ABSTRACT MASTERS’ THESIS

GIS AND REMOTE SENSING FOR COASTAL EVOLUTION STUDIES: MULTI-PROXY SHORELINE CHANGES IN THE OVAR–MARINHA GRANDE AREA (PORTUGAL) FROM 1984-2011 AND 2022 SCENARIOS

Candidate: Luca Cenci
Supervisor: Professor Leonardo Disperati
Co-supervisor: Professor Maria de Fátima Lopes Alves

1. INTRODUCTION

The evolution of shoreline position over time is a matter of great importance for Integrated Coastal Zone Management (ICZM) purposes because coastal managers require information about where the shoreline is located, where it has been in the past, and where it is predicted to be in the future. In this context it is problematic to define in a static position the undefined and dynamic boundary of the shoreline, hence, other coastal features are exploited as proxies to represent the proper shoreline position (Boak and Turner, 2005). A procedure was developed during this research based on integration of geomatics data and tools to perform multitemporal shoreline analysis of the central region of Portugal in order to find the more reliable proxy for the study area, *circa* 140 km between the counties of Ovar and Marinha Grande (NW Portugal), according to the available data source.

The aims of this master’s thesis were to study shoreline evolution over time and obtain predictive short-term future scenarios to quantitatively support the regional coastal zone management. The time period assessed ranged from 1984 to 2011 and short term predictions were forecasted for 2022. Results were integrated into the Coastal Zone Management Plan -CZMP (Horizon – 2022; APA, 2013) and they will help coastal managers during decision-making processes.

Importantly this methodological planning approach will also provide visual coastline change information for regional decision-makers and stakeholders.

2. STUDY AREA

The study area (Figure 1) is composed almost exclusively by beaches locally interrupted by urban settlements and bordered by a dune system, covered by vegetation. The typical coastal profile is characterised by three features: the dune area with stable vegetation, an area of barren lands (whose width ranges from 0 to *circa* 300 m) and the beach. Shoreline continuity is interrupted by the Ria de Aveiro lagoon with its artificial harbour, the cliff of Serra da Boa Viagem and the cliff of São Pedro de Moel. The tidal range is mesotidal (2-4 m). The wave regime, agreeing with the prevalent winds, is mainly north-west oriented and the longshore transport, mainly due to wave action, is southwards (MAMAOT/APA I.P., 2012). The study area is affected by severe erosion problems mainly due to: urbanization of natural areas, coastal defence interventions, port construction works (*e.g.* Aveiro harbour) and reduced sediment supply of the Douro River (located to the North of the study area - MAMAOT/APA I.P., 2012).

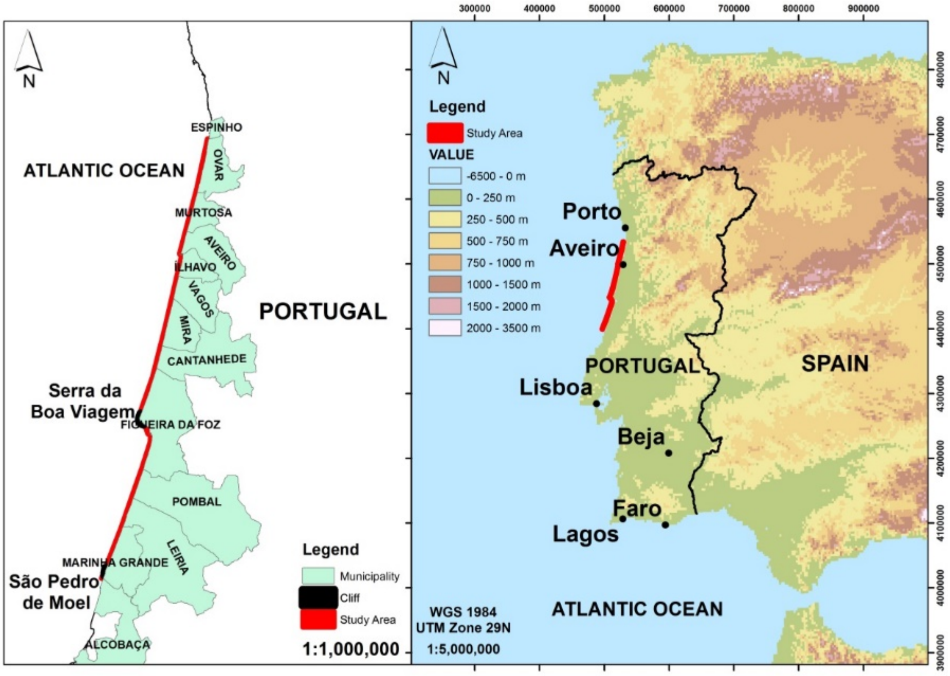

Figure 1 Study area

3. METHODOLOGY AND RESULTS

The coastal features considered as proxy in the elaborations of this master's thesis were the Stable Dune Vegetation Line (StDVL), the Seaward Dune Vegetation Line (SwDVL) and the Instantaneous Water Line (IWL), intended as the lines that separate the following features: dune areas with stable vegetation; barren lands; beach; ocean (Figure 2)

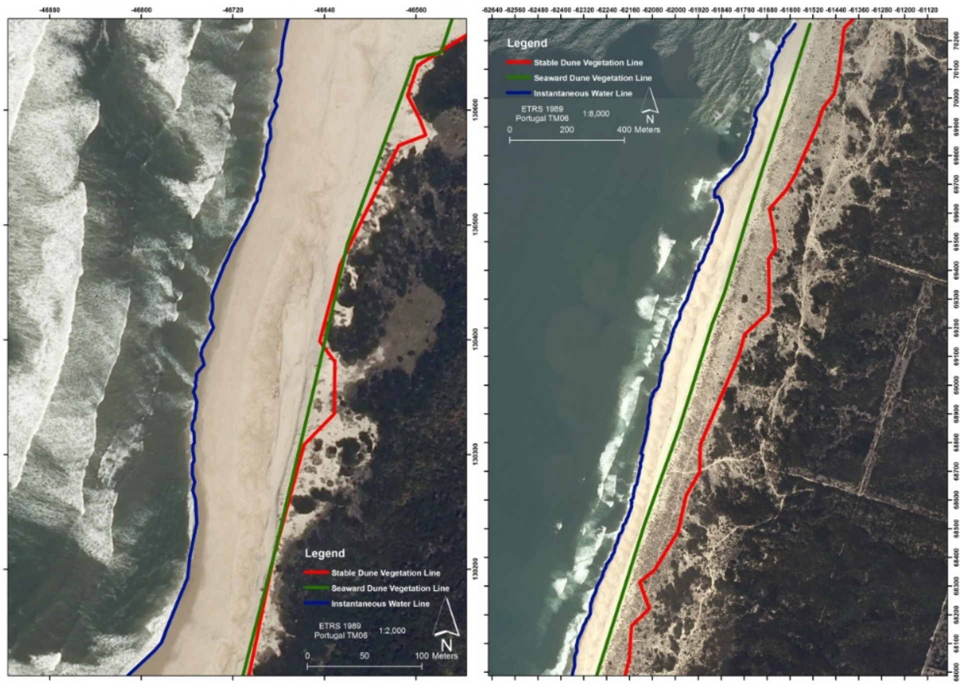

Figure 2 Proxies manually mapped onto orthophotos (2011) of the study area. Legend: red: Stable Dune Vegetation Line (StDVL); green: Seaward Dune Vegetation Line (SwDVL); blue: Instantaneous Water Line (IWL).

Due to its temporal resolution and and synoptic vision Landsat imagery archive was exploited as data source to obtain orthorectified, cloud free images in order to perform feature-extraction procedures (Table 1).

Taking into account shoreline retreat rates obtained from aerial photograph interpretation between 1947 and 1990 in the Aveiro-Cape Mondego stretch (up to 4.5 m/y; Ferreira and Dias, 1992) Landsat data, having spatial resolution of 30 m, were considered adequate for performing multi-temporal shoreline analyses. Moreover, 2011 natural colour digital orthophotos with a spatial resolution of 0.5 m (National Environment Agency, formerly INAG I.P) and covering the whole study area were used.

Table 1 Dataset of Landsat imagery and Root Mean Square Error (RMSe) in the study area subset.

Sensor	**TM**	**TM**	**ETM +**	**TM**	**TM**	**TM**	**TM**
Acquisition epoch	09/08/ 1984	07/31/ 1987	06/24/ 2000	08/12/ 2003	08/07/ 2007	10/15/ 2009	10/05/ 2011
RMSe (m)	7.95	7.33	1.06	5.04	6.84	6.78	7.63

In order to obtain a reliable change detection estimate, the multitemporal image dataset was geometrically co-registered and radiometrically normalised (Lunetta and Elvidge, 1998 amongst others). Landsat imagery high geometric co-registration was firstly assessed by evaluating the RMSe of the orthorectification process in the study area (Table 1) and, thereafter, a double-step relative radiometric co-registration was executed in order to guarantee a high degree of reliability when performing multitemporal analyses (Cenci *et al*., 2013). The image data were firstly converted from calibrated Digital Numbers (DNs) to at-sensor spectral radiance by using the equations and rescaling factors of Chander *et al*. (2009). Subsequently, the effects due to the scattering were mitigated by applying the Dark Object Subtraction (DOS) method (Brivio *et al*., 2006). Finally, the residual radiometric differences between the images (mainly related to different atmospheric conditions) were reduced by applying a linear Relative Radiometric Normalization (RRN) based on Pseudo Invariant Features (PIFs) (Schott *et al*., 1988).

The images were then enhanced by applying the Difference Vegetation Index (DVI = NIR-R; Lillesand and Kiefer, 1987) in order to detect the Vegetation Line-based proxies. These were extracted as vector features by implementing a semi-automatic procedure based on a statistical identification of the radiance threshold values to be applied to both DVI-enhanced images (Cenci *et al*., 2013). On the contrary the IWL proxy was detected and extracted by thresholding Landsat band 7 (Jupp, 1985; Wilson, 1997; White and El Asmar, 1999).

These features were ultimately exploited to calculate shorelines proxies' rate-of-change statistics (Linear Regression Rate and R-squared) by using the Digital Shoreline Analysis System (DSAS), a freely available software application developed by the USGS that works within the GIS software ESRI-ArcGis (Thieler *et al*., 2009).

For every proxy it was also quantified the uncertainty associated to the data: StDVL (34 m), SwDVL (33 m), IWL (65 m). These uncertainties were calculated by taking into account the factors (positional and measurement errors) that affected the shoreline/proxy extraction procedures (Fletcher *et al.*, 2003).

A comparison of the results in terms of linear regression rates (LRR), R-squared (R2) and uncertainty values allowed the identification of the best proxy, namely the Stable Dune Vegetation Line (Figure 3 and Table 2). This proxy was considered as the more reliable for the study area because its uncertainty is one of lowest whereas it has the greatest percentage of transects with higher values of R2 (Table 2). These considerations are also supported by the literature: the StDVL is considered a good erosion indicator (Boak and Turner, 2005), hence, it's suitable for the area under investigation that is affected by severe erosion problems. Taveira-Pinto *et al.* (2009) provided an additional demonstration of that by adopting the Vegetation Line as proxy in their shoreline advance/retreat analyses performed in part of the study area.

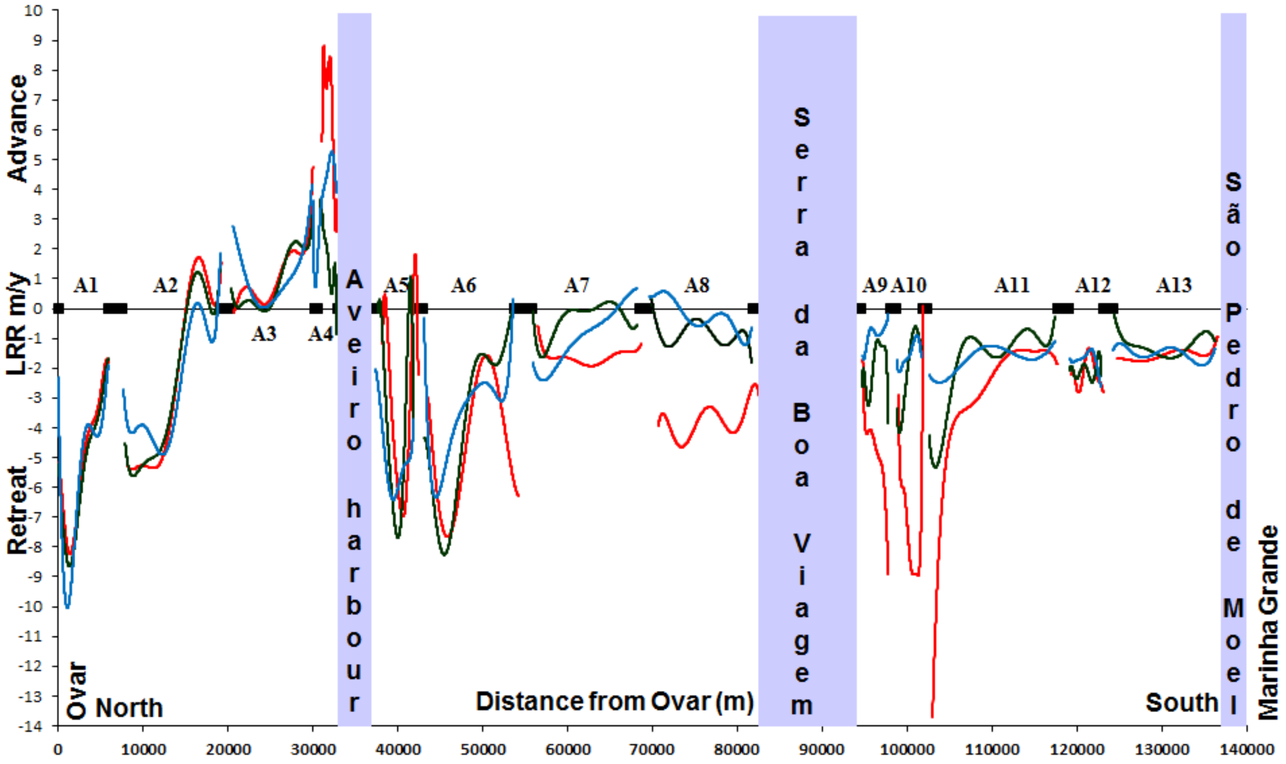

Figure 3 LRR-Interpolation lines comparison: These lines were obtained by interpolating LRR data. Legend: red: DVI-StDVL; green: DVI-SwDVL; light blue: IWL. Grey stripes represent areas excluded from shoreline change analyses (cliffs and the Aveiro harbour). Black rectangles represent urban settlements where statistics were not calculated

Table 2 R2 statistics comparison.

R2	**% of transects StDVL**	**% of transects SwDVL**	**% of transects IWL**
0 - 0.5	13%	66%	40%
0.6 - 0.7	21%	12%	23%
0.8 - 1	66%	22%	37%

The selected proxy (StDVL) was used to predict a 2022 scenario. After Fenster *et al*. (1993) the shoreline rate of change is a reasonable parameter for the estimation of the future shoreline position. This empirical approach does not need to implement other parameters because the cumulative effect of all the processes involved in the coastal dynamics are assumed to be represented by the position history (Li et al., 2001). In order to accomplish this goal the LRR-StDVL values were associated to specific transects representative of different shoreline stretches developing between either consecutive urban settlements or cliffs (Figure 4). These final LRR values were used to extrapolate an informed 2022 DVI-StDVL scenario in GIS environment.

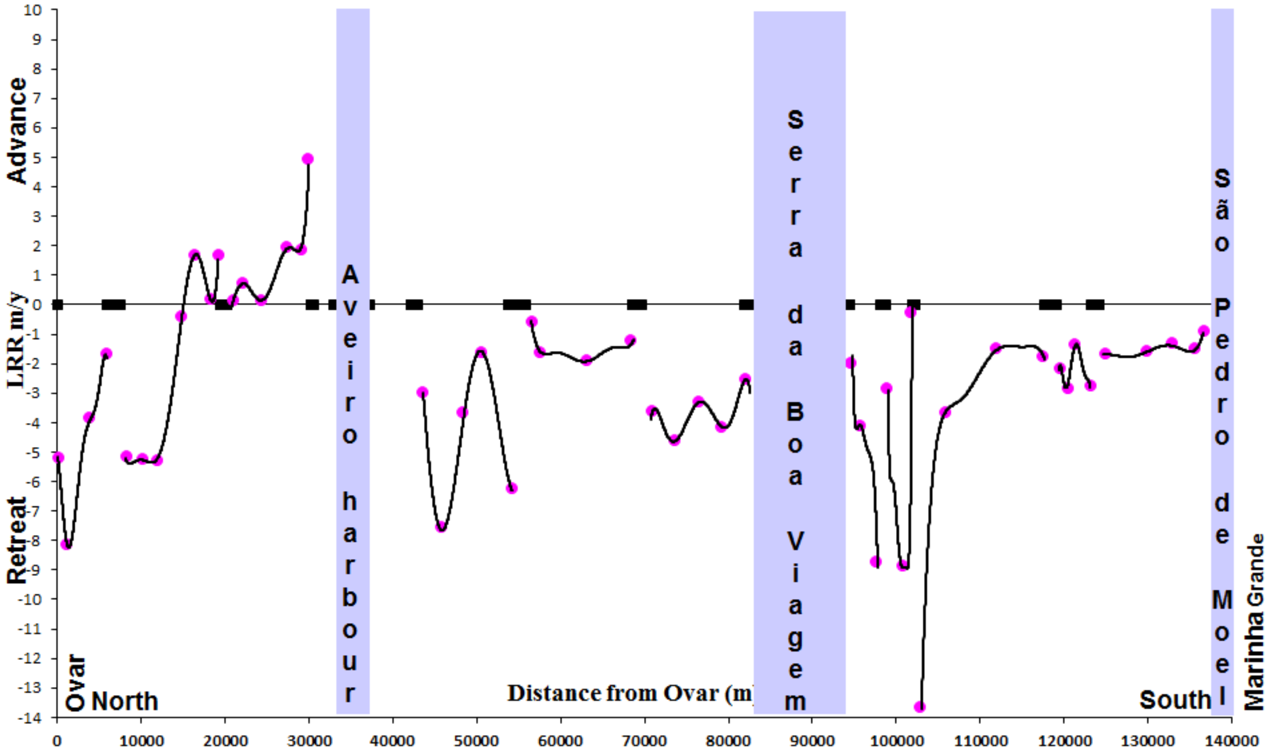

Figure 4 LRR-StDVL interpolating function. Interpolated LRR values (black line) associated to specific transects (pink circles). Areas nearby the Aveiro harbour were excluded from the prediction because their evolution is assumed to be highly influenced by the engineering interventions on the harbour.

Comparisons were performed also between LRR results and time series' analyses. Time series represent the relationship between time (Landsat image epoch when the shoreline data were collected) and distance (between the proxies and a reference baseline) calculated for every A_n area (refer to Figure 3). A general agreement was found between LRR results and those obtained by the time series, in term of advance/retreat measurements and linearity of the phenomena.

Another 2022 scenario was predicted by exploiting linear regression rates obtained from the time series' analysis. It was compared with the previous one (Figure 5) by taking into consideration differences in StDVL shape (connected to the different conditions of the vegetation) and methodological approaches (DSAS-LRR and time series). It was found that that discrepancy between the two predicted scenarios is larger where the stable dune vegetation is altered or damaged, like in the southern part of the study area (Figure 5 B). On the contrary the 2022 scenarios provide similar results when the Stable Dune Vegetation Line is well defined and generally rectilinear (northern part of the study area - Figure 5 A). Ultimately, the 2022 scenario obtained by interpolating LLR results was believed to be more accurate because time series' approach has the effect of smoothing local anomalies due to either vegetation growth or erosion patterns.

In the end, a literature comparison carried out, by taking into account other studies' results.

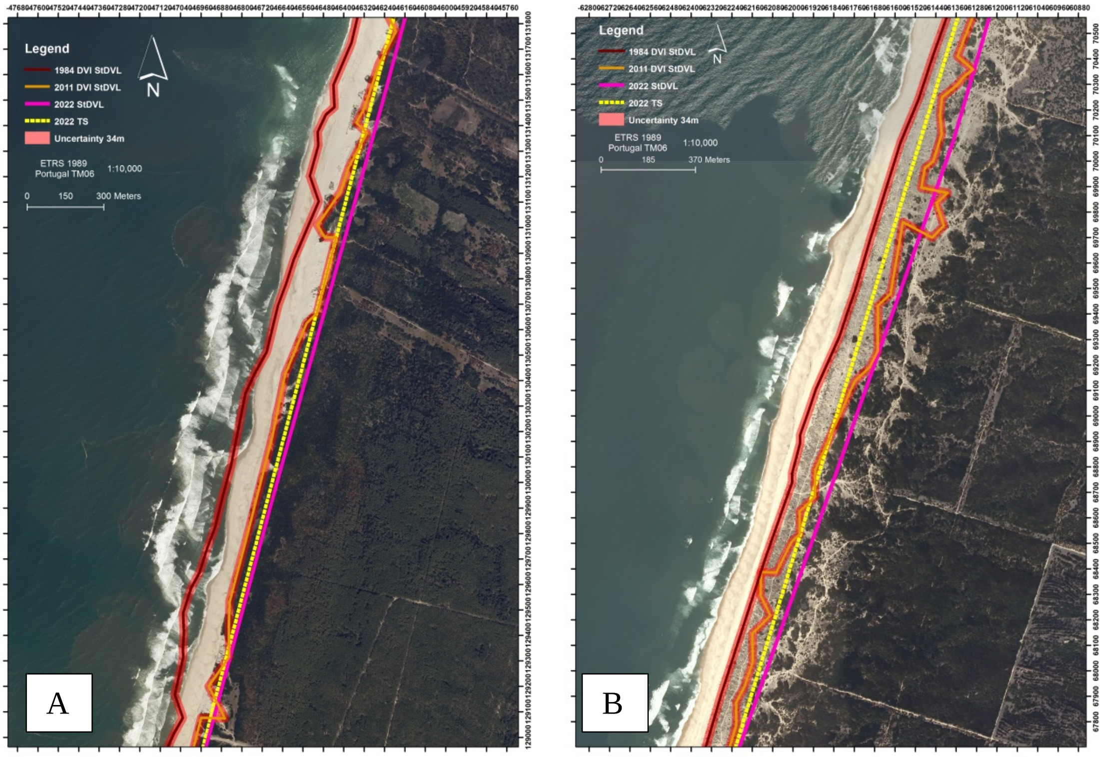

Figure 5 2022 Stable Dune Vegetation Line scenarios. Legend: brown: 1984 StDVL; orange: 2011 StDVL; pink: 2022 StDVL Scenario (LRR based); yellow: 2022 StDVL Scenario (time series based); red buffer: 34 m uncertainty StDVL.

4. CONCLUSIONS

Shoreline Evolution

It can be stated that the general trend obtained from the proxies' dynamics is retreat. This phenomenon can be seen as decreasing (in terms of rate) from North to South. It can also be interpreted as an extension of the erosion processes towards the South (Figure 3). In particular, by taking into account the results of the proxy considered as the more reliable for the study area (namely the Stable Dune Vegetation Line), it is argued that coastal vegetation cover has progressively reduced its role as beach protection. This condition may be associated to the occurrence of active erosion processes which should be carefully checked by means of other independent evaluation/measurement tools. Other proxies' results support these considerations.

Methodology

Compared to traditional procedures of visual shoreline delineation, the semi-automatic procedure here implemented and applied is time saving for regional scale analyses and is less user-dependent: hence more objective and repeatable. Another advantage of this *modus-operandi*, within areas where the change signal is in the order of tens of meters, is that the data cost is nil, because Landsat images covering a long time span may be acquired and processed free of charge. Furthermore, the method allows inclusion of images with different resolution (spatial, temporal, spectral or radiometric) within the same source dataset. They can be available either free of charge (*e.g.* Landsat 8, Aster – educational use; NASA, 2013; Aster, 2013) or purchased (*e.g.* Quickbird, Ikonos). This may enhance the quality and the reliability of the results decreasing the uncertainty factors and increasing the signal/noise ratio measured. Different image-enhancement approaches can be adopted to extract proxies (*e.g.* pan-sharpening, IR/R, NDVI, supervised or unsupervised classification techniques) and other data sources may also enable the use of other proxies (such as *Tidal datum–based indicators*). All of this could whether confirm or contradict findings obtained by this thesis. Other algorithms may be exploited to predict 2022 scenarios in order to test reliability and compare results. Concerning the scenarios predicted in this thesis, a statistical analysis of the uncertainties associated to the data obtained by regression procedures may be undertaken to assess the statistic reliability of the results. However a continuous or periodic monitoring of the shoreline evolution, at least along a set of specific transects, is suggested to check the accuracy of the predictions, even considering unexpected anthropic influences (*e.g.* engineering structures, dredging, nourishments) or natural events (*e.g.* storms, coastal floods, tsunamis).

REFERENCES

APA, 2013. *Revisão do Plano de Ordenamento da Orla Costeira Ovar - Marinha Grande, Relatório de Fase 3 - Projecto de POOC e Plano de Intervenções, Volume VI - ANÁLISE MULTI-TEMPORAL DA EVOLUÇÃO DA LINHA DE COSTA E CENÁRIO FUTURO.* Agência Portuguesa do Ambiente I.P., 42 p.

Aster, 2013: https://lpdaac.usgs.gov/products/aster_policies - Accessed: 25/03/2013.

Boak, E.H. and Turner, I.L., 2005. Shoreline definition and detection: a review. *Journal of Coastal Research*, 21(4), 688–703.

Brivio, P.A., Lechi, G. and Zilioli, E., 2006. *Principi e metodi di telerilevamento*. Città Studi Edizioni, Torino, 525 p.

Cenci, L., Disperati, L., Sousa, L.P., Phillips, M. and Alves, F.L., 2013. Geomatics for Integrated Coastal Zone Management: multitemporal shoreline analysis and future regional perspective for the Portuguese Central Region. *Proceedings 12th International Coastal Symposium (Plymouth, England), Journal of Coastal Research*, Special Issue 65, 1349-1354.

Chander, G., Markham, B.L. and Helder, D.L., 2009. Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors. *Remote Sensing of Environment*, 113, 893-903.

Fenster, M., Dolan, R. and Elder, J., 1993. A new method for predicting shoreline positions from historical data. *Journal of Coastal Research*, 9, 147-171.

Ferreira, O. and Dias A.J.M., 1992. Dune erosion and shoreline retreat between Aveiro and Cape Mondego (Portugal). Prediction of future evolution. *Proceedings. Int. Coastal Congress*, Kiel, 187–200.

Fletcher, C., Rooney, J., Barbee, M., Lim, S.C. and Richmond, B., 2003. Mapping shoreline change using digital orthophotogrammetry on Maui, Hawaii. *Journal of Coastal Research*, Special Issue 38, 106–124.

Jupp, D. L., 1985. Landsat based interpretation of the Cairns section of the Great Barrier Reef Marine Park. *CSIRO*, Melbourne.

Li, R., Liu, J. and Felus, Y., 2001. Spatial modelling and analysis for shoreline change and coastal erosion monitoring. *Marine Geodesy*, 24, 1-12.

Lillesand, T.M. and Kiefer R.W., 1987. *Remote Sensing and Image Interpretation, 2nd edition*. New York: John Wiley and Sons, 721 p.

Lunetta, R.S. and Elvidge, C.D. (ed.), 1998. *Remote Sensing Change Detection: Environmental Monitoring Methods and Application*. Chelsea, Michigan, USA: Ann Arbor Press, 318 p.

MAMAOT/APA I.P., 2012. *POOC OVAR-MARINHA GRANDE: VOLUME I. RELATÓRIO: Caracterização e Diagnóstico Prospectivo*. CEDRU/ Universidade de Aveiro. Lisboa, Portugal, 829 p.

Nasa, 2013: http://science.nasa.gov/missions/ldcm/ - Accessed 04/09/2013

Schott, J.R., Salvaggio, C. and Volchok, W.J., 1988. Radiometric scene normalization using pseudoinvariant features. *Remote Sensing of Environment*, 26, 1–16.

Taveira-Pinto, F., Pais-Barbosa, J. and Veloso-Gomes, F., 2009. Coastline Evolution at Esmoriz-Furadouro Stretch (Portugal). *Proceedings of the 10th International Coastal Symposium (*Lisbon, Portugal*), Journal of Coastal Research,* Special Issue 56, 673–677.

Thieler, E.R., Himmelstoss, E.A., Zichichi, J.L. and Ergul, A., 2009. *Digital Shoreline Analysis System (DSAS) version 4.0 — An ArcGIS extension for calculating shoreline change*: U.S. Geological Survey Open-File Report 2008-1278. *current version 4.2, 81 p.

White, K. and El Asmar, H.M., 1999. Monitoring changing position of coastlines using thematic mapper imagery, an example from the Nile Delta. *Geomorfology*, 29, 93-105.

Wilson, P.A., 1997. Rule-Based Classification of Water in Landsat MSS Images Using the Variance Filter. *Photogrammetric Engineering and Remote Sensing*, 63(5), 485-491 p.