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Economic valuation of Mediterranean Ramsar coastal wetlands under conservation and climate change scenarios

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ABSTRACT

This study provides a spatially explicit economic assessment of 133 Ramsar-designated wetlands located within 10 km of the Mediterranean coastline under conservation and climate-induced degradation scenarios. We apply a meta-regression–based benefit transfer framework that combines the value function developed by Ghermandi et al. (2010) with the scarcity-adjusted projection methodology proposed by Brander et al. (2012). The approach estimates site-specific marginal annual ecosystem service values under a 2024 conservation baseline, and projects changes in ecosystem service values to 2050 under a conservation scenario and three alternative degradation scenarios. Two degradation scenarios assume uniform reductions in wetland extent (22.5% and 40%), while a third uses country-specific loss rates that reflect spatial heterogeneity in climate exposure and vulnerability. Results reveal substantial spatial and typological heterogeneity in marginal values and projected ecosystem service value losses. Under all degradation scenarios, marginal per-hectare values increase as wetland area contracts, reflecting scarcity-driven economic adjustments embedded in the valuation function rather than improvements in ecological performance. Aggregate ecosystem service value losses rise with the severity of wetland reduction, shaped by differences in wetland extent, typological composition, and surrounding socio-economic conditions. Robustness analysis confirms that comparative patterns remain structurally stable across alternative central-tendency measures, despite right-skewed value distributions. The findings contribute spatially explicit, policy-relevant insights to support conservation prioritization and strategic restoration planning in Mediterranean Ramsar coastal wetlands, particularly where projected losses in ecosystem service value are most pronounced.

1. Introduction

Coastal wetlands rank among the most productive and multifunctional ecosystems on the planet, delivering critical ecosystem services, including flood regulation, water purification, carbon sequestration, biodiversity support, and recreational benefits. Despite their globally recognized ecological and economic importance and the protection efforts, these ecosystems face mounting pressures from land-use change, urbanization, agricultural expansion, and, increasingly, climate change (Halls, 1997; Schuyt and Brander, 2004; Brander et al., 2024; Costanza et al., 2014). Even Ramsar-designated wetlands – protected under an international conservation framework – are experiencing degradation, raising concerns about the long-term effectiveness of global wetland commitments (Seto et al., 2012; Davidson, 2014; Hu et al., 2017; Xu et al., 2019; Yagmur and Musaoglu, 2020; Nicholls et al., 2021; Secretariat of the Convention on Biological Diversity, 2020; Ramsar Secretariat, 2021; Convention on Wetlands, 2025; Li et al., 2025).

In the Mediterranean Basin, the degradation of coastal wetlands has been particularly severe, driven by extensive land reclamation, hydrological modifications, tourism development, and coastal urban sprawl (EEA, 2015; González del Tánago et al., 2012; Plan Bleu, 2018, 2020). It is estimated that more than 50% of Mediterranean wetlands were lost during the 20th century, and degradation continues today despite international conservation efforts (MedWet Initiative, 2018; Leberger et al., 2020). Over the past two decades, climate change has become a critical compounding threat. The Mediterranean region is a recognized climate change hotspot, warming approximately 20% faster than the global average (MedECC, 2020; IPCC, 2023; Lionello & Scarascia, 2018). According to the IPCC Sixth Assessment Report, the Mediterranean is one of the most affected regions in terms of temperature rise,

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reduced precipitation, and increased frequency of extreme weather events (IPCC, 2023). This warming exacerbates existing environmental stressors, accelerating the degradation of coastal ecosystems, including wetlands. Coastal wetlands are increasingly exposed to sea-level rise, salinization of coastal aquifers, elevated evapotranspiration, and altered precipitation and storm regimes, all of which are accelerating ecosystem decline (Nicholson et al., 2021; Taylor et al., 2021; Blankespoor et al., 2012). Recent modeling studies suggest that, without substantial adaptation efforts, between 69% and 92% of Mediterranean coastal wetlands could be lost by 2100 (Schuerch et al., 2025). At the global scale, mid- to high-emission scenarios project wetland losses of around 28% by the end of the century (Hardouin et al., 2024). Moreover, climate change may trigger fragmentation, reduce wetland resilience, disrupt hydrological connectivity, and erode the capacity of coastal wetlands to deliver ecosystem services (Ji et al., 2025; Fluet-Chouinard et al., 2023).

As wetland extent declines, the marginal economic value of remaining ecosystems may increase due to scarcity effects, even though aggregate ecosystem service provision declines. This mechanism underscores the importance of forward-looking, spatially explicit economic assessments that quantify projected changes in ecosystem service values across alternative climate pathways. Such assessments are particularly relevant in transboundary regions such as the Mediterranean, where ecological processes and governance responsibilities span multiple national jurisdictions.

A growing body of international research has sought to quantify the economic consequences of wetland degradation using diverse valuation paradigms. Ashournejad and Garshasbi (2024) provide a retrospective assessment of changes in ecosystem service values across 77 Ramsar wetlands in West Asia from 1984 to 2021. Using remote-sensing data to track changes in surface-water extent, they estimate aggregate value losses by applying fixed per-hectare ecosystem service coefficients derived from global valuation syntheses. While effective in documenting long-term degradation trends, this area-based accounting approach assumes proportional relationships between surface change and economic value and does not incorporate forward-looking climate scenarios or marginal scarcity adjustments. Kompas et al. (2024) adopt a prospective framework to estimate non-market value losses from sea-level rise and storm surge in Western Australia. Their approach combines projected inundation maps with total economic value coefficients per hectare derived from benefit transfer. Although integrated with physical climate projections, the valuation assumes constant per-hectare values across affected areas, implying linear changes in aggregate ecosystem service values proportional to the reduction in area. The framework does not explicitly model how marginal values adjust as wetlands become scarcer or vary across socioeconomic contexts. Fant et al. (2022) employ a physically explicit marsh-migration model to project wetland transitions under alternative sea-level rise scenarios in the United States. Their valuation is service-specific – primarily focusing on carbon sequestration and flood protection – and relies largely on cost-based and avoided-damage estimates. While this approach enables detailed assessment of physical impacts, it does not estimate aggregated ecosystem service values across multiple services within a unified meta-analytic framework.

Taken together, these studies provide important but methodologically distinct perspectives. Retrospective area-based accounting, constant-coefficient forward projections, and physically explicit service-specific modelling each capture specific dimensions of wetland loss. However, they generally assume proportional relationships between area change and economic value or focus on selected ecosystem services, limiting their capacity to model marginal value adjustments under increasing ecological scarcity.

In contrast, the present study applies a meta-regression–based benefit transfer function that incorporates estimated elasticities of value with respect to wetland size, surrounding wetland abundance, and socioeconomic characteristics. By integrating forward-looking climate scenarios within a marginal valuation framework, our approach captures scarcity effects and non-linear adjustments in ecosystem service values as wetland area declines, while allowing site-level heterogeneity and cross-country comparison within a harmonized Mediterranean-wide setting.

Methodologically, the study is most closely aligned with forward-oriented assessments such as EEA (2010), Brander et al. (2012), and Eppink et al. (2014), which employed meta-analytic benefit transfer functions and spatial scaling-up methodologies to estimate large-scale wetland values under evolving ecological and socioeconomic conditions. While EEA (2010) and Brander et al. (2012) examined climate-induced wetland losses across Europe and Eppink et al. (2014) extended similar approaches to West Asia, the present study adapts and applies this framework within a Mediterranean-wide, site-level, and multi-scenario context.

This study estimates projected economic losses in ecosystem service values associated with reductions in wetland extent across 133 Ramsar-designated coastal wetlands in the Mediterranean Basin. Specifically, we ask: What are the projected changes in ecosystem service values by 2050 relative to a conservation baseline?

The analysis focuses on value changes attributable to reductions in wetland extent, capturing both site-level contraction and changes in surrounding wetland abundance within a 50 km radius. By comparing projected 2050 degradation scenarios with a counterfactual 2050 conservation baseline, in which wetland extent remains constant while socioeconomic drivers evolve, the framework isolates the economic effects of wetland contraction from underlying demographic and income growth.

Methodologically, the study integrates the meta-regression function of Ghermandi et al. (2010), which models per-hectare wetland values as a function of biophysical and socioeconomic drivers, with the scaling logic proposed by Brander et al. (2012) to estimate economic losses under alternative climate-induced reduction scenarios. This spatially explicit approach captures scarcity-driven marginal adjustments as wetland stocks decline, moving beyond proportional area-based accounting. The resulting estimates provide policy-relevant insights for conservation prioritization, ecosystem accounting, and climate adaptation strategies in one of the world's most climate-sensitive regions.

The remainder of the paper is structured as follows. Section 2 describes the study area, data sources, valuation methodology, and climate scenarios. Section 3 presents site-level and national results. Section 4 discusses broader implications, and Section 5 concludes.

2. Materials and methods

2.1. Study area and policy sites

For this exercise, we adopted a broad definition of coastal Ramsar-designated wetlands, including all Ramsar-designated wetlands located within a terrestrial area extending up to 10 km inland from the Mediterranean shoreline, consistent with the European Environment Agency (EEA, 2006) definition of coastal zones. This coastal buffer approach ensures spatial consistency with Ramsar site designations and aligns with previous large-scale wetland valuation efforts (e.g., Brander et al., 2012; Ghermandi et al., 2010). Moreover, the 10-km inland strip captures the ecologically and socio-economically significant transition zone, which is most vulnerable to sea-level rise, salinization, and anthropogenic pressures (Marcos et al., 2016). Based on this definition, we identified 133 Ramsar-designated wetlands situated within the 10-km coastal buffer. The Ramsar Sites Information Service (RSIS) database was accessed and frozen in June 2025 to ensure internal consistency of spatial and socioeconomic inputs across scenarios. Wetlands designated after this date are therefore not included in the analysis. These sites (see Fig. 1) are distributed across 19 Mediterranean countries, encompassing a total surface area of 886,109 ha, and represent a diverse array of wetland typologies, including marine, estuarine, riverine, palustrine, and artificial systems. This ecological diversity

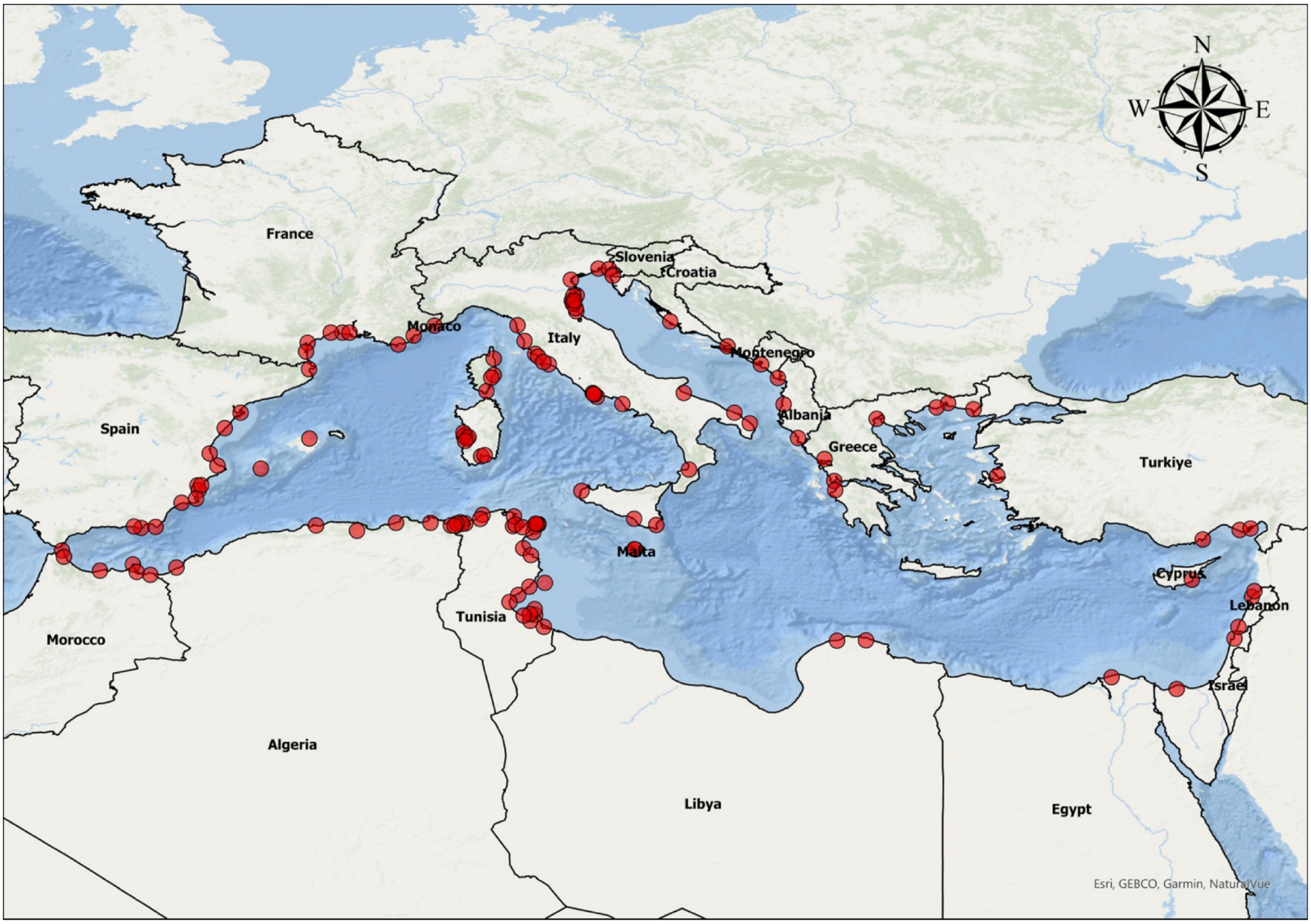

Fig. 1. Geographical distribution of policy sites. Spatial distribution of the 133 Ramsar-designated coastal wetlands included in the assessment across the Mediterranean Basin.

enhances the dataset's representativeness, reflects the complex mosaic of wetland ecosystems across the Mediterranean Basin, and supports the external validity of the valuation exercise. Countries that border the Mediterranean Sea but lack Ramsar sites within this defined coastal buffer, namely Bosnia and Herzegovina, Syria, the United Kingdom (Gibraltar), and Palestine, were excluded from the final site selection.

To assess the sensitivity of the coastal delineation, we replicated the site selection procedure using alternative inland buffers of 5 km and 15

Table 1
Summary of Ramsar Coastal Wetlands by Country and Typology. Overview of the spatial extent, size distribution, number of sites, and typological composition of the 133 Mediterranean Ramsar coastal wetlands included in the assessment.

Country	Total Area (ha)	Mean Area (ha)	Min Area (ha)	Max Area (ha)	wetland sites	Type of wetlands						
						M	I	HM	I-M–HM	I-HM	M–HM	I-M
Albania	33,500	16,750	13,500	20,000	2	1	0	1	0	0	0	1
Algeria	72,243	6567	5	42,100	11	3	0	1	2	2	3	3
Croatia	18,490	9245	5748	12,742	2	0	0	1	0	0	0	0
Cyprus	1107	1107	1107	1107	1	0	1	0	0	0	0	0
Egypt	105,700	52,850	46,200	59,500	2	0	0	2	0	0	0	0
France	151,933	13,812	212	85,000	11	1	1	6	3	3	0	1
Greece	131,039	18,720	6302	33,687	7	0	0	5	0	0	0	0
Israel	66	66	66	66	1	0	0	0	0	0	1	0
Italy	63,559	1718	94	13,500	37	8	3	13	3	3	2	8
Lebanon	1495	498	380	700	3	1	0	1	1	1	0	1
Malta	117	58.5	5	112	2	0	0	0	0	0	1	0
Monaco	23	23	23	23	1	1	0	0	0	0	0	1
Montenegro	1627	813.5	150	1477	2	0	0	0	0	0	0	0
Morocco	28,867	4811	500	14,000	6	2	0	3	1	1	0	2
Slovenia	650	650	650	650	1	0	0	0	0	0	1	0
Spain	64,844	4323	73	20,956	15	0	0	8	0	0	4	0
State of Libya	83	41.5	33	50	2	1	0	0	1	1	0	1
Tunisia	146,274	6360	7	39,266	23	9	2	2	4	4	3	9
Turkey	64,453	16,113	14,700	19,853	4	1	0	0	2	2	0	1

Note: M: Marine, I: Inland; HM:Human-Made; I-M–HM:Inland –Marine – Human-made; M–HM:Marine-Human-made; I-M:Inland-Marin km from the Mediterranean shoreline. The 5 km buffer identifies 111 sites covering 585,446 ha, whereas the 15 km buffer includes 144 sites covering 989,575 ha. Relative to the 10 km baseline (133 sites; 886,109 ha), the narrower buffer excludes approximately 34% of the total wetland area, while the broader buffer increases total area by approximately 12%. This comparison suggests that the 10 km delineation captures the majority of ecologically and socioeconomically relevant coastal wetlands while avoiding excessive inland expansion. A detailed sensitivity assessment is reported in the Supplementary Material.

Table A1 in the Supplementary Material (SM), Section A, presents key information for each policy site. Data obtained from the Ramsar Sites Information Service includes attributes such as extent, location, wetland typology, and ecosystem service categories for each site. Table 1 provides summary statistics disaggregated by country, offering a comprehensive overview of the geographic distribution and ecological diversity of the 133 Ramsar coastal wetlands included in the analysis.

Egypt has the largest average wetland area (approximately 52,850 ha), followed by Greece (18,720 ha) and Albania (16,750 ha). The largest single wetland is in France (85,000 ha), while the smallest is in the Principality of Monaco (23 ha). Italy hosts the most Ramsar sites in the coastal zone (37), followed by Tunisia (23) and Spain (15). By contrast, some countries have only one or two wetlands (e.g., Monaco, Israel, Slovenia, and Malta), which are often tiny and highly specialized ecosystems.

The dataset covers a range of wetland types: Marine (M), Inland (I), Human-made (HM), and combinations of these three: Marine–Inland (M-I), Inland–Human-made (I-HM), Marine–Human-made (M-HM), and Marine–Inland–Human-made (M-I-HM). Italy shows significant diversity in wetland types, with a balanced representation of marine, inland, and human-made wetlands, as well as more complex combinations. Tunisia also stands out for its high functional diversity, with a substantial number of wetlands spanning all categories. Conversely, countries with only a few sites (such as Monaco, Israel, Slovenia, and Malta) tend to have tiny, specialized, and often urban-influenced ecosystems.

Wetland typologies (Marine, Inland, Human-made, and their combinations) follow the official categorization adopted by the Ramsar Secretariat and reported in the RSIS database. The ecosystem service categories presented in Table 2 are derived from standardized service descriptions in Ramsar site documentation and harmonized into four broad groups – regulating, provisioning, cultural, and supporting – for analytical consistency. This harmonized framework enables a systematic comparison of multifunctionality and variation in ecosystem service provision across different wetland typologies.

Table 2
Number of ecosystem service occurrences by wetland typology. Distribution of ecosystem service provision across wetland types, highlighting differences in multifunctionality and ecological roles among Mediterranean Ramsar coastal wetlands.

Type	Sites	Regulating services	Provisioning services	Cultural services	Supporting services
Human Made (HM)	5	9	3	10	1
Inland (I)	7	4	3	9	0
Inland – Human Made (I-HM)	45	18	4	28	2
Marine (M)	28	57	20	44	3
Marine-Human Made (M-HM)	18	30	9	32	3
Marine Inland (M-I)	17	37	9	32	0
Marine – Inland and Human Made (M-I-HM)	43	91	33	82	6

Note: M: Marine, I: Inland; HM: Human-Made; I-M-HM: Inland –Marine- Human made; M-HM: Marine-Human made; I-M: Inland-Marine.

The numbers reveal substantial variation in service provision across wetland typologies, reflecting differences in ecological complexity, human use, and landscape integration (Almeida et al., 2020; UNEP, 2022).

- Mixed systems, particularly those classified as Marine–Inland and Human-made, demonstrate the highest multifunctionality, encompassing 91 regulating, 33 provisioning, 82 cultural, and 6 supporting service categories. This rank underscores their composite structure and their capacity to deliver a broad range of benefits to both ecosystems and people.
- Marine wetlands alone also show a high level of ecosystem service richness, particularly in regulating (57) and cultural services (44), consistent with their role in coastal protection, carbon sequestration, and recreational value.
- Human-made wetlands contribute significantly to cultural services (10) and regulating services (9), but exhibit fewer supporting functions, likely due to their engineered nature and limited support for biodiversity.
- Inland wetlands, while contributing modestly overall, appear especially important for cultural services (9), potentially linked to traditional uses or landscape heritage.
- Categories that combine marine and human-made elements or inland and artificial systems generally show intermediate levels of service diversity, suggesting that anthropogenic influence can both enhance (e.g., recreation) and constrain (e.g., supporting) service provision depending on context.

Generally, more diverse and multifunctional wetlands provide a broader range of ecosystem services. Wetlands combining marine, inland, and artificial elements are among the most productive in terms of ecosystem services, thanks to the variety of functions they support. Marine wetlands offer critical benefits, including supporting fisheries, conserving biodiversity, and regulating water. Artificial (human-made) wetlands play a more limited role: while they can deliver targeted services such as wastewater treatment or flood mitigation, they typically lack the functional richness of natural systems (Almeida et al., 2020; UNEP, 2022). This evidence supports the idea that structural and functional complexity, i.e., wetlands spanning multiple physical and management types, is associated with higher ecosystem service delivery.

2.2. The benefit transfer scaling-up approach

The environmental valuation literature offers a broad range of methods to assess the economic value of both market and nonmarket ecosystem services provided by wetlands (Turner et al., 2000; Brander et al., 2006; Champ, 2017). These include primary valuation methods such as stated-preference techniques (e.g., contingent valuation, choice experiments), revealed-preference approaches (e.g., travel cost, hedonic pricing), cost-based methods, production function models, and hybrid frameworks. While these methods provide robust, site-specific estimates, they are often data-intensive, time-consuming, and costly to implement – especially across large geographic areas or in transboundary policy applications involving numerous wetland sites. This constraint has led to growing interest in secondary valuation methods, particularly the benefit transfer approach. Among these, the scaling-up benefit transfer methodology has gained prominence for its ability to extend site-specific valuation results to broader regional or national contexts. The benefit transfer scaling-up approach extends economic valuations derived from specific sites to a larger geographical area (Brander et al., 2010; Brander et al., 2013; Johnston et al., 2018; Johnston & Bauer, 2020). This exercise is typically performed using a meta-analytic regression function, which synthesizes findings from many primary valuation studies and statistically models the variation in economic values as a function of biophysical, socioeconomic, and methodological characteristics. This approach allows analysts to control for heterogeneity across studies and to produce policy-relevant value functions applicable to a wide range of sites (Rosenberger & Stanley, 2006; Brouwer, 2000; Brouwer & Bateman, 2005; Ready et al., 2004; Kaul et al., 2013; Brander et al., 2013; Johnston et al., 2018; Bockstael et al. 2000; Bateman et al. 2006, 2014; Brander et al. 2012; Rolfe and Wang 2011; Ferrini et al., 2015; Johnston & Wainger, 2015; Schaafsma 2015). Moreover, integrating meta-analytic value functions with spatial datasets via Geographic Information Systems (GIS) enhances the capacity to scale the benefit transfer approach and generate spatially explicit estimates.

In this study, we employed a spatially explicit benefit-transfer scaling-up approach grounded in the meta-regression model of Ghermandi et al. (2010) and the welfare-scaling framework proposed by Brander et al. (2012). Among more than forty wetland valuation meta-analyses published over the past three decades, we selected the specification developed by Ghermandi et al. (2010) as the most suitable for this application. The model satisfies several criteria required for generating reliable, spatially disaggregated, and policy-relevant value estimates. First, it is based on a large and geographically diverse dataset encompassing both natural and artificial wetlands across developed and developing countries, including several Mediterranean cases, thereby enhancing its external validity for the present policy context. Second, the specification incorporates a comprehensive set of spatially explicit biophysical, socioeconomic, and land-use pressure variables, enabling the model to capture heterogeneity across Ramsar-designated coastal wetlands. Third, the availability of standard errors for all estimated coefficients allows the construction of confidence and prediction intervals, thereby accounting for transfer uncertainty (Johnston et al., 2018). Finally, the original study reports extensive diagnostic testing and sensitivity analyses, strengthening confidence in the robustness of the estimated value function. We adopt Model B, identified by Ghermandi et al. (2010) as the best-performing specification (see Table 3). In this formulation, the dependent variable is the natural logarithm of wetland economic value expressed in 2003 USD per hectare per year.

To operationalize such a meta-regression function, we first collected the required input variables for each policy site. Site-level information on wetland characteristics, typologies, and associated ecosystem services was obtained from the official Ramsar Sites Information Service (RSIS) database. Country-level GDP per capita figures were obtained from the World Bank (2024), while spatially explicit site-specific data on population density and wetland area within a 50 km radius were derived from global raster datasets provided by NASA SEDAC (Gridded Population of the World, Version 4 – GPWv4, 2018) and the Global Lakes and Wetlands Database (GLWD v2; Lehner et al., 2025), respectively. These datasets were processed using Geographic Information Systems (GIS), employing the Zonal Statistics and Summarize Within tools of ArcGIS. Values for the human pressure variable were assessed using the criteria of Ghermandi et al. (2010).

Subsequently, we applied the meta-regression function, plugging in the site-specific values of each explanatory variable to predict values for the 2024 conservation scenario. Marginal per-hectare annual values were predicted by summing the products of each regression coefficient

Table 3
Estimates of the meta-regression function. Model B (Ghermandi et al. 2010). Estimated parameters of the benefit-transfer function applied to derive site-level marginal ecosystem service values across Mediterranean coastal wetlands.

Variable	Meaning	Units and measurement	Coefficient	Standard Error
nYP	Year of publication	Number of years since first valuation (1974)	−0.041	0.016
Marginal	Marginal	Binary (range: 0 or 1)	0.713	0.338
T1	Estuarine	Binary (range: 0 or 1)	0.27	0.288
T2	Marine	Binary (range: 0 or 1)	0.754	0.280
T3	Riverine	Binary (range: 0 or 1)	0.38	0.257
T4	Palustrine	Binary (range: 0 or 1)	−0.48	0.271
T5	Lacustrine	Binary (range: 0 or 1)	0.332	0.268
T6	Human-made	Binary (range: 0 or 1)	1.023	0.403
Wsize	Wetland size (ln)	Natural log of hectares	−0.234	0.040
ES1	Flood control, storm buffering	Binary (range: 0 or 1)	0.432	0.329
ES2	Surface and groundwater supply	Binary (range: 0 or 1)	−0.099	0.334
ES3	Water quality improvement	Binary (range: 0 or 1)	0.727	0.332
ES4	Commercial fishing and hunting	Binary (range: 0 or 1)	0.266	0.253
ES5	Recreational fishing	Binary (range: 0 or 1)	−1.007	0.334
ES6	Recreational hunting	Binary (range: 0 or 1)	−0.082	0.349
ES7	Harvesting of natural materials	Binary (range: 0 or 1)	−0.202	0.286
ES8	Fuel wood	Binary (range: 0 or 1)	−0.968	0.416
ES9	Nonconsumptive recreation	Binary (range: 0 or 1)	0.67	0.303
ES10	Amenity and aesthetics	Binary (range: 0 or 1)	0.529	0.392
ES11	Natural habitat, biodiversity	Binary (range: 0 or 1)	1.143	0.330
PH-ml	Medium-low human pressure	Binary (range: 0 or 1)	0.572	0.256
PH-mh	Medium-high human pressure	Binary (range: 0 or 1)	1.243	0.358
PH-h	High human pressure	Binary (range: 0 or 1)	1.992	0.500
GDP per capita	GDP per capita (ln)	Natural log of 2024 dollars (PPP)	0.358	0.110
Pop50Km	Population in 50 km radius (ln)	Natural log of inhabitants in 50 km radius	0.399	0.073
Wet50km	Wetland area in 50 km radius (ln)	Natural log of hectares in 50 km radius	−0.058	0.035
Constant	Constant		−0.681	1.652
R^2	0,47			
Adjusted R^2	0,44			

and the corresponding variable value for the site, then exponentiating the resulting sum to return values in level form, consistent with the semi-log functional form used in Ghermandi et al. (2010).[1] The predicted point marginal unit values were then adjusted to 2024 USD using a GDP deflator-based conversion factor of 1.7, ensuring that all monetary estimates are expressed in constant prices for comparability and policy relevance.[2] The projections should therefore be interpreted as conditional scenario-based estimates rather than probabilistic forecasts, as they assume structural stability of the meta-regression elasticities over time.

The methodological framework proposed by Brander et al. (2012) extends the initial calculations conducted under the 2024 conservation scenario by introducing additional steps to estimate ecosystem service value losses in 2050 resulting from projected changes in wetland extent under three climate change-induced scenarios.

First, we projected the baseline 2024 conservation scenario to a 2050 conservation scenario by updating two key explanatory variables in the meta-regression function developed by Ghermandi et al. (2010): GDP per capita and population density within a 50 km radius of each wetland site. These forward-projected values were substituted into the meta-regression equation to generate updated predictions of the log-transformed marginal per-hectare-per-year values. The resulting estimates were then exponentiated to derive the marginal unit values per hectare for each site in the 2050 conservation scenario. These values, denoted as V_{i0}, represent the projected annual economic values of wetland ecosystem services in the 2050 conservation scenario, assuming no climate-induced reductions in wetland area.

Next, we applied the same computational procedure to each of the three climate change scenarios projected for 2050. In this step, two additional variables − wetland area (i.e., the surface area of each site) and wetland abundance within a 50 km radius − were adjusted to reflect anticipated losses due to climate change. These adjustments were made using either uniform reduction rates of 22.5% and 40%, corresponding to moderate and severe climate impact scenarios, or country-specific reduction factors derived from regional vulnerability assessments.

Projected economic losses in ecosystem service values are estimated by comparing site-level values under each 2050 degradation scenario with a 2050 conservation baseline in which wetland extent remains unchanged relative to 2024, while socioeconomic drivers are updated. This counterfactual framework isolates the economic effect of wetland area contraction from underlying demographic and income growth.

After obtaining the marginal values for each site under both the 2050 conservation scenario (V_{i0}) and the 2050 climate scenarios (V_{ij}), we estimated the total annual ecosystem service value loss for each site i under each scenario j using the following formula, adapted from Brander et al. (2012):

$$WL_{ij} = \Delta A_{i0j} \bullet \frac{V_{i0} + V_{ij}}{2}$$

where:

$i = 1, 2, \ldots 133$ denotes each Ramsar site,

$j = 1, 2, 3$, indexes the three loss scenarios (22.5%, 40% and tailored country-specific),

$\Delta A_{i0j} = A_{i0} - A_{ij}$ is the change in wetland area between the 2050 conservation baseline and the scenario j,

V_{i0} is the marginal value per hectare per year under the 2050 conservation scenario,

V_{ji} is the marginal value per hectare per year under the 2050 climate scenario j.

Hereafter, WL_{ij} denotes the annual ecosystem service value loss associated with projected reductions in wetland extent under scenario j, relative to the 2050 conservation baseline.

This formula accounts for the nonlinear relationship between scarcity and value, as marginal values tend to rise when ecosystems become rarer, even as total service provision declines. The semi-log functional form implies that marginal unit values respond nonlinearly to changes in wetland extent: as wetland area declines, the marginal value per remaining hectare increases, reflecting scarcity effects embedded in the meta-regression specification. This adjustment mechanism captures economic marginal responses rather than improvements in ecological performance. Importantly, the increase in marginal unit values under degradation scenarios does not imply higher total ecosystem service provision. Aggregate ecosystem service flows decline as wetland area contracts; the escalation of per-hectare values reflects the rising marginal importance of the remaining stock.

The result is a site- and scenario-specific estimate of the total annual loss of ecosystem service values by 2050, corresponding to projected reductions in wetland stocks under the three climate change scenarios described below.

Two alternative but equivalent approaches can be used to estimate marginal annual unit values under scenarios 1 and 2. The first approach requires entering the reduction in wetland area (*Wsize*) and total wetland area within a 50 km buffer (*Wet50km*) variables for each policy site into the meta-regression function, and then directly applying the formula suggested by Brander et al. (2012) and described earlier. In this study, we adopted an alternative yet equivalent approach, whereby site-specific annual unit values were adjusted using scenario-specific factors (AF_j) derived from the following expression:

$$\exp = \{[\ln(1) - \ln(x)][0.234 + 0.058]\}$$

where:

x is the complement to unity (x = 1–x) and represents the percentage of wetland area remaining after the supposed reduction in scenario RCP4.5 or in scenario RCP8.5

0.234 is the absolute value of the coefficient for the variable *Wsize,* indicating the natural logarithm of wetland area in a 50 km radius;

0.058 is the absolute value of the coefficient for the variable *Wet50km* representing the natural logarithm of wetland area in a 50 km radius.

In the first scenario, in which $x = 0.775$, AF_1 is equal to 1.08. In the second scenario, in which $x = 0.60$, AF_2 is equal to 1.16. In the third scenario, in which x is varied in relation to the percentage reductions in wetland extent by country, we have several AF_3.

Fig. 3 presents the estimated AF_3 values, whereas Fig. 2 provides a schematic overview of the analytical framework and sequential steps used to assess ecosystem service value losses.

[1] We are aware that in log-linear *meta*-regression models, retransformation from logarithmic to level scale should include a correction for bias caused by the log-normal distribution of the error term. Following Johnston & Wainger (2015, p. 266), the predicted annual marginal value per hectare should be calculated by adding in the power of the exponential a correction factor represented by the half value of the residual variance (see Johnston & Wainger (2015), formula 12.10, page 266. Not having any information on residual variance, we were forced to omit this correction. Consequently, all values are systematically underestimated.

[2] We also predicted 95% confidence interval for each unit value using the delta method (Wooldridge J. M., 2010), assuming the log-linear model and a constant standard error of the predicted log-value. In the absence of site-specific prediction errors or reported residual variance from the original *meta*-regression model, we adopted a constant standard error of 0.35 for the log-transformed monetary estimates. This value is consistent with those reported in prior wetland *meta*-analyses using semi-log or log-linear specifications, where standard errors for the dependent variable typically range between 0.30 and 0.40 (Brander et al., 2013; Ghermandi et al., 2010; Brouwer et al., 1999; Kaul et al., 2013). This approach ensures a conservative estimation of uncertainty, aligning with standard practice in benefit transfer literature when full model variance–covariance structures are not available (Johnston et al., 2015).

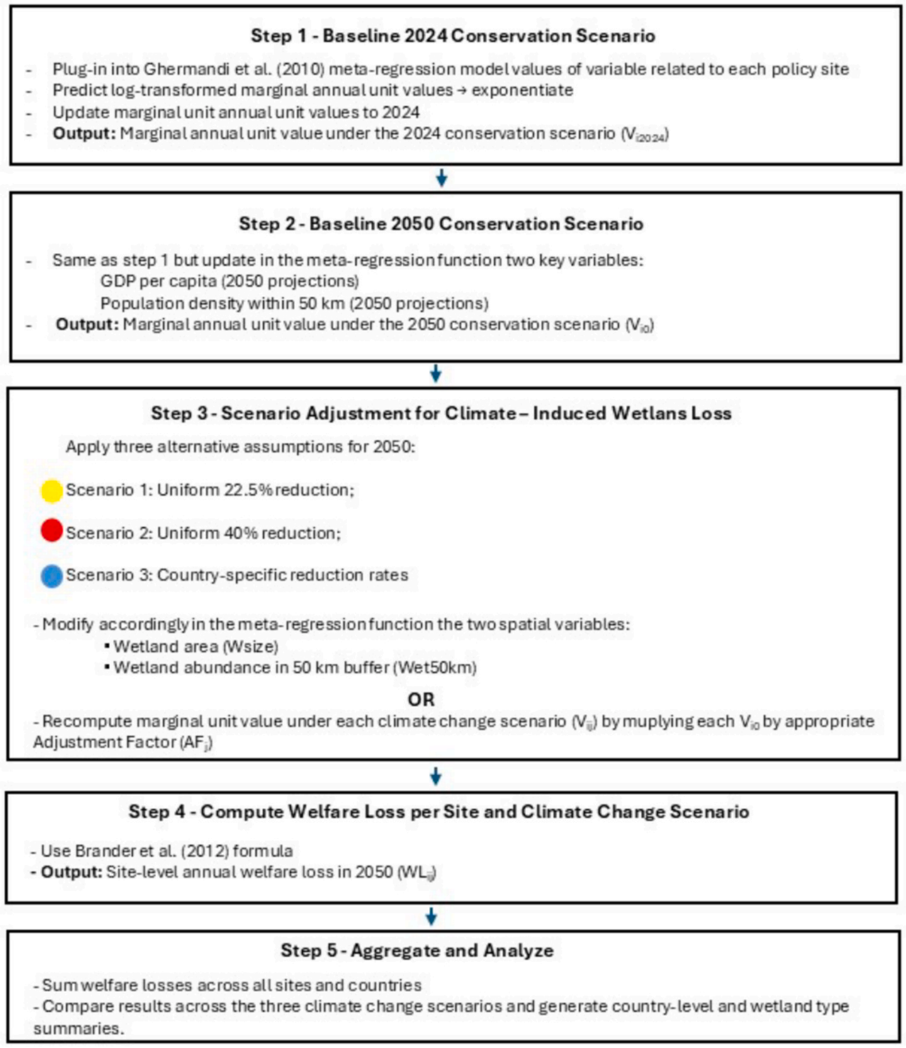

Fig. 2. Analytical workflow for estimating ecosystem service value losses. Overview of the methodological steps used to estimate current ecosystem service values and project changes under alternative climate-induced degradation scenarios.

2.3. Climate change scenarios

To assess projected ecosystem service value losses in 2050 relative to a conservation baseline, we developed three climate change scenarios reflecting varying degrees of impact and spatial differentiation:

- Scenario 1: Moderate Uniform Reduction (RCP4.5). This scenario is based on Representative Concentration Pathway 4.5 (RCP4.5), which assumes moderate greenhouse gas mitigation and stabilization by the end of the century (Thomson et al., 2011; Barredo et al., 2017; Van Vuuren et al., 2011). It represents a plausible future in which emissions peak around 2040 and subsequently decline. Under RCP4.5, climate-driven pressures such as moderate sea-level rise, changes in precipitation patterns, and hydrological stress are projected to reduce wetland functionality and extent. Based on projections from Taylor et al. (2021) and Hardouin et al. (2024), a uniform 22.5% reduction in wetland area was applied to all sites. This percentage reflects basin-wide expectations under moderate climate impact trajectories.
- Scenario 2: High-Impact Uniform Reduction (RCP8.5). This scenario reflects a more severe climate pathway aligned with Representative Concentration Pathway 8.5 (RCP8.5), which assumes continued growth in greenhouse gas emissions throughout the century (Riahi et al., 2011). RCP8.5 implies higher temperature increases, accelerated sea-level rise, and more intense climatic disruptions. According to Hardouin et al. (2024), vulnerable wetland systems may experience losses of 30%-50% under this trajectory. Accordingly, we applied a uniform 40% reduction in wetland extent across all sites. This scenario captures the potential economic impacts on ecosystem service values under limited climate mitigation and higher exposure conditions.
- Scenario 3: Country-Specific Reduction (country-specific reduction scenario). This scenario introduces spatial differentiation by assigning country-specific wetland loss rates derived from a structured synthesis of recent peer-reviewed studies assessing projected climate impacts on Mediterranean coastal wetlands (e.g., Schuerch et al., 2025; Lefebvre et al., 2019; Estrela-Segrelles et al., 2021; Taylor et al., 2021). Rather than applying a uniform percentage across all sites, the assigned reduction rates reflect the range of loss magnitudes reported in the literature for different Mediterranean subregions under comparable climate trajectories. The resulting percentages represent literature-informed scenario assumptions rather than probabilistic or site-specific dynamic modelling outputs. Consistent with the macro-scale scope of the meta-analytic benefit transfer framework adopted in this study, the objective is not to generate physical projections of wetland loss at the site level, but to construct internally coherent and scenario-consistent reduction parameters suitable for basin-wide economic scaling. This country-

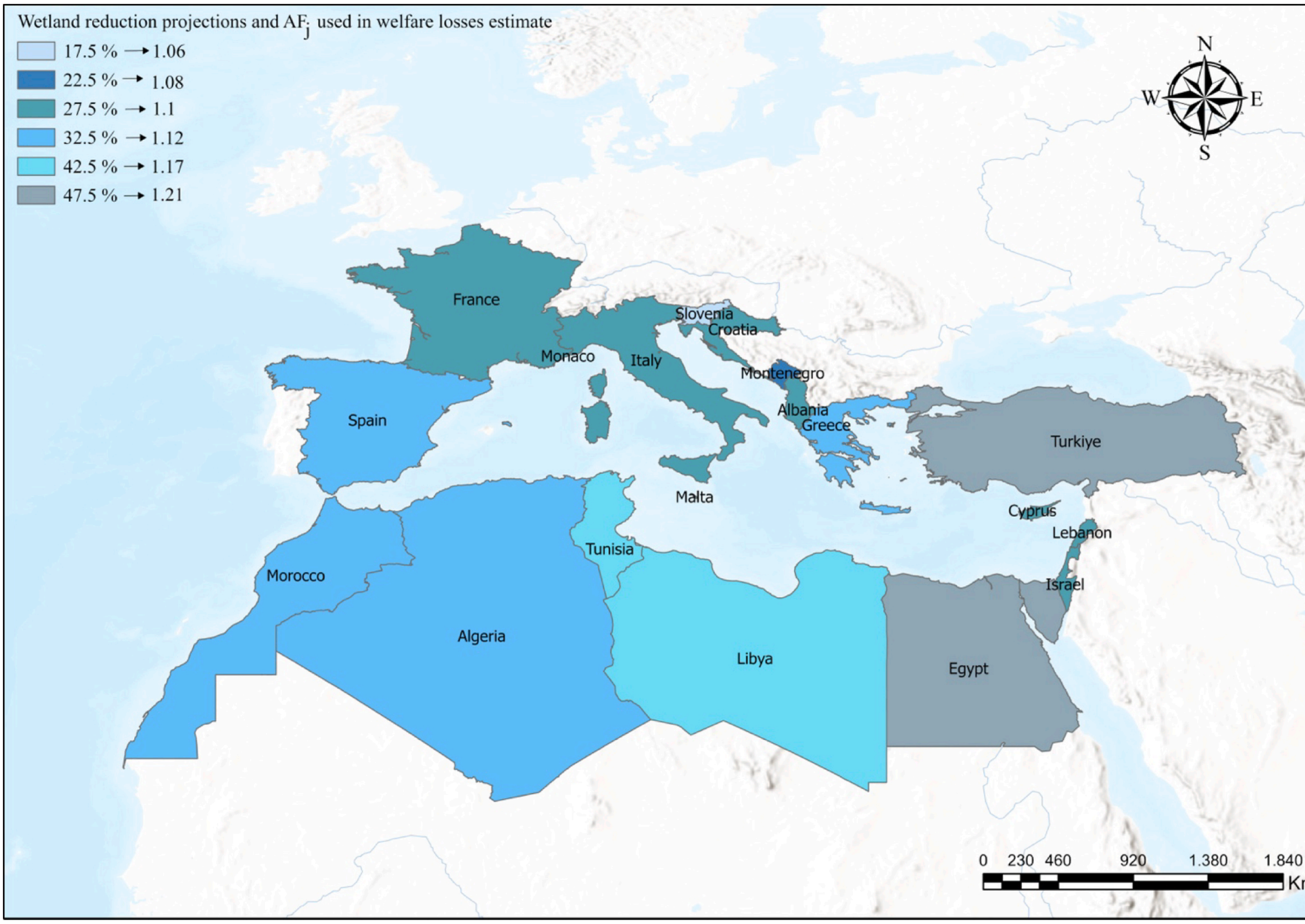

Fig. 3. Country-specific wetland loss rates and corresponding adjustment factors used for economic scaling. Illustration of projected wetland loss rates by country and the corresponding adjustment factors applied to scale ecosystem service values under climate scenarios.

specific reduction scenario allows the value-loss assessment to reflect spatial heterogeneity in projected wetland decline across the Mediterranean Basin while maintaining methodological consistency with the scaling-up benefit-transfer approach.

Together, these three scenarios capture a range of plausible trajectories for wetland loss in the Mediterranean Basin, incorporating both uniform and spatially differentiated assumptions, and support a structured sensitivity analysis of projected losses in ecosystem service values under alternative climate conditions.

Fig. 3 presents the country-specific wetland loss rates and corresponding adjustment factors used for economic scaling. Reduction rates were assigned within the loss intervals reported in the referenced studies under comparable climate trajectories. These values represent scenario-consistent assumptions employed for macro-scale economic scaling and do not constitute site-specific physical projections of wetland loss. The corresponding adjustment factors are used to scale site-level values in accordance with country-level vulnerability patterns discussed in the referenced studies, including differences in coastal exposure, aridity gradients, and anthropogenic pressure. For all three 2050 scenarios, changes in wetland extent were integrated into the scaling-up benefit transfer model by updating two key spatial variables: site-specific wetland area (*Wsize*) and total wetland coverage within a 50 km buffer (*Wet50km*). These updates, based on uniform or country-specific reduction assumptions, allow the model to account for the spatially explicit effects of wetland degradation on ecosystem service values. This specification captures both within-site area reduction and changes in surrounding wetland abundance, allowing the model to account for regional scarcity effects operating at multiple spatial scales.

To complement the main analysis, additional robustness and distributional diagnostics were performed.

To ensure the stability of comparative results across scenarios, we conducted a set of robustness and distributional diagnostics covering the 2024 baseline, the 2050 conservation projection, and the three degradation scenarios. For each case, alternative aggregation measures—including the mean, median, 10% trimmed mean, and 10% winsorized mean—were computed at the site, country, and wetland typology levels. Ranking stability was evaluated using Spearman rank correlations between mean- and median-based country and typology orderings. Distributional asymmetry was further assessed through bootstrap confidence intervals (2000 replications) for mean–median differences. Detailed results are reported in the Supplementary Material (Sections B and C).

3. Results

Fig. 4 illustrates the projected wetland extents (in hectares) by 2050 under the three predefined climate change scenarios. The first scenario applies a uniform 22.5% reduction in wetland surface, the second assumes a 40% uniform reduction, and the third introduces differentiated country-specific loss rates. The figure clearly shows how the magnitude of wetland contraction varies across the Mediterranean Basin and across scenario assumptions.

Under both uniform scenarios, reductions occur proportionally across all countries, generating a mechanically consistent contraction of wetland area. By contrast, the country-specific scenario produces a more

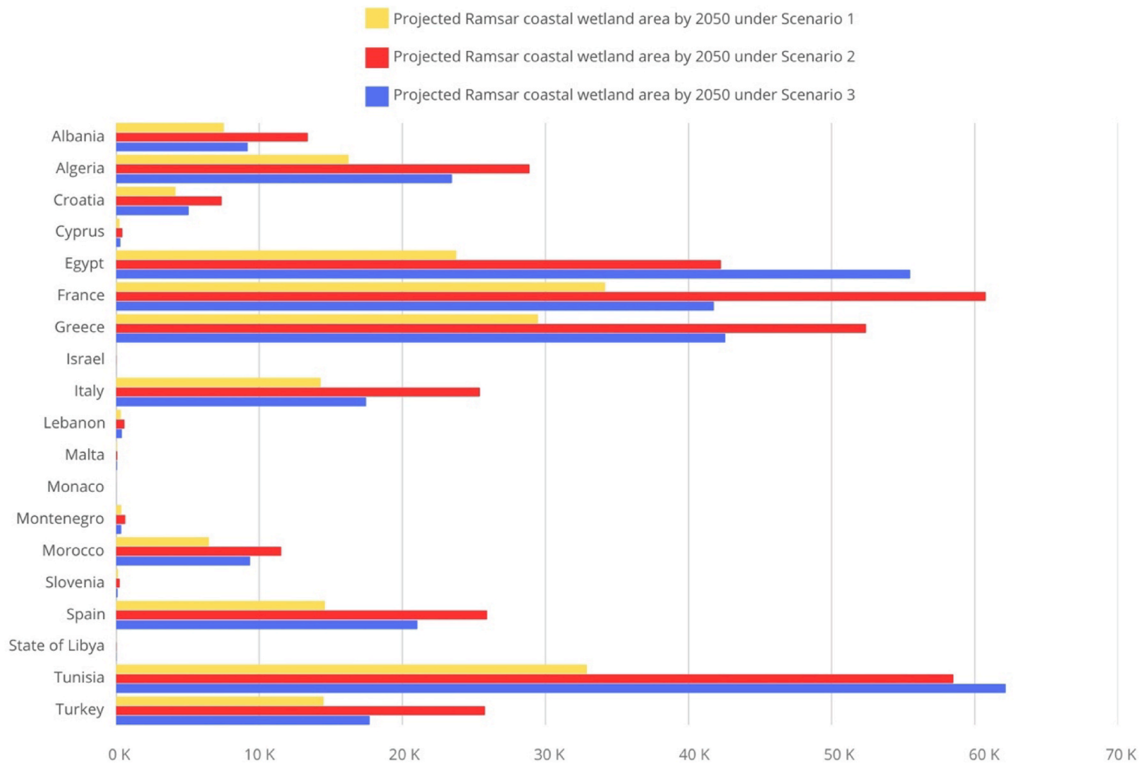

Fig. 4. Projected wetland extent in 2050 under the climate change scenario (hectares). Estimated changes in total wetland area by 2050 under the considered climate-induced degradation pathways.

differentiated spatial pattern that reflects heterogeneous national exposure to sea-level rise, hydrological stress, land-use pressure, and adaptive capacity. Tunisia, France, Greece, Egypt, and Algeria experience the largest absolute reductions in wetland extent across scenarios. Tunisia exceeds 62,000 ha of projected loss under the country-specific scenario, reflecting both the scale of its coastal wetlands and their exposure to climatic stressors. France records losses exceeding 60,000 ha under the 40% scenario, while Egypt exhibits a marked escalation from approximately 23,800 ha under the moderate scenario to more than 55,000 ha under the country-specific reduction scenario. Italy falls within the mid-to-high range, with projected reductions of approximately 14,300 to 25,400 ha, depending on the scenario. Conversely, countries such as Monaco, Malta, Israel, Slovenia, and Cyprus display relatively small absolute reductions, largely reflecting the limited size of their wetland systems rather than intrinsic ecological resilience.

Spain and Turkey show intermediate yet substantial losses, amounting to approximately 26,000 ha each under Scenario 2. Morocco and Algeria display similar upward trends, indicating heightened vulnerability to climate change, potentially linked to existing water scarcity and anthropogenic pressures.

Table A2 in the SM, Section A, provides the estimated marginal unit values (per hectare per year) for each of the 133 policy sites. These values, expressed in 2024 USD, are shown across five scenarios: the 2024 baseline conservation scenario, the projected 2050 conservation scenario, and three climate change scenarios reflecting varying levels of wetland loss (moderate, high-impact, and country-specific degradation). For the 2024 baseline, we also provided site-level 95% confidence intervals to reflect uncertainty around the predicted values. In the SM, Tables A3–A5 provide a detailed comparative overview of how marginal unit annual wetland values and welfare losses vary across space and wetland typology, and how they evolve under different assumptions about ecological and socioeconomic change.

Table 4 presents descriptive statistics of marginal annual ecosystem service values for the 2024 conservation baseline, the projected 2050 conservation scenario, and the three climate-induced degradation scenarios. All statistics are based on the full sample of 133 wetlands to ensure strict comparability across scenarios.

Table 4
Statistics of marginal unit annual values across scenarios, expressed in 2024 USD/ha/year. Summary statistics of projected site-level marginal ecosystem service values under current conservation conditions and alternative climate-induced degradation scenarios.

Scenario	Statistics				
	Mean	Median	Min	Max	Std. Dev.
2024 Conservation scenario	46,831	21,482	64	440,765	67,304
2050 Conservation scenario	165,437	81,953	572	1,490,018	234,188
First climate change scenario (22.5% reduction)	181,188	89,308	1345	1,609,220	256,660
Second climate change scenario (40% reduction)	196,874	99,103	3337	1,728,421	275,052
Third climate change scenario (custom reduction)	185,441	95,343	54	1,639,020	262,196

A first clear pattern concerns the systematic escalation of marginal unit values as wetland scarcity intensifies. The mean marginal value increases from 46,831 USD/ha/year under the 2024 conservation baseline to 165,437 USD/ha/year under the 2050 conservation scenario. This corresponds to an increase of approximately 253%, driven exclusively by projected socioeconomic growth (GDP per capita and surrounding population density) while holding wetland extent constant. When climate-induced area reductions are introduced, mean values rise further to 181,188 USD/ha/year under the 22.5% reduction scenario (+9.5% relative to 2050 conservation), 196,874 USD/ha/year under the

40% reduction scenario (+19.0% relative to 2050 conservation), and 185,441 USD/ha/year under the country-specific scenario (+12.1% relative to 2050 conservation). These percentage increases confirm the nonlinear scarcity mechanism embedded in the semi-log meta-regression specification: as wetland stocks contract, marginal per-hectare values increase at an accelerating rate. Importantly, this escalation reflects rising marginal economic intensity rather than improvements in ecological performance. Total ecosystem service provision declines as area contracts; the increase in unit values captures scarcity rents associated with diminishing natural capital stocks.

A second structural feature concerns distributional asymmetry. Across all scenarios, mean values substantially exceed medians, indicating persistent right-skewness. In the baseline year, the median (21,482 USD/ha/year) is approximately 54% lower than the mean. Under the 40% reduction scenario, the median (99,103 USD/ha/year) remains roughly 50% below the mean. This stability in the mean–median gap across scenarios suggests that skewness reflects structural heterogeneity in wetland portfolios rather than isolated outliers.

Third, dispersion increases markedly with scenario severity. The standard deviation rises from 67,304 USD/ha/year in the 2024 baseline to 234,188 USD/ha/year under the 2050 conservation projection, and further to 275,052 USD/ha/year under the 40% reduction scenario. This widening dispersion reflects increasing heterogeneity in marginal economic responses as scarcity intensifies, with wetlands embedded in densely populated and high-income coastal regions experiencing disproportionately stronger value amplification.

The upper bound illustrates this amplification effect: the maximum marginal value increases from 440,765 USD/ha/year in the baseline to 1,728,421 USD/ha/year under the 40% reduction scenario. Such extreme values are economically interpretable within the scarcity framework, characterizing wetlands combining high ecological multifunctionality with strong socioeconomic embedding.

Overall, the descriptive statistics reveal three coherent structural properties of the valuation framework: (i) scarcity-driven escalation of marginal values; (ii) persistent right-skewed distributions reflecting ecological and socioeconomic heterogeneity; and (iii) increasing dispersion under more severe degradation pathways.

The robustness analysis reported in the Supplementary Material (Section B) confirms that distributional asymmetry does not alter comparative conclusions. Detailed diagnostics are presented at the end of this section. Spearman rank correlations between mean-based and median-based rankings remain very high at the country level (ρ consistently above 0.90 across scenarios) and high at the typology level, indicating strong ordinal stability despite distributional asymmetry. Accordingly, cross-country and cross-typology comparisons are structurally robust to alternative aggregation measures.

These empirical patterns are fully consistent with the theoretical properties of the semi-log meta-regression specification and provide the quantitative foundation for the aggregate ecosystem service value loss estimates presented in subsequent sections.

In addition to their internal consistency and theoretical coherence, the magnitude of the baseline estimates is also externally plausible when benchmarked against the broader valuation literature. Brander et al. (2024), drawing on the Ecosystem Service Valuation Database (ESVD), report global average annual values for coastal wetlands of approximately 41,740 USD/ha/year (adjusted to 2024 values). Our baseline mean of 46,831 USD/ha/year lies close to this benchmark and slightly above the global average, consistent with the ecological richness, multifunctionality, and socioeconomic pressures characterizing many Mediterranean coastal wetlands. Overall, this benchmarking exercise suggests that the estimated marginal values are empirically grounded within the range documented in large-scale global meta-analytic assessments.

Having established the internal consistency and external plausibility of the baseline estimates, we now turn to their spatial distribution across Mediterranean countries. Fig. 5 presents a Voronoi mosaic chart illustrating the spatial distribution of average marginal annual unit values under the 2024 conservation scenario. Each polygonal cell represents a Mediterranean country included in the analysis. The size of each cell is scaled proportionally to the country's average marginal unit value, calculated as the mean of all site-level estimates within that national territory. The color gradient, from light to dark blue, reflects the number of wetlands assessed per country, with darker shades corresponding to countries with more designated Ramsar coastal sites. This dual encoding effectively captures both the economic intensity (via average unit value) and wetland representation (via site count), offering a concise visual summary of spatial disparities in ecosystem service valuation across the Mediterranean Basin.

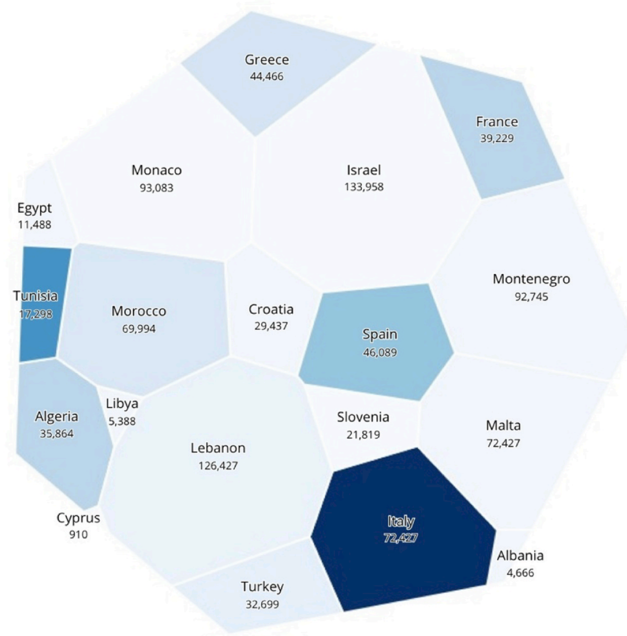

Fig. 5. Average marginal values of Ramsar coastal wetlands by countries, expressed in 2024 USD/ha/year. Country-level mean marginal annual ecosystem service values under current conservation conditions.

The analysis shows pronounced cross-country variability in marginal unit values. Israel stands out with the highest average value across all countries, exceeding 133,000 USD/ha/year, despite hosting a limited number of sites. This result suggests a high concentration of economic value per site, likely reflecting the ecological uniqueness or strategic functional importance of its wetlands.

Lebanon and Monaco also report notably high average values, approximately 126,000 USD/ha/year and 93,000 USD/ha/year, respectively, demonstrating that even a small number of ecologically significant or highly productive wetland sites can contribute disproportionately to a country's overall ecosystem service value.

Italy, which accounts for the most significant number of Ramsar coastal wetlands in the dataset (37 sites), has an average value of around 72,800 USD/ha/year. While this is lower than that of the top-ranking countries, it still represents a robust national valuation and reflects the breadth of Italy's wetland network. Comparable values are observed in Malta (72,000 USD/ha/year) and Montenegro (92,700 USD/ha/year), while other countries, such as France and Greece, report more moderate averages, ranging between 39,000 USD/ha/year and 44,000 USD/ha/year.

At the lower end of the distribution are countries such as Cyprus, Albania, Libya, and Egypt, with average values of approximately 910 USD/ha/year, 4666 USD/ha/year, 5388 USD/ha/year, and 11,488 USD/ha/year, respectively. These figures may reflect a combination of limited wetland extent, lower ecosystem service productivity, or possible data limitations in the underlying model inputs. Overall, the results highlight a clear divide between countries with relatively high-value, low-frequency wetland sites and those with broad but lower-value networks. Such results underscore the importance of ecological quality, landscape context, and site-level management in shaping the economic value of wetland ecosystems. It also reinforces the need for tailored conservation strategies that recognize both the scarcity and strategic value of specific high-performing sites.

To assess whether country-level comparisons are sensitive to distributional asymmetry, we computed median, trimmed, and winsorized estimators (see Section B in the SM). The ordinal ranking of countries remains highly stable across aggregation methods. Spearman rank correlations between mean- and median-based country rankings exceed 0.9 across all scenarios (Table A4), indicating strong monotonic association. Trimmed and winsorized means closely track conventional means, confirming that cross-country differences are not driven by isolated extreme values.

Fig. 6 presents a radial chart showing the hierarchical distribution of the average marginal annual unit values for different wetland types (expressed in 2024 USD/ha/year) by country. The chart's concentric layers represent two levels of aggregation: the inner ring displays the national-level average values. At the same time, the outer segments correspond to the values for individual wetland typologies in each country. This visual structure facilitates an intuitive comparison of both within-country heterogeneity (by wetland type) and between-country differences in the economic valuation of wetland ecosystem services throughout the Mediterranean Basin. To aid interpretation, each outer-ring segment is labeled with its corresponding average value, rounded to the nearest thousand USD/ha/year (e.g., "72 K" indicates 72,000 USD/ha/year in 2024). This format highlights national valuation profiles and the relative contribution of different wetland types to each country's overall economic value estimates.

The analysis of annual unit values in the 2024 conservation scenario (expressed in 2024 USD) reveals marked differentiation across wetland typologies, highlighting the influence of ecological complexity and management intensity on economic valuation outcomes.

Wetlands classified as M_I_H-M, those combining marine, inland, and human-made components, record the highest average annual unit values across the Mediterranean Basin. These multifunctional systems provide a broad suite of ecosystem services, including water regulation, carbon sequestration, biodiversity conservation, and recreational or tourism benefits. For example, the "Trapani and Paceco salt ponds" (Italy) exhibit a marginal value exceeding 440,000 USD/ha/year, among the highest in the dataset, and the "Tyre Coast Nature Reserve" (Lebanon), also categorized as M_I_H-M, reaches nearly 250,000 USD/ha/year per hectare.

In contrast, single-category wetlands (e.g., M for marine, I for inland, or H-M for human-made) generally show lower average values, though with important exceptions, such as the "Reserve Naturelle du Lac de Réghaïa" (Algeria), classified as M_I, whose unit annual value exceeds 100,000 USD/ha/year, and the "Evros Delta" (Greece). This large and ecologically significant M_I_H-M wetland is valued at more than 130,000 USD/ha/year.

These examples underscore that wetland typology alone does not fully explain economic variation—site-specific attributes such as area size, location, protection level, and anthropogenic pressures also significantly influence valuation.

High intra-type variability is another notable trend. For example, among marine (M) wetlands, values range from under 5000 USD/ha/year (e.g., "Karavasta Lagoon" in Albania) to over 80,000 USD/ha/year (e.g., "Palm Islands" in Lebanon). Such variability reinforces the

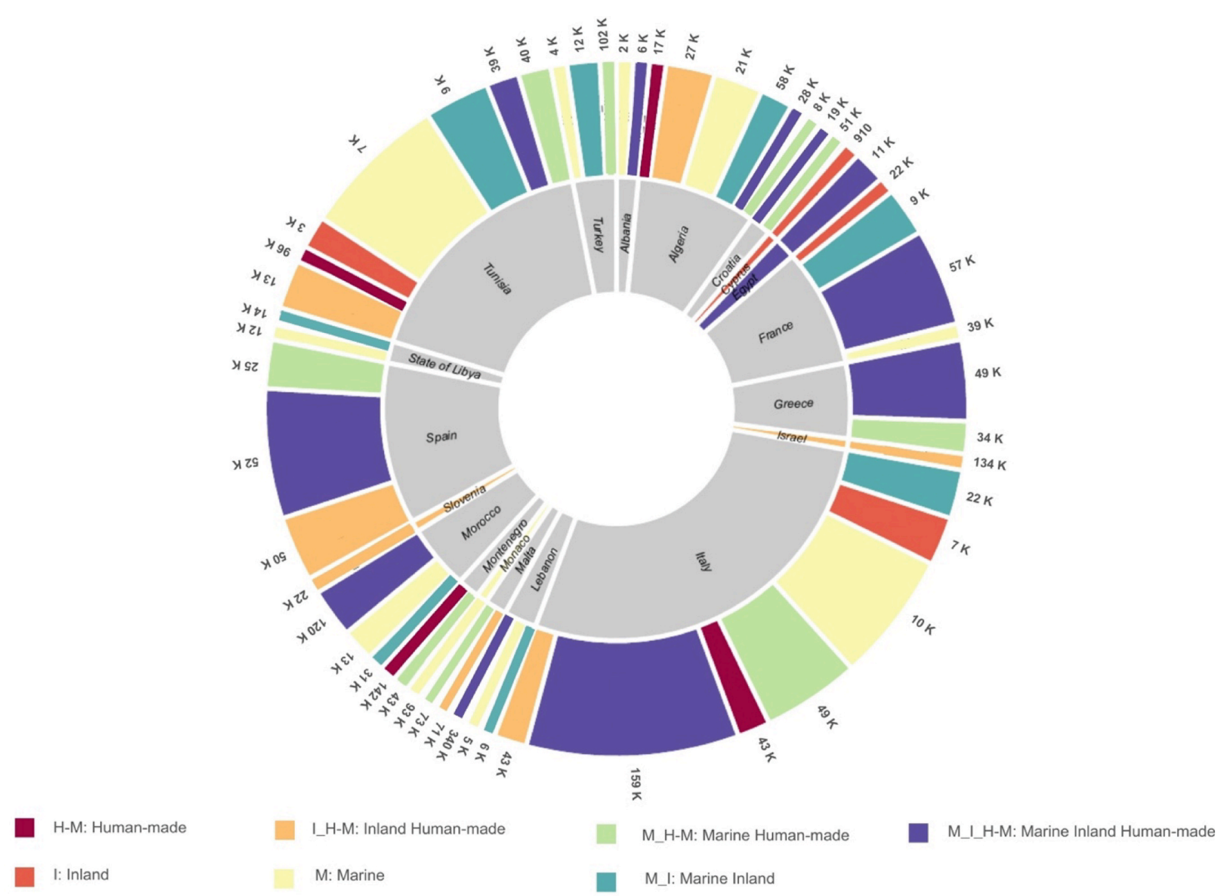

Fig. 6. Sunburst chart of the average marginal values of Ramsar coastal wetlands by country and types, expressed in 2024 USD/ha/year. Hierarchical representation of country-level marginal values and their typological composition.

importance of incorporating contextual and spatial characteristics into valuation models.

Across countries, Lebanon reports exceptionally high average values for M_I_H-M wetlands (over 340,000 USD/ha/year), while Israel's I_H-M wetlands reach 134,000 USD/ha/year. Italy, the country with the most significant number of wetland sites, exhibits notable heterogeneity, ranging from around 7000 USD/ha/year for inland (I) wetlands to over 159,000 USD/ha/year for M_I_H-M wetlands. France, Greece, and Spain show more balanced profiles, with diverse wetland types valued at 30,000–60,000 USD/ha/year on average. Spain's strongest contributions come from M_I_H-M (52,000 USD/ha/year) and H-M (50,000 USD/ha/year) wetlands.

By contrast, North African and Balkan countries, such as Tunisia, Algeria, Morocco, Croatia, and Albania, tend to display lower average values, frequently under 20,000 USD/ha/year, with some localized exceptions, such as Tunisia which records M_H-M wetlands with an average value of 40,000 USD/ha/year, and a few sites in Morocco and Montenegro whose value exceed 30,000 USD/ha/year in specific typologies.

Finally, Libya, Cyprus, and Egypt show limited representation across both the number of ecological categories and economic valuation, with most estimates falling below 10,000 USD/ha/year.

Importantly, typology-level comparisons remain robust to alternative estimators. Table B2 in SM shows that median, trimmed, and winsorized aggregation preserve the hierarchical ordering of wetland categories. Spearman correlations between mean- and median-based typology rankings (Table B4) remain high, although slightly lower than at the country level due to greater within-category dispersion. These findings indicate that the high valuation of multifunctional and human-influenced wetlands reflects structural ecological and socioeconomic characteristics rather than statistical artefacts.

When the 2024 baseline is projected forward to 2050 under the conservation scenario—updating only socioeconomic drivers while holding wetland area constant—the mean marginal value increases from 46,831 USD/ha/year to 165,437 USD/ha/year, while the median rises to 81,953 USD/ha/year. This represents a 253% increase in the mean relative to the baseline, driven primarily by projected growth in GDP per capita and surrounding population density within the meta-regression framework. Dispersion also expands substantially, reflecting stronger socioeconomic differentiation across sites.

When climate-induced wetland reductions are introduced, the model projects a further escalation of marginal unit values. Under the moderate reduction scenario (22.5% uniform loss), the mean increases to 181,188 USD/ha/year and the median to 89,308 USD/ha/year. In the high-impact scenario (40% uniform reduction), the mean reaches 196,874 USD/ha/year and the median 99,103 USD/ha/year. The country-specific reduction scenario yields a mean of 185,441 USD/ha/year and a median of 95,343 USD/ha/year. These progressive increases confirm the nonlinear scarcity mechanism embedded in the semi-log specification: as wetland stocks contract, the marginal value per remaining hectare rises at an accelerating rate.

Variability increases markedly across scenarios. The standard deviation grows from 67,304 USD/ha/year in the 2024 baseline to 275,052 USD/ha/year under the 40% reduction scenario, indicating widening dispersion in marginal economic responses. This expanding variability reflects growing differentiation among wetlands as scarcity intensifies. Sites embedded in densely populated or high-income coastal regions experience disproportionately larger increases in marginal valuation intensity, whereas less-exposed systems exhibit more moderate adjustments.

The amplification effect is also evident in the upper tail of the distribution. The maximum marginal value increases from 440,765 USD/ha/year in the baseline to 1,728,421 USD/ha/year under the 40% reduction scenario. Such extreme values are economically interpretable within the scarcity framework: wetlands combining ecological multifunctionality with strong socioeconomic embedding generate very high marginal economic intensity as remaining stocks become rarer.

Finally, the data illustrate a nonlinear relationship between wetland loss and value escalation. The increase in mean unit values between the 22.5% and 40% reduction scenarios is not proportional, confirming the concave response function posited in the benefit transfer literature (e.g., Brander et al., 2012). As wetland loss accelerates, remaining hectares become disproportionately valuable in marginal terms, reinforcing the economic rationale for early and proactive conservation measures to prevent irreversible ecological degradation and associated losses of ecosystem service values.

Fig. 7 shows how projected country-level mean marginal annual unit values (USD per hectare per year) vary across countries under the three climate change scenarios. These values are computed as the arithmetic average of site-level predicted marginal values within each national territory. The results indicate that increasing wetland loss is systematically associated with a progressive rise in the marginal unit value of the remaining wetland extent, reflecting scarcity effects embedded in the meta-regression framework.

Israel and Lebanon report the highest country-level mean marginal annual unit values across scenarios. Despite hosting relatively few wetlands, both countries include sites characterized by exceptionally high per-hectare values. In particular, the Tyre Coast Nature Reserve (Lebanon) exceeds 1 million USD/ha/year across all scenarios, while the En Afeq Nature Reserve (Israel) approaches 800,000 USD/ha/year. These sites represent some of the most economically intensive wetlands in the Mediterranean Basin in marginal terms, reflecting strong ecological multifunctionality combined with high socioeconomic embedding.

Italy stands out for its high aggregate ecosystem service value and broad distribution of moderately high-value wetlands. Rather than relying on a few isolated peaks, Italy exhibits a constellation of valuable sites – including Laguna di Venezia, Massaciuccoli, Lago dei Monaci, Trapani e Paceco, and Stagno di Molentargius – that collectively drive national totals. At the country level, Italy's mean marginal annual unit value increases from approximately 266,098 USD/ha/year under the 22.5% reduction scenario to 271,026 USD/ha/year under the country-specific scenario, remaining among the highest in the region.

France, Turkey, and Spain also report elevated country-level mean values, driven by a combination of multiple Ramsar sites and the presence of high-performing wetlands. In France, sites such as Étang de Salses-Leucate, Les Étangs de Villepey, and Camargue contribute significantly to national averages. In Spain, Mar Menor, Delta del Ebro, and Albufera de Valencia stand out as economically relevant systems.

Among smaller countries, Monaco, Malta, and Montenegro display relatively high mean values due to the presence of individual high-value wetlands despite limited overall wetland surface. For example, the Réserve sous-marine du Larvotto (Monaco) exceeds 400,000 USD/ha/year under the country-specific scenario.

Algeria presents an interesting pattern: its country-level mean value rises from approximately 197,112 USD/ha/year (scenario 1) to 211,713 USD/ha/year (scenario 2), before slightly decreasing to around 201,446 USD/ha/year under the country-specific scenario. This non-monotonic pattern may reflect differentiated exposure across sites combined with nonlinear marginal adjustments. High-value Algerian wetlands include Réghaïa, Béni-Bélaïd, Lac Tonga, and Lac Oubeïra.

In contrast, countries such as Albania, Cyprus, Libya, Tunisia, Egypt, and Morocco show lower overall mean marginal annual unit values. These patterns likely reflect combinations of lower surrounding population density, lower income levels, narrower ecosystem service portfolios, or greater relative wetland abundance (and hence lower scarcity). Nevertheless, even within these contexts, some sites exhibit high local marginal values, underscoring the importance of site-level heterogeneity.

As shown in Fig. 8, H-M wetlands (human-influenced systems with mixed characteristics) record the highest average marginal annual unit values across all three scenarios: 339,005 USD/ha/year (scenario 1),

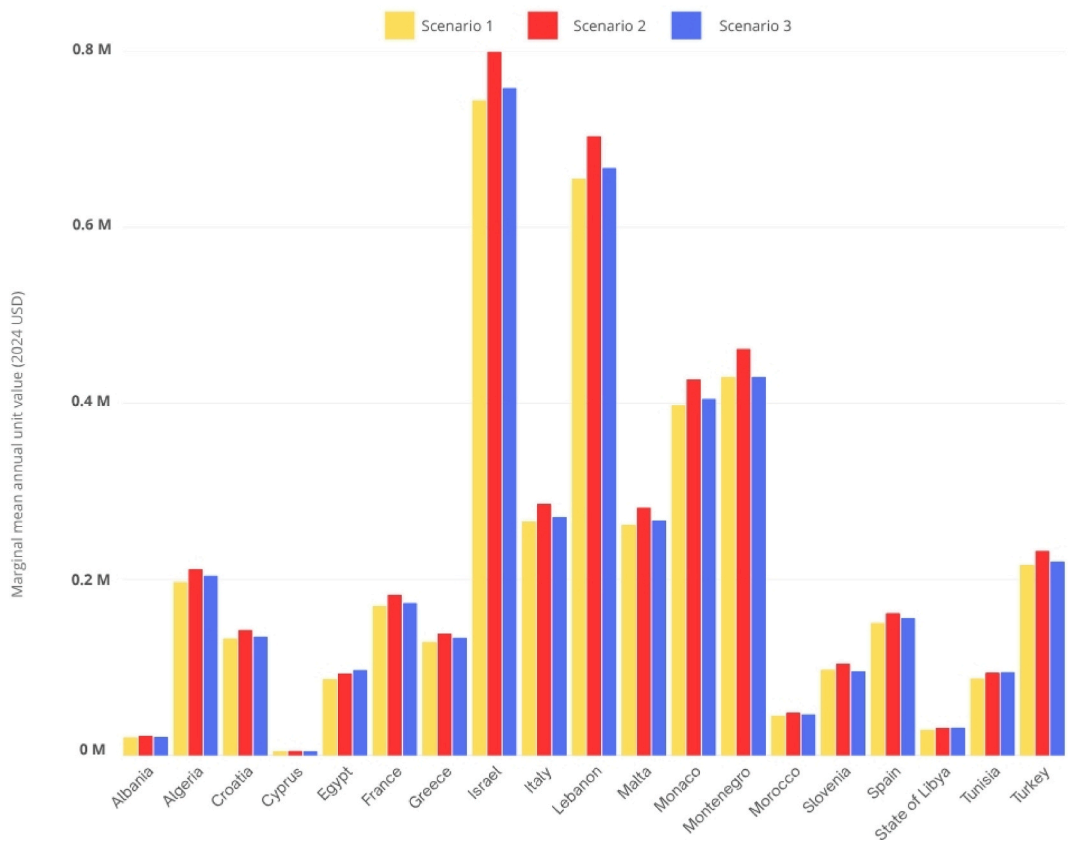

Fig. 7. Mean marginal annual unit values across the three climate change scenarios and countries (expressed in 2024 USD/ha/year). Projected changes in country-level marginal ecosystem service values under three climate-induced wetland reduction scenarios. **Note:** Scenario 1 corresponds to the 22.5% uniform wetland area reduction applied across all countries (moderate climate change pathway); Scenario 2 corresponds to the 40% uniform wetland area reduction applied across all countries (severe climate change pathway). Scenario 3 corresponds to the country-specific reduction scenario, where wetland losses differ by country based on harmonized exposure estimates from the literature.

364,116 USD/ha/year (scenario 2), and 350,015 USD/ha/year (scenario 3).

Similarly, the M_I_H-M category—combining marine, inland, and high-pressure characteristics—exhibits consistently high values, ranging from 312,086 to 335,203 USD/ha/year across scenarios.

These results suggest that functionally complex and anthropogenically embedded wetlands generate the highest marginal economic intensity. Importantly, this pattern reflects scarcity and socioeconomic exposure rather than superior ecological integrity per se.

Conversely, inland (I) wetlands and purely marine (M) wetlands display lower average marginal values, ranging approximately from 29,634 to 30,505 USD/ha/year for inland systems and from 72,604 to 74,969 USD/ha/year for marine systems. These lower values likely reflect narrower service portfolios or reduced socioeconomic demand intensity.

Fig. 9 visualizes the spatial distribution and relative magnitudes of projected total ecosystem service value losses in 2050, facilitating comparison of national exposure to climate-induced wetland decline. The reported values represent aggregate annual losses relative to the 2050 conservation baseline and are expressed in million 2024 USD.

Aggregate losses increase markedly from the moderate (22.5% uniform reduction) to the high-impact (40% uniform reduction) scenario, reflecting both greater wetland-area contraction and the nonlinear marginal-value response embedded in the meta-regression specification. Under the country-specific scenario, however, the pattern becomes more differentiated, as loss magnitudes reflect heterogeneous national exposure rather than uniform proportional reductions.

Italy records the highest projected aggregate losses across scenarios, rising from approximately 4.25 billion USD under the moderate scenario to 7.85 billion USD under the high-impact scenario, before adjusting to 5.25 billion USD under the country-specific specification. This reflects the combination of extensive wetland coverage, high marginal values, and strong socioeconomic embedding.

France ranks second in aggregate losses, peaking at 6.87 billion USD under the 40% reduction scenario and remaining substantial under the country-specific scenario (4.59 billion USD). Turkey and Egypt follow, with Turkey ranging between 3.52 and 6.50 billion USD depending on scenario severity, and Egypt exceeding 4 billion USD under the high-impact specification. Greece exhibits a similar escalation pattern, increasing from 2.81 billion USD under the moderate scenario to 5.18 billion USD under the 40% scenario.

Spain and Algeria also display significant projected losses, driven by a combination of wetland extent and marginal valuation intensity. Spain reaches approximately 3.85 billion USD under the high-impact scenario, while Algeria exceeds 2.6 billion USD before moderating under the differentiated scenario.

Countries with smaller wetland portfolios – such as Cyprus, Monaco, Malta, Israel, and Slovenia –show substantially lower aggregate losses. Notably, Israel's relatively modest aggregate loss (tens of millions USD) contrasts with very high per-hectare marginal values, illustrating how limited wetland extent constrains national totals despite high unit valuation intensity.

Fig. 10 presents the projected annual ecosystem service value losses in 2050, disaggregated by wetland typology, highlighting how different wetland types exhibit heterogeneous exposure and economic sensitivity under alternative climate-induced degradation scenarios.

The M_I_H-M typology consistently exhibits the largest total losses, reaching approximately 14 billion USD under the moderate scenario and

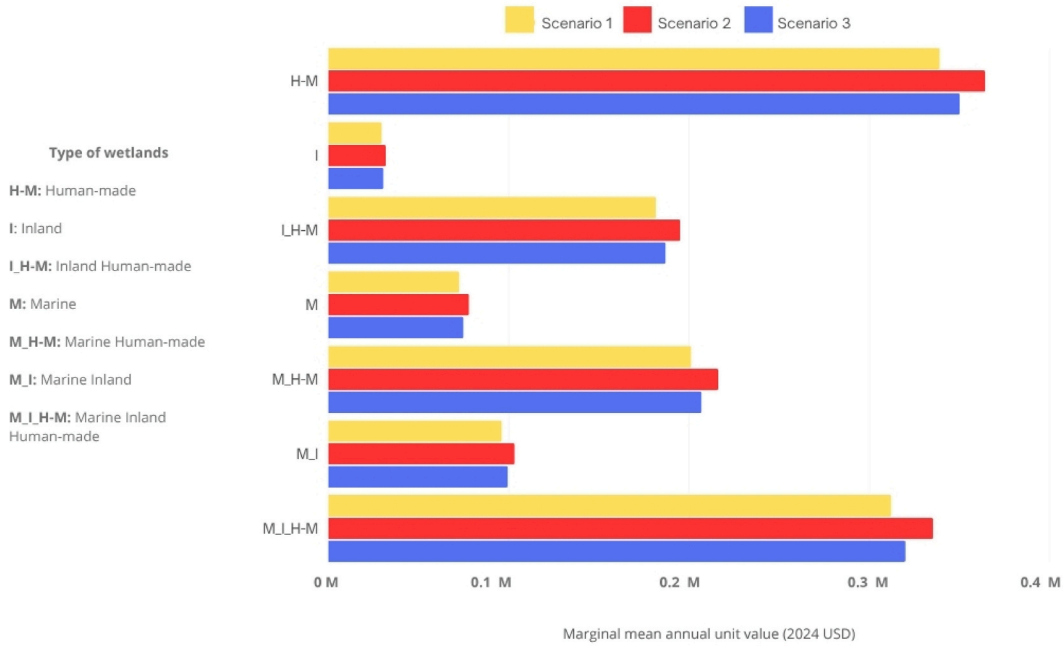

Fig. 8. Marginal mean annual unit values across the three climate change scenarios and wetland type (expressed in million 2024 USD/ha/year). Projected changes in typology-level marginal ecosystem service values under the three climate-induced wetland reduction scenarios. **Note:** Scenario 1 corresponds to the 22.5% uniform wetland area reduction applied across all countries (moderate climate change pathway); Scenario 2 corresponds to the 40% uniform wetland area reduction applied across all countries (severe climate change pathway). Scenario 3 corresponds to the country-specific reduction scenario, where wetland losses differ by country based on harmonized exposure estimates from the literature.

nearly 26 billion USD under the 40% scenario, before declining under the country-specific specification. This reflects the combination of large aggregate surface area and high marginal values in multifunctional and anthropogenically embedded systems.

Marine high-pressure (M_H-M) and purely marine (M) wetlands also show substantial aggregate losses, particularly under the 40% reduction scenario. Inland (I) and H-M categories exhibit lower aggregate totals, though local site-level variation remains considerable.

The observed pattern confirms that functional complexity and socioeconomic embedding amplify not only marginal unit values but also aggregate exposure to climate-induced losses.

Finally, to assess whether the pronounced distributional asymmetry observed in marginal annual unit values affects comparative conclusions, we conducted a comprehensive robustness analysis across all scenarios. The full set of diagnostics is reported in Tables A1–A6 and Figs. A1–A10 in the Supplementary Material.

Descriptive statistics confirm persistent right-skewness across scenarios, with means systematically exceeding medians. To evaluate the sensitivity of aggregate comparisons, we computed alternative aggregation metrics – including 10% trimmed means and 10% winsorized means – at both the country and typology levels (Tables B1 and B2 in Section B of SM). Across all scenarios, these robust estimators remain closely aligned with arithmetic means, and no systematic reordering of countries or wetland categories emerges under alternative central tendency measures.

Ranking stability was further assessed using Spearman rank correlation coefficients between mean- and median-based rankings (Tables B3 and B4). At the country level, correlations remain consistently high and statistically significant across all scenarios (ρ ranging from 0.870 to 0.967), indicating strong ordinal consistency despite increasing dispersion under climate scenarios. At the typology level, correlations are likewise high (ρ between 0.893 and 0.964), confirming that category-level hierarchies are structurally preserved even in the presence of right-skewed distributions.

Bootstrap confidence intervals (2000 replications) for mean–median differences (Table B5) confirm persistent distributional asymmetry across scenarios, with mean–median gaps widening under climate-induced scarcity. However, this increasing skewness does not translate into instability in comparative rankings. Boxplots presented in Figs. B1–B10 corroborate these findings, showing coherent upward shifts in entire distributions across climate scenarios rather than erratic expansions of isolated upper-tail observations.

Additional spatial sensitivity tests varying the inland buffer radius (5 km, 10 km, and 15 km) further support the structural scarcity mechanism embedded in the specification. While expanding the buffer increases the abundance of surrounding wetlands and reduces predicted marginal unit values, the relative ordering of countries and wetland typologies remains stable across spatial delineations. This indicates that comparative conclusions are not artifacts of a specific buffer definition but reflect structurally robust scarcity dynamics.

4. Discussion

The results presented above reveal pronounced spatial, typological, and distributional heterogeneity in projected losses of ecosystem service value across Mediterranean Ramsar coastal wetlands. Several interrelated mechanisms help explain these patterns and clarify their economic interpretation.

First, the systematic increase in marginal annual unit values as wetland area declines reflects scarcity-driven adjustment embedded in the semi-log meta-regression framework. As wetland size and surrounding wetland abundance decrease, the predicted per-hectare value of the remaining ecosystem increases nonlinearly. Importantly, this escalation should not be interpreted as an improvement in ecological performance. Rather, it captures the rising marginal economic importance of increasingly scarce natural capital. In this sense, higher per-hectare values under climate-reduction scenarios represent scarcity rents associated with diminished ecological stocks.

To place the magnitude of the baseline estimates into a broader empirical context, it is useful to compare them with recent global meta-

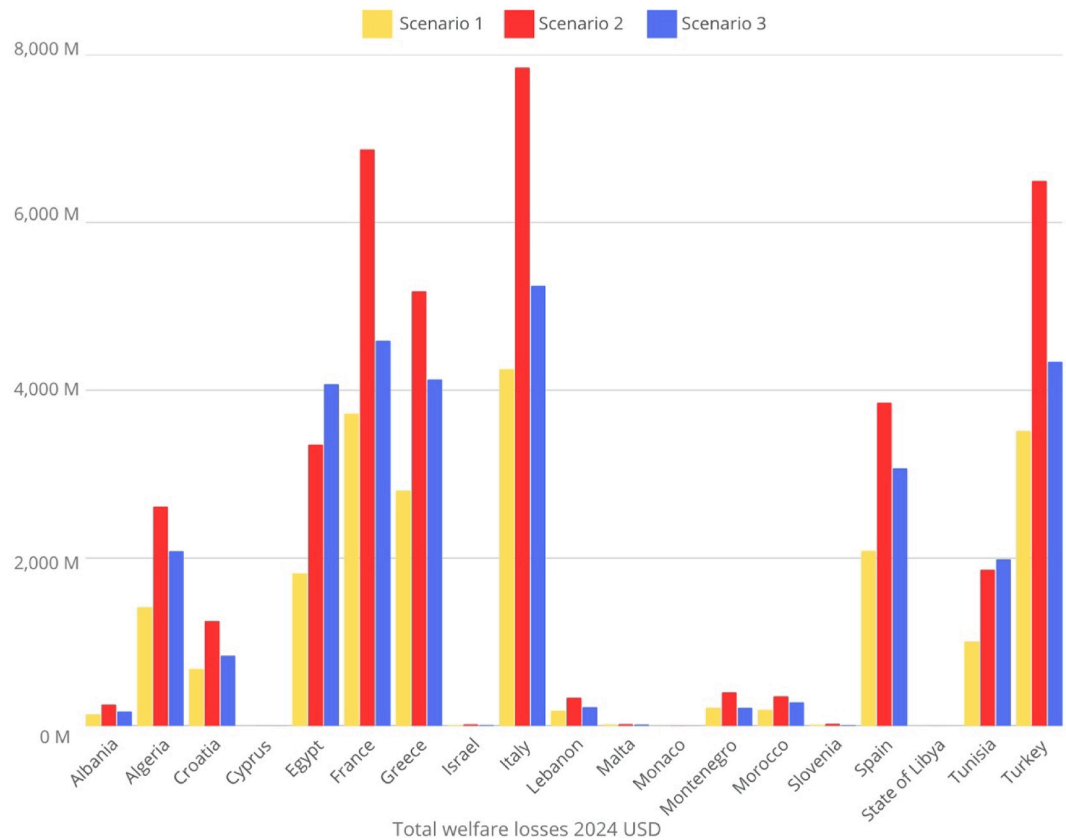

Fig. 9. Total projected annual ecosystem service value losses in 2050 under the three climate change scenarios, disaggregated by country (million 2024 USD/year). Estimated total annual ecosystem service value losses in 2050 under the three wetland degradation scenarios. **Note:** Scenario 1 corresponds to the 22.5% uniform wetland area reduction applied across all countries (moderate climate change pathway); Scenario 2 corresponds to the 40% uniform wetland area reduction applied across all countries (severe climate change pathway). Scenario 3 corresponds to the country-specific reduction scenario, where wetland losses differ by country based on harmonized exposure estimates from the literature.

analytic evidence. Brander et al. (2024), drawing on the Ecosystem Service Valuation Database (ESVD), report global average annual values for coastal wetlands of approximately 41,740 USD/ha/year (adjusted to 2024 values). The baseline marginal values estimated in this study—particularly for countries such as Italy, Greece, France, and Spain—fall within or moderately above this global benchmark. This alignment is consistent with the high ecological richness, multifunctionality, and significant anthropogenic pressures characterizing many Mediterranean coastal wetlands. Overall, this comparison suggests that the magnitude of our estimates is empirically grounded within the range documented in large-scale meta-analytic studies, supporting their external validity.

Additional sensitivity tests varying the spatial buffer radius (5 km, 10 km, and 15 km) further corroborate the scarcity mechanism embedded in the meta-regression specification. Expanding the buffer—thereby increasing surrounding wetland abundance—systematically reduces predicted marginal unit values, consistent with the estimated elasticity of wetland abundance. The 10 km specification represents a balanced delineation that captures the majority of ecologically and socioeconomically relevant coastal wetlands while remaining consistent with the estimated elasticity of surrounding wetland abundance.

Second, cross-country differences in projected aggregate losses cannot be attributed solely to the number of wetlands within each national territory. While Italy records the largest aggregate losses across scenarios, this outcome reflects a combination of extensive wetland coverage, a diverse typological composition, a high surrounding population density, and relatively high-income levels. Similar mechanisms explain elevated projected losses in France, Turkey, Greece, and Egypt. By contrast, countries hosting fewer wetlands may exhibit extremely high marginal values per hectare yet display comparatively modest aggregate losses due to scale constraints. These findings underscore the joint role of ecological structure and socioeconomic embedding in shaping both unit values and aggregate impacts.

Third, typological differences reveal the importance of ecological multifunctionality and anthropogenic context. Wetlands classified as Marine–Inland–Human-made (M–I–H–M) or as systems under significant human pressure consistently exhibit the highest marginal unit values and the largest aggregate projected losses. This pattern reflects their composite ecological structure and their integration within densely populated coastal regions. The results do not imply that anthropogenic pressure enhances ecological quality. Rather, they indicate that wetlands located in socioeconomically intensive contexts generate higher marginal economic value due to elevated demand for regulating, cultural, and supporting services. The distinction between ecological performance and economic valuation is therefore crucial: high marginal value may reflect strong human demand and scarcity rather than superior ecological integrity.

The pronounced dispersion observed in marginal unit values – particularly under more severe climate scenarios – warrants careful interpretation. Descriptive statistics reveal persistent right skewness across all scenarios, with means substantially exceeding the medians. The robustness analysis reinforces the structural stability of the comparative findings. Although marginal unit values exhibit right-skewed distributions, reflecting heterogeneity in wetland size, ecological multifunctionality, and socioeconomic embedding, alternative aggregation measures yield consistent ranking patterns across countries and wetland typologies. This stability indicates that the observed cross-country and cross-typology differences are not driven by extreme

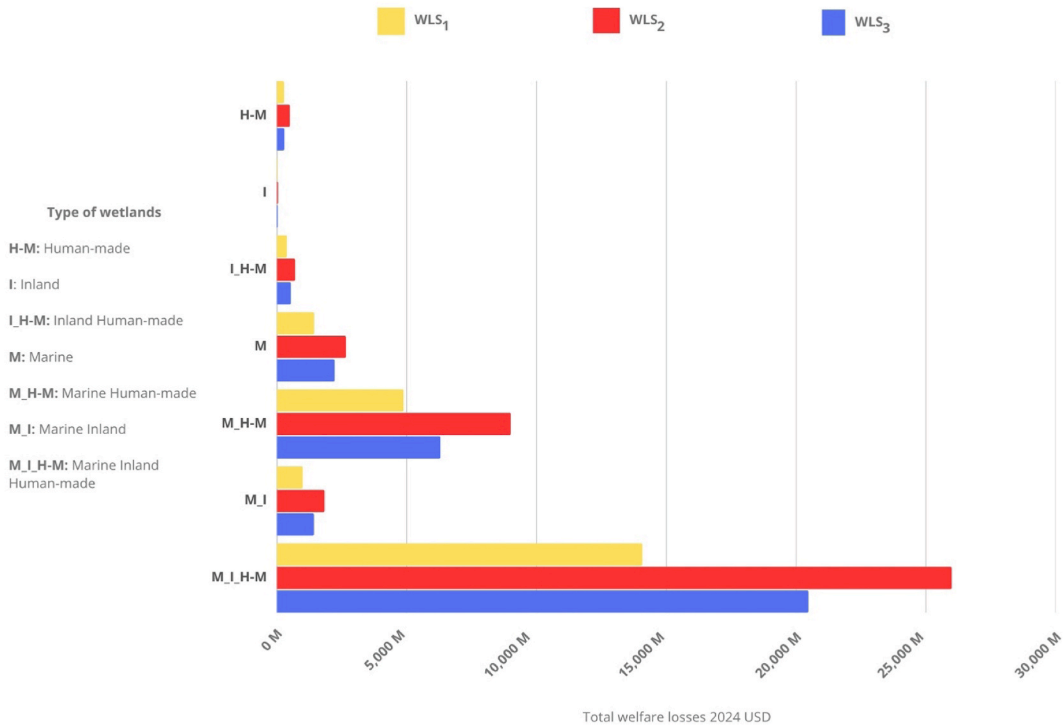

Fig. 10. Total projected annual ecosystem service value losses in 2050 under the three climate change scenarios, disaggregated by wetland typology (million 2024 USD/year). Estimated annual ecosystem service value losses in 2050 by wetland type under the three wetland loss scenarios (WLS_1–WLS_3). **Note:** WLS_1, WLS_2, and WLS_3 indicate projected annual ecosystem service value losses in 2050 (Wetland Loss Scenario 1–3). Scenario 1 (WLS_1) corresponds to a 22.5% uniform reduction in wetland extent across all countries (moderate climate pathway). Scenario 2 (WLS_2) corresponds to a 40% uniform reduction (severe climate pathway). Scenario 3 (WLS_3) uses country-specific wetland loss rates derived from harmonized climate-exposure estimates in the literature. Values represent projected annual changes in ecosystem service value for 2050.

observations but reflect systematic structural variation.

Overall, the convergence of results across alternative central tendency measures supports the reliability of the comparative conclusions and strengthens the policy relevance of the projections.

From an economic perspective, such skewness is consistent with log-linear valuation structures and heterogeneous distributions of ecological size, surrounding wetland abundance, population density, and income. High-value wetlands, therefore, represent structurally distinct systems rather than statistical anomalies, reflecting economically meaningful heterogeneity rather than statistical distortion.

The nonlinear escalation of marginal values between the 22.5% and 40% reduction scenarios reflects the concave scarcity response embedded in the benefit transfer framework. As reductions intensify, incremental losses generate disproportionately higher marginal values for remaining hectares. While this behavior is theoretically consistent with scarcity-based economic valuation, it does not incorporate ecological thresholds, tipping points, or spatial interaction effects. The model captures marginal economic responses conditional on gradual area reduction but does not simulate potential regime shifts or irreversible ecosystem collapse under severe degradation. Consequently, projected value losses should be interpreted as conditional scenario-based estimates rather than probabilistic forecasts of ecological futures.

The country-specific scenario introduces additional spatial realism by incorporating heterogeneous national exposure profiles. However, it remains based on scenario synthesis rather than fully probabilistic climate modelling. While loss rates were informed by peer-reviewed studies and vulnerability indicators, uncertainty around country-specific reductions cannot be interpreted as stochastic confidence intervals. Instead, the country-specific reduction scenario should be understood as a structured sensitivity exercise that complements the two uniform pathways by exploring differentiated regional impacts.

The use of a meta-regression function originally estimated using primary valuation studies expressed in 2003 USD introduces an additional structural assumption: namely, that the estimated elasticities linking value to wetland size, surrounding abundance, GDP per capita, and human pressure remain stable over time. Although socioeconomic drivers are updated to 2050, the structural relationship between environmental and economic variables is assumed constant. This assumption is common in large-scale benefit transfer applications but may not fully capture future shifts in preferences, institutional arrangements, valuation paradigms, or ecological baselines. Results should therefore be interpreted as internally consistent, conditional scenario-based projections rather than probabilistic forecasts of evolving ecological or valuation dynamics.

The observed heterogeneity across wetland types also highlights a broader methodological implication. Economic valuation at large spatial scales inherently integrates ecological attributes with socioeconomic exposure. High marginal values may emerge in systems experiencing both ecological complexity and high human demand. Distinguishing between natural capital productivity and scarcity-induced economic intensity is therefore essential. In this study, the valuation framework captures economic marginal responses rather than intrinsic ecological health. Conservation prioritization strategies should therefore consider ecological integrity indicators alongside economic value metrics to avoid conflating scarcity-driven valuation with ecosystem condition.

Overall, the findings demonstrate that projected ecosystem service value losses under climate change are shaped by complex interactions among wetland extent, typological composition, socioeconomic embedding, and scarcity dynamics. The robustness of comparative patterns across aggregation methods strengthens confidence in the structural interpretation of results. At the same time, the limitations identified above emphasize the importance of integrating dynamic ecological modelling, probabilistic climate projections, and updated primary valuation studies in future research.

In this context, the present analysis should be viewed as a spatially explicit, scenario-based economic assessment that quantifies the potential magnitude and distribution of ecosystem service value losses under plausible climate pathways. By revealing how scarcity amplifies marginal value while aggregate service provision declines, the study underscores the economic urgency of proactive conservation and restoration strategies in Mediterranean coastal wetlands.

5. Conclusions

This study applied a spatially explicit meta-regression–based benefit transfer framework to estimate marginal annual ecosystem service values and projected aggregate ecosystem service value losses associated with climate-induced reductions in wetland extent across 133 Ramsar-designated coastal wetlands in the Mediterranean Basin. By combining a 2024 conservation baseline with forward projections to 2050 under alternative degradation scenarios, the analysis isolates projected economic losses attributable to wetland decline while accounting for expected socioeconomic change.

Across all scenarios, marginal per-hectare ecosystem service values increase as wetland area contracts. This result reflects scarcity-driven adjustments embedded in the valuation function: as wetlands become scarcer, the marginal economic value of remaining hectares rises, even as total ecosystem service provision declines. The escalation in per-hectare values should therefore be interpreted as a scarcity effect rather than as an improvement in ecological performance. In economic terms, shrinking wetland stocks generate higher marginal valuation intensity because remaining ecosystems become increasingly valuable relative to demand, not because their ecological condition improves.

The robustness analysis further strengthens the credibility of these findings. Although marginal values exhibit persistent right-skewness, driven by structurally distinct, multifunctional wetlands embedded in high-demand socioeconomic contexts, alternative aggregation metrics and non-parametric diagnostics confirm that comparative patterns remain stable across countries and wetland typologies. Ranking structures are preserved under different central tendency measures, indicating strong ordinal consistency across scenarios.

This stability demonstrates that comparative conclusions are not artefacts of extreme values but reflect consistent structural heterogeneity in ecological complexity, wetland size distribution, human pressure intensity, and surrounding population density.

At the aggregate level, projected ecosystem service value losses increase with the severity of wetland reduction scenarios. Cross-country differences are shaped not only by the number of wetlands but also by variations in average wetland size, typological composition, socioeconomic exposure, and income levels. Countries with large, multifunctional wetlands embedded in densely populated coastal regions exhibit disproportionately higher projected losses. Conversely, countries with fewer or smaller wetlands, lower surrounding population density, or less multifunctional typologies display lower aggregate losses even under comparable percentage reductions. These findings confirm that ecological structure and socioeconomic embedding jointly determine the spatial distribution of projected losses in ecosystem service value.

The country-specific degradation scenario further highlights the importance of spatial heterogeneity in climate vulnerability. Countries facing greater exposure to sea-level rise, hydrological stress, and anthropogenic pressures exhibit disproportionately larger projected losses compared to less exposed systems. This heterogeneity underscores the limitations of uniform conservation strategies and emphasizes the need for context-sensitive adaptation and restoration policies tailored to national ecological and socioeconomic conditions.

Several methodological limitations warrant consideration. The benefit transfer approach assumes structural stability of meta-regression elasticities estimated from primary studies expressed in 2003 USD. Although socioeconomic drivers are updated to reflect projected 2050 conditions, the functional relationships linking ecosystem service values to wetland size, abundance, and human pressure are assumed to remain constant. Moreover, the framework captures marginal economic responses to area reduction but does not incorporate ecological thresholds, regime shifts, or spatial interaction effects that may arise under severe degradation. The country-specific scenario reflects a structured synthesis of regional climate impact studies rather than fully probabilistic climate modelling; projections should therefore be interpreted as conditional scenario-based estimates rather than predictive forecasts. Residual heterogeneity between the original study sites and the policy sites may also influence transferred values, despite the inclusion of multiple ecological and socioeconomic covariates.

This study produces high-resolution, spatially explicit estimates of ecosystem service values for Mediterranean Ramsar coastal wetlands and provides a forward-looking, policy-relevant assessment of projected economic losses under climate-induced degradation scenarios. The results support national ecosystem service accounting within the SEEA EA framework (United Nations, 2021), inform national and transboundary conservation planning and financing strategies, and contribute to the implementation of international biodiversity and restoration commitments, including the Ramsar Convention, the EU Biodiversity Strategy for 2030, the EU Nature Restoration Law, and the Kunming–Montreal Global Biodiversity Framework (CBD, 2022).

Future research should build on this framework by integrating dynamic ecological modelling with economic valuation approaches, developing probabilistic climate-degradation scenarios, and expanding the empirical base of primary valuation studies—particularly in underrepresented Mediterranean contexts. Enhancing the spatial resolution of ecological and socioeconomic data would further improve the precision and policy relevance of large-scale valuation exercises.

In a climate-constrained Mediterranean Basin, systematically overlooking the economic value of coastal wetlands risks underestimating the true cost of ecosystem degradation and misallocating conservation and adaptation resources across the region.

CRediT authorship contribution statement

Giovanni Signorello: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Marika Cerro:** Investigation, Data curation. **Maria De Salvo:** Validation, Methodology, Conceptualization. **Laura Giuffrida:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jnc.2026.127314.

Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request, subject to ethical and confidentiality considerations.

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