PROTECTING VAGUEIRA (PORTUGAL) WATERFRONT: PRESERVING NATURAL, RECREATIONAL, RESIDENTIAL, AND COMMERCIAL FUNCTIONS

Rita Pombo[1], Carlos Coelho[1], Peter Roebeling[2,3]
[1]RISCO – Department of Civil Engineering, University of Aveiro, Campus Universitário de Santiago – 3810-193 Aveiro (Portugal), e-mail: ritanovo@ua.pt
[2]CESAM – Department of Environment and Planning, University of Aveiro, Campus Universitário de Santiago – 3810-193 Aveiro (Portugal)
[3]Wageningen Economic Research, Wageningen University and Research, Droevendaalsesteeg 4, 6708PB Wageningen (The Netherlands)

Abstract – Vagueira is a Portuguese village located on the northwest coast of the country. The waterfront of the coastal settlement hosts relevant economic activities and the beach is well visited by tourists, hence concerning a diversity of assets of interest to protect. Nevertheless, it has been affected by a persistent trend of erosion, due to the prevailing deficit of coastal sediments in the littoral drift, and experienced overtopping and flooding events in the past. Consequently, the inefficiency of existing coastal defences (a longitudinal revetment along the waterfront and a groin located on its downdrift limit) to mitigate coastal hazards is being discussed.
The objective of this study is to determine if the deployment of a detached breakwater in front of Vagueira beach would help protect the coastal community and safeguard its natural services and general assets. For this purpose, elements at risk were assembled into uniform Land Use and Land Cover (LULC) classes, following the classification adopted in the COS2018 Portuguese map. The numerical modelling of the case study was made using the LTC shoreline evolution model, considering local hydrodynamic and topo-bathymetric conditions and historical sets of data. Thereafter, the LULC map was overlapped with LTC projections, in a GIS-based environment, to determine the future exposure to coastal erosion and flooding considering the situation of "do nothing" versus the breakwater deployment.
Results demonstrate that the construction of the breakwater can have a global positive performance, with benefits from halting land losses, increasing the emerged beach area and reducing flood risk. However, it is not a "one-size-fits-all" solution. Despite several configurations have been tested, the salient does not cover the whole extension of the waterfront and there is a negative impact on some LULC classes.

Introduction

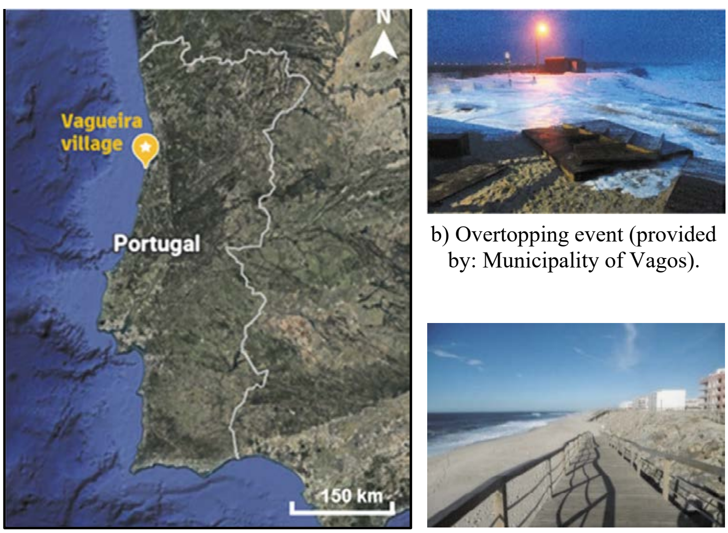
By the end of the 21st century, erosion of sandy beaches and shoreline retreat may become predominant across the globe [1]. This is due to a diversity of natural and anthropic factors, mainly resulting in sediment deficit and sea-level rise. Particularly, the northwest coast of Portugal (see Figure 1a), which is characterized by sandy beaches with a typical northwest wave climate [2], had been undergoing a generalised sediment deficit caused by dam constructions, intense port activity, and the construction of hard coastal structures

Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)
Rita Pombo, Carlos Coelho, Peter Roebeling, *Protecting Vagueira (Portugal) waterfront: preserving natural, recreational, residential, and commercial functions,* pp. 283-292
10.36253/979-12-215-0030-1.26

updrift. In Vagueira, the shoreline retreat averaged 4.4 m year^{-1} between 1958 and 2018 [3] and overtopping events in the urban settlement reached flooding extension approximately 50 m distant from the mean shoreline (see Figure 1b). According to mathematical modelling and recent observations [4], events with an average discharge greater than 1 ls^{-1}m^{-1}, that may cause damage to buildings located behind the defence [5], are estimated to occur two times every three years.

Nevertheless, Vagueira beach provides relevant recreational services (such as tourist-oriented activities) and regulating services (such as flood and erosion mitigation), that are of interest to be protected and maintained. In fact, the beach provides a natural defence to the forefront promenade which is occupied by several bars and restaurants, commercial establishments and residential buildings. In terms of tourism, the beach is well visited by inhabitants from the Center region of Portugal and also from Spain due to the proximity to the A25 highway [6]. In addition, Vagueira hosts an active community of artisanal fishing, which became also a tourist attraction.

Current coastal protection conditions of Vagueira include a longitudinal defence along the urban waterfront (see Figure 1c) and a groin located in its southern limit, which have demonstrated inefficiency to mitigate coastal hazards alone. Hence, although in Portugal detached breakwaters have not yet been applied for coastal protection, their effectiveness in controlling coastal erosion has been reported in successful case studies worldwide [7]. Therefore, the objective of this work is to investigate the efficiency of deploying a detached breakwater to help preserve Vagueira's natural and built capital by providing a wave shelter zone and promoting sand accretion.



b) Overtopping event (provided by: Municipality of Vagos).

a) Location.

c) View of the waterfront and the longitudinal defence.

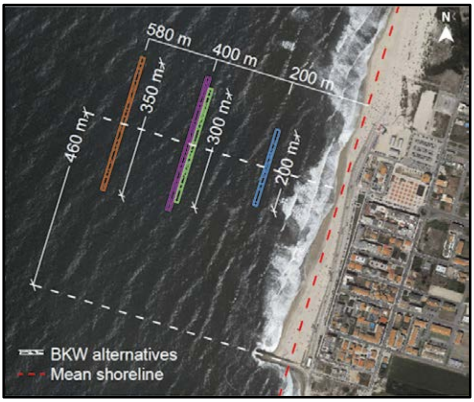
Figure 1 – Characterization of the case study.

Materials and methods

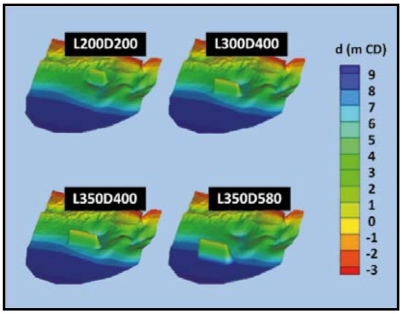
In order to find a solution for protecting Vagueira village and help secure the housing stock and the regular development of local economic activities, the performance of a detached breakwater was analysed. The analysis considered two distinct targets: i) reduce the risk of coastal flooding in the urban settlement and ii) mitigate coastal erosion of natural areas. For this, several alternatives for the detached breakwater were analysed.

The preliminary design of the new coastal structure comprised the test of several parameters within a suitable range of values. These tests were made through mathematical modelling and included criteria for the maximum value of the mean overtopping discharge and the number of overtopping events with discharges greater than certain thresholds. It was also analysed the sedimentary dynamics and the morphological evolution in the vicinity of the structure in the short and medium-term, under average hydrodynamic conditions.

This analysis allowed to conclude that a breakwater with a linear configuration, parallel to the shoreline, with seaward and landward slopes of 1:10 and 1:2 respectively, a crest width of 10 m and a cross-shore axis located 460 m north of Vagueira groin, is considered efficient to meet the targets proposed. The submersion level was fixed at 0.5 m below the mean level of the Low Perigean Spring Tide (= +0.84 m CD, Chart Datum) to avoid visual impact. In regard to the optimum dimensions and location, it was found that a structure with 300 m length (L) and 400 m distance (D) to the shoreline (configuration L300D400), constitutes the technical solution that best fulfils the objectives prioritized. The configuration L350D400 is concluded to be the second-best solution, so it is also considered relevant for the present analysis. In addition, the performance of L200D200 and L350D580 configurations, which represent extreme scenarios in terms of the structure' dimensions and detachment to the shoreline, are also analysed. Figure 2 depicts the final set of breakwater alternatives selected for further investigation.



a) Deployment area.



b) Configurations and local bathymetry [8].

Figure 2 – Alternative scenarios of a detached breakwater for coastal protection at Vagueira.

To assess the efficiency of each alternative, the following steps were completed. First, a comprehensive assessment of the case study to characterize its physical, social and environmental framework and define the modelling setup was made. From this, the model domain was considered centred on Vagueira beach, covering an area of 6×5.6 km^2, including the breakwater deployment zone and a wide vicinity to encompass the area of influence of the coastal structure.

Second, natural and artificial assets existing in the study domain were classified into uniform classes according to the nomenclature of the Portuguese Land Use and Land Cover (LULC) map, designated COS2018. This system follows a hierarchical classification that discriminates 4 levels of detail, the last one including 83 classes.

Third, LTC – *Long-Term Configuration* software [9, 10] was properly calibrated with local hydrodynamic and topo-bathymetric conditions and validated with historical data. This software allowed to forecast the evolution of the shoreline over time, for each scenario (*i.e.*, "do nothing" and "breakwater deployment"), relevant for the calculations of eroded areas. To predict flooded areas, the flooding extensions observed in the past were taken as a reference. Hence, the limit of the flooding area was considered displaced 50 m landward, parallel to the position of the shoreline previously projected.

Next, QGIS software (version 3.10.7-A Coruña) was applied to identify the exposure of each LULC to the coastal hazards (*i.e.*, flooding and erosion). The open-source software allowed managing and analysing georeferenced data, including overlapping the LTC shoreline projections in the LULC map to determine potentially flooded and eroded areas. It should be noted that for the flooding assessment only artificialized areas were considered and for the erosion assessment only natural areas. Hence, although some natural classes are expected to be flooded as well, they were not considered to be damaged. Similarly, artificialized areas were not admissible to be eroded as the retreat of the shoreline is limited by the existing longitudinal defence.

Finally, the performance of the breakwater alternative scenarios was assessed considering that it has positive benefits if results in areas gained or not eroded/not flooded by comparison with the scenario of "do nothing", and negative benefits if results in a worse situation. It should be noted that the "do nothing" scenario consists of the natural progression of the shoreline assuming the maintenance of the existing coastal structures.

In terms of beach areas, a distinction has been made: "Vagueira beach" (comprising an extension of 1.2 km centred in the urban settlement) was assessed separately from "other beach areas" existing in the model domain since the last does not provide recreational service (they are not usually sought by tourists). Also, since this study aimed to assess the performance of the breakwater in the medium-term, it was considered a time horizon of 20 years, for which annual values were interpolated from projections to years 5, 10, 15 and 20.

Results

Figure 3 depicts the LULC model produced for the case study, detailed at the second level of COS2018 nomenclature. According to this classification, it is possible to outline the spatial distribution of the LULC classes existing in the model domain: 56 % are coastal waters, 18 % are forests (mostly maritime pine on the east part of the map and invasive species alongside the beach), 15 % are temporary crops, 5 % is urban fabric (predominantly vertical near the waterfront) and 2 % are open spaces, which include the beach areas. The shoreline is always bordering 7.1 (beach) and 9.3 (ocean) LULC classes.

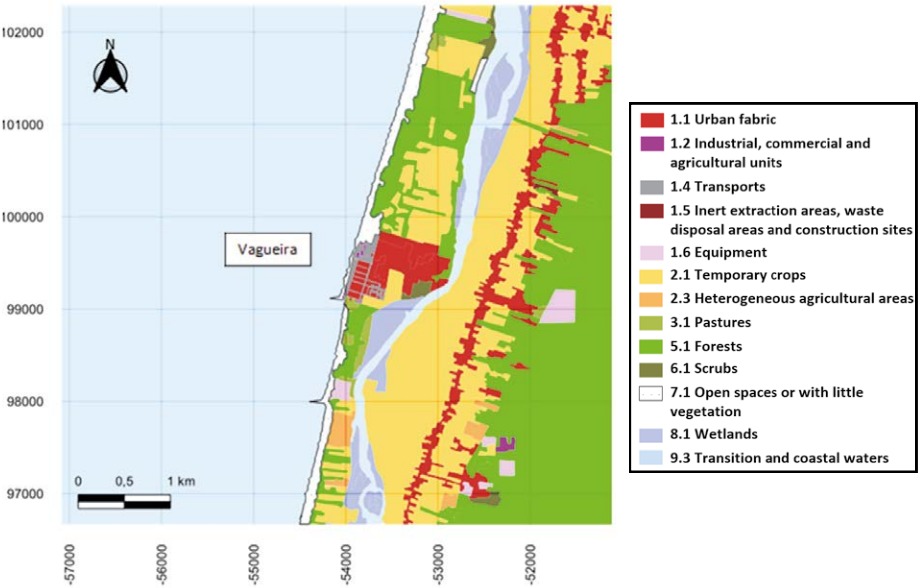


Figure 3 – Map of LULC classes existing in the model domain, according to the COS2018 nomenclature.

Table 1 summarizes 20-year LTC projections of flooded and eroded areas for each scenario, concluding that six LULC classes might be affected by these coastal phenomena. Namely, classes 1.1.1.1 (built-up fabric), 1.2.2.1 (commercial establishments), 1.4.1.1 (road network) and 1.6.2.2 (leisure equipment) are expected to have some areas flooded and classes 5.1.1.6 (forests) and 7.1.1.2 (beaches) are expected to have some areas eroded.

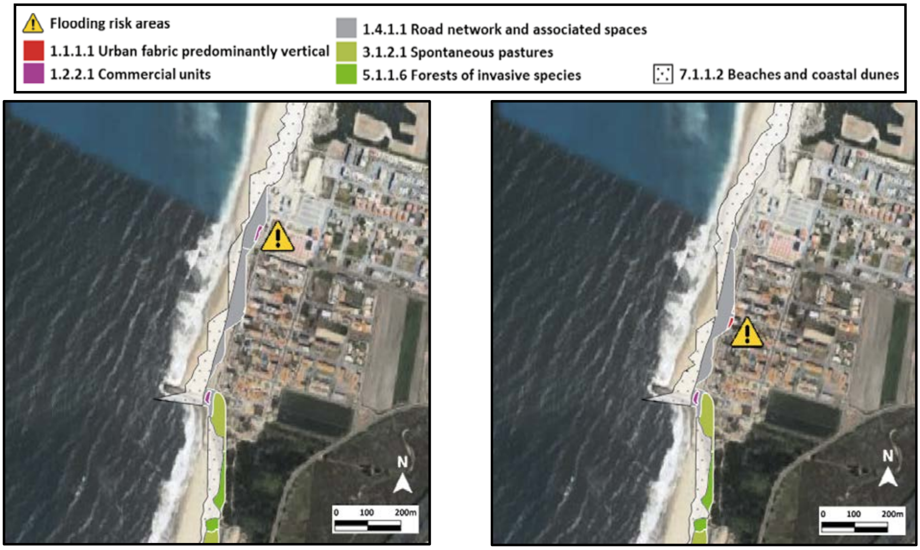
In terms of avoiding coastal flooding, the highest benefits of deploying the breakwater are perceived by the road network (class 1.4.1.1) and the commercial establishments (class 1.2.2.1) closer to the salient formed by the breakwater. As a trade-off, built-up fabric (class 1.1.1.1) is anticipated to be more impacted since there is an increase of erosion downdrift the salient, which reduces the beach width near the residential area. Finally, the leisure equipment affected (class 1.6.2.2) refers to a water park existing near a second groin located further south of Vagueira. The water park is expected to be similarly affected with or without the breakwater.

Table 1 – Areas of LULC classes exposed to coastal flooding and erosion (green cells represent benefits from the breakwater deployment, red cells represent an increase of flooded/eroded areas due to the breakwater).

Scenario	Year	Flooded areas (m²)				Eroded areas (m²)		
		1.1.1.1	1.2.2.1	1.4.1.1	1.6.2.2	5.1.1.6	7.1.1.2*	7.1.1.2**
Do nothing	5	0	1 149	16 705	140	0	10 226	56 055
	10	32	1 170	17 484	196	0	13 189	78 340
	15	33	1 172	17 635	216	35	12 529	87 938
	20	37	794	16 486	341	0	12 277	97 700
L200D200	5	39	487	15 560	140	0	7 342	56 059
	10	46	508	15 743	196	0	9 842	78 291
	15	48	534	15 841	218	34	9 358	87 893
	20	54	1 335	16 800	344	0	10 397	97 335
L300D400	5	46	389	13 500	140	0	3 623	56 036
	10	320	389	14 695	196	0	5 707	78 189
	15	358	389	14 030	216	32	4 668	87 895
	20	372	389	14 417	334	0	5 016	97 289
L350D400	5	296	389	14 793	140	0	4 402	56 009
	10	348	389	15 126	196	0	6 899	78 302
	15	372	389	14 418	214	32	6 415	87 872
	20	368	389	14 391	342	0	7 264	97 237
L350D580	5	45	389	13 703	140	0	2 458	56 320
	10	300	389	14 097	192	0	3 424	78 465
	15	334	389	14 002	227	38	3 148	88 034
	20	355	389	13 928	338	0	3 546	97 603

[1.1.1.1 Continuous built-up fabric predominantly vertical; 1.2.2.1 Commercial establishments; 1.4.1.1 Road network and associated spaces; 1.6.2.2 Leisure equipment; 5.1.1.6 Forests of invasive species; 7.1.1.2 Beaches and coastal dunes (*Vagueira beach; **Other beach areas)].

Support illustrations depicting the flooding extension expected for the reference scenario and scenario L300D400 by the year 20 are presented in Figure 4. The triangle warning signs highlight the transference of risk with the breakwater deployment from the new sheltered zone (accretion of sediments promotes higher protection, particularly for commercial units painted purple) to immediately south (increase of erosion downdrift the salient promotes extension of flooded areas, particularly affecting the urban fabric painted red).



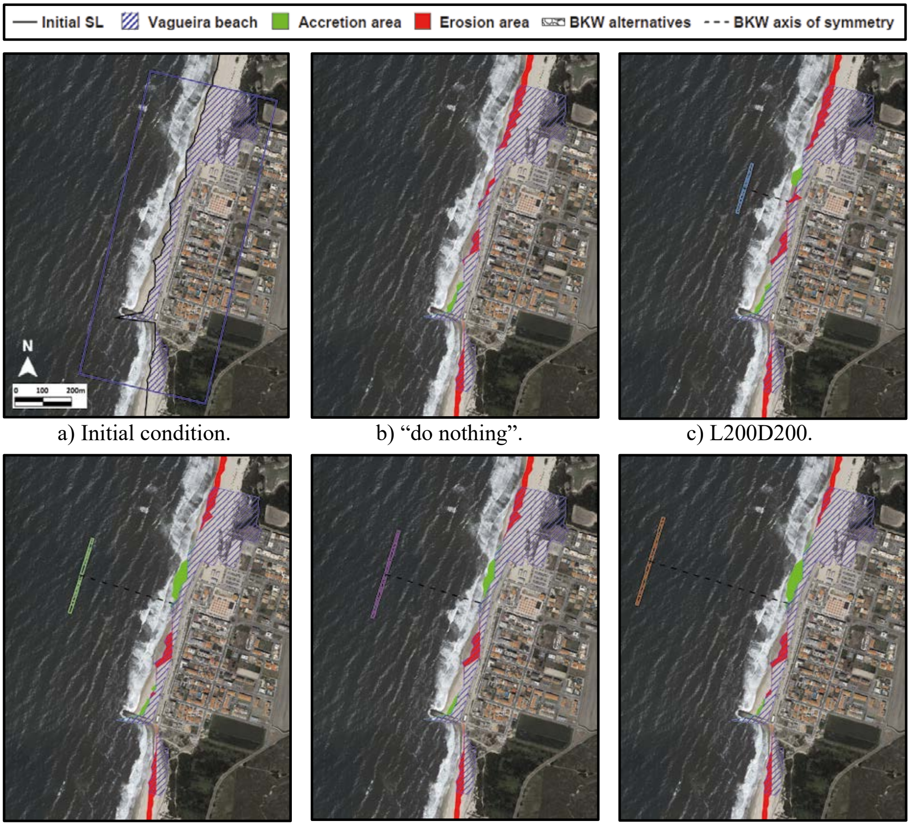
a) “Do nothing”. b) L300D400.

Figure 4 – Flooding extension and LULC classes affected at year 20 of simulations.

In what concerns coastal erosion, the columns of “eroded areas” in Table 1 represent in fact net erosion, *i.e.*, the sum of erosion (preponderant) and accretion. This is because it is predicted the maintenance of a generalized erosional trend, in spite of the occurrence of punctual accretion. Regarding the 7.1.1.2 class, it is predictable to lose around 10 ha of beach area by the last year of the simulation (11 % at Vagueira beach and 89 % in other beach areas) if no intervention is made. The detached breakwater scenarios have a residual impact in other beach areas but can reduce more significantly the areas lost by coastal erosion in front of Vagueira. It is also noticeable the positive impact proportional to the increment of length and distance: scenario L350D580 is expected to represent a beach loss in Vagueira of only 3 546 m^2 by the year 20 which is significantly lower than 12 277 m^2 lost without it; scenario L200D200 would still represent losses of 10 397 m^2 in the same year. Finally, the forests (class 5.1.1.6) are expected to be little affected in any scenario since they are further away from the breakwater influence zone.

Figure 5a illustrates the position of the initial shoreline (SL) and the corresponding initial area of Vagueira beach (in striped blue hatch). The boundary that limits Vagueira beach comprises an extension of 1.2 km alongshore and encloses the area typically occupied by beach tourists, representing 16 % of class 7.1.1.2. Other beach areas existing in the model domain represent the remaining 84 % (see Figure 3). Figures 5b to 5f illustrate erosion and accretion areas for each scenario, at the end of 20-year simulations, where it is noticeable the salient formed in each breakwater scenario. According to these results, it is possible to conclude that the detached breakwater scenarios reduce erosion areas between 6 % to 27 % and increase accretion areas by 2 000 m^2 to 5 300 m^2 within the Vagueira beach domain.

Globally, scenario L200D200 is the least efficient in preventing flooding (particularly, classes 1.2.2.1 and 1.4.1.1) and erosion (particularly, class 7.1.1.2*).



a) Initial condition. b) "do nothing". c) L200D200.

d) L300D400. e) L350D400. f) L350D580.

Figure 5 – a) Initial shoreline and delimitation of the initial area of Vagueira beach; b) to f) Expected erosion and accretion areas (class 7.1.1.2) at year 20 of simulations.

Discussion

The results of the present study are mainly driven by the accuracy of the numerical model used to forecast the beach response, which determines the performance of the detached breakwater in protecting Vagueira village and its natural and built capital. Although numerous computational tools exist for this purpose, all rely on simplifying assumptions. This study applied the LTC model since it is an in-house software which has already reported its accuracy in a recent study [4] that compared 15-year simulations made in the past with the real evolution of the shoreline in a coastal stretch near Vagueira.

On the other hand, this work has analysed the impact of the detached breakwater alone. However, the Portuguese Environmental Agency, which is the entity responsible for the coastal management in Portugal, has increasingly been performing artificial nourishments along the west coast. These interventions can significantly alter the forecasted morphodynamical balance and add greater benefits to the breakwater performance. Thus, additional scenarios combining beach nourishments with the detached breakwater deployment should be further investigated. In addition, to prevent the increase of erosion in front of the residential zone, scenarios for a segmented breakwater should also be simulated.

Conclusions

The objective of this work was to investigate the efficiency of deploying a detached breakwater in front of Vagueira beach, to help preserve Vagueira's natural and built capital and respective services. For this, two distinct targets were proposed: i) reduce the risk of coastal flooding in the urban settlement and ii) mitigate coastal erosion of natural areas. The numerical modelling of the case study was made in LTC software, which allowed forecasting the beach response for each scenario ("do nothing" and breakwater deployment - considering alternative lengths [L] and distances to the shoreline [D]). Complementarily, the classification of land use and land cover classes existing in the study area helped link the projections of the coastal morphodynamics with assets and services expected to be affected.

According to the simulations, the deployment of the detached breakwater is expected to promote the formation of a salient (*i.e.*, increase of the beach width) updrift its cross-shore axis of symmetry and, consequently, the increase of erosion downdrift, since no sediments were added to the system. This morphological response of the beach helps reduce the extension of flooding at the road network and commercial establishments in case of overtopping occurrence. As a trade-off, the residential area is anticipated to be more impacted since it is located downdrift the salient. The leisure equipment observed southern in the model domain and other natural areas are expected to be similarly affected with or without breakwater because they are further away from the influence zone of the coastal structure. Finally, in what concerns the recreational service that the Vagueira beach provides, it is expected to benefit from the breakwater deployment since all structural configurations analysed result in less net erosion than if no intervention was made.

Results demonstrate that there is no "one-size-fits-all" solution and future coastal management strategies must take this into account. Irrespectively of the punctual benefits and disadvantages detailed, it was noticeable a proportional relationship between the increment of the breakwater length and distance in relation to its global performance, founding out that scenario L350D580 is the one that best fits the goals proposed, followed by L300D400, and scenario L200D200 is the least efficient.

Acknowledgements

The results derive from the Program coordinated by the Portuguese Environment Agency co-promoted by POSEUR - Programa Operacional Sustentabilidade e Eficiência no Uso de Recursos (Reference: POSEUR-02-1809-FC-000039). The work was also financially supported by the project "Integrated Coastal Climate Change Adaptation for Resilient Communities", INCCA - POCI-01-0145-FEDER-030842, funded by FEDER, through "Competitividade e Internacionalização" in its FEDER/FNR component and by national funds (OE), through FCT/MCTES. Rita Pombo was supported by the doctoral Grant

SFRH/BD/151357/2021 financed by the Portuguese Foundation for Science and Technology (FCT), and with funds from the Portuguese state budget, under MIT Portugal Program. Thanks are also due to FCT/MCTES for the financial support to CESAM (UIDB/50017/2020 and UIDP/50017/2020) and RISCO (FCT/UIDB/ECI/04450/ 2020), through national funds and the co-funding by European funds when applicable.

References

[1] López-Olmedilla L., Almeida L.P., de Figueiredo S.A., Fontán-Bouzas Á., Silva P.A., Alcántara-Carrió J. (2022) - *Effect of alongshore sediment supply gradients on projected shoreline position under sea-level rise (northwestern Portuguese coast)*, Estuarine, Coastal and Shelf Science, 107876.

[2] Pombo R., Fernández-Fernández S., Baptista P., Coelho C., Bernardes C. (2022) - *Old forecasts vs actual shoreline evolution: Assessing model's performance and projections accuracy*, Coastal Engineering, 104143.

[3] Fernández-Fernández S., Baptista P., Bernardes C., Silva P., Fontán-Bouzas A., López-Olmedilla L., Ferreira C. (2019) - *Variação da Linha de Costa em Praias Arenosas: Aveiro (Portugal)*, Proceedings of the IX Congress on Planning and Management of Coastal Zones in Portuguese-speaking Countries, Lisbon, Portugal. (In Portuguese)

[4] Pombo R., Roebeling P., Coelho C., Sancho F. (2021) - *Estudo de um quebra-mar destacado multifuncional em frente à praia da Vagueira. (T4) Análise custo-benefício da melhor solução técnica e conjunto de soluções alternativas – Relatório 11*. LNEC - Proc. 0604/1201/21221. Relatório 345/2021 DHA/NEC, 92 pp.

[5] Pullen T., Allsop N., Bruce T., Kortenhaus A., Schüttrumpt H., Van der Meer, J. (2007) - *EurOtop Wave Overtopping of Sea Defences and Related Strutctures: Assessment Manual*, ISBN 978-3-8042-1064-6, 193 pp.

[6] Noordegraaf, I. (2020) - *Economic valuation of increased beach width at Praia da Vagueira (central Portugal)*, Master's Thesis, University of Wageningen, Netherlands, 80 pp.

[7] Bricio L., Negro V., Diez J.J. (2008) - *Geometric detached breakwater indicators on the Spanish Northeast Coastline*, Journal of Coastal research, 24(5), pp.1289-1303.

[8] Oliveira F., Sancho F., Neves M., Pinheiro L., Fortes C., Teixeira S., Reis T., Coelho C., Pombo R. (2020) - *Estudo de caracterização e viabilidade de um quebramar destacado multifuncional em frente à praia da Vagueira. (T1) Estudos em modelo matemático: Alternativas de quebra-mar destacado para proteção contra galgamentos e erosão costeira. Relatório 8*. LNEC - Proc. 0604/121/21221. Relatório conjunto 231/2020 DHA/NEC, 154 pp.

[9] Coelho C. (2005) - *Riscos de exposição de frentes urbanas para diferentes intervenções de defesa costeira*, PhD Thesis, University of Aveiro, 405 pp.

[10] Lima M., Coelho C. (2017) - *LTC shoreline evolution model: assumptions, evolution, validation and application*. J. Integr. Coast. Zone Manag. 17 (1), 5 - 17.