

COST-BENEFIT MEETS COASTAL MANAGEMENT: THE PORTUGUESE PARADIGM SHIFT

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Cost-benefit analysis emerges as an indispensable component for coastal management by governing state agencies, for defining intervention priorities along the coastline, enabling greater technical and economic sustainability in decision-making. The paradigm shift towards proactive coastal zone planning is imperative and leads to increasingly effective management of worldwide coastlines. The COAST4US project was founded on this purpose, presenting a management strategy for the Portuguese west coast based on the results of applying the COAST (Coastal Optimization Assessment Tool). The COAST4US project was initiated with the objective of defining coastal erosion mitigation scenarios and assess their cost-benefit, applying COAST across three severely eroded coastal stretches along the Portuguese coast: Aveiro, Figueira da Foz, and Costa de Caparica. Therefore, the primary aim of this work is to present the principal findings, conclusions, and insights for the future, not only regarding the northwest Portuguese coast, but also its potential of applicability to other sandy beaches worldwide. The application of the COAST tool to the Portuguese coastline supports the adoption of preventive management policies and sustainable long-term planning towards more effective management. A crucial insight derived from this work is that almost all the proposed scenarios were considered valid and feasible solutions from a physical point of view. However, the COAST tool revealed that more than half of these scenarios would not be economically viable in the analyzed time-horizon (20 years). Thus, these findings underscore the importance of cost-benefit analysis and the COAST4US project as valuable assets in supporting coastal management.

Keywords: COAST tool; COAST4US project; coastal erosion; coastal interventions; shoreline evolution.

INTRODUCTION

Coastal regions are known for their economic and ecological significance, providing access to a diverse array of unique services. The concentration of population in these areas, combined with the challenges of coastal erosion and the impacts of climate change, underscores the necessity of devising strategies for forecasting, preventing, or mitigating shoreline retreat. The western coast of Portugal serves as a notable example where coastal erosion has been a persistent issue (Santos *et al.*, 2017). This coastal area is exposed to the energetic wave climate of the North Atlantic and suffers of the disruption of the natural fluvial sediment supply (mainly due to river dams), essential for nourishing coastal areas (Santos & Miranda, 2006; Syvitski *et al.*, 2009; Valle, 2014). Consequently, safeguarding coastal regions assumes paramount importance for both stakeholders and governmental authorities. Nevertheless, given the constraints of finite resources, the ability to prioritize areas for protection and to evaluate the most cost-effective measures assumes a critical role in coastal management (O'Riordan *et al.*, 2014). Therefore, a sensible analysis of alternative approaches during the planning and design phases of coastal defense interventions becomes of utmost importance. It is noteworthy that interventions to address coastal erosion often tend to be reactive, neglecting the optimization of implemented solutions and a comprehensive analysis of the cost-benefit aspects associated with each intervention scenario.

To address this knowledge gap, the COAST4US project emerged to obtain knowledge and concrete data to enable a preventive approach to coastal management (as opposed to the usual reactive methodology, responding to catastrophic events of coastal erosion and overtopping), allowing for the definition of a sustainable coastal zone management strategy applied to each specific area in a medium to long-term perspective, leading to reduced costs with coastal defense interventions and preservation of national territory.

The COAST4US project aimed to contribute to the mitigation of coastal erosion phenomenon by applying the COAST tool to three high-risk stretches of coastal erosion on the Portuguese west coast (Figure 1): Aveiro (São Jacinto - Gafanha da Boa Hora, in the municipalities of Aveiro, Ílhavo, and Vagos); Figueira da Foz (Cabo Mondego - Praia da Cova Gala, in the municipality of Figueira da Foz); and Costa de Caparica (Cova do Vapor - Cornélia, municipality of Almada). These stretches were chosen in accordance with the Portuguese Environment Agency, the entity responsible for coastal management in Portugal. The first study area corresponds to a territory with severe erosion issues (7.38 ± 0.2 m/year, Lira *et al.*, 2016), associated with a lagoon region of unique value in Portugal (Ria de Aveiro). The

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second study area also exhibits severe erosion issues (3.77 ± 0.2 m/year, Lira *et al.*, 2016) and was chosen because it is the location where the Portuguese Environment Agency anticipated carrying out a major artificial nourishment intervention. The third study area chosen corresponds to a zone with high population density and recreational interest during the bathing season, where the Portuguese Environment Agency carries out frequent operations of artificial sand nourishment to mitigate the effect of coastal erosion (which reaches recession rates in the order of 4.57 ± 0.2 m/year, Lira *et al.*, 2016).

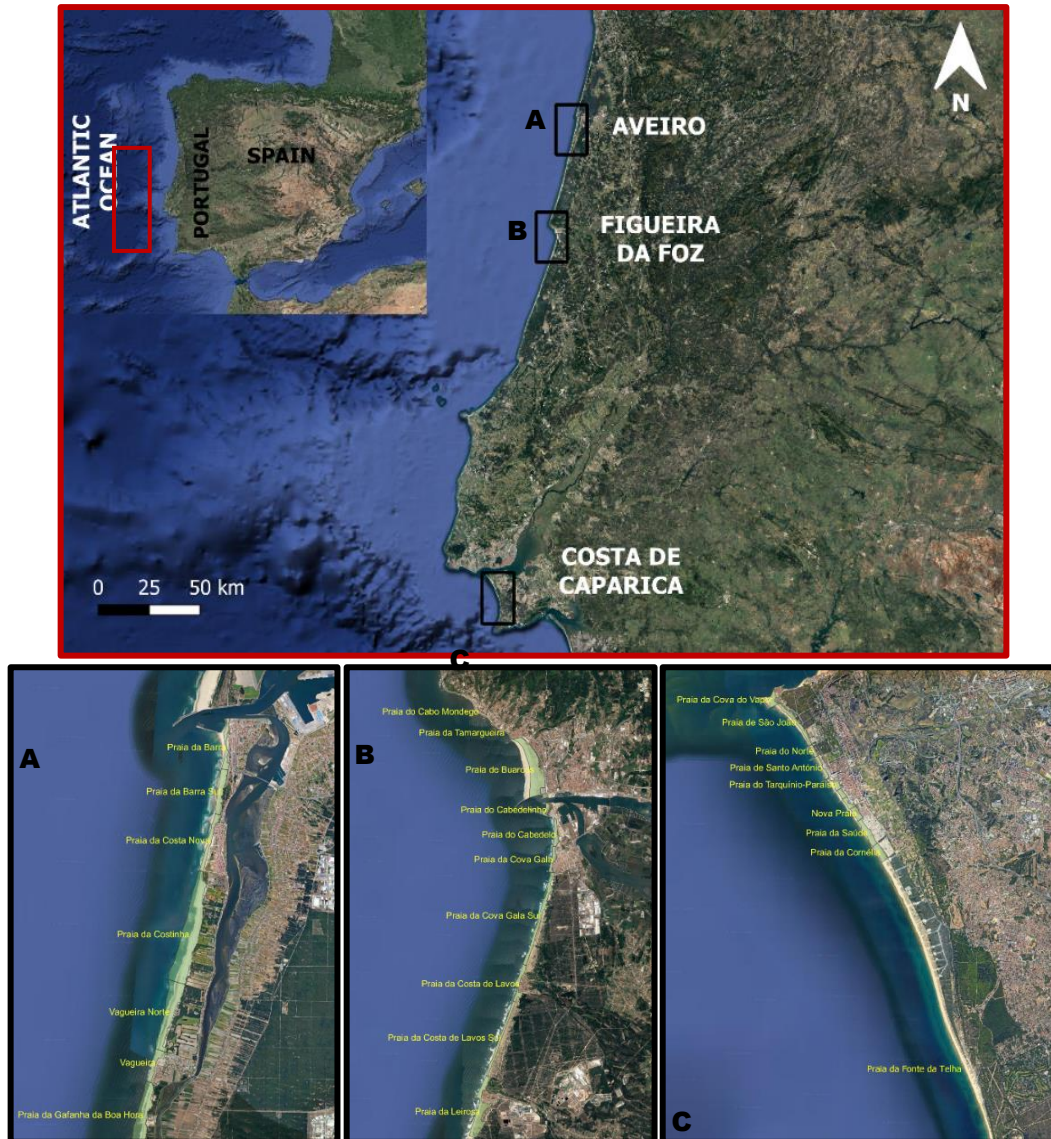


Figure 1. Case studies of COAST4US project (black rectangles) on the northwest Portuguese coast: A – Aveiro; B – Figueira da Foz; and, C – Costa de Caparica (Ferreira *et al.*, 2023a).

COAST (Coastal Optimization ASsessment Tool, Lima, 2018) is a tool for analyzing coastal defense interventions, allowing for cost-benefit analyses, taking into account factors such as solution effectiveness, impact on adjacent areas, socio-economic value of the areas to be protected, and the areas that may be affected by the intervention. COAST is based on a sequential and well-defined methodology, supported by uniquely integrated numerical models, facilitating the comparison of different scenarios' performance. It can be applied to most threatened coastal territories facing the problem of coastal erosion, exacerbated by the potential impact of climate change. The COAST tool combines three different 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. Since a cost-benefit analysis involves comparing the intervention scenario for mitigating coastal erosion with a reference scenario - against which indicators are obtained to evaluate whether the solution is economically profitable - the cost-benefit module enables the analysis of the economic balance of the reference scenario, as well as the cost-benefit analysis of each intervention scenario.

COAST tool had already been implemented in recent research and studies, related to the cost-benefit analysis of groins (Lima *et al.*, 2020), artificial nourishments (Coelho *et al.*, 2022), bypass systems (Ferreira *et al.*, 2023b; Lima *et al.*, 2023) and in the vulnerability and risk assess of other stretches with high coastal erosion rates (Pais-Barbosa *et al.*, 2023).

In this work, the COAST tool was applied in the scope of the COAST4US project to present the principal findings, conclusions, and insights for the future, not only regarding the northwest Portuguese coast, but also its potential of applicability to other sandy beaches worldwide.

METHODOLOGY

The COAST4US project applied the COAST tool to study coastal erosion mitigation scenarios, adding significant value to the global analysis of coastal interventions. This tool simultaneously evaluates the physical and economic performance of different scenarios, enabling a straightforward and rapid comparison between them, helping coastal management entities in assessing the effectiveness of coastal erosion mitigation measures. The methodology was consistent for the three study areas, with tasks related to the physical characterization of the study areas and definition of possible intervention scenarios, and to the socioeconomic characterization of the study areas.

To achieve the previous, several steps were undertaken: 1) definition of the reference scenario and intervention scenarios, for each coastal stretch; 2) physical characterization of the study area and numerical modelling of the shoreline evolution, for each scenario; 3) socioeconomic characterization of the study area; and 4) cost-benefit analysis, using the COAST tool to evaluate the economic viability of the interventions. The following sections elaborate on each of these steps:

Definition of scenarios

A cost-benefit analysis should compare scenarios. Therefore, for each coastal stretch under study, the reference scenario (REF) was defined, assuming the maintenance of existing structures without any additional coastal intervention. The intervention scenarios were compared with it. The intervention scenarios presented for each of the 3 study areas were defined following a participatory approach (Matos *et al.*, 2022; Coelho *et al.*, 2023) meaning they were discussed with local and national stakeholders and provided responsible coastal management entities with concrete information based on cost-benefit analysis results. The intervention scenarios initially proposed by the project team, were subsequently discussed with the municipalities in the study areas, and finally validated by the Portuguese Environment Agency.

Physical characterization

The morphological impacts of the different intervention scenarios were predicted using the first module of COAST, the shoreline evolution model, LTC (Coelho, 2005; Lima and Coelho, 2017; Lima and Coelho, 2019). This model allowed to obtain erosion/accretion areas when compared with the REF scenario, in addition to the shoreline position on a time scale of 20 years (the time horizon of the COAST4US project), considering climate change (RCP4.5 – IPCC) and mean sea level rise (0.0075 m/year - Antunes, 2019).

Socioeconomic characterization

The subjective nature of ecosystems makes them difficult to assess, with the most common approach being to estimate the maximum value an individual is willing to pay for access to the ecosystem. Considering that the majority of the territory expected to be lost corresponds to beach areas, the methodology for assessing benefits focused on the benefits derived from the presence of sandy beaches. Thus, the decision was made to identify the values resulting from the existence of beaches, characterizing the following main categories: providing natural defense against extreme events (protection value); providing space for recreational, leisure, and cultural activities (recreational value); promoting improvement in the local economy (economic value); providing a relevant habitat from an environmental perspective (environmental value of the beach).

The economic value of the coastal territories was evaluated based on a methodology that combines the land uses and the value of the ecological systems with benefits transfer, through 4 monetary value-

based ecosystem valuation approaches: Travel Cost Method; Replacement Cost Method; Hedonic Pricing Method and Transfer Method (Ferreira *et al.*, 2023a).

Cost-benefit analysis

The verification of the economic sustainability of each scenario was based on the accumulated net flows of benefits and costs, through the COAST tool. For each scenario, benefits are obtained through the areas gained and lost over time and the monetary value of the territory, while costs result from intervention and maintenance costs over the project time horizon. The NPV (Net Present Value) and the BCR (Benefit-Cost Ratio) are economic indicators that allow comparing interventions performance (Lima, 2018). An intervention is economically viable if NPV is positive and BCR is greater than 1.

RESULTS

Following the methodological steps, the main results of the COAST4US project, which contributed to the paradigm shift in Portuguese coastal management, are presented in this section.

Definition of scenarios

Initially, the project team defined 20 intervention scenarios for each study area, encompassing new structures, the extension and/or removal of existing structures, and artificial sand nourishments, varying volumes, intervention frequency and deposition location. These scenarios were discussed with the Portuguese Environment Agency and later presented to local municipalities. In addition to the reference scenario for each of the three stretches (Scenario REF, representing the maintenance of existing conditions), the scenario selection process resulted in a total of 59 scenarios across the three coastal stretches: 21 intervention scenarios for Aveiro, 16 for Figueira da Foz, and 22 for Costa de Caparica. All scenarios included new interventions (either isolated or combined, such as groins, longitudinal revetments, artificial nourishments, and bypass systems), the extension of existing interventions, or their demolition. Figure 2 represents the existing structures in each of the three study areas, while Tables 1, 2, and 3 present the scenarios proposed for the Aveiro, Figueira da Foz, and Costa de Caparica stretches, respectively.

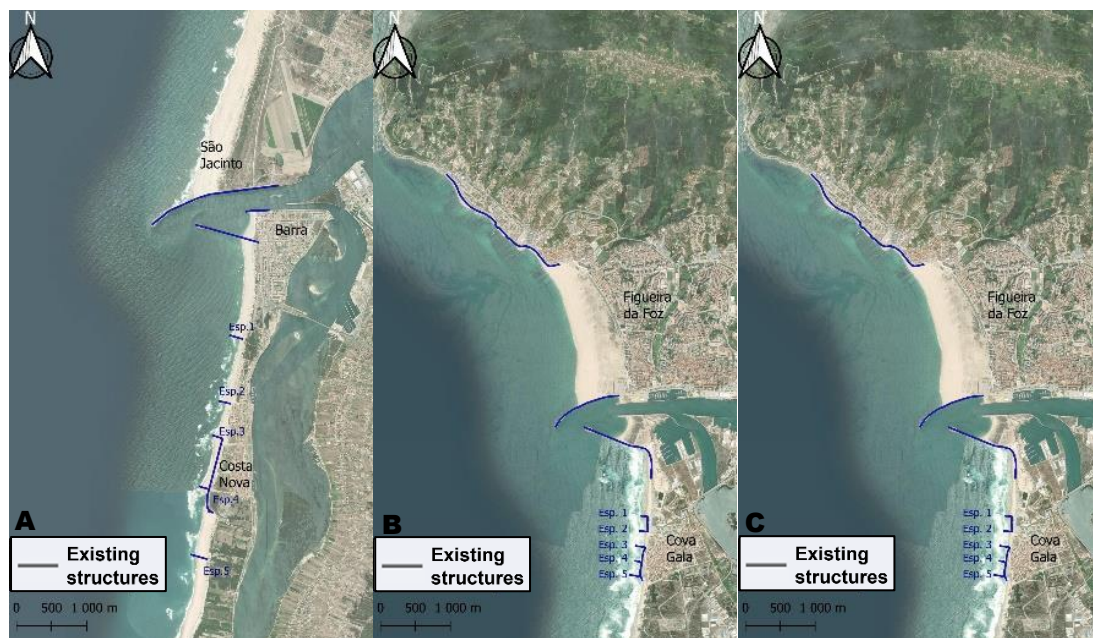


Figure 2. Representation of the existing structures in each of the three study areas: A – Aveiro; B – Figueira da Foz; and, C – Costa de Caparica.

Physical characterization

Applying LTC model, the annual shoreline position over the 20 years was predicted, and the consequent annually areas gained and lost (relative to the reference scenario) were obtained. A graphical example is provided in Figure 3, for each reference scenario, after 20 years. Table 4 presents a summary of the physical balance for each scenario, compared to the reference scenario (areas gained to the reference scenario represent a positive balance, while losses represent a negative balance).

2.1	Construction of a 100m groin at the center of Barra Beach
2.2	Construction of a 200m groin at the center of Barra Beach
3.1	Construction of a 200m attached longitudinal structure, south of groin 2 at Costa Nova
3.2	Construction of a 400m attached longitudinal structure, south of groin 2 at Costa Nova
4.1	Extension of groin 3 at Costa Nova by 100m
4.2	Extension of groin 3 at Costa Nova by 200m
5.1.1	AN of 300k m ³ /year between groins 3 and 5 at Costa Nova
5.1.2	AN of 600k m ³ /year between groins 3 and 5 at Costa Nova
5.1.3	AN of 900k m ³ /year between groins 3 and 5 at Costa Nova
5.1.4	Mega-shot of 2.4M m ³ in the first year and nourishment of 300,000 m ³ /year from the 4th year onwards
5.2	AN of 300k m ³ /year in the groin field at Costa Nova
6.1.1	Removal of groins 1 and 2 at Costa Nova
6.1.2	Removal of groins 1 and 2 at Costa Nova and AN of 300k m ³ /year in the groin field
6.1.3	Removal of groins 1 and 2 at Costa Nova and AN of 600k m ³ /year in the groin field
6.1.4	Removal of groins 1 and 2 at Costa Nova, AN of 300k m ³ /year in the groin field, and extension of groin 5 by 100 meters
6.2.1	Removal of groins 2 and 4 at Costa Nova
6.2.2	Removal of groins 2 and 4 at Costa Nova and AN of 300k m ³ /year in the groin field
6.2.3	Removal of groins 2 and 4 at Costa Nova and AN of 600k m ³ /year in the groin field
6.2.4	Removal of groins 2 and 4 at Costa Nova, AN of 300k m ³ /year in the groin field, and extension of groin 5 by 100 meters
7.1	Extension of Labrego groin by 200m
7.2	Extension of Labrego groin by 400m

2.1	Construction of a 400m breakwater in Buarcos
2.2	Construction of a 400m breakwater in Buarcos, and dredging of 300k m ³ /year at Praia da Claridade with deposition north of the breakwater
2.3	Construction of a 400m breakwater in Buarcos, and implementation of a bypass system with transposition of 300k m ³ /year from Praia da Claridade and with deposition north of the breakwater
3.1.1	Reduction of Praia da Claridade, through dredging of 300k m ³ /year with deposition between breakwater 3 and breakwater 5
3.1.2	Reduction of Praia da Claridade, through dredging of 600k m ³ /year with deposition between breakwater 3 and breakwater 5
3.2	Implementation of a bypass system with transposition of 300k m ³ /year from Praia da Claridade and with deposition between breakwater 3 and breakwater 5
5	Construction of a 200m longitudinal structure between breakwater 2 and breakwater 3 in Cova Gala
6.1	AN of 300k m ³ /year between breakwater 1 and breakwater 3, in Cova Gala
6.2	AN of 300k m ³ /year between breakwater 1 and breakwater 5, in Cova Gala
6.3	AN of 300k m ³ /year south of breakwater 5, in Cova Gala
7.1	Extension of the longitudinal structure by 400m, south of the breakwater field of Cova Gala
7.2	Extension of the longitudinal structure by 600m, south of the breakwater field of Cova Gala
8.1	Construction of a 270m longitudinal structure, on the urban front of Costa de Lavos
8.2	Construction of a 310m longitudinal structure, on the urban front of Leirosa
9.1	Construction of a 200m breakwater, north of Costa de Lavos
9.2	Construction of a 200m breakwater, south of Costa de Lavos

2.1	Removal of breakwater EV1
2.2	Extension of breakwater EV1 by 200 m
2.3	Removal of breakwater EV1 and extension of breakwater EV2 by 200 m
3.1	AN of 1M m ³ every 5 years at Praia de São João (EV1-EC7)
3.2	AN of 1M m ³ every 5 years in the breakwater field (EC7 up to 500 m south of EC1)
3.3	AN of 1M m ³ every 5 years between São João – Caparica (EV1 up to 500 m south of EC1)
4.1.1	Removal of breakwater EC7
4.1.2	Removal of breakwaters EC5 and EC7
4.1.3	Removal of breakwaters EC3, EC5, and EC7
4.1.4	Removal of breakwaters EC1, EC2, and EC3
4.2.1	Removal of breakwater EC7, with AN of 1M m ³ every 5 years between EC1-EC7
4.2.2	Removal of breakwaters EC5 and EC7, with AN of 1M m ³ every 5 years between EC1-EC7
4.2.3	Removal of breakwaters EC3, EC5, and EC7, with AN of 1M m ³ every 5 years between EC1-EC7
4.2.4	Removal of breakwaters EC1, EC2, and EC3, with AN of 1M m ³ every 5 years between EC1-EC7
4.3.1A	Extension of breakwater EC4 by 100 m
4.3.1B	Extension of breakwater EC7 by 100 m
4.3.2	Extension of breakwaters EC4 and EC7 by 100m
4.3.3A	Extension of breakwater EC4 by 100 m and removal of breakwaters EC5 and EC6
4.3.3B	Extension of breakwater EC7 by 100 m and removal of breakwaters EC5 and EC6
4.3.3C	Extension of breakwaters EC4 and EC7 by 100m and removal of breakwaters EC5 and EC6
5.1	Extension of the adherent longitudinal structure of Praia da Saúde by 700 m
5.2	Extension of the adherent longitudinal structure of Praia da Saúde by 1200 m

Note: AN means artificial nourishment; *k* means thousands of m³ of sand; and *M* means million of m³ of sand.

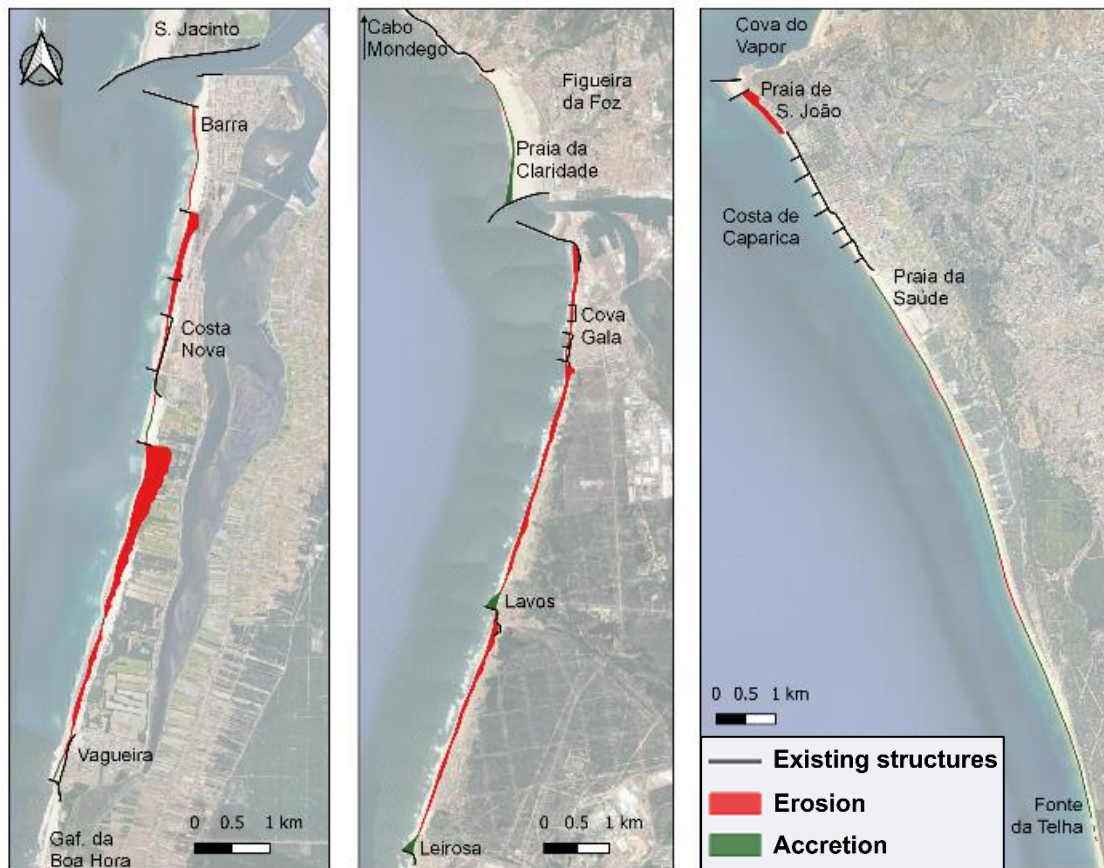


Figure 3. Areas in erosion and accretion in the 20-year projection (up to 2040), for each reference scenario.

Table 4. Summary of scenarios physical performance: land areas (ha), in 2040.

Aveiro				Figueira da Foz				Costa de Caparica			
#	Gain	Lost	Balance	#	Gain	Lost	Balance	#	Gain	Lost	Balance
REF	0.00	-83.31	-83.31	REF	8.65	-43.82	-35.17	REF	-20.98	0.00	-20.98
2.1	4.53	-1.51	3.02	2.1	1.97	-1.94	0.03	2.1	0.02	0.00	1.99
2.2	4.92	-1.39	3.52	2.2	7.32	-6.86	0.46	2.2	0.00	-0.04	0.40
3.1	4.57	0.00	4.57	2.3	4.40	-8.10	-3.70	2.3	0.00	-0.06	-1.98
3.2	4.61	0.00	4.61	3.1.1	13.15	-6.48	6.67	3.1	0.00	-0.03	7.80
4.1	2.12	-0.11	2.01	3.1.2	14.14	-10.55	3.60	3.2	0.00	-0.37	9.35
4.2	1.83	-0.08	1.76	3.2	12.17	-7.10	5.07	3.3	0.00	-0.39	7.07
5.1.1	14.32	-2.11	12.22	5	0.64	0.00	0.64	4.1.1	0.00	0.00	0.18
5.1.2	17.29	-0.94	16.35	6.1	15.03	0.00	15.03	4.1.2	0.00	0.00	0.18
5.1.3	26.88	-2.70	24.19	6.2	11.99	0.00	11.99	4.1.3	0.01	0.00	0.17
5.1.4	27.45	-5.14	22.30	6.3	11.58	0.00	11.58	4.1.4	0.14	0.00	-0.06
5.2	19.41	-2.02	17.39	7.1	1.77	-0.48	1.29	4.2.1	0.00	-0.44	5.19
6.1.1	5.88	-1.95	3.94	7.2	7.94	0.00	7.94	4.2.2	0.00	-0.44	5.23
6.1.2	23.95	-6.24	17.71	8.1	3.85	0.00	3.85	4.2.3	0.00	-0.44	5.18
6.1.3	35.80	-0.69	35.11	8.2	3.42	-0.56	2.86	4.2.4	0.00	-0.29	5.35
6.1.4	37.14	-1.83	35.32	9.1	2.14	-6.99	-4.85	4.3.1A	0.00	0.00	0.08
6.2.1	3.59	-0.10	3.48	9.2	1.83	-3.17	-1.34	4.3.1B	0.00	-0.01	-0.30
6.2.2	17.95	-1.35	16.60					4.3.2	0.00	-0.11	-0.20
6.2.3	17.88	-0.62	17.26					4.3.3A	0.00	-0.09	0.16
6.2.4	24.57	-1.33	23.24					4.3.3B	0.01	0.00	0.05
7.1	0.00	-38.99	-38.99					4.3.3C	0.00	-0.10	-0.05
7.2	0.00	-63.12	-63.12					5.1	0.05	0.00	0.05
								5.2	0.16	0.00	0.17

Socioeconomic characterization

Land use and ecosystem service monetary values were determined by combining the four referenced methods (Ferreira *et al.*, 2023a). This approach enabled to distinguish the value of the territory along the coastal stretches, according to a summarized description, as follow:

Aveiro. In the coastal stretch of Aveiro (São Jacinto – Gafanha da Boa Hora), the application of land valuation methodologies resulted in dividing the study area into 8 different sections (Barra, South Barra, Costa Nova, Costinha, North Vagueira, Vagueira, Gafanha da Boa Hora, and Areão – see Figure 1A), with a variation in land value ranging from 10 to 170 €/m²/year.

Figueira da Foz. In the coastal sector of Figueira da Foz (Cabo Mondego - Leirosa), 8 distinct sections were also considered (Cabo Mondego – Tamargueira, Buarcos – Figueira da Foz, Cabedelinho – Cabedelo, Cova Gala, Cova Gala South, Costa de Lavos, Costa de Lavos South, Leirosa – see Figure 1B), with the land value ranging from 20 to 145 €/m²/year.

Costa de Caparica. In the coastal sector of Costa de Caparica (Cova do Vapor – Fonte da Telha), 11 segments were considered in the application of the 4 methodologies (Cova do Vapor, São João Norte – Santo António, Tarquínio – Praia Nova, Nova Praia, Saúde, Cornélia, Mata – Pescador, Rei – Bela Vista, Fonte da Telha, Fonte da Telha Sul – see Figure 1C), with the land value ranging from 15 to 135 €/m²/year.

Cost-benefit analysis

The economic balance of each of the 3 reference scenarios (following the same criterion for each of the 3 coastal stretches under analysis) and the cost-benefit analysis of the 59 intervention scenarios analyzed (21 scenarios in the Aveiro stretch, 16 scenarios in the Figueira da Foz stretch, and 22 scenarios for the Costa de Caparica) considered the values of costs and benefits updated, with a discount rate of 3%. Table 5 presents the cost-benefit analysis results, for each scenario, in each of the 3 study areas.

Table 5. Summary of scenarios economic performance, in 2040.

Aveiro			Figueira da Foz			Costa de Caparica		
#	NPV (€)	BCR (-)	#	NPV (€)	BCR (-)	#	NPV (€)	BCR (-)
REF	-170 972 945 €	-3.18	REF	-150 333 636 €	-0.80	REF	-169 452 133 €	-0.32
2.1	9 980 758 €	1.84	2.1	-15 854 265 €	0.65	2.1	2 931 370 €	1.42
2.2	-4 611 757 €	0.82	2.2	28 073 766 €	1.46	2.2	-27 844 583 €	-0.11
3.1	-6 339 863 €	0.60	2.3	-14 692 497 €	0.80	2.3	-29 526 052 €	0.00
3.2	-21 907 567 €	0.30	3.1.1	24 391 623 €	2.56	3.1	33 940 191 €	4.07
4.1	-3 498 618 €	0.72	3.1.2	23 433 464 €	1.75	3.2	75 286 883 €	7.82
4.2	-20 762 007 €	0.24	3.2	8 343 114 €	1.29	3.3	54 188 722 €	5.91
5.1.1	16 066 294 €	2.03	5	-12 007 355 €	0.23	4.1.1	-1 319 263 €	0.76
5.1.2	15 718 883 €	1.50	6.1	37 062 048 €	3.37	4.1.2	-9 128 800 €	0.41
5.1.3	3 469 582 €	1.07	6.2	31 300 526 €	3.00	4.1.3	-13 247 006 €	0.43
5.1.4	39 624 597 €	2.90	6.3	13 353 024 €	1.85	4.1.4	-3 447 312 €	0.79
5.2	-1 224 965 €	0.92	7.1	-24 007 010 €	0.23	4.2.1	56 372 306 €	4.41
6.1.1	4 076 454 €	1.44	7.2	-33 842 842 €	0.28	4.2.2	35 640 221 €	2.34
6.1.2	32 264 404 €	2.29	8.1	-10 235 778 €	0.52	4.2.3	20 550 111 €	1.60
6.1.3	-5 104 782 €	0.87	8.2	-14 657 826 €	0.40	4.2.4	38 329 979 €	2.39
6.1.4	-7 356 398 €	0.80	9.1	-39 275 272 €	-0.16	4.3.1A	-11 277 763 €	0.01
6.2.1	1 260 702 €	1.14	9.2	-28 308 155 €	-0.03	4.3.1B	-12 260 912 €	-0.08
6.2.2	-9 791 303 €	0.60				4.3.2	-24 604 900 €	-0.08
6.2.3	-6 568 660 €	0.84				4.3.3A	-23 773 123 €	0.18
6.2.4	-13 454 261 €	0.63				4.3.3B	-23 508 759 €	0.19
7.1	-43 264 815 €	-0.53				4.3.3C	-49 371 644 €	0.11
7.2	-110 107 591 €	-0.67				5.1	-72 627 582 €	0.04
						5.2	-125 621 948 €	0.03

DISCUSSION

The significant sediment deficit, increasing social pressure, and worsening climate change make mitigation strategies for coastal erosion effects increasingly necessary across most coastal areas. The west coast of Portugal is one such case where coastal erosion has been worsening over the years. Coastal defense interventions lead to high investment and maintenance costs with increasing trends over time, which sometimes leads to the debate between intervening to defend, or relocating the population from risk areas. Therefore, a weighted analysis of alternatives through cost-benefit analyses is of utmost importance.

In this regard, the physical and economic feasibility of proposed intervention scenarios for the three stretches at high risk of coastal erosion on the Portuguese West Coast (Aveiro, Figueira da Foz and Costa de Caparica, chosen in agreement with the Portuguese Environment Agency) represented the main objective of the COAST4US project, through the implementation of cost-benefit analyses using the COAST tool.

For the Aveiro region, results show that without intervention, approximately 84 ha of land, valued at around 170 million euros, will be lost over the next 20 years. Out of the 21 proposed scenarios, 19

present positive physical impacts (gains of territory), but only 8 are economically feasible, with the most economically advantageous involving artificial nourishment (scenario being the initial nourishment of 2.4 million cubic meters of sand, with reinforcements of 300 thousand cubic meters annually, between the 4th and 20th year) and structure removal.

In Figueira da Foz, inaction could lead to a loss of approximately 150 million euros and 35 ha of territory. Among the analyzed scenarios, 81% have positive physical impacts, but only 44% are economically viable. The most economically advantageous scenario involves the artificial nourishment of 300 thousand cubic meters of sediments deposited per year, between the first groin and the third groin, in Cova Gala.

Concerning Costa de Caparica, potential losses are estimated at about 170 million euros. The scenarios with the best economic performance also involve artificial nourishment and the removal of existing structures. These results show a trend for addressing coastal erosion causes through restoring sediment balance and prioritizing artificial nourishments, aligning with the strategy of the Portuguese Environmental Agency. Of the 22 proposed intervention scenarios, it is observed that 95% of the scenarios have a positive physical balance, and only 36% of the intervention scenarios are economically viable.

These results should be evaluated carefully, as making decisions and developing policies related to coastal adaptation are always implemented with uncertainty (Maier *et al.*, 2016) and dilemmas (Dronkers & Stojanovic, 2016). Understanding the level of vulnerability of human and natural systems to climate variability and change is one valuable part of making decisions and developing policies related to coastal adaptation and climate resilience, as it provides a foundation for establishing priority actions. Other valuable part is understanding how investing in adaptive capacity now will prevent losing money in damages in the future (das Neves *et al.*, 2023).

CONCLUSION

The results of the COAST4US project reinforce the importance of applying the COAST tool and demonstrate that, despite all the uncertainties and costs inherent in the entire analysis process, cost-benefit analysis proves to be a significant asset in assisting coastal management. It provides crucial data to help responsible entities make strategic decisions for effective and sustainable coastal management. Specific conclusions for the three analyzed study areas include:

- If no intervention is carried out in the next 20 years, approximately 140 hectares of national territory will be lost, corresponding to a monetary loss of around €500 million, according to the simulation assumptions made for the three study areas. To reverse the erosive situation observed in the reference scenarios, approximately 60 intervention scenarios were proposed, chosen in line with the Portuguese Environment Agency and local municipal councils.
- Out of the approximately 60 scenarios, over 80% justify intervention from a physical standpoint, meaning it is possible to reverse some of the erosive trend of the reference scenario. However, the entirety of the erosive trend of the reference scenario is never fully recovered, reinforcing the premise that the current trend is towards territorial losses.
- Despite the majority of the studied scenarios being physically advantageous, the application of the COAST tool and the results of the cost-benefit analysis showed that more than half of the proposed scenarios are not economically viable within the project's time horizon.
- Artificial sediment nourishment, whether implemented alone or combined with other interventions (such as groin removal), was the type of intervention that showed the best physical and economic results for the three analyzed stretches. This leads to the unequivocal conclusion that the future should involve actions addressing the causes of coastal erosion, focusing on sediment balance replenishment. These results support the national strategy adopted by the Portuguese Environment Agency, emphasizing artificial nourishment over heavy construction works.

As a final note, it is worth mentioning that coastal management based on cost-benefit analyses, the focus of the COAST4US project, emerges as an indispensable component for defining intervention priorities in the coastal zone by the state agencies overseeing it, enabling greater technical and economic sustainability in decision-making. The paradigm shift towards proactive coastal zone planning is imperative and leads to increasingly effective coastal management. The COAST4US project was built upon this purpose, benefiting the country and its citizens by presenting a management strategy for the Portuguese west coast based on the results of applying the COAST tool over a 20-year time horizon.

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