COAST4US: APPLICATION OF THE COAST TOOL TO THE PORTUGUESE WEST COASTLINE

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Over the years, people have been settling in coastal areas, as they provide opportunities, both economically and in terms of well-being and leisure. However, the coastline is also exposed to serious problems of coastal erosion, particularly on urban fronts, increasing the consequences derived from adjacent phenomena such as overtopping and flooding. It is therefore essential to deepen the study of strategies for the prediction, prevention and mitigation of this phenomenon. In this sense, COAST (Coast Optimization Assessment Tool), a tool for integrated cost-benefit analysis of coastal interventions to mitigate erosion problems, was developed. The COAST4US project - Application of the COAST tool to the Portuguese coast - aims to contribute to the feasibility of applying this tool in real situations, contributing to an efficient mitigation of coastal erosion, and providing decision makers with more and better information. The project proposes to apply COAST to three stretches of coastline at high risk of coastal erosion on the Portuguese west coast: Aveiro, Figueira da Foz, and Costa de Caparica. The project is divided in several tasks, including scenario modeling, cost prediction and benefit assessment, being this work focused on benefit assessment by estimating the value of each beach, and analyzing the effectiveness of three nourishment scenarios.

Keywords: COAST software; coastal erosion; artificial nourishment

INTRODUCTION

Coastal areas are characterized by their economic and environmental wealth, providing access to several unique services. The settlement of the population in these areas combined with coastal erosion and climate change effects makes it essential to develop strategies to predict, prevent or mitigate shoreline retreat. The west littoral of Portugal is one of these cases where coastal erosion is present over the years (Santos *et al*., 2017). This is mainly due to the energetic North Atlantic wave climate, combined with the construction of hydroelectric dams, affecting the supply of sediments that fed coastal areas (Syvitski *et al*., 2009). The estimated retention is more than 80% of the volumes of sand that were transported by rivers, in natural conditions (Valle, 2014). All of these processes combined increased coastal erosion problems, making 14% of the Portuguese coastline defended by artificial structures, including groins, breakwaters, and longitudinal revetments, which totalize about 140 km of the Portuguese coastline (Santos & Miranda, 2006).

The protection of coastal areas is crucial to stakeholders and government entities. However, with finite resources available, the capacity to prioritize which areas to protect and assess the most cost-effective measures is essential in coastal management. Thus, thoughtful analysis of alternatives in planning and design phase of a coastal defense intervention is extremely important. As an aggravating factor, it appears that the strategies to mitigate coastal erosion problems are often essentially reactive, not considering the optimization of the solutions to be implemented and the analysis between the costs and benefits of each scenario of intervention (O'Riordan *et al*., 2014).

In this sense, the COAST4US project (Narra *et al*., 2021; Mendiguren *et al*., 2022) emerged, aiming to fill this gap, and evaluate mitigation measures, by applying the COAST (Coastal Optimization Assessment Tool – Lima, 2018) to three coastal stretches with severe erosion on the Portuguese coast: Aveiro, Figueira da Foz and Costa de Caparica (Figure 1).

This work aimed to present the methodology of the definition of benefits and some preliminary results of the erosional mitigation scenarios of the coastal stretch between Barra and Areão, located in the Aveiro region, covering a coastline length of approximately 14km (Figure 2a).

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Figure 1. Case studies of COAST4US project (black squares) at west coast of Portugal (google earth).

METHODOLOGY

The Coastal Optimization ASsessment Tool (COAST) combines three modules. The first one is a shoreline evolution model (LTC – Coelho, 2005), that enables the analysis of the impact of coastal interventions on shoreline evolution, allowing to calculate benefits (territory maintained, gained or lost). Secondly, a pre-design of coastal structures module (XD-COAST – Lima *et al*., 2013), allows to design coastal structures, to define the dimension and quantify the material volumes of the structure, in order to calculate the costs of their construction and maintenance. Finally, a cost-benefit module is considered, to make easier the assessment of costs and benefits.

This tool adds important value to global analysis of coastal interventions measures, based on their simultaneous physical and economic performance. Adding to this, the COAST allows an easy and quick comparison between different coastal intervention scenarios, assisting coastal management entities in evaluating coastal erosion mitigation measures. Finally, it allows a simple sensitivity study, where several variables associated with the interventions can be analyzed, such as physical (length, location, etc.) and/or economic variables (land value and material costs) (Lima, *et al*., 2020; Coelho *et al*., 2020; Coelho *et al*., 2022).

The COAST4US project uses this tool to study mitigation strategies. Several aspects were considered: (1) physical characterization of the study area; (2) socioeconomic characterization; (3) costs of coastal defenses; (4) definition of possible intervention scenarios; (5) modeling shoreline evolution for the intervention scenarios; (6) evaluate the economic viability of the interventions; and (7) propose management strategies for the west coast of Portugal.

The morphological impacts of the different intervention scenarios idealized for each stretch were simulated by applying the first module of COAST, the shoreline evolution model, LTC (Coelho, 2005; Lima and Coelho, 2017; Lima and Coelho, 2019). The model allowed to obtain erosion/accretion patterns in addition to the position of the coastline on a time scale of 20 years, considering climate change (RCP4.5 – IPCC) and mean sea level rise (0.0075 m/year - Antunes, 2019). Distinct typologies of scenarios were defined in partnership with the Portuguese Environmental Agency, consisting of one reference scenario (REF), assuming the maintenance of the existing structures (Figure 2) without any additional intervention, and several erosion mitigation scenarios based on fixed structures interventions and nature-based solutions: construction of groins, construction of sea-walls, extension of existing groins, execution of artificial nourishments and combinations of interventions.

This work focused on the methodology description of the definition of benefits and a study case of the benefit assessment related to artificial nourishment interventions.

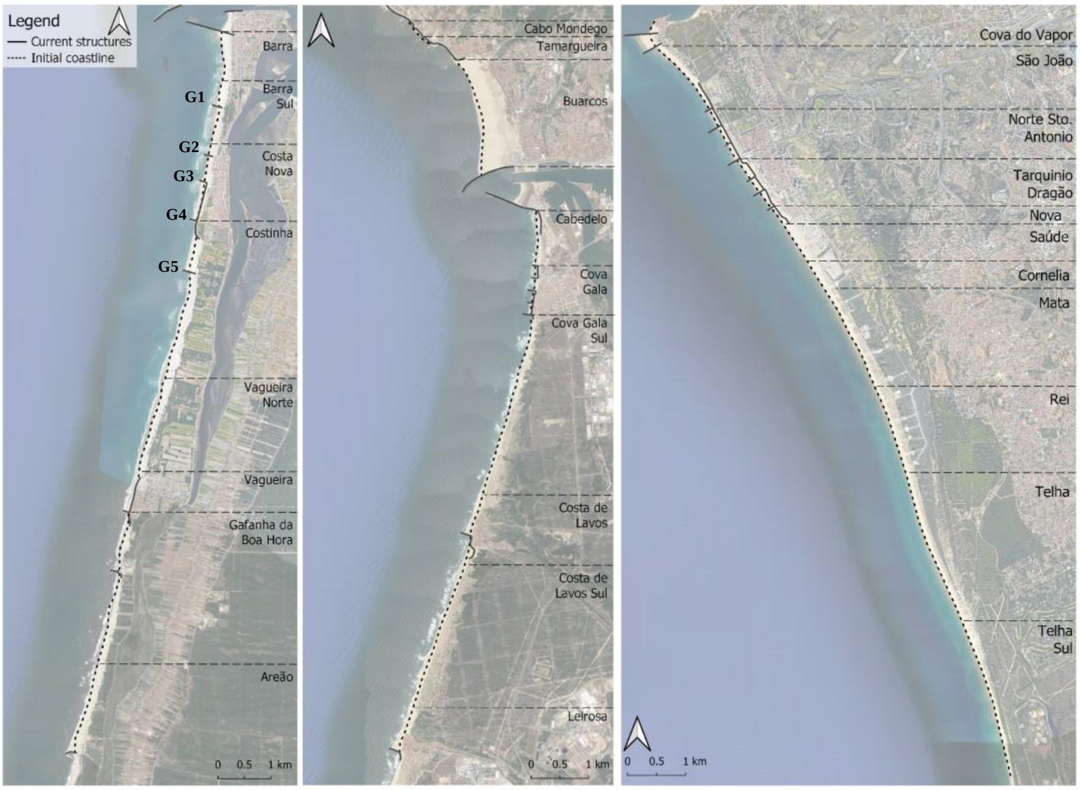

Figure 2 – Studied sector of Aveiro (a), Figueira da Foz (b) and Costa de Caparica (c). Initial coastline position, in dashed, and groins in gray (G).

Benefit

Given the expectation that most areas to be lost are sandy beaches, the task was focused on assessing the value of this type of ecosystem. In this way, it was decided to identify the uses that come from the beach existence, from which the following main categories were identified: (1) provides a space for recreational, leisure and cultural activities; (2) provides a natural defense against extreme events; (3) provides an environmentally relevant habitat; and (4) promotes the improvement of the local economy, as a consequence of the factors listed above.

Therefore, it was decided to section these four factors into independent ecosystem assessments. For each of these factors, monetary value-based ecosystem valuation approaches described in scientific papers were used: Travel Cost Method (Das, 2013; Zhang *et al*., 2015), Replacement Cost Method (King *et al*., 2018), Hedonic Pricing Method (Dahal *et al*., 2019; Fraser & Spencer, 1998) and Transfer Method (Constanza *et al*., 1997; Groot *et al*., 2012).

<u>Travel Cost Method</u>

For the evaluation of recreational activities, it was considered that the travel cost method (e.g., Das, 2013) would be the appropriate to estimate the economic value generated due to tourism and recreational activity. This method has been used in several cases of ecosystem valuation. The methodology assesses the *willingness-to-pay*, interpreting that the amounts spent to visit a given place represent the minimum value that a person values the environment and is willing to pay to access it. It is, a method based on market behavior. In other words, the amount an individual spends traveling to a place, and all the expenses associated with that visit, represent a minimum value that the individual values that place.

The most common way of executing this methodology would be to conduct questionnaires in a given location, asking where they came from and what additional costs they had in that location. Based on this information, a demand function is constructed, where the YY axis is the annual cost per person, and the XX axis is the cumulative number of total visits.

Replacement Cost Method

The assessment of the value of beach protection was considered using the replacement cost method. This approach does not provide restricted economic values that are based on the response of the population or their *willingness-to-pay* for a service. This method assumes that the costs of avoiding damage provide estimates of the value of these ecosystems. This is based on the assumption that if people pay to prevent damage caused by the loss of ecosystems, then those ecosystems must be worth at least the value of that structure. For this study the dimensioning of a breakwater was considered, and the construction cost of this will be the minimum value that the ecosystem will have. Thus, this method is applied in cases where damage is to be avoided.

Hedonic Pricing Method

The subjective nature of ecosystems makes them difficult to evaluate. The hedonic pricing method (e.g., Dahal *et al*., 2019) is used to estimate the influence that an ecosystem has on market prices. The basic idea is that a value of a given good can be divided by its characteristics, and the total price of that good reflects the sum of those characteristics (Penning-Rowsell, 1992). The housing market is often used in the hedonic pricing method, as it is straightforward to divide a house into a group of characteristics: being structural (i.e., number of bedrooms, bathrooms, stories, garage, etc.), from neighborhood (i.e., population density, median age, income, airport, hospital, railroad) or environmental (i.e., proximity to park, stream, river, beach). For example, a house value can be divided into the area it has, the commodities it provides, its location, and many other parameters. Thus, if a specific characteristic that translates to the ecosystem value is isolated, the value of that characteristic can be considered as the value of the ecosystem. This approach is a revealed willingness-to-pay method, since it is based on values paid by individuals to benefit from the ecosystem (Sander & Haight, 2012).

In order to apply the hedonic pricing method to the locations, data from the whole country of Portugal was collected, focusing mainly on traits given by location, namely: number of schools, number of beds for renting, number of companies, average wage and, distance to the coastline. Using an ordinary least square regression (OLS) function (Hutcheson, 1999), the housing price was correlated with the traits mentioned above, being possible to estimate the valorization of housing due to proximity of the coastline per square meter. This function was then applied in a geographic information system environment and used to estimate the value of each beach.

Transfer Method

The transfer method is a simple economic valuation tool that uses values estimated elsewhere and applies them to similar locations (Brouwer, 2000). Constanza *et al*. (1997) proposed global values for 16 ecosystem types, with the values proposed in 1997 being updated through the work of Constanza *et al*. (2014). Groot *et al*. (2012) suggested values for 10 ecosystem types. In these studies, the monetary values of ecosystems were obtained by compiling several existing studies on ecosystem value and applying benefit transfer approaches (Constanza *et al*., 2014).

In order to calculate the value associated with environmental potential, the study by Constanza *et al*. (2014) was considered. This assigned monetary values to the ecosystems of the coastal region by adjusting between the different ecosystems and the distinct land use types from the Land Use and Occupancy Cartography (COS, 2022). The values proposed by Constanza *et al*. (2014) were converted into 2022 Euros using the exchange rate indicated by the Bank of Portugal (Banco de Portugal, 2022) and updated using the update factor provided by the Statistics National Institute platform (SNI, 2022).

Territory Value

The goods and services offered by coastal ecosystems correspond to the benefits that people extract from these ecosystems. Thus, with the methods listed above, it was defined that their combination allows a complete evaluation of the coastal sector:

$$Territory\,Value = \frac{Hedonic+Travel}{2} + Replacement + Transfer \qquad (1)$$

The average territory value obtained by Hedonic and Travel is due to the fact that they are related. Hedonic considers the surrounding urbanization, Travel, its affluence. The greater the urbanization there is more people demand in this sector.

Benefit Analysis

The benefits over a given period required a financial updating of the values (Lima, 2018). Thus, all monetary values (V) must be converted into discounted values (VA) by applying an actualization or discount rate (r – 2% in this study), (Zerbe and Dively, 1994), considering a certain period, t (year under analysis):

$$VA_t = V_t/(1+r)^t \quad (2)$$

Mitigation measures for coastal erosion are related to the ability to slow down this trend and thus, reduce the loss of territory, this being the main benefit. In the COAST software, the benefits are determined according to the areas maintained or gained (positive benefits), or lost (negative benefits) over time under analysis and varied according to the value attributed to the territory (Lima, 2018).

Intervention Scenarios

In this work, three artificial nourishment scenarios were studied at Aveiro coastal stretch, in Costa Nova area, between groins 3 and 5 (G3 and G5, respectively, in Figure 2a), deposited at $0.01x10^6$ m^3/day rate, but with different proportions. Scenario A consists of a nourishment of $0.3x10^6$ m^3/year; scenario B consists of $0.6x10^6$ m^3/year; and scenario C of $0.9x10^6$ m^3/year, for a 20-year period. It was considered a unit value of 4€/m^3 for the costs of the artificial nourishment interventions (Almeida, 2011). The costs of these interventions range between 1.2 and 3.6M€/year.

Cost-benefit Analysis

The verification of the economic sustainability of each intervention is based on the accumulated net flows of benefits and costs. The NPV (Net Present Value) and the BCR (Benefit-Cost Ratio) are economic indicators that allow for comparing interventions considering the costs and benefits of the projects (Lima, 2018). The NPV represents the accumulated balance between current benefits and costs. If the value of this index is positive, it means that the intervention is economically viable. The BCR is the ratio between the sum of current values of benefits and the sum of current values of costs. An intervention is profitable if the BCR is greater than 1.

RESULTS

Benefits

Travel Cost Method

With the information acquired in the survey done in the summer of 2022, a demand function was built. Where the YY axis is the annual cost per person, and the XX axis is the accumulated number of total visits, obtaining the following function for the Aveiro sector: y=-260ln(x)+1788.70; R^2=0.89.

Considering the total number of questionnaires per sector and the total number of tourists, it was possible to extrapolate a new demand function based on the previous. Then, based on the area under the demand curve, it was possible to obtain the total estimate of economic benefits from the recreational uses of the site. Subsequently, based on the survey, it is possible to verify the percentage of affluence of each beach and, relating this with the total value of the territory, to obtain the absolute value of the land for each beach per year. Finally, this is divided by the beach area under study, and thus the annual value of each sector is obtained, which varies between 146.86 and 4.14€/m^2/year.

Replacement Cost Method

The projection of breakwaters for the distinct study areas was defined. For this, it was necessary to calculate the runup of each section. Initially, the wave height and period were calculated for a 100-year return period to consider this value in the runup calculation and thus design structures that protect the coastal zone from these extreme waves with the help of XD-COAST (second module of COAST). With the budget estimate of each breakwater for the different sectors under study is obtained the value of the territory of each zone being that for the Aveiro sector, values varying between 9.92 and 2.10€/m^2/year, were obtained.

Hedonic Pricing Method

In order to execute the ordinary least square regression function, a database with 571 entries was built. Each entry is related to a parish in Portugal and has the housing price per square meter, as well as the traits mentioned previously.

A regression considering all these characteristics was obtained with an r-square of 0.93 and p-values below 0.05 for all factors, showing validity and suitability. Therefore, according to the regression, the housing price per square meter devalues 58.93 €/m^2 per kilometer, with increasing distance to the coastline. Using Geographic Information Systems, the urban areas around the study sites were identified and attributed a valuation due to their proximity to the coastline. The preliminary results show a considerable influence of the proximity to the coastline in the house pricing, with around 36 million euros of valuation in Aveiro, with some sectors reaching values above 160€/m^2/year, while others only reach 2€/m^2/year.

Transfer Method

The monetary value assigned to the coastal ecosystem (beaches, dunes, and coastal sand), based in the study of Constanza *et al*. (2014) was 0.72€/m^2/year.

Territory Value

To obtain the monetary value of the different sectors, Eq. 1 was applied. Through the consideration of the different methods, there is a considerable variation of the territory value between different areas within the same sector, varying in the Aveiro sector between 168.99 to 6.3€/m^2/year.

Cost-benefit

These data are preliminary, and only the cost of artificial nourishments has been considered. The results for the studied scenarios are presented in Figure 3. It is observed an erosive trend, clearly greater than accretion (red and green, respectively), bigger in the reference scenario and that is decreased in the intervention scenarios. The dashed line corresponds to the initial coastline and the red line to the evolution in 20 years of simulation. It is also observed that the most affected sector is located at south of Costa Nova, allowing for a breach of the Atlantic Ocean with the Ria de Aveiro, if no action is taken.

In the REF scenario, where no intervention is carried out, there is a loss of more than 80ha and more than 150M€ in territory, at the end of the analyzed period. For scenarios A, B, and C, there areas not loss of 12, 16, and 24ha, respectively, compared to the REF scenario, after 20 years. By carrying out the nourishments, an estimate of benefits in 20 years of 24, 26, and 17M€ is obtained for scenarios A, B, and C, respectively, in relation to the REF scenario.

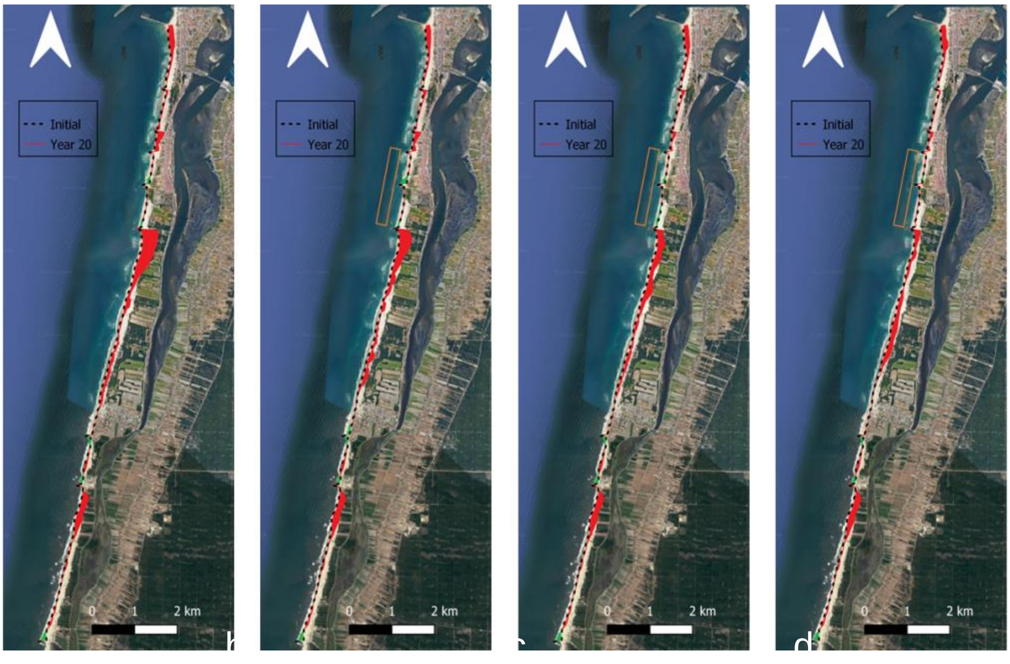

Figure 3 – Areas in erosion and accretion (red and green, respectively) in the 20-year projection. (a) REF scenario; (b) scenario A (nourishment of 0.3x10^6 m^3/year in orange); (c) scenario B (nourishment of 0.6x10^6 m^3/year in orange); (d) scenario C (nourishment of 0.9x10^6 m^3/year in orange).

In scenario C, the area not lost of the territory is higher than in scenario B, while the benefits generated are lower. That is due to the fact that in scenario C the areas not lost are located where the value of the territory is lower. As presented in Table 1, the NPV is negative for scenarios B and C, which means that these interventions at a timescale of 20 years are not economically viable. Furthermore, the BCR results are lower than 1. The results show that the interventions B and C are not cost-effective. On the other hand, scenario A presents a positive NPV, and a BCR greater than 1, showing viability of these intervention.

Comparing scenarios B and C, with different nourishment volumes, it was found that in 20 years the feeding of $0.6x10^6$ m^3/year (B) is more profitable than the one of $0.9x10^6$ m^3/year (C), with BCR of 0.67 and 0.29, respectively.

Table 1. Summary of economic results of the artificial nourishments scenarios.

Scenario	NPV (M€)			BCR (-)		
	5 yr	10 yr	20 yr	5 yr	10 yr	20 yr
A	-1.87	-0.60	5.16	0.67	0.94	1.26
B	-7.29	-12.99	-12.92	0.36	0.40	0.67
C	-14.94	-27.90	-41.66	0.12	0.14	0.29

CONSLUSIONS

This work aimed to present preliminary results of the cost-benefit analysis for the Aveiro stretch and a broad and complete methodology for acquiring the benefits to be applied in the COAST4US project.

The work showed the importance of carrying out cost-benefit studies, since it can support decision-making by estimating the physical, but also the economic impacts of different intervention scenarios. Overall, the findings show that in coastal areas susceptible to erosion, important economic losses will occur if no decisions are adopted. The study of three nourishment scenarios, with distinct applied volumes, was defined to discuss the cost and benefits of the interventions. The bigger the amount of nourished sediments, the better physical performance, avoiding losses of territory. However, as the areas maintained or not lost are located in not so valuable territory, the cost of bigger interventions do not represent an economic attractive solution. Thus, COAST can assist on defining the annual nourishment volumes that represent a higher economic return in these twenty years analyze. It is highly important to define the main goal of the intervention, as the lower losses of territory are related to the bigger volumes, but lower BCR and NPV.

The COAST4US project aims to support action plans for long-term coastal adaption for Portuguese coastal management, as well as to validate and establish COAST as a reference tool at the national and international level, in terms of feasibility and cost-benefit analysis of coastal interventions.

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