Co-creation of future scenarios for wetland habitat restoration in a coastal lagoon

Integrating participatory mapping and the InVEST coastal blue carbon model

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STUDY AREA

High environmental and socio-economic value

Coastal Protection

Reduction of damage caused by storms, waves, and erosive processes that threaten coastal communities.

Wildlife Habitat

Shelter and feeding areas for fish, crustaceans, and migratory birds. Ecosystem services of socioeconomic value.

Water Quality

Nutrient filtration and cycling, improving water quality and ecosystem health.

STUDY AREA

Blue Carbon Habitats

Seagrass Meadows

- Plants that grow in shallow coastal waters (*Zostera noltei*)
- Carbon sequestration in biomass and sediment
- Sediment stabilization
- Nursery habitat

Salt Marshes

- Halophytic vegetation (Juncus maritimus)
- Long-term carbon storage
- Sediment accumulation
- Coastal protection

Intertidal mudflats

- Unvegetated intertidal sediments
- Carbon and nutrient storage
- Habitat for birds and benthic fauna
- Sediment retention and nutrient cycling

Habitats play a fundamental role in climate change mitigation by storing carbon over the long term and contributing to coastal resilience

HYDROMORPHOLOGICAL CHANGES
Ria de Aveiro

Channel dredging
↓

↑ tidal range • ↑ Hydrodynamic changes
↓

↑ altered inundation patterns
↓

↑ Pressure on habitats

Loss and degradation of salt marshes and seagrass meadows

Salt marsh erosion

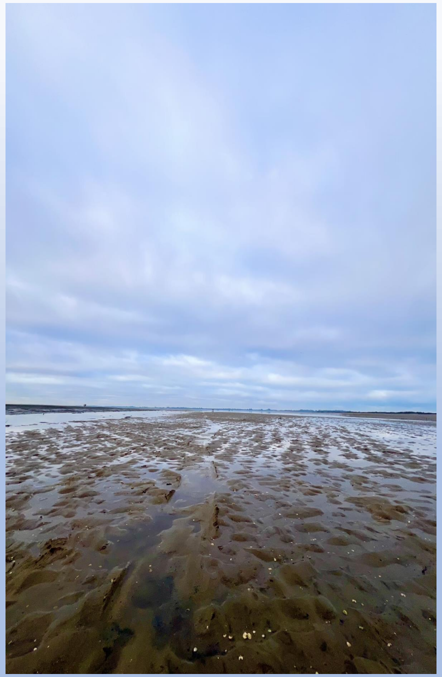
Pressure on seagrass habitats

↓

Potential changes in
ecosystem service
Blue Carbon

How do salt marsh and seagrass meadow habitats respond to changes, and what is their future capacity to sequester and store blue carbon?

Habitat change → Carbon stock & sequestration



Current status:
loss

The loss and degradation of these habitats can result in reduced blue carbon storage and sequestration, as well as a decline in other ecosystem services. It is crucial to understand how restoration strategies can mitigate this trajectory.

OBJECTIVES

Assess the future trajectories of blue carbon stocks, net sequestration, and avoided or lost emissions under three restoration scenarios:

1. Allowing nature to take its course and evolve from salt marshes into subtidal mudflat areas, which also constitute a natural habitat in the region;

2. Mitigating salt marsh habitat loss by planting seagrasses well-adapted to intertidal and subtidal conditions;

3. Reducing loss by promoting sediment accumulation (accretion), which would raise the vegetated mudflat and maintain intertidal conditions (this could also involve transplanting typical salt marsh plants).

MATERIALS AND METHODS

DATA COLLECTION

Co-creation of restoration scenarios

PARTICIPATORY WORKSHOP

Who contributed?

- Public administration & municipalities
- NGOs & companies
- Researchers & educational institutions
- Professionals & environmental managers

Goal: identify priority restoration areas

JANUARY 2025
Ria de Aveiro

30 PARTICIPANTS
multi-sector expertise

4 EU PROJECTS
RESTORE4Cs • A-AAGORA • REWRITE • LIFE SeagrassRIAwild

Stakeholder-driven restoration prioritization

Participatory workshop translated local knowledge into spatially explicit restoration scenarios

PROSPECTIVE ECOLOGICAL SCENARIOS

1. **Natural evolution**

   Salt marsh → tidal flat under increasingly subtidal conditions

2. **Seagrass restoration**

   Mitigate habitat loss through planting of Zostera noltei

3. **Salt-marsh maintenance**

   PSediment accretion and, where needed, transplant halophytic vegetation

PRIORITY AREAS

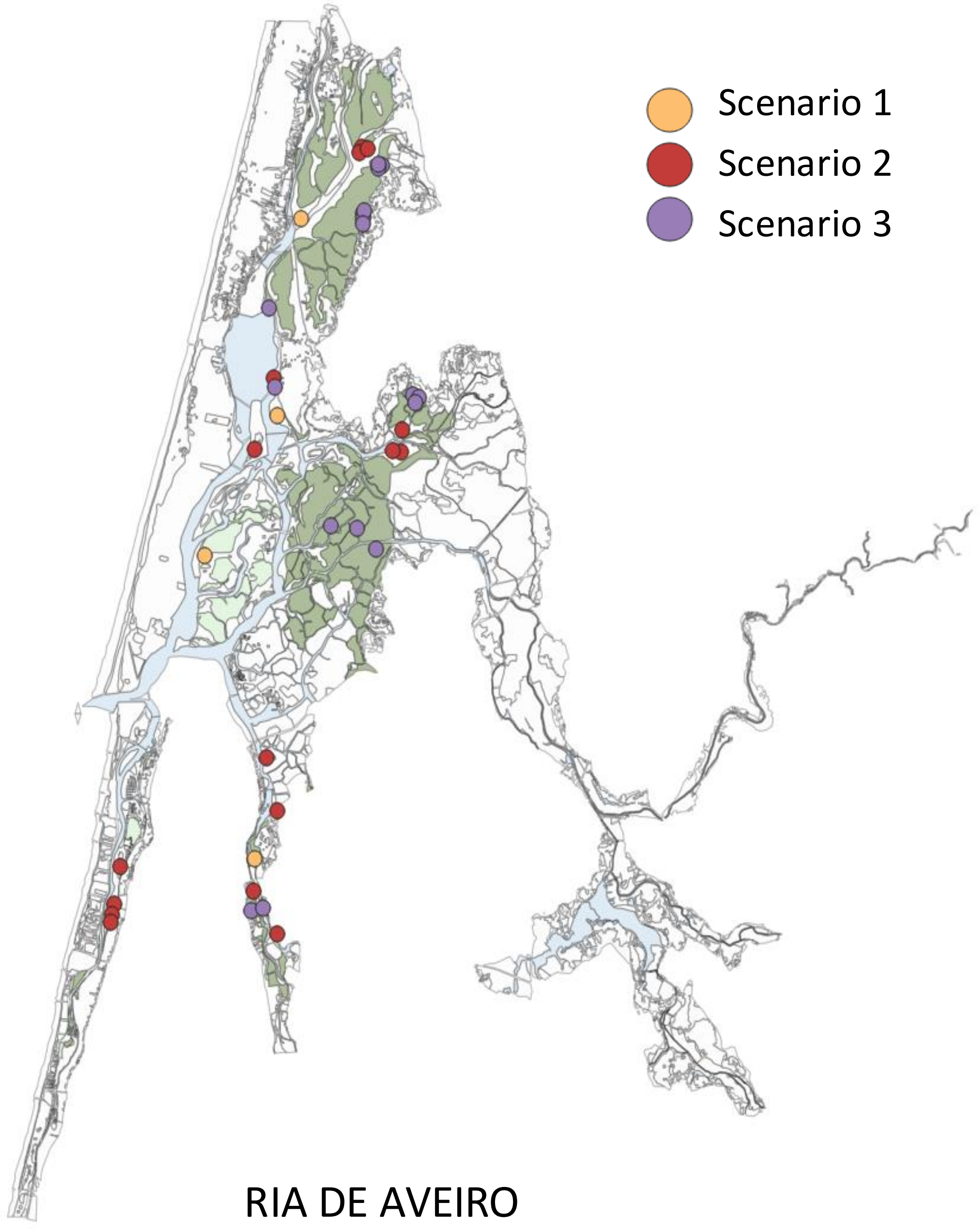
Consensus-based areas selected on a printed map

MATERIALS AND METHODS
DATA ANALISYS

Spatial Data analysis - QGIS software (v.3.14).

Georeference points indicated on the workshop map

1	**Natural evolution** salt marsh → tidal flat / mudflat	**4**	locations
2	**Seagrass restoration** plantio/expansão de Zostera noltei	**16**	locations
3	**Salt-marsh maintenance / recovery** acreção + manutenção/recuperação do sapal	**17**	locations



MATERIALS AND METHODS
DATA ANALISYS

The spatialization process took place in different stages to preserve social priority and impose ecological restrictions

SIG / QGIS

01
Generate areas shapefiles
Scenarios 1, 2, 3 / Habitats

02
Geographic projection
ETRS89 / Portugal TM06 — EPSG:3763

03
Buffer + dissolve
500 m radius per point; union of the overlaps

08
Intersect
Intersect layers: buffers × Habitats

09
Select eligible areas
EUNIS classification to identifying ecologically eligible geographic areas

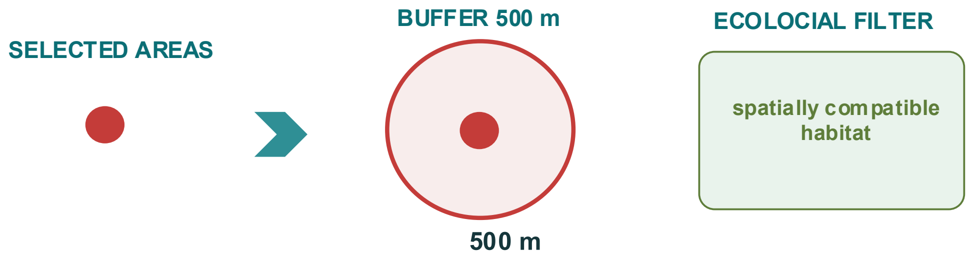
10
Clean geometries
dissolve / fix geometries / multipart / layer mask

11
Rasterize
5 × 5 m aligned to the raster baseline

Result: vectors of eligible areas → scenario LULC classes → rasters compatible with InVEST CBC.

MATERIALS AND METHODS
DATA ANALISYS

The buffer was a standardized spatial window used to transform approximate points into ecological search zones.

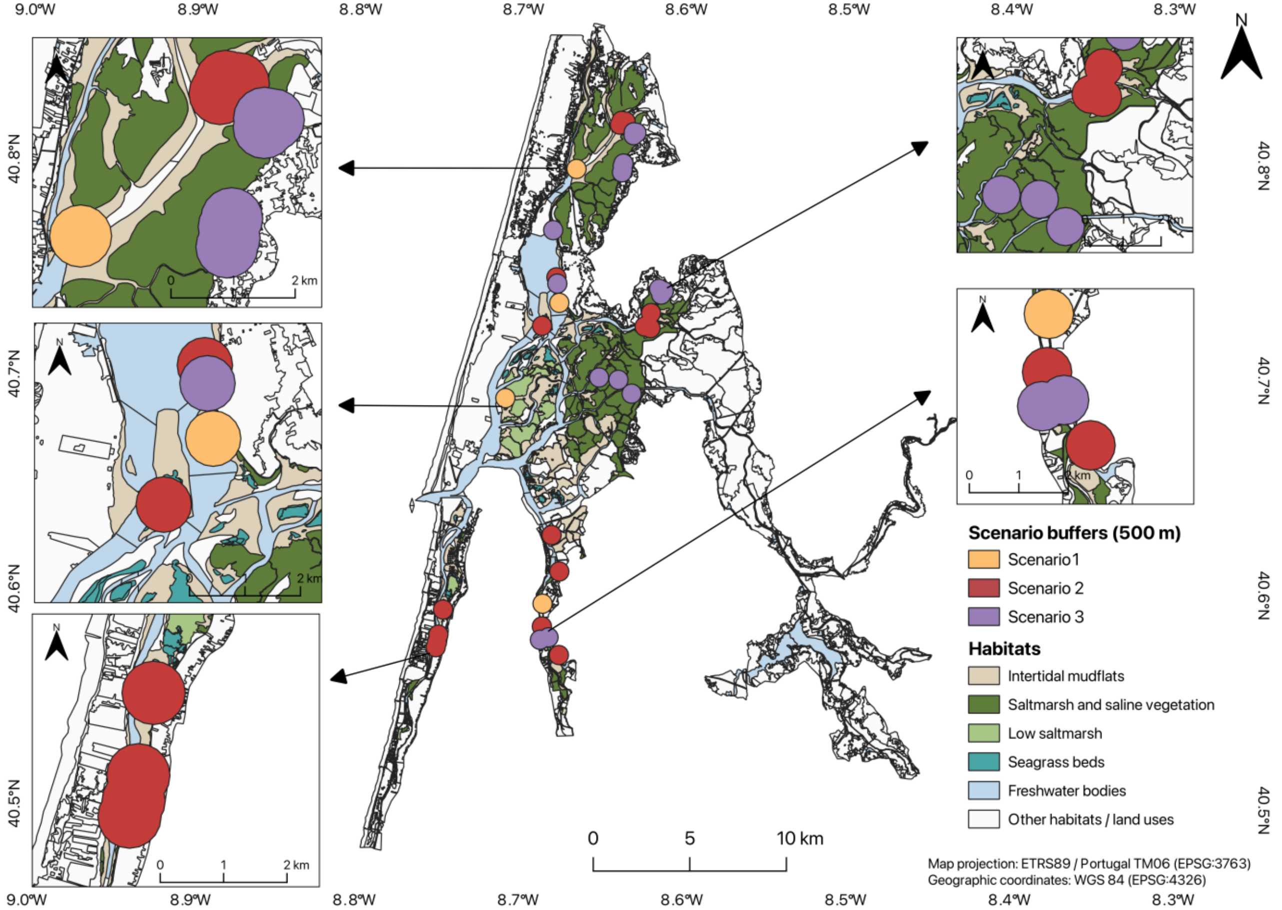


500 m = standardized search radius

All scenarios were evaluated using the same spatial scale

Oliveira et al. (2025) support the feasibility of *Z. noltei* expansion

Only the pixels from ecologically eligible areas were used as the scenario for the carbon model



MATERIALS AND METHODS

DATA ANALISYS

Priority stakeholders + ecological eligibility = modelled area

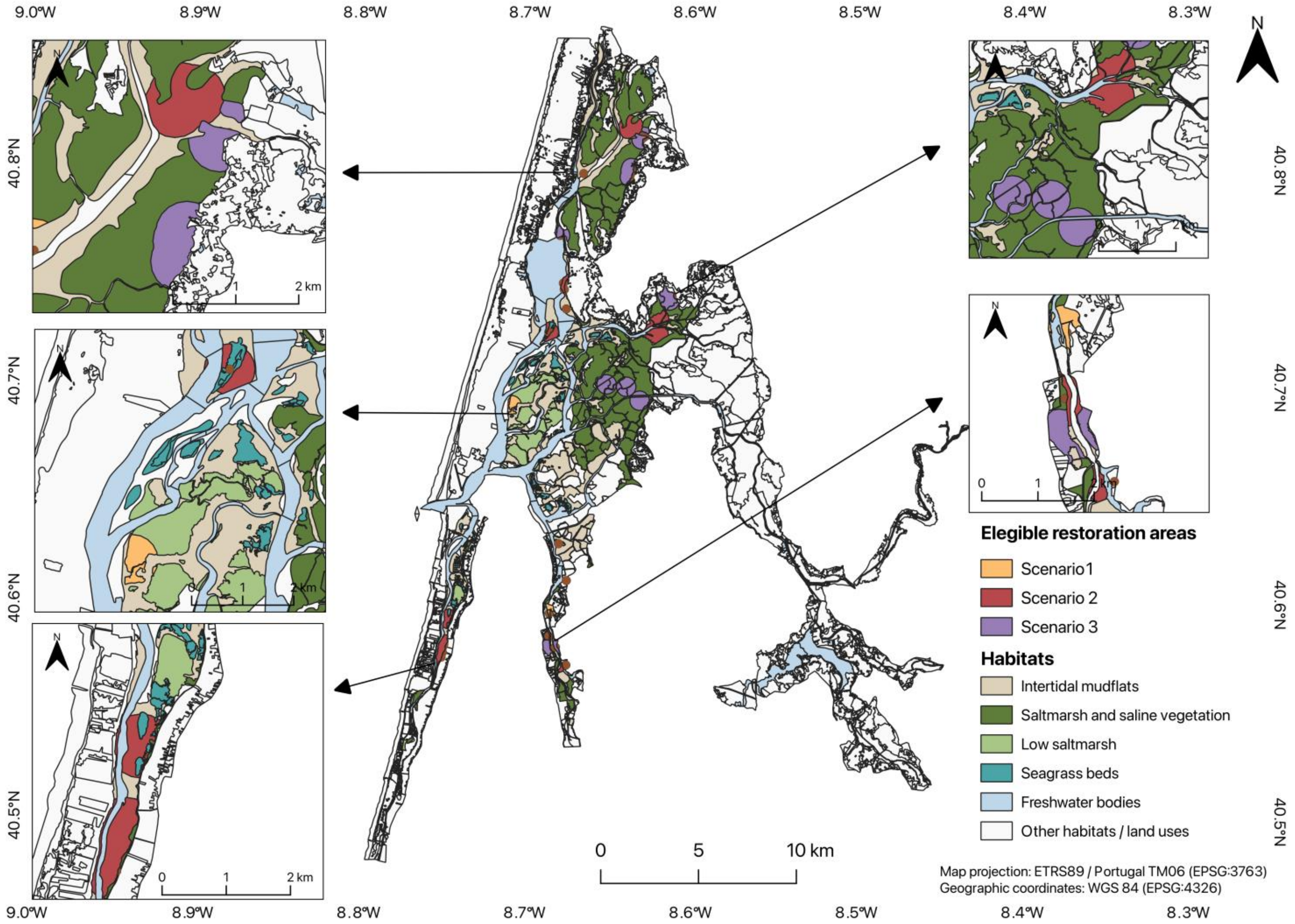
spatially compatible habitat

Table 1. Priority areas, stakeholder-defined for each prospective scenario, and their distribution across EUNIS habitat classes in the Ria de Aveiro.

SCENARIO	AREAS	EUNIS CODE	ELIGIBLE AREA
1	4	A2.3 = 2 pontos; A2.554 = 1; A2.5 = 1	55.5047 ha
2	16	A2.3 = 11; A2.61 = 2; A2.5 = 1; J5.11 = 1; I1.1 = 1	354.8057 ha
3	17	A2.5 = 16; A2.3 = 1	472.5059 ha

Table 2. EUNIS habitat classes used to characterize the baseline land-use/land-cover (LULC) map and to define habitat eligibility and representation under the InVEST Coastal Blue Carbon (CBC) scenarios.

EUNIS CODE	HABITAT CLASS	SCENARIOS
A2.554	Low saltmarsh (*Spartina spp.)*	CBC habitat eligible under scenario 1
A2.5	Existing Saltmarsh	CBC habitat eligible under scenario 1 and 3
A2.61	Seagrass beds	*Zostera noltei* existing in the baseline
A2.3	Natural mudflat	Mudflat for scenario 2, use natural subtype class: Lodacal
-	Restored *Zostera noltei*	Future scenarios
-	Other non-target	Grouped as Other habitats



European Environment Agency (EEA). (2025). EUNIS terrestrial habitat classification 2021_1 including crosswalks. EEA Datahub. europa.eu

MATERIALS AND METHODS

DATA ANALISYS

InVEST
Coastal Blue Carbon model
(version 3.4.0/Copyright©2023)

Estrutura temporal dos cenários

1 — 2025 — Baseline

Initial system condition: current distribution of coastal habitats in the Ria de Aveiro

2 — 2026 — Static / Reference

Reference condition without restoration interventions; natural trajectory of the system

3 — 2036 — Alternative scenarios

Three co-created restoration scenarios compared

Modeled carbon pools: [above-ground biomass, below-ground biomass, soil carbon—specify]. Spatially mapped habitat transitions for each scenario

10-year time horizon
(2026–2036)

SHARP, R. *et al.* (2020) *InVEST User's Guide*. Stanford: The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund.

MATERIALS AND METHODS
DATA ANALISYS

InVEST CBC model analisys

All scenarios had the same spatial resolution and the same set of parameters; only the LULC/transition changed

GeoTIFF • 5 × 5 m • 25 m²/pixel = 0.0025 ha • EPSG:3763 • identical extent + alignment

Inputs

2025 baseline

LULC 025

common initial landscape

2026 reference scenario snapshot

one raster per trajectory

common initial landscape

2036

Scenarios : Static | 1 | 2 | 3

carbon projected for 10 years

Outputs

SNAPSHOTS CSV

year + path for each LULC raster

LULC LOOKUP

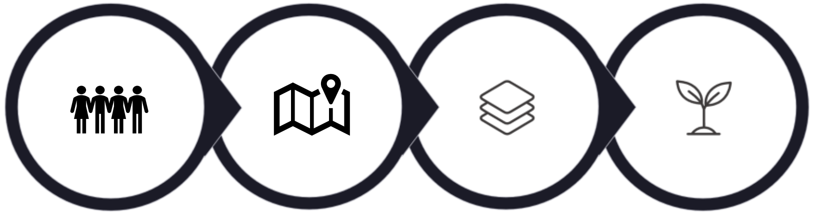
codes 1–6 + CBC habitat flag

BIOPHYSICAL TABLE

stocks • accumulation • half-lives • disturbance

TRANSITION MATRIX

accum • NCC • low-impact-disturb



participatory knowledge → ecological screening → spatial scenario → biophysical modelling

MATERIALS AND METHODS
DATA ANALISYS

carbon_biophysical_table_C1_500m_READY_MgC

code	lulc-class	biomass-initial	soil-initial	litter-initial	biomass-half-life	biomass-low-impact-disturb	biomass-med-impact-disturb	biomass-high-impact-disturb	biomass-yearly-accumulation
1	other_non_target	0	0	0	1.0	0	0	0	0
2	low_saltmarsh_a2_554	3.734	35.62	0	0.5	0.5	0.5	1	0
3	saltmarsh_a2_5	13.841	55.0	0	0.5	0.5	0.5	1	0
4	existing_zostera_a2_61	0.627	1.377	0	0.274	0.5	0.5	1	0
5	natural_mudflat_a2_3_lodacal	0	0	0	1.0	0	0	0	0
6	restored_zostera	0.627	1.377	0	0.274	0.5	0.5	1	0

Table data was imported and can be a

carbon_pool_transition_C1_500m_READY

lulc-class	other_non_target	low_saltmarsh_a2_554	saltmarsh_a2_5	existing_zostera_a2_61	natural_mudflat_a2_3_lodacal	restored_zostera
other_non_target	NCC					
low_saltmarsh_a2_554					low-impact-disturb	
saltmarsh_a2_5			accum		low-impact-disturb	
existing_zostera_a2_61				accum		
natural_mudflat_a2_3_lodacal					NCC	
restored_zostera						

LOW-IMPACT DISTURBANCE

Saltmarsh

biomass 0.50
soil 0.30

Zostera

biomass 0.50
soil 0.10

Biomass annual accumulation = 0
Litter pools = 0

RESULTS

How the carbon stock is distributed in 2036

1 Natural mudflat expansion

55.48 ha
raster-mapped area

35.29 ha low saltmarsh
20.19 ha saltmarsh

Saltmarsh / low saltmarsh → natural mudflat

↓ accumulation + 646.52 Mg C of emissions
Net: 6,755.50 Mg C (−16.51% vs. reference)

The conversion of vegetated habitat to mudflat reduces the future capacity to sequester carbon.

2 Seagrass restoration

354.71 ha
raster-mapped area

Natural mudflat → restored *Zostera noltei* meadows

↑ accumulation to 9,297.70 Mg C
Modeled emissions: 0
Net: 9,297.70 Mg C (+14.90%)

Gain from of new vegetated surface area capable of sequestering carbon across the modeled horizon.

C3 Saltmarsh loss

472.66 ha
raster-mapped area

The salt marsh became a non-counterfactual setting

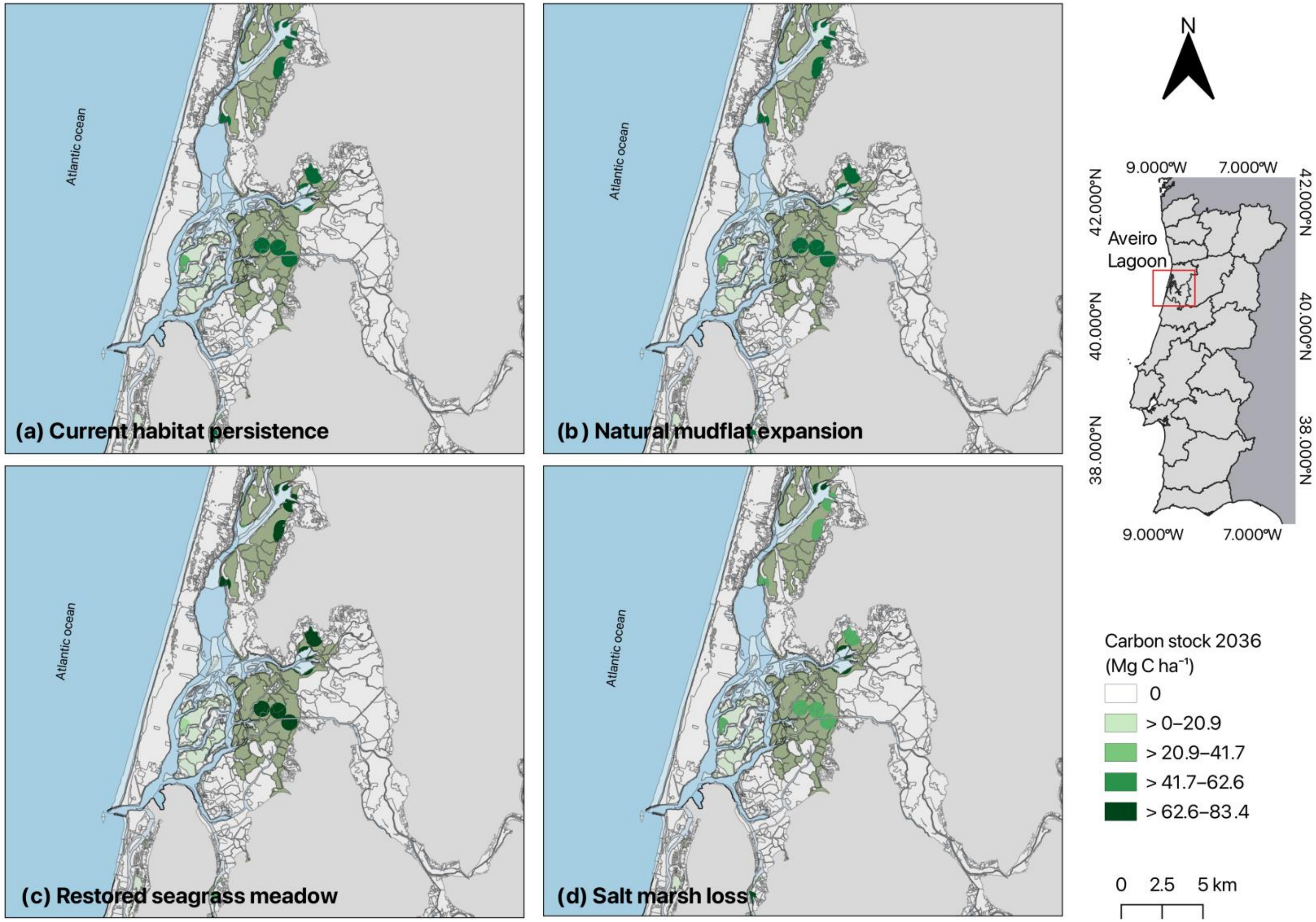
Saltmarsh maintenance / loss

Accumulation: 1,819.45 Mg C
Emissions: 8,088.47 Mg C
Net: −6,269.02 Mg C

This scenario quantifies carbon at risk. The contrast with persistence represents the potential benefit of avoiding salt marsh loss.

RESULTS

How the carbon stock is distributed in 2036



Spatial reading

Scenario 2 maintains/expands areas of higher stock in zones restored with *Zostera noltei* Scenario 1 shows localized losses where salt marsh transitions to mudflat.

Higher contrast

Scenario 3 presents the most evident spatial reduction, especially in the salt marsh areas converted to mudflats.

Map = spatial pattern • Totals = magnitude of the effect

KEY RESULTS ALREADY OBSERVED

Stock 2036 / Net 2026–2036 (Mg C)

	REF	C1	C2	C3
Stock 2036	49,452.58	48,116.39	50,658.59	35,091.86
Net 2026–2036	8,091.68	6,755.50	9,297.70	−6,269.02

RESULTS

KEY RESULTS ALREADY OBSERVED	REF	C1	C2	C3
Stock 2036 / Net 2026–2036 (Mg C)	49,452.58	48,116.39	50,658.59	35,091.86
	8,091.68	6,755.50	9,297.70	−6,269.02

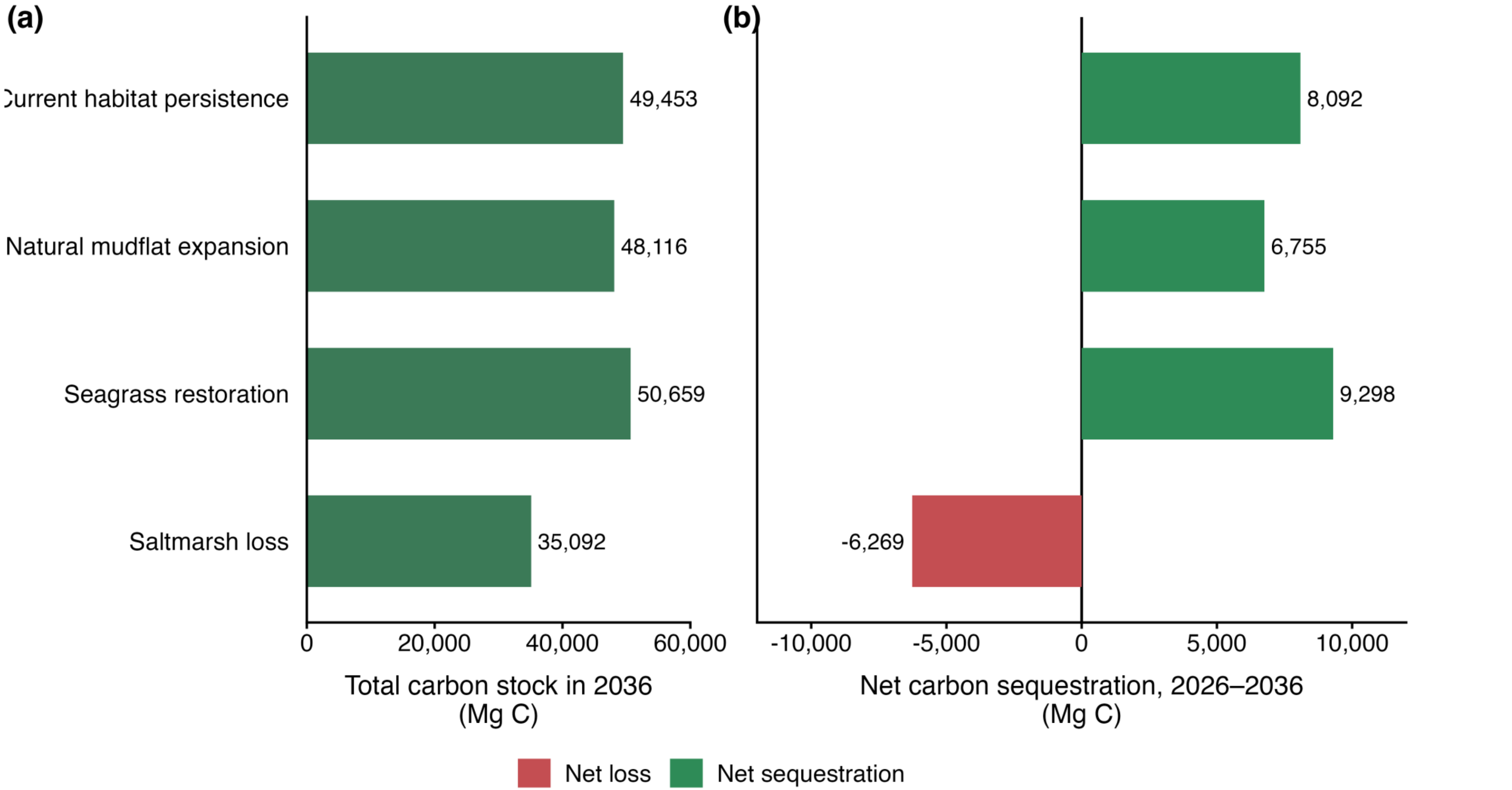


Figure 2. *Projected blue carbon outcomes under the four habitat scenarios in Ria de Aveiro. (a) Total carbon stock in 2036 (Mg C) and (b) net carbon sequestration over the 2026–2036 period (Mg C). Positive values indicate net carbon sequestration, whereas negative values indicate net carbon loss. The scenarios represent current habitat persistence, natural mudflat expansion, seagrass restoration, and saltmarsh loss.*

RESULTS

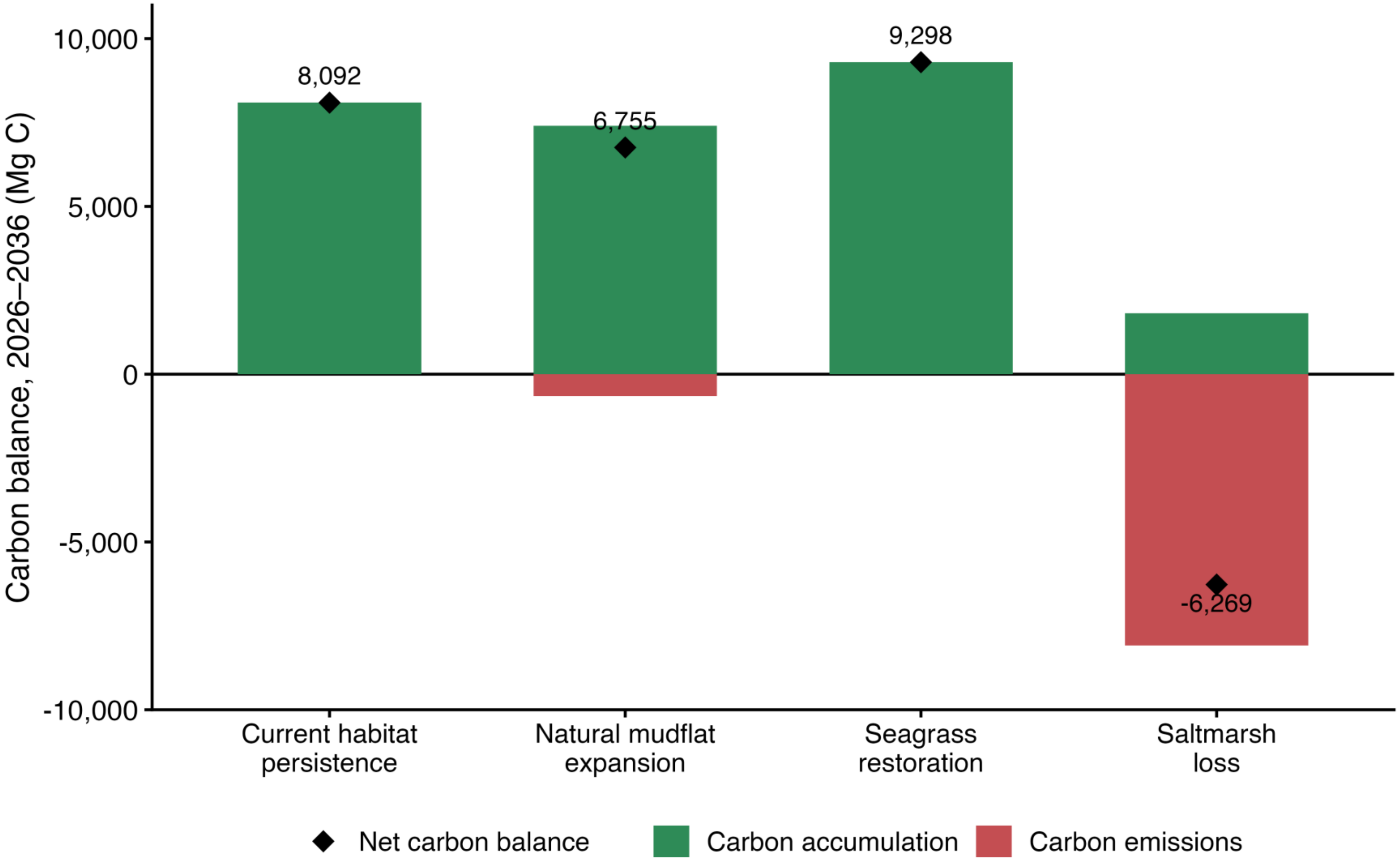


Figure 3. Carbon balance under the four habitat scenarios in Ria de Aveiro for the 2026–2036 period. Green bars represent carbon accumulation, red bars represent carbon emissions associated with habitat transitions, and black diamonds indicate the resulting net carbon balance (Mg C). Positive net values represent carbon sequestration, whereas negative values indicate a net carbon loss.

DISCUSSION

Seagrass restoration increased carbon stocks and net carbon sequestration in 2036 (+2.44% in stocks and +14.90% in net sequestration);

Saltmarsh loss reduced 2036 restoration gain over 10 years. carbon stock by 29% and reversed the carbon balance , and exceeded the modeled

Recommended management: avoid salt marsh loss + targeted restoration of seagrass meadows in ecologically suitable areas.

Maintaining salt marshes offers a significant "avoided carbon" benefit: preventing habitat loss and preserving existing carbon stocks and avoiding emissions resulting from habitat conversion.

Restoration play complementary roles can enhance future carbon sequestration prevents the loss of previously accumulated carbon stocks..

CONCLUSIONS

Co-created future scenarios influence the future trajectory of coastal habitats in the Ria de Aveiro, as well as their carbon stocks and net carbon balance.

Participatory planning combined with tools (SIGS/InVEST) supports restoration prioritization;

The integrated methodology can be used in restoration and management plans for blue carbon habitats;

The combination of participation, GIS, and InVEST can be translated into spatially and ecologically scenarios;

Thank You!

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