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Assessing Costs and Benefits of Coastal Structures to Mitigate Erosion

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Abstract: Future investments required for the construction and maintenance of coastal defence structures are expected to increase due to growing coastal erosion problems along social, environmental and economically valuable coastal areas. The high costs related with coastal erosion mitigation structures require improved knowledge on their performance, considering impacts, costs and benefits. The benefits of a coastal intervention scenario can be estimated through the evaluation of the territory maintained, gained, or lost, along the time. For this purpose, the shoreline evolution numerical model LTC (Long-Term Configuration) was considered and applied. Coastal intervention costs (construction and maintenance) are based on structures dimensions and required material. To define the structure geometry (cross-section and length) and, consequently, the structure volume (knowing local bathymetry and topography), the numerical pre-design tool XD-Coast (Xpress Design of COAstal Structures) was applied. To compare and assess the economic viability of different coastal intervention scenarios, a cost-benefit analysis was performed, considering the net present value (NPV) and the benefit-cost ratio (BCR) evaluation criteria. The developed work shows that the definition of coastal structures is complex, where the best physical solutions are sometimes related to very high costs and, on the other hand, best economic scenarios lead to high territory losses.

Keywords: coastal defence, numerical modelling, coastal structures impacts, land values, coastal management

1 Introduction

Coastal zones experience increased rates of erosion, mainly due to fluvial sediment supply reduction, as well as coastal areas degradation and transformation due to anthropogenic actions. Additionally, climate change effects also increase coastal erosion problems (Nicholls, 2002; EEA, 2006; Alves et al., 2009; Robinson, 2017). As a coastal erosion consequence, a growing trend of conflicts between shoreline evolution, land use and erosion mitigation measures is observed (Coelho et al., 2016). Despite coastal erosion impacts being confined to coastal areas, these areas host over 40% of the world population, as well as a wide variety of coastal ecosystems that provide various different services (Martínez et al., 2007; Roebeling et al., 2011). One approach to mitigate erosion problems is coastal protection, involving defence techniques to preserve vulnerable areas, such as population centres, economic activities and natural resources. These strategies to mitigate coastal erosion are mainly reactive and tend to not include local stakeholders in the decision-making process (O'Riordan et al., 2014). Although some erosion impacts can be mitigated through coastal protection works, such measures may represent negative second order impacts for coastal environments and social and economic life (EEA, 2013).

Over the last decades the focus of studies moved from physical effectiveness to a more comprehensive management of coastal zones, evaluating adaptation measures with economic tools such as cost-effectiveness, cost-benefit and efficiency analyses (Breil et al., 2007). According to Roebeling et al. (2018), cost-effectiveness studies provide insight in what adaptation measures achieve coastal protection objectives at least cost. Cost-benefit studies provide insight in what adaptation measures/strategies provide largest net benefits, assessing costs and benefits of engineering measures. In short, coastal zone managers should, amongst others, rely on cost-benefit analyses when defining protection, adaptation and/or retreat strategies (Nicholls and Tol, 2006).

Coastal protection works, like groins and longitudinal revetments, need to be thoroughly evaluated before the intervention, as they represent a particular interference with the coastal environment and, hence, lead to multiple, divergent and location-specific impacts, and imply large investment, as well as maintenance costs. Therefore, this work aims to present a methodology to analyse and discuss the most adequate coastal structures to mitigate coastal erosion in combination with socio-environmental-economic expertise, considering the costs and benefits related to each intervention, by applying a cost-benefit approach. The goal of the proposed methodology is to support decision-making for planning and coastal management with sustainable coastal interventions, by encompassing the assessment of the shoreline evolution impacts (with a shoreline evolution model, LTC, Coelho, 2005), and the design of coastal structures (applying a coastal structures design model, XD-Coast, Lima et al., 2013), allowing the final costs and benefits analysis. To show the relevance of the methodology, different interventions scenarios have been proposed to protect a hypothetical urban waterfront from a coastal erosion trend. The adopted scenarios encompass groins and longitudinal rubble mound revetments. Considering the previous, in the next section the costs and benefits coastal assessment method is described. Next, a description of the hypothetical case study is presented, including the reference scenario, and all the proposed intervention scenarios. Then, the results are shown and major conclusions are drawn.

2 Methodology

The proposed methodology encompass three stages (Fig. 1) to evaluate the physical and economic performance of groins and longitudinal rubble mound revetments: shoreline evolution projection in a medium-term horizon (by applying the LTC numerical model; Coelho, 2005), that leads to estimate the benefits of the intervention; pre-design of the coastal structure and its material volumes (with the support of XD-Coast model; Lima et al., 2013), that allows to estimate the construction and maintenance costs; and finally, taking into account the previous results, a cost-benefit assessment to each intervention scenario (based on Roebeling et al., 2011 methodology).

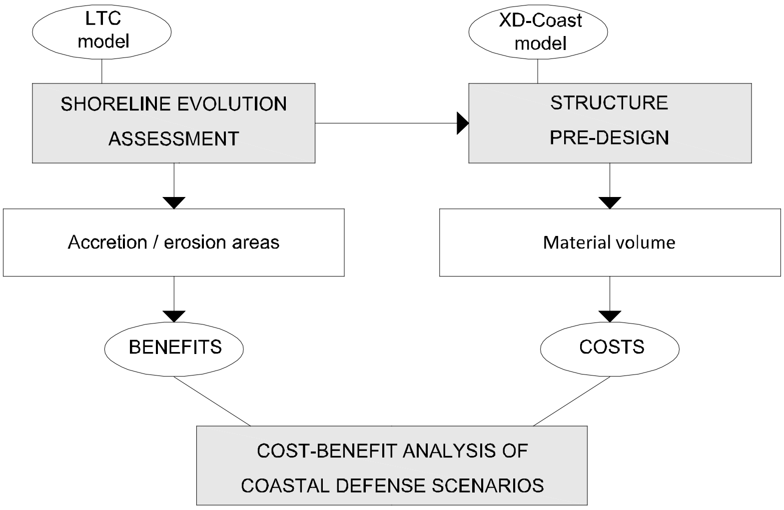


Fig. 1. Methodology to assess the physical and economic performance of different coastal interventions scenarios.

2.1 Shoreline Evolution Assessment

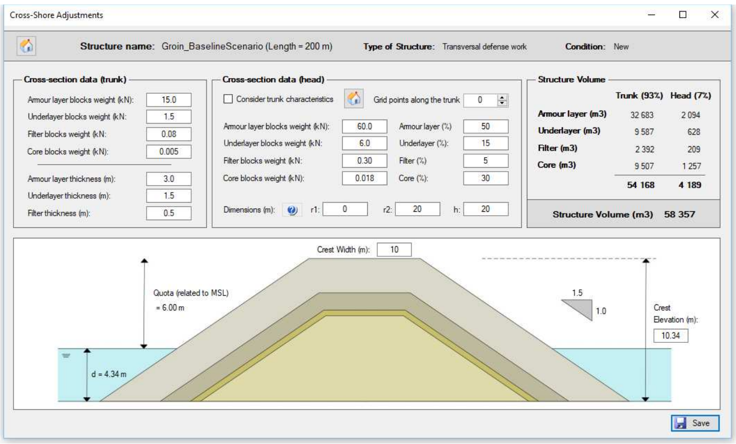
The one-line theory was introduced by Pelnard-Considère (1956) and its purpose is to describe long-term variations in shoreline position (Larson et al., 1987). The theoretical work of Pelnard-Considère is the basis for many numerical models that have been successfully applied to simulate shoreline response to wave and current actions. In this theory, the beach profile is assumed to maintain a constant shape, implying that all bottom contours are parallel. Consequently, under this assumption it is sufficient to consider the movement of one line in studying the shoreline change, and that line is conveniently taken to be the shoreline (Larson et al., 1987). One-line models are formulated based on the conservation equation of sediments in a control volume or shoreline stretch and on an alongshore sand transport equation (Rosati et al., 2002).

The numerical model to simulate shoreline evolution (LTC – Long-Term Configuration) was developed to support coastal zone planning and management in relation to erosion problems (Coelho, 2005; Coelho et. al, 2007). LTC combines a simple classical one-line model with a rule-based model for erosion/accretion volumes distribution along the beach profile. This model was designed for sandy beaches, where the main cause of shoreline evolution is the alongshore sediment transport gradients, dependent on the wave climate, water levels, sediment sources' and sinks, sediment characteristics and boundary conditions. The model inputs are the wave's climate and water level and the bathymetry and topography of the landward adjacent zones which is changed during calculation (Silva et al., 2007).

The sediment transport volumes are estimated by formulae that consider the angle of the shoreline to oncoming breaking waves, the breaking wave height, the beach slope and the sediment grain size. Using three-dimensional topographic data that is continuously updated during simulation, the model assumes that each wave acts during a certain period of time Δt (computational time step) and is able to distribute erosion or accretion resulting from longshore transport along the active cross-shore profile. The 3D topo-bathymetric model is continuously updated during simulation, allowing distributing erosion or accretion sediment volumes between each computational time step. The wave transformation by refraction, diffraction and shoaling is modelled in a simplified manner (Coelho et al., 2007), always taking into consideration the updated bathymetric data of each time step. According to Coelho (2005), the refraction effects in LTC are estimated through Snell's law, while the shoaling effect is calculated assuming that Airy's linear theory of sinewaves is valid. The diffraction effects are only calculated for beach extensions located downdrift the groins, considering a simplified method, based on Sorensen et al. (2003). The shoreline evolution numerical model LTC was considered to estimate the benefits of a coastal intervention scenario through the evaluation of the territory maintained, gained, or lost, along the time. In the cost-benefit assessment, a land use value is assigned to every year area gained, maintained or lost along the shoreline evolution simulation time horizon.

2.2 *Structures Pre-Design*

Coastal intervention costs estimate (construction and maintenance) is based on structures dimensions and required material. Thus, it is necessary to define the type of blocks and geometry of the structure (cross-section and length) and, consequently, the structure volume (knowing local wave climate and bathymetry and topography from the shoreline evolution assessment). The numerical pre-design tool XD-Coast was applied (Lima, 2018). XD-Coast software (Xpress Design of COAstal Structures) was developed in Microsoft Visual C# language, allowing the calculation of armour layer blocks unit weight, considering different formulations and types of structures. Furthermore, the main characteristics of the cross-section are also defined, in function of the armour layer blocks unit weight (Lima et al., 2013). Thus, the XD-Coast is divided into two main parts: estimative of the armour layer blocks unit weight; and cross-shore geometric characteristics definition (Fig. 2).



Structure name: Groin_BaselineScenario (Length = 200 m)
Type of Structure: Transversal defense work
Condition: New

Cross-section data (trunk)
Armour layer blocks weight (kN): 15.0
Underlayer blocks weight (kN: 1.5
Filter blocks weight (kN: 0.08
Core blocks weight (kN): 0.005
Armour layer thickness (m): 3.0
Underlayer thickness (m): 1.5
Filter thickness (m): 0.5

Cross-section data (head)
☐ Consider trunk characteristics
Grid points along the trunk 0
Armour layer blocks weight (kN): 60.0
Underlayer blocks weight (kN: 6.0
Filter blocks weight (kN: 0.30
Core blocks weight (kN): 0.018
Armour layer (%): 50
Underlayer (%): 15
Filter (%) 5
Core (%): 30
Dimensions (m): r1: 0 r2: 20 h: 20

Structure Volume

	Trunk (93%)	Head (7%)
Armour layer (m3)	32 683	2 094
Underlayer (m3)	9 587	628
Filter (m3)	2 392	209
Core (m3)	9 507	1 257
	54 168	**4 189**

Structure Volume (m3) 58 357

Crest Width (m): 10
Quota (related to MSL) = 6.00 m
d = 4.34 m
Crest Elevation (m): 10.34

Fig. 2. Design of the groin cross-section with XD-Coast.

In the first part, the user chooses the type of structure and the formulation required to calculate the block weight of its resistant layer. Afterward, in the second part, depending on the first part results, a schematization of the cross-section can be obtained (Lima, 2018). The software allows to consider three different formulations for calculations related to non-overtopped structures: Hudson (1974), van der Meer (1988a) for rocks and van der Meer (1988b) and De Jong (1996) for tetrapod. For low-crested and submerged structures, the model has one formulation available: van der Meer (1991) for rocks. The coastal structures are exposed to several energetic loads, as waves, currents and tides, but the software only considers the load represented by the wave height. Once the cross-section is defined, knowing the bathymetry and topography at the structures location, the total dimension and the volume of each structure layer and type of material is calculated. In the cost-benefit module, monetary values are assigned to the materials volumes and structures maintenance requirements (Lima, 2018).

2.3 *Cost-Benefit Analysis*

To compare and assess the economic viability of different coastal intervention scenarios, a cost-benefit analysis is performed (following Roebeling et al., 2011), considering the net present value (NPV) and the benefit-cost ratio (BCR) evaluation criteria (Zerbe and Dively, 1994). Costs and benefits are compared to the no intervention scenario, where costs (C_t) are defined as the additional initial investment and recurrent maintenance costs (in €/year) and benefits (B_t) are defined as territory maintained, gained or lost, due to the intervention (in €/year). Initial investment and recurrent maintenance costs are based on XD-Coast structures design, and erosion/accretion areas are based on LTC shoreline evolution results.

The NPV evaluation criterion is given by the sum of discounted benefits minus the sum of discounted costs that occur in each period t, over the lifetime of the project T (Zerbe and Dively, 1994), and is given by:

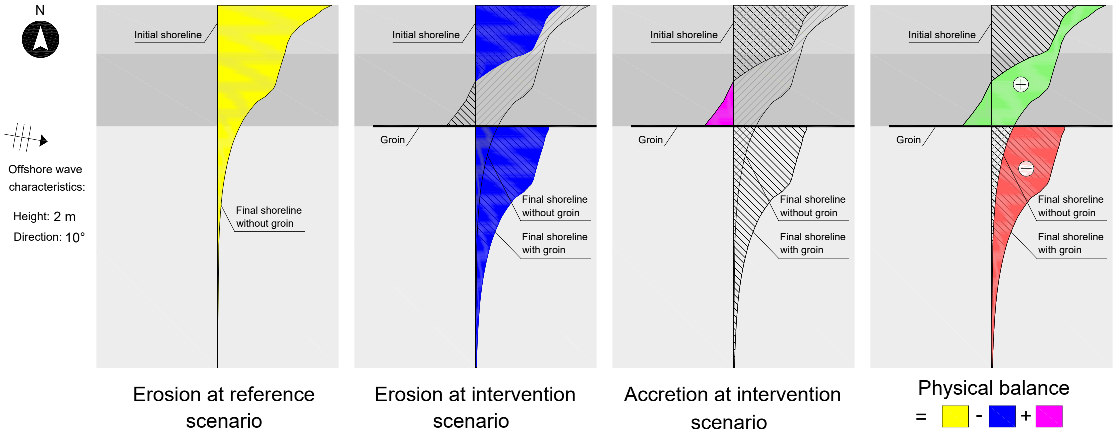
$$\mathrm{NPV} = \sum_{t=0}^{T} \frac{B_t}{(1+r)^t} - \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} \tag{1}$$

Where is the time discount rate. The investment is considered economically viable when the NPV > 0, i.e. when the present value benefits (first term on right-hand side of Equation 1) exceed the present value costs (second term on right-hand side). The BCR evaluation criterion is given by the sum of discounted benefits relative to the sum of discounted costs that occur in each period t, over the lifetime of the project T (Zerbe and Dively, 1994), and is given by:

$$\mathrm{BCR} = \sum_{t=0}^{T} \frac{B_t}{(1+r)^t} \Bigg/ \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} \tag{2}$$

The investment is considered economically viable when the BCR > 1, *i.e.* when the present value benefits (numerator on right-hand side of Equation 2) exceed the present value costs (denominator on right-hand side). Note that the BCR = 1 when the NPV = 0.

The benefits (positive if the territory is maintained or gained, and negative if the territory is lost) are obtained taking into account the land value (considering all the environmental, social and cultural aspects in the adopted value). Costanza *et al.* (1997) present provided services of different ecosystems that can work as preliminary reference for land use values. Maintained, gained or lost territory along time results of comparing the shoreline evolution of two different scenarios: the intervention scenario and the reference scenario. In Fig. 3, the methodology for benefits calculation considered in this work is schematized. The positive benefits (green hatch) encompass the accretion area due to the coastal intervention (a groin, in the presented example) and the area not eroded due to the groin presence. The negative benefits correspond to the increased erosion in the coastal intervention scenario that would not occur in the reference scenario (red hatch).



Erosion at reference scenario

Erosion at intervention scenario

Accretion at intervention scenario

Physical balance = 🟨 - 🟦 + 🟪

Fig. 3. Scheme representing the shoreline physical balance adopted to define the intervention benefits.

Considering Fig. 3, the physical impact is understood as the difference between the erosion areas of the reference scenario and the intervention scenario, added to the accretion area of the intervention scenario, at the time instant under analysis. The economic performance of each coastal intervention scenario is evaluated by the net present value (NPV), the ratio between benefits and costs (BCR) and the break-even point, which represents the instant, during the simulation period, when the total benefits equal the total costs of the intervention (BCR = 1 and NPV = 0).

3 The case study

The reference scenario adopted in this study represents the natural shoreline evolution, without coastal interventions. To allow the comparison between the different scenarios, a baseline scenario for groins and longitudinal rubble mound revetments were also defined. Starting from each baseline scenario, some intervention characteristics were changed and 17 other scenarios were defined and analysed (10 scenarios with groins, 4 scenarios with longitudinal revetments and 3 combining both structures).

3.1 Reference Scenario

The reference scenario is a hypothetical scenario with a regular topo-bathymetry represented by a regular square grid (20 m spaced), with 401 x 501 points (respectively, in the cross-shore and longshore directions), which results in a spatial domain area of 8 000 x 10 000 m^2. The bathymetry was generated according to the Dean profile (Dean, 1991), considering the parameter A and m, respectively 0.127 and 2/3. For the topography (above reference water level, 0.0 m) a constant slope of 2% was considered. The wave climate was considered constant in all the simulations, with offshore wave height (H_0) of 2 m, wave period of 9.34 seconds (T) and 10 degrees wave direction with West, clockwise (α_0). The active cross-shore profile was limited by the depth of closure (DoC = 8 m) and by the wave run-up (R_u = 2 m), which result in a total active profile height of 10 m (considered constant along the time horizon of the simulations). At the northern boundary of the domain, a null input of sediments was considered and in the southern boundary, an extrapolation of the longshore sediment transport nearby conditions was adopted. A time-step of one hour and a time horizon of 20 years were admitted in all the scenarios. Annual shoreline position outputs were recorded allowing the evaluation of every year eroded and accreted areas. Different time horizons could be considered. In extended time horizons, the shoreline would tend to an equilibrium position and results would depend on the maintenance costs of the structures and the land use values evolution. However, long periods of analysis have higher uncertainties, as other factors may present relevant changes (prices evolution, unexpected interventions, changing policies, etc.).

To estimate territory value, the land use provided services were considered by defining three different zones along the coast, with landward constant value (Tab. 1). From North to South, beaches, an urban area and forests were considered, where the highest value was attributed to the urban area, in a longshore extension of 1.5 km. The beach allows coastal protection and recreational uses, the urban area may support several different activities and uses (restaurants, hotels, economic services, etc.) and finally, the forest provide climate regulation, timber, habitat for biodiversity, erosion control and many others (Costanza et al., 1997; 2014; Roebeling et al., 2018). The time discount rate (r) was considered 3% (based on Roebeling et al., 2018).

Tab. 1. Economic land value defined in the case study (based on Roebeling et al., 2018).

	Description (km)	Location	Extension (km)	Value (€/m^2/year)
Zone 3	Beaches	North limit	1.0	2.00
Zone 2	Urban area	Intermediate	1.5	10.00
Zone 1	Forests	South limit	7.5	0.20

Fig. 4 shows that the shoreline evolution represents important erosion problems along time (5, 10 and 20 years) and all the urban waterfront extension is affected by erosion.

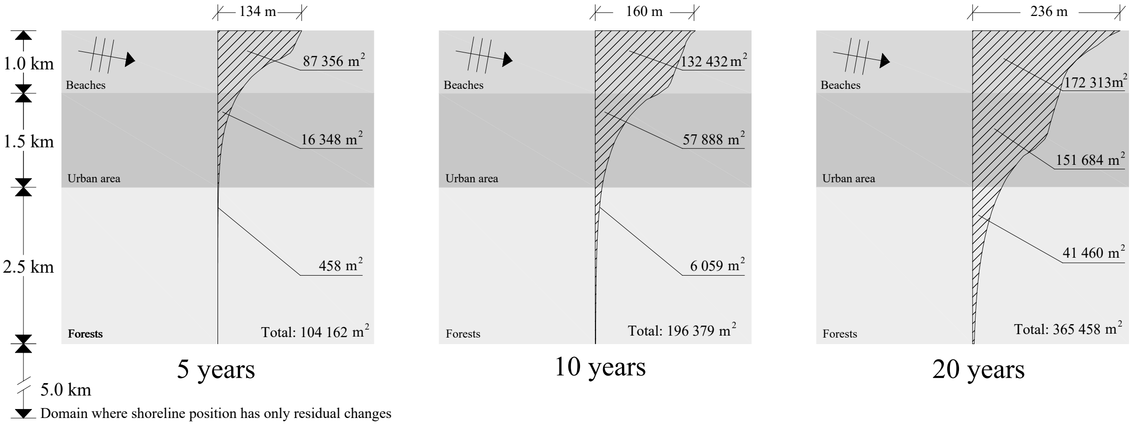


Fig. 4. Shoreline position in the reference scenario, along the time (horizontal scale 10 times the vertical scale).

The economic performance is based on the unit values considered for each coastal zone (€/m^2/year). The NPV was estimated at the end of each year of simulation: after 5 years of simulation, erosion and land losses represent about 0.8 million euros; after ten years, the costs exceed 3 million euros (values updated to year 0); at the end of the simulation, the land losses represent about 12 million euros. Although hypothetical, the reference scenario shows that important economic losses will occur if no interventions are performed. Thus, different intervention scenarios are proposed to mitigate the erosion problems presented in the reference scenario.

3.2 Baseline Scenarios

The groin baseline scenario was characterized by a 200 m groin length, located 2.5 km far from the northern border of the modelled domain (at the southern limit of the urbanized and most valuable area of the territory). The rubble mound baseline scenario encompasses a 1500 m length structure, with a crest elevation of 6 m, over the entire urbanized zone (Fig. 5). LTC was applied to both baseline scenario to predict the shoreline evolution along the 20 years' time horizon.

Smaller shoreline retreat rates near the northern border and deposition near the urban zone, updrift of the groin, are obtained in the groin scenario. However, the erosion trends and shoreline retreat rates are higher at downdrift. Thus, in order to evaluate the scenario effectiveness, the costs involved in the structure construction and maintenance were evaluated, by defining the groin characteristics (through XD-Coast model). Based on a 2 m wave height action, the cross-section characteristics (resistant layer and filters, crest width and elevation, and slope) were designed. A crest width of 10 m and a crest elevation of 6 m above the water surface reference level were considered. The groin head is located at about 4.5 m depth, and groin total volume is around 58 000 m^3. Considering the groin's dimension, its direct and indirect construction costs were calculated, representing a total first investment costs of about € 1 462 200. Different maintenance costs were adopted for each part of the structure (head and trunk), considering maintenance works every five years for the trunk and every 2 years for the head. Benefits were defined based on shoreline evolution, taking into account the every year accretion and erosion areas and the unitary land values defined in the reference scenario (Fig. 4 e Tab. 1).

The longitudinal rubble mound revetment scenario ensures the total protection of the urbanized zone and presents smaller shoreline retreat rates near the northern border, when compared with the reference scenario, but similar to the ones obtained in the groin baseline scenario. The rubble mound cross-section presents constant characteristics (resistant layer and filters, crest width and elevation, and slope) along the coastline, similar to the ones adopted to the groin cross-section. The total volume of the structure is around 132 000 m^3, which represents a construction total first investment costs of about 2 million euros. Maintenance costs were based on a percentage of the initial investment (30%, which corresponds approximately to 600 thousand euros), every 5 years. Overtopping and flooding events were not considered during the simulation period.

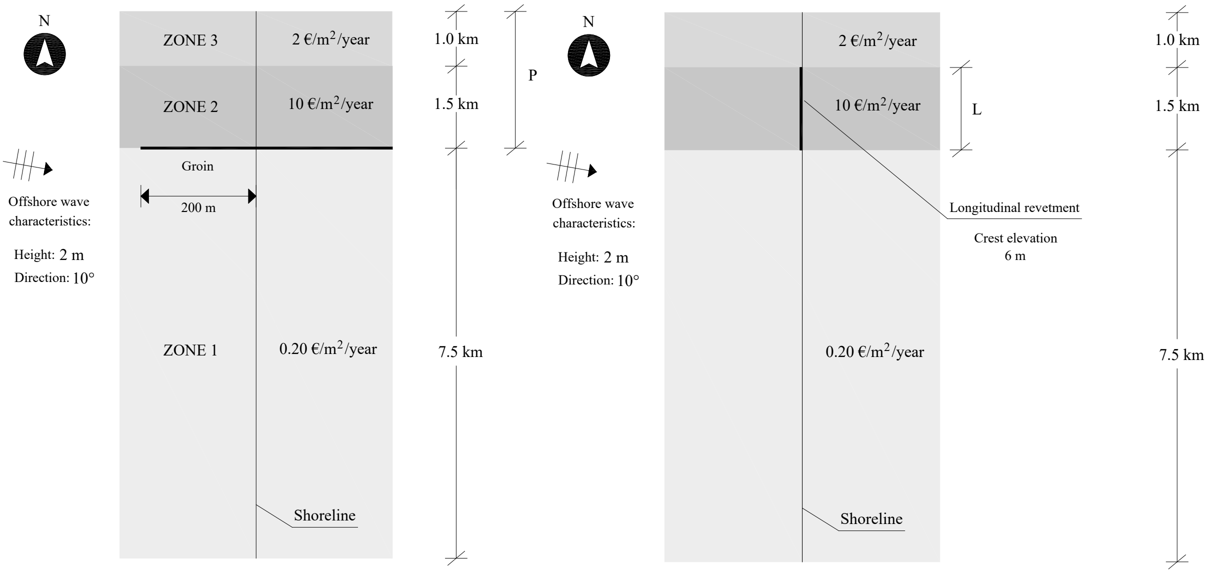


Fig. 5. Study area schematization: left - groin baseline scenario; right - longitudinal rocky revetment baseline scenario.

3.3 Alternative Scenarios

Two different baseline scenarios were presented. However, different coastal structures characteristics may lead to different simulation results and thus, different hypothetical scenarios were additionally proposed to discuss intervention characteristics influence on each type of baseline scenario (Tab. 2).

Three aspects were considered to test the groin scenarios: length, location and number of groins. Longer structures promote a bigger barrier to the littoral drift and provide more effective protection to the updrift areas, but increase the intervention costs and the shoreline evolution negative impacts at downdrift. The best groin location should correspond to the downdrift limit of the area to protect, but it is important to understand the groin location influence in the physical and economic results over time. Groins fields consider the conjugation of different number of groins and there location. The longitudinal revetment length must be in accordance with the coastline extension to be protected. To avoid overtopping events (which can trigger the toe scour and, consequently, the rubble mound collapse), the structure height should be as large as possible. However, the high costs and/or the aesthetic constraints prevent the choice of long and high structures, making urban fronts more susceptible to erosion, overtopping and flooding events. Another important aspect are the scenarios that combine longitudinal revetment and groin, mitigating downdrift groin erosion.

Tab. 2. Coastal erosion mitigation scenarios characteristics.

			1	2	3	4
Groin	Length	*i*	L = 100 m	L = 300 m	L = 400 m	-
	Location	*ii*	P = 1.5 km	P = 2.0 km	P = 3.0 km	P = 3.5 km
	Number of groins	*iii*	2 groins spaced by 500 m	2 groins spaced by 1000 m	3 groins spaced by 500 m	-
Longitudinal revetment	Length	*iv*	L = 500 m	L = 1 000 m	-	
	Crest elevation	*v*	C = 5 m	C = 4 m	-	
	Combination with baseline groin	*vi*	Groin and L = 500 m	Groin and L = 1 000 m	Groin and L = 1 500 m	-

4 Results

The main results of all the analysed scenarios are presented and discussed here, including each baseline scenario and the other 17 alternatives.

For the groin baseline scenario, the groin impact on the shoreline evolution is positive at updrift, resulting in 2.4 ha accretion area (which protects partially the urbanized and most valuable zone). The baseline scenario (BS) presents a higher total erosion area than the reference scenario, representing losses of around 4 ha, and a general negative physical impact. However, this scenario is economically positive, and after seven years, the break-even point is reached. In spite of the groin costs, the benefits resulting from the intervention represent economic gains of about 12 million euros at the end of the 20 years (resulting from the areas gained updrift the groin, where the land value is higher). Thus, the groin baseline scenario net present value (NPV) after the 20 years' was about 8 million euros. Tab. 3 shows the total accreted and eroded areas after 20 years (and the respective physical impact) and presents the economic results (BCR and NPV values after 20 years, initial and total costs and break-even point) corresponding to all the groin scenarios, allowing a quantitative comparison between them.

Tab. 3. Summary of the physical and economic results of the groin scenarios.

Scenario		**Territory area (ha)**			**BCR$_{20\,yr}$ (-)**	**NPV$_{20\,yr}$ (€)**	**Costs**		**Break-even (years)**
		Accretion	**Erosion**	**Impact**			**Initial (€)**	**Total* (€)**	
RS	Fig. 4	0	36.5	-36.5	-	-12 000 000	-	-	-
BS	Fig. 5	2	43.2	-4.2	**3.31**	8 316 103	1 462 293	3 602 359	**7**
i.1	L = 100 m	0.09	38.05	-1.42	1.48	1 263 061	**975 627**	**2 615 491**	15
i.2	L = 300 m	7.50	47.44	-3.39	2.96	**11 612 679**	2 291 617	5 925 785	9
i.3	L = 400 m	8.27	47.90	-3.08	2.06	9 150 555	3 263 128	8 670 313	11
ii.1	P = 1.5 km	1.81	40.82	-2.46	-0.82	-6 556 228	1 462 293	3 602 359	-
ii.2	P = 2.0 km	2.03	42.09	-3.52	1.20	714 226			19
ii.3	P = 3.0 km	3.04	44.24	-4.66	2.18	4 259 681			11
ii.4	P = 3.5 km	3.78	45.41	-5.09	1.45	1 624 686			16
iii.1	2 groins spaced by 500 m	3.81	44.68	-4.33	2.01	7 291 156	2 924 586	7 204 718	11
iii.2	2 groins spaced by 1000 m	3.61	43.55	-3.39	1.79	5 678 216			13
iii.3	3 groins spaced by 500 m	3.45	43.29	-3.30	1.24	2 560 639	4 386 879	10 807 077	17

*Values updated for initial simulation instant, according to the discount rate (r).

An overall analysis of the longitudinal revetment baseline scenario shows that this coastal intervention presents both physical and economic positive impacts. In addition, this scenario guarantees the total protection of the urbanized zone during all the analysed period and, comparing with the reference scenario, territory losses of about 20 ha are avoided. From the economic point of view, the longitudinal revetment baseline scenario break-even is obtained after 13 years, with an updated total investment of approximately 4 million euros. The physical and economic indexes resulting from the longitudinal revetment baseline scenario are shown in Tab.4, which also summarizes the results obtained for the remaining 7 longitudinal revetment scenarios.

Tab. 4. Summary of the physical and economic results of the longitudinal revetment scenarios.

Scenario		Territory area (ha)			BCR$_{20\ yr}$ (-)	NPV$_{20\ yr}$ (€)	Costs		Break-even (years)
		Accretion	Erosion	Impact			Initial (€)	Total* (€)	
RS	Fig. 4	0	36.5	-36.5	-	-12 000 000	-	-	-
BS	Fig. 5	0	16.6	**20.0**	2.34	5 078 161	2 052 484	3 777 949	13
iv.1	*L* = 500 m	0	32.7	3.8	1.15	188 168	**684 161**	**1 259 317**	19
iv.2	*L* = 1 000 m	0	25.4	11.0	1.77	1 950 645	1 368 322	2 518 633	16
v.1	*C* = 5 m	0	16.6	**20.0**	1.76	3 828 289	1 761 598	5 027 822	14
v.2	*C* = 4 m				1.41	2 557 708	1 481 963	6 298 402	16
vi.1	Groin and *L* = 500 m	2.4	24.6	14.3	2.51	7 336 235	2 146 454	4 861 675	**9**
vi.2	Groin and *L* = 1 000 m		22.4	16.5	2.00	6 123 709	2 830 615	6 120 992	11
vi.3	Groin and *L* = 1 500 m		20.9	18.1	1.66	4 893 780	3 514 777	7 380 308	13

*Values updated for initial simulation instant, according to the discount rate (r).

5 Conclusions

To understand the benefits of coastal intervention scenarios, long-term shoreline evolution estimates are required. In spite of their simplified assumptions, one-line models allow exploring how the patterns and rates of shoreline erosion and accretion are affected by shifts in wave climate and alongshore sediment transport characteristics. Pre-design of coastal structures may follow several different formulations, mainly based on the incident wave heights to define the adequate block for the armour layer. Moderate shifts on the modelling parameters can alter the patterns of shoreline erosion and accretion or the design of the coastal structure, with consequent impact on the developed analysis.

The considered case study intended to highlight the interest in evaluating costs and benefits of different coastal interventions. 19 coastal intervention scenarios were evaluated (2 baseline scenarios and 17 scenarios discussing different intervention characteristics) to mitigate persistent coastal erosion problems identified in a reference scenario. All of the presented groin scenarios result in a negative physical impact, being the 100 m groin scenario the one with lower erosion areas and at the same time, presenting the lower initial and total investment costs. The groin scenario presenting the earlier break-even is the baseline scenario (groin with 200 m, located at the south border of the urbanized zone). The highest net present value after 20 years was obtained to the 300 m groin scenario and the scenario corresponding to the longer groin is the most effective in protecting the urbanized zone. In the longitudinal revetment scenarios it was verified that: smaller extension than the one adopted in the baseline scenario (1500 m long, in front of whole the urbanized zone) results in less attractive physical and economic indexes; lower crest elevation lead to an increased number of overtopping events and increases the required structure maintenance costs (this was the worst economic scenario); and a groin combined with a longitudinal revetment scenario was not economically attractive.

The obtained results show that it is difficult to combine, in the same intervention scenario, the best option taking into account both physical and economic factors. Thus, when defining and designing the intervention it is fundamental to make clear all the objectives of the intervention, considering the extension of the urban zone to protect, the initial investment, the generalized erosion, the time needed to recover the investment made, the general physical impacts, etc. The hypothetical study case results application to real world situations is limited by the specific conditions of each situation (land use values, but also wave climate conditions, coastal intervention characteristics and scenarios, etc.). However, the proposed approach allows a quick sensitivity analysis to those conditions, permitting its general worldwide application. It is considered that the proposed study represents one-step toward a well-supported decision-making process, helping on coastal management and planning.

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