal field, more and more often refer to Physiographic Units (e.g. [1] [2]) as the definition of "areas in which it is meaningful to extend surveys to define sedimentary movements (due to wind, waves, currents and anthropogenic actions) or the effects produced (erosion and deposition phenomena)" [1].

In order to proceed with the description of the method, it should be emphasised that the spatial analysis of coastal dynamics is applied to the low sandy/pebbly stretches of coastline included in a UF, excluding elements such as the rocky shoreline, river mouths and portions of coastline that include man-made works, which are not taken into account, or are replaced with their fictitious stretches. This is put into practice by querying over a specific binary attribute, namely, [Flag_modifica] (values yes/no) which is recorded at the moment of the update of the LC feature of the Geodatabase, so to allow the selection of only those stretches of coastline for which the calculation of changes is to be carried out.

Next, at each update of the LC information layer, the analysis of coastal variations is performed, through the identification of all coastal stretches that are at least 5 m farther than the reference coastline (e.g. for the 2020 update, the reference LC is that of 2006, and so on), applying a corresponding buffer. This analysis is recorded by a specific attribute, namely, [Modifica_ORTO#_#] (where "#" represents the LC year), which reports the observed changes in the coastline through a direct comparison of the current line with the previous one, both of them filtered as described above. The attribute allows the following values: "Advancement", "Erosion", "Stability": for each stretch of the two LC's under comparison, the 5 m buffer is applied, within which the deviation is not considered relevant. In this case, the value 'Stability' is assigned to those stretches; differently, where the corresponding coastlines exceed that distance,

the values 'Erosion' or 'Advancement' are assigned, in case the newer line is set back or advanced with respect to the older one, respectively. Only in the 1950-2000 comparison, the buffer has been set to 25 m, given the lower accuracy of the 'historic' line. As a result, the originally digitised coastline is divided into several further contiguous stretches, characterised by variation from the reference coastline. For all those stretches which were filtered-out, the [Modifica_ORTO#_#] attribute reports the value 'No information'.

With the base data organized in this way, the user - once the desired data have been downloaded - may select the physiographic unit of reference and query the GeoDB, through the LC attribute [Modifica_ORTO#_#], in relation to the "Erosion", "Advancement" or "Stability" value, depending on the information to be obtained.

Results

According to the note received by ISPRA from the 'Save the Coast' committee, the area involved in the region authority project goes from Le Rocchette to the built-up area of Castiglione della Pescaia, covering slightly less than 8 km, and falls within the UF of Castiglione della Pescaia, located between Punta Ala and Talamone (coast length of around 50km). We report, in Table 1, the values concerning the coastal dynamics, for the entire UF of reference, as obtained from the attribute tables of the 2020, 2006 and 2000 LC layers, through the following query (in the example, value "Stability" and LC of year 2006):

[Nome_UF] = 'Castiglione della Pescaia' AND [Modifica_Orto2006_2000] = 'Stabilità'

Table 1 – Coastal change in the years 1950 to 2020 in the UF Castiglione della Pescaia.

UF Castiglione della Pescaia (data in km)				
Reference period	Advance	Stability	Erosion	Not Calculated *
1950-2000	16	10,6	6,2	20
2000-2006	12,6	12,5	4,6	20
2006-2020	11,7	12,8	6,8	21,5
* Uncalculated stretches include those of rocky coastline.				

From the results shown for the whole UF, we observe that stability/advancement seem to prevail with respect to erosion on stretches of natural low coast; even if we neglect the data relative to the 1950-2000 period, due to the limits of precision mentioned above, the smaller extent of the stretches in erosion compared to those in advancement and stability is still evident. Of course, the level of local detail is here lost, as the information is integrated over the wide area set by the UF.

For the stretch of coast affected by the beach nourishment and re-balancing project, a more detailed analysis has therefore been conducted, with data concerning the 2006-2020 time range; in fig.1(A), we show the analysis of the coastal dynamics in the stretch of coastline from Punta Le Rocchette to Riva del Sole: erosion stretches are highlighted in red, stable stretches in yellow and advancing stretches in green. For the beaches immediately over Punta Le Rocchette, a trend of stability and in some cases of

advancement can be seen, while in the Roccamare area a trend of erosion can be seen, which reaches its maximum extent in the Riva del Sole area. Going further, in the stretch of coastline from Riva del Sole to Punta Capezzòlo and towards the town of Castiglione della Pescaia, we mainly observe stability, except for a small advancing tract and a few eroding ones close to Punta Capezzòlo (figure 1(B)).

Figure 1 – Analysis of the stretch of coastline from Punta Rocchette to Riva del Sole (A), and from Riva del Sole, through Punta Capezzòlo, to Castiglione della Pescaia (B). Boxes in part (A) of the figure correspond to the extents of figure 2 and 3.

As far as the stretches in evident erosion are concerned, it can be stated that the retreat of the coastline has shown up in the last decade. In figures 2 and 3 we show a zoom-in of the two boxes inserted in Fig. 1(A), around Riva del Sole (West) and Roccamare (East), respectively, where the detail of the LC's at different years is displayed. In the first case, it is possible to observe the evolution of this stretch, about 800 m long: even assuming a lower precision of the historical data from 1950, the first two surveys show an average advance of about 15 m until 2006, after which there is a definite average retreat of about 20 m. In the second coastline stretch (Fig. 3), a completely different evolution is noted over the years; however, in the last decade, a retreat of the coastline can be observed, albeit of little significance.

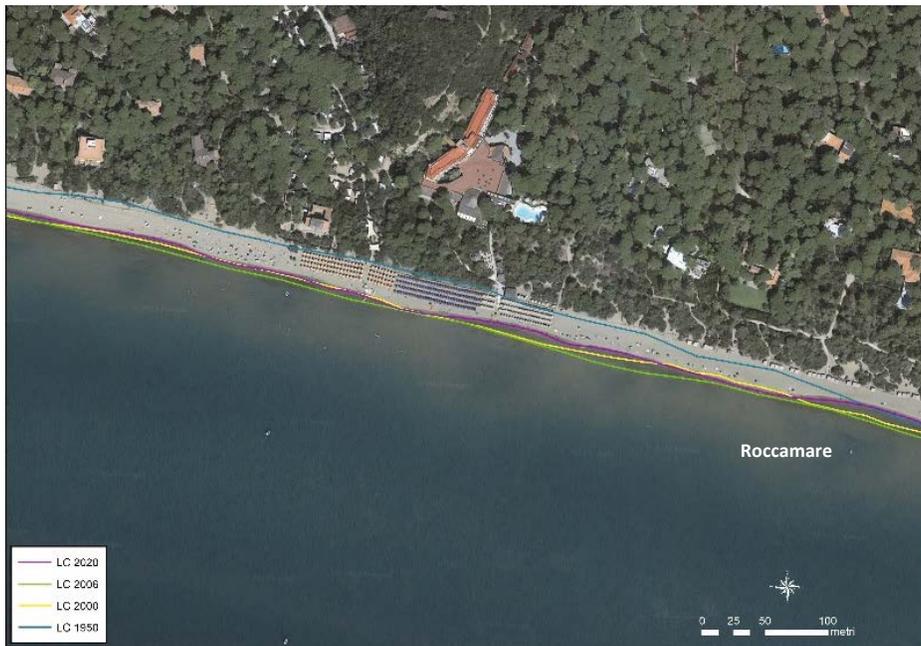Figure 2 – Detail of the LC evolution at Riva del Sole.

Figure 3 – Evolution in the stretch west of Roccamare.

From 1950 to 2006 there is a marked advance that in some areas reaches 30 m, but from 2006 to 2020 there is a reversal of the trend that leads to a non-uniform, but constant erosion. From the LR information layer it was possible to obtain the length of the stretches with different land use, located immediately behind the beach. A state of general naturalness of the territory emerges, underlined by the presence of coastal dunes, as summarized in Table 2:

Table 2 – Summary of data deduced from the LR.

Characterization of the Backshore Line (data in metres)					
Year	Vegetation/ bare soil	Urban scattered	Road infrastructure	Bathing facilities	Not calculated*	Total
2000	4788	2064	70	570	229	7721
2006	4784	2062	48	567	310	7771
2020	4631	1928	62	900	226	7747
* rocky coastline (e.g. Punta Capezzolo) or river mouths.						

Moreover, the data in the table show a general condition that has remained fairly constant over the decades, with one exception: in the period between 2006 and 2020, the main changes in the backshore environment concerned the transformation of natural areas

or scattered urbanisation into areas occupied by bathing facilities, which increased in that period alone by about 60 %. It should be noticed that, out of the 900 m occupied by bathing facilities, about half correspond to the sites highlighted above where coastal erosion is most pronounced.

A further informative layer of the ISPRA coastal coverage concerns the beach polygons. By the standard GIS tools, we calculated the total surface area of the beaches in the study area, displayed in fig. 4. The shoreline under examination consists of a single stretch of low sandy coastline, within which the beaches are interrupted by two elements: the armed mouths of a canal and the small promontory of Punta Capezzolo. For a better characterization of the stretch under analysis, we have defined "Beach1" the shoreline between Le Rocchette and the mouth of the waterbody, "Beach2" the shoreline between the mouth and Punta Capezzòlo, "Beach3" the shoreline between Punta Capezzàlo and the canal port of Castiglione. The results are shown in Table 3, where we can notice a decrease of the 2020 data when compared to 2006, but still an increase if compared to the data from year 2000. In particular, "Beach2", which is in retreat, is the one that includes the areas most occupied by bathing facilities (Fig. 5).

Table 3 – Surface area of beaches in the analysis area.

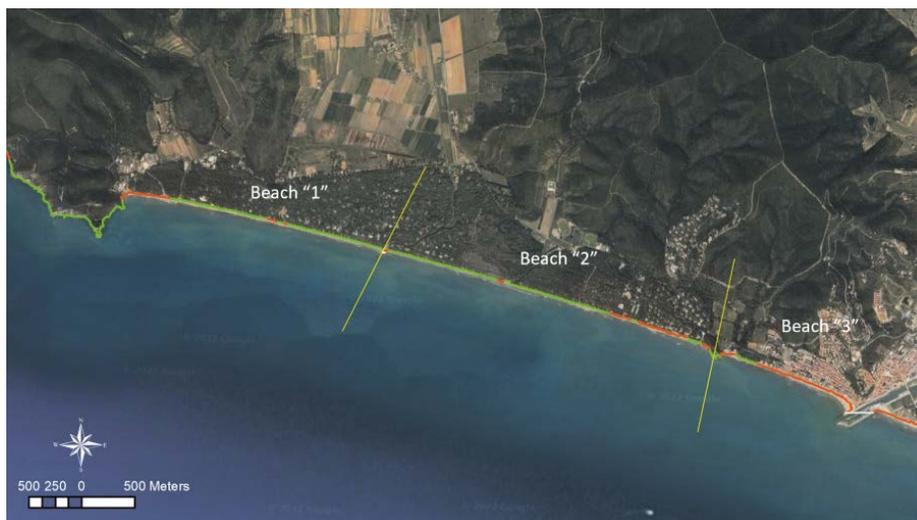| Surface of Beaches (m²)			
Year	Beach 1	Beach 2	Beach 3	TOTAL SURFACE AREA
2000	64905	69463	31882	166251
2006	63281	82354	37587	183222
2019	63798	68183	40266	172247

Figure 4 – Subdivision of the beaches under examination.

Figure 5 – "Beach2": detail at the largest recorded setback.

Discussion

The procedure described and the results reported above highlight how the "Linea di Costa" ISPRA allows the application of a simple method that can quickly give an idea not only of the current state of the coastline, but also of its evolutionary trend and can thus be used as starting information for further in-depth studies in specific areas of interest. In the pilot project that has been presented, as already mentioned, the LC2020v1.0 version that has just been published on the Portal of the Coast is being used for the year 2020, while for the analysis of the beaches the update has only been carried out for the coastal sections of the study area, as the beach information layers have not yet been updated at national level. In general, the update of the "Linea di Costa " Ispra 2020 is proceeding by successive versions, as new criteria for the photo-interpretation of the images have been defined, which have reached a higher level of quality with respect to 2006. First of all, this has entailed the modification of many elements of the Geodatabase for both digitisation and characterisation: at present, more than 10,000 elements relating to the Coastline and Backshore Line layers alone have been corrected in order to comply with the new standard. In addition, it was necessary to start the spatial analysis based on the possible co-registration issues between the LC06 and LC20 image sources and its correction, which is still ongoing and will lead to the publication of the LC2020v2 version by the end of the year.

Conclusion

In this paper we have presented a pilot case chosen to test the simple processing method based on the use of the "Linea di Costa" ISPRA and how it is possible to apply it to different scalesand different purposes. Indeed, we went from analysing coastal dynamics from the Physiographic Unit level (i.e. over approximately 50 km of coastline) to a much more detailed one (over approximately 100 m of coastline), demonstrating the excellent possibilities of using this tool to support stakeholders who need to focus on specific stretches of coastline of interest, both for management and study purposes. Clearly, this tool needs periodic updates and revisions of the standards of its structure in order to be increasingly effective and easy to use. For this reason, the ISPRA team in charge of the realisation of the information layers needs continuous feedback from the stakeholders who want to use both the procedure specifically and the Coastline data in general. This will allow the various versions of the information layers, and the documents associated with them, to be published on the Ispra Portal of the Coast over time in an increasingly effective and user-friendly manner. In the near future (by the end of the year), the LC2020.v2 version is expected to be published with the correction of image coregistration errors and some further modifications to the GeoDB that will make the procedure presented for the analysis of coastal dynamics even more user-friendly. Subsequently, the Guidelines for the use of the "Linea di Costa" ISPRA will be published.

References

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